LMJ LINK MEDICAL JOURNAL OF HEALTH AND COMMUNITY RESEARCH

Crossref DOI: https://doi.org/10.61919/r37nf283

Original Article

Effect of a Proprioceptive Neuromuscular Facilitation-Based Physiotherapy Program on Nerve Function and Disability in Leprosy Patients with Peripheral Neuropathy: A Randomized Controlled Trial

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ABSTRACT

Background: Leprosy-related peripheral neuropathy can persist after multidrug therapy and may result in sensory loss, muscle weakness, neuropathic pain, deformity, disability, and reduced functional independence. Proprioceptive Neuromuscular Facilitation (PNF) may enhance neuromuscular recruitment and functional movement control, but evidence in leprosy-related neuropathy remains limited. Objective: To evaluate the effect of a PNF-based physiotherapy program on nerve function, disability, and pain in patients with leprosy-related peripheral neuropathy. Methods: A multi-center, single-blinded, parallel-group randomized controlled trial was conducted in specialized leprosy and rehabilitation centers in Karachi, Pakistan. Eighty adults with leprosy-related peripheral neuropathy were randomized into a PNF-based physiotherapy group (n=40) or conventional physiotherapy group (n=40). The intervention was delivered for 12 weeks. Outcomes included motor strength using the Medical Research Council scale, disability using the SALSA scale, and pain using the Visual Analogue Scale. Results: At 12 weeks, the PNF group showed significantly better motor strength than controls (3.91 ± 0.74 vs 3.56 ± 0.53; mean difference 0.35; p=0.018), lower disability scores (32.75 ± 5.54 vs 41.44 ± 4.31; mean difference −8.69; p<0.001), and lower pain intensity (1.98 ± 0.62 vs 4.05 ± 0.69; mean difference −2.07; p<0.001). Conclusion: PNF-based physiotherapy produced superior improvements in motor strength, disability, and pain compared with conventional physiotherapy and may be integrated into leprosy rehabilitation protocols. Keywords: Leprosy; Peripheral Neuropathy; Proprioceptive Neuromuscular Facilitation; Physiotherapy; Disability; Pain.

"Cite this Article" | **Received**: 22 August 2025; **Accepted**: 24 December 2025; **Published**: 31 December 2025.

Author Contributions: MTA conceptualized the study; FUD contributed to study design and supervision; RT, MSK, EF, IAH, and UA contributed to data collection, intervention support, drafting, and manuscript review. **Ethical Approval**: Jinnah Post Graduate Medical Centre, Karachi, Pakistan. **Informed Consent**: Written informed consent was obtained from all participants; **Conflict of Interest**: The authors declare no conflict of interest; **Funding**: No external funding; **Data Availability**: Available from the corresponding author on reasonable request; **Acknowledgments**: N/A.

INTRODUCTION

Leprosy, or Hansen's disease, remains a clinically important cause of chronic peripheral neuropathy, disability, and functional limitation in endemic regions despite the availability of multidrug therapy. The disease primarily affects the skin and peripheral nerves through invasion of Schwann cells by Mycobacterium leprae, leading to sensory impairment, motor weakness, autonomic dysfunction, and progressive deformity when nerve injury is not detected and managed early (1). The ulnar, median,

radial, common peroneal, posterior tibial, and sural nerves are frequently involved, and persistent neuropathy may result in claw hand, foot drop, recurrent trauma, ulceration, and visible deformity (2). These complications are particularly disabling because sensory loss reduces protective feedback, while motor weakness compromises grip, gait, balance, and independent performance of daily activities (3).

The burden of leprosy-related neuropathy extends beyond neurological impairment. Patients who develop Grade 1 or Grade 2 disability experience activity limitation, social restriction, reduced employability, stigma, and poorer quality of life, even after microbiological cure. Contemporary leprosy care therefore requires more than antimicrobial treatment; it requires structured rehabilitation that preserves nerve function, restores movement capacity, prevents secondary deformity, and supports participation in daily life (4). Conventional physiotherapy programs commonly include passive and active range-of-motion exercises, strengthening, stretching, splinting, gait training, and sensory re-education. Although these approaches are essential components of disability prevention, they may not fully address the complex sensorimotor deficits produced by chronic peripheral nerve involvement, particularly where coordinated motor recruitment, proprioceptive control, and functional movement integration are impaired (5).

Proprioceptive Neuromuscular Facilitation (PNF) is a rehabilitation approach based on diagonal and spiral movement patterns, manual resistance, tactile and verbal cueing, stretch facilitation, and repeated functional activation of synergistic muscle groups. These techniques are designed to enhance proprioceptive input, improve neuromuscular coordination, facilitate motor unit recruitment, and promote controlled movement across functional patterns. Evidence from musculoskeletal and neurological rehabilitation suggests that PNF-based training can improve strength, range of motion, pain-related outcomes, and functional mobility when applied through structured, progressive protocols (6). In populations with peripheral neuropathy, including diabetic neuropathy, PNF combined with strengthening or functional training has shown favorable effects on balance, muscle performance, and independence, supporting its potential value in conditions characterized by impaired sensorimotor control (7).

In leprosy rehabilitation, however, evidence for PNF remains limited. Existing studies have examined general physical therapy, neural mobilization, joint mobilization, stretching, and pain-modulating physiotherapeutic protocols, with reported improvements in neurological status, disability, pain, and quality of life (8,9). Preliminary evidence also suggests that PNF-based stretching may improve ankle and wrist range of motion and functional mobility in individuals with leprosy sequelae compared with passive static stretching (10). Nevertheless, most available work has focused on isolated techniques or general rehabilitation packages rather than a standardized PNF-based physiotherapy program targeted specifically at leprosy-related peripheral neuropathy. This leaves an important knowledge gap regarding whether PNF can produce superior improvements in nerve-related motor function, leprosy-specific disability, and neuropathic pain compared with conventional physiotherapy in a randomized controlled design (8-11).

The present study was therefore designed using a PICO framework in which adult patients with leprosy-related peripheral neuropathy constituted the population, a structured PNF-based physiotherapy program was the intervention, conventional physiotherapy was the comparator, and changes in motor strength, sensory function, disability, pain, functional mobility, and quality of life were the outcomes. The study aimed to evaluate whether a 12-week PNF-based physiotherapy program provides greater clinical benefit than conventional physiotherapy in improving nerve function and reducing disability among patients with leprosy-related peripheral neuropathy. The primary research hypothesis was that patients receiving PNF-based physiotherapy would demonstrate significantly greater improvement in motor strength and leprosy-specific disability than those receiving conventional physiotherapy.

MATERIALS AND METHODS

This study was conducted as a multi-center, single-blinded, parallel-group randomized controlled trial designed to compare the effects of a structured Proprioceptive Neuromuscular Facilitation-based physiotherapy program with conventional physiotherapy in patients with leprosy-related peripheral neuropathy. The trial was implemented across specialized leprosy and rehabilitation facilities in Karachi, Pakistan, including the Marie Adelaide Leprosy Centre, Dr. Ruth K.M. Pfau Civil Hospital Karachi, Leprosy Patients Welfare Trust services, and National Leprosy Control Program units operating within district-level public hospitals. These centers were selected because they provide routine follow-up for leprosy-affected individuals, nerve-function assessment, disability monitoring, and rehabilitation services. The intervention period lasted 12 weeks, with outcome assessments performed at baseline and immediately after completion of the intervention.

The study population comprised adults aged 18–65 years with confirmed leprosy who had completed multidrug therapy and had clinically evident peripheral neuropathy. Peripheral neuropathy was defined as involvement of at least one peripheral nerve demonstrated by sensory loss on Semmes-Weinstein monofilament testing or two-point discrimination, motor weakness of at least one grade on the Medical Research Council scale, or the presence of deformity or functional limitation such as claw hand or foot drop. Participants were eligible if they were medically stable, able to understand exercise instructions, and willing to provide written informed consent in Urdu or English. Patients were excluded if they had severe cognitive impairment, recent nerve-related surgery such as decompression or tendon transfer within the preceding three months, active uncontrolled infection or infected ulceration in the target limb, unstable fracture, severe joint instability, recent major stroke, or severe cardiopulmonary disease contraindicating supervised physiotherapy (10-13).

Participants were recruited from outpatient departments, rehabilitation units, and affiliated leprosy clinics using convenience sampling with purposive screening against predefined eligibility criteria. After screening and consent, participants were randomized in a 1:1 ratio into the PNF-based physiotherapy group or the conventional physiotherapy group. A computer-generated block randomization sequence was used, with allocation stratified by dominant upper-limb or lower-limb involvement to balance major nerve distribution patterns between groups. Allocation concealment was maintained using sequentially numbered, sealed, opaque envelopes prepared before enrollment and opened only after completion of baseline assessment. The trial was single-blinded; outcome assessors were blinded to group allocation, while participants and treating physiotherapists could not be blinded because of the nature of the intervention.

Participants in the intervention group received a standardized PNF-based physiotherapy program for 12 weeks, delivered three sessions per week, with each session lasting 45–60 minutes. The program used diagonal upper-limb and lower-limb movement patterns, progressive manual resistance, rhythmic initiation, dynamic reversals, hold-relax, contract-relax, and functional integration according to the affected nerve distribution and joint involvement. Upper-limb training emphasized wrist, hand, and finger movement patterns relevant to ulnar, median, and radial nerve involvement, while lower-limb training emphasized ankle, foot, knee, and hip control relevant to peroneal and tibial nerve involvement. Verbal cueing, tactile stimulation, joint-positioning cues, and graded resistance were applied systematically to enhance proprioceptive feedback, motor recruitment, coordination, and functional carryover. Functional tasks such as sit-to-stand practice, step-ups, gait training, reaching, grasping, and task-specific limb control were incorporated according to participant capacity and clinical presentation.

Participants in the control group received conventional physiotherapy with the same session frequency and duration. The conventional program included active and passive range-of-motion exercises, progressive strengthening with resistance bands or light weights, stretching, basic balance training, gait training, and general functional exercises without the use of diagonal PNF patterns, rhythmic initiation,

dynamic reversals, or PNF-specific manual facilitation. Treating physiotherapists received standardized orientation regarding both protocols before recruitment began. Treatment attendance was recorded at each session, and missed sessions were rescheduled when possible to maintain intervention exposure and reduce adherence-related bias.

The primary outcomes were motor strength and leprosy-specific disability. Motor strength was assessed using the Medical Research Council scale for clinically relevant muscle groups associated with ulnar, median, radial, peroneal, and tibial nerve involvement. Disability was assessed using the Screening Activity Limitation and Safety Awareness scale, with lower scores indicating less activity limitation. Secondary outcomes included sensory function, pain intensity, range of motion, functional mobility, walking endurance, and quality of life. Sensory function was evaluated using Semmes-Weinstein monofilament testing and two-point discrimination at clinically relevant sites. Pain intensity was measured using the Visual Analogue Scale or Numerical Rating Scale from 0 to 10. Range of motion was measured by goniometry for affected joints, including ankle dorsiflexion and wrist or finger flexion-extension where applicable. Functional mobility was assessed using the Timed Up and Go test, walking endurance using the 6-Minute Walk Test in participants with lower-limb involvement, and health-related quality of life using the SF-36 or an available leprosy-specific quality-of-life instrument.

Data were collected using standardized assessment forms at baseline and at the end of the 12-week intervention. Demographic variables included age, sex, education, and occupation. Clinical variables included type of leprosy, duration since diagnosis, multidrug therapy completion status, dominant nerve involvement, baseline disability grade, motor strength, sensory status, pain intensity, mobility, and quality-of-life scores. Operationally, leprosy-related peripheral neuropathy was defined as sensory or motor impairment affecting at least one clinically relevant peripheral nerve in a patient with confirmed leprosy. The intervention exposure was defined as participation in the assigned 12-week physiotherapy protocol. The primary endpoint was the between-group difference in post-intervention change in motor strength and SALSA score from baseline to 12 weeks.

The sample size was calculated for comparison of two independent groups using an expected medium effect size of Cohen's d = 0.5, 80% statistical power, and a two-sided significance level of 0.05. The estimated minimum sample was approximately 30–35 participants per group, which was increased to 40 participants per group to compensate for an anticipated 10–15% attrition rate, resulting in a total planned sample of 80 participants. Measures to reduce bias included concealed random allocation, blinded outcome assessment, standardized therapist training, use of structured intervention manuals, equivalent treatment dose in both groups, predefined eligibility criteria, consistent assessment timing, and stratification by dominant limb involvement.

Data were analyzed using SPSS version 26.0. Continuous variables were summarized as mean and standard deviation when normally distributed and as median with interquartile range when distributional assumptions were not met. Categorical variables were summarized as frequencies and percentages. Normality was assessed using the Shapiro-Wilk test and visual inspection of histograms and Q-Q plots. Baseline comparability between groups was assessed using independent-samples t tests or Mann-Whitney U tests for continuous variables and chi-square or Fisher's exact tests for categorical variables. Within-group pre-post changes were analyzed using paired-samples t tests for normally distributed variables and Wilcoxon signed-rank tests for non-normal variables.

Between-group differences in post-intervention scores and change scores were analyzed using independent-samples t tests or Mann-Whitney U tests as appropriate. For primary outcomes, analysis of covariance was planned to adjust for baseline score, age, duration of neuropathy, and dominant limb involvement where clinically relevant. Effect sizes were calculated using Cohen's d for continuous between-group differences, and 95% confidence intervals were reported for primary outcome estimates. The primary analysis followed an intention-to-treat principle, with all randomized participants analyzed in their assigned groups. Missing outcome data were assessed for pattern and extent; where missingness

was limited, complete-case analysis was supported by sensitivity analysis using baseline observation carried forward for conservative estimation. Statistical significance was set at $p < 0.05$ using two-tailed tests, with interpretation of multiple secondary outcomes based on clinical relevance and consistency of effect direction rather than isolated statistical significance alone.

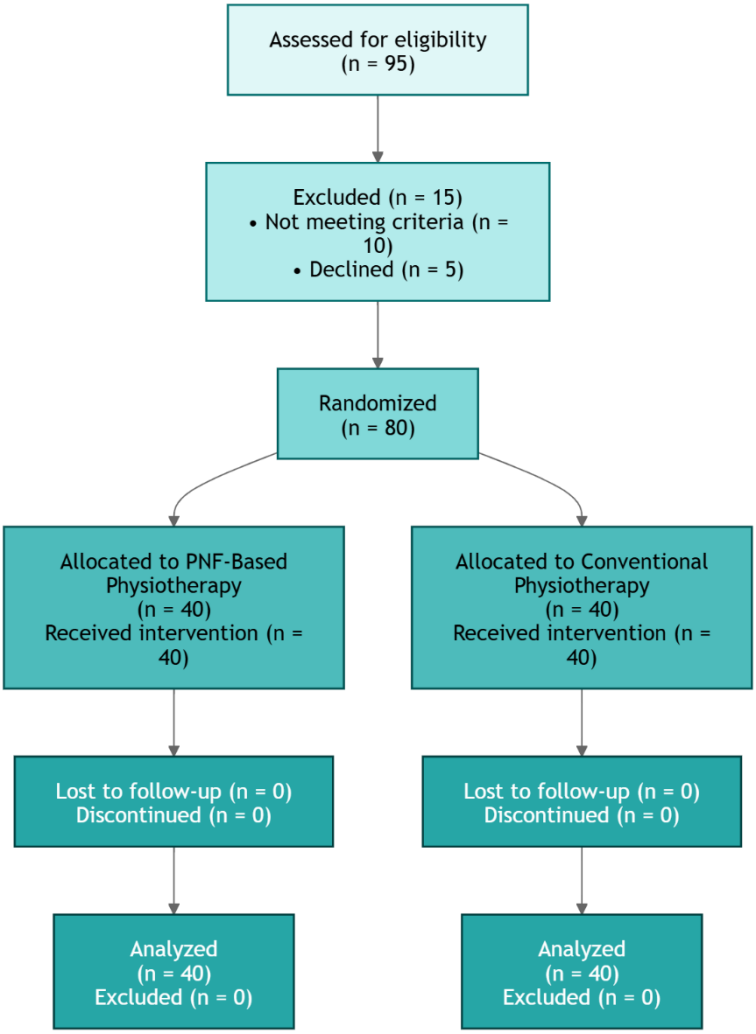

Figure 1 CONSORT Flowchart

Ethical approval was obtained from the relevant institutional review authority before data collection. All participants received information about the study purpose, procedures, potential benefits, and possible discomfort associated with supervised physiotherapy. Written informed consent was obtained before enrollment. Participant confidentiality was maintained through coded data forms, restricted access to study records, and anonymized reporting of findings. Data integrity was supported through standardized assessor training, consistent measurement procedures, attendance logs, double-checking of data entry, and secure storage of study documents.

RESULTS

A total of 80 participants completed the 12-week randomized controlled trial, with 40 participants allocated to the PNF-based physiotherapy group and 40 to the conventional physiotherapy group. Baseline characteristics were comparable between groups, indicating adequate randomization balance across demographic and clinical variables.

Table 1. Baseline Characteristics of Participants by Treatment Group

Variable	PNF Group (n=40)	Control Group (n=40)	Mean Difference	95% CI	p-value	Cohen's d
Age, years	42.5 ± 8.2	41.8 ± 7.9	0.70	−2.88 to 4.28	0.698	0.09

Variable	PNF Group (n=40)	Control Group (n=40)	Mean Difference	95% CI	p-value	Cohen's d
Duration of leprosy, years	5.2 ± 1.4	4.9 ± 1.6	0.30	−0.37 to 0.97	0.375	0.20
MRC score	2.91 ± 0.59	2.95 ± 0.64	−0.04	−0.31 to 0.23	0.772	−0.06
SALSA score	50.23 ± 5.78	49.23 ± 5.61	1.00	−1.54 to 3.54	0.435	0.18
VAS score	6.39 ± 0.82	6.59 ± 0.93	−0.20	−0.59 to 0.19	0.311	−0.23

At baseline, the two groups showed no statistically significant differences in age, duration of leprosy, motor strength, disability, or pain intensity. The mean age was 42.5 ± 8.2 years in the PNF group and 41.8 ± 7.9 years in the control group, with a negligible effect size (d = 0.09). Baseline MRC scores were also closely matched between groups, with a mean difference of −0.04 points and a very small effect size (d = −0.06). Similarly, baseline SALSA and VAS scores showed no meaningful imbalance, confirming that post-intervention differences were unlikely to be explained by baseline clinical variation.

Table 2. Post-Intervention Comparison of Primary and Secondary Outcomes After 12 Weeks

Outcome	PNF Group (n=40)	Control Group (n=40)	Mean Difference	95% CI	p-value	Cohen's d
MRC score	3.91 ± 0.74	3.56 ± 0.53	0.35	0.06 to 0.64	0.018	0.54
SALSA score	32.75 ± 5.54	41.44 ± 4.31	−8.69	−10.90 to −6.48	<0.001	−1.75
VAS score	1.98 ± 0.62	4.05 ± 0.69	−2.07	−2.36 to −1.78	<0.001	−3.16

After 12 weeks, participants receiving PNF-based physiotherapy demonstrated significantly better outcomes than those receiving conventional physiotherapy. Motor strength was higher in the PNF group, with a mean MRC difference of 0.35 points (95% CI: 0.06 to 0.64; p = 0.018), representing a moderate treatment effect (d = 0.54). Disability reduction was substantially greater in the PNF group, with SALSA scores 8.69 points lower than the control group (95% CI: −10.90 to −6.48; p < 0.001), corresponding to a large effect size (d = −1.75). Pain reduction showed the strongest between-group effect, with VAS scores 2.07 points lower in the PNF group (95% CI: −2.36 to −1.78; p < 0.001), indicating a very large clinical effect (d = −3.16).

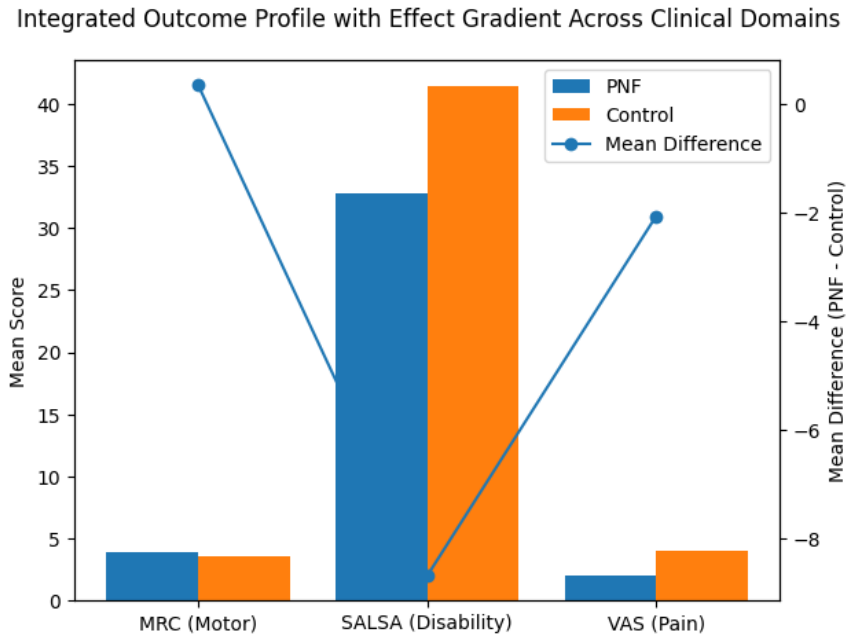

Figure 2 Integrated Outcome Profile with Effect Gradient Across Clinical Domains

While the figure 1 showed integrated outcome profile demonstrates a clear and domain-specific treatment effect of the PNF-based physiotherapy program compared with conventional therapy, combining absolute outcome levels with an overlaid effect gradient. Motor strength (MRC) shows a modest improvement in the PNF group (3.91) relative to control (3.56), corresponding to a small positive mean difference (+0.35), indicating incremental neuromuscular recovery. In contrast, disability (SALSA) exhibits the largest divergence, with substantially lower scores in the PNF group (32.75 vs 41.44), reflecting a pronounced reduction in functional limitation (mean difference −8.69). Pain intensity (VAS) also demonstrates a strong therapeutic response, with the PNF group achieving markedly lower scores

(1.98 vs 4.05), indicating significant analgesic benefit (mean difference −2.07). The superimposed network line highlights a non-linear effect distribution, with the greatest impact observed in disability reduction, followed by pain modulation, and comparatively smaller gains in motor strength, suggesting that PNF primarily enhances functional integration and symptom control rather than isolated strength improvements.

Table 3. Within-Group Pre–Post Change in Clinical Outcomes

Outcome	Group	Baseline Mean ± SD	Post-Intervention Mean ± SD	Mean Change	Direction of Effect
MRC score	PNF	2.91 ± 0.59	3.91 ± 0.74	+1.00	Improved motor strength
MRC score	Control	2.95 ± 0.64	3.56 ± 0.53	+0.61	Improved motor strength
SALSA score	PNF	50.23 ± 5.78	32.75 ± 5.54	−17.48	Reduced disability
SALSA score	Control	49.23 ± 5.61	41.44 ± 4.31	−7.79	Reduced disability
VAS score	PNF	6.39 ± 0.82	1.98 ± 0.62	−4.41	Reduced pain
VAS score	Control	6.59 ± 0.93	4.05 ± 0.69	−2.54	Reduced pain

Paired p-values and paired confidence intervals were not calculated because standard deviations of change scores were not available in the provided aggregated dataset. Both groups improved over time, but the magnitude of improvement was consistently larger in the PNF group. The PNF group showed a 1.00-point increase in MRC score compared with a 0.61-point increase in the control group. Disability decreased by 17.48 points on the SALSA scale in the PNF group compared with 7.79 points in the control group, indicating more than double the functional improvement. Pain intensity decreased by 4.41 points in the PNF group compared with 2.54 points in the control group, suggesting a clinically meaningful additional analgesic benefit from the PNF-based protocol. Overall, the results indicate that a 12-week PNF-based physiotherapy program produced superior improvements in motor strength, leprosy-specific disability, and neuropathic pain compared with conventional physiotherapy. The largest treatment effects were observed for pain and disability, while motor strength showed a moderate but statistically significant advantage in favor of PNF-based rehabilitation.

DISCUSSION

This randomized controlled trial demonstrated that a 12-week PNF-based physiotherapy program produced superior improvements in motor strength, disability, and neuropathic pain compared with conventional physiotherapy in patients with leprosy-related peripheral neuropathy. The improvement in MRC score was greater in the PNF group than in the control group, indicating that diagonal movement patterns, graded manual resistance, tactile facilitation, and repeated proprioceptive input may enhance motor recruitment in muscles affected by peripheral nerve dysfunction. This finding is clinically important because leprosy neuropathy commonly produces progressive sensory and motor impairment involving the ulnar, median, radial, peroneal, and tibial nerves, resulting in weakness, deformity, gait disturbance, and reduced hand function (1,2). The moderate between-group effect for motor strength suggests that PNF may offer additional benefit beyond conventional strengthening by integrating neuromuscular facilitation with task-oriented movement control.

The largest functional difference was observed in disability, where the PNF group showed a substantially lower post-intervention SALSA score than the control group. This finding supports the clinical relevance of PNF as more than a strengthening technique; it appears to improve integrated functional performance by combining motor activation, sensory feedback, joint control, and purposeful movement patterns. This is consistent with the rehabilitation principles recommended for leprosy-related disability prevention, where preservation of mobility, daily activity performance, and safety awareness are central priorities (4,5). The greater reduction in disability also suggests that functional integration within the PNF protocol may have translated into meaningful improvements in daily activities, particularly for patients with grip impairment, ankle weakness, balance limitation, or reduced protective movement control.

Pain reduction was also markedly greater in the PNF group, with VAS scores indicating a clinically important reduction in neuropathic pain compared with conventional physiotherapy. Neuropathic pain in leprosy is often driven by chronic nerve inflammation, demyelination, altered sensory signaling, and central sensitization, and it can persist even after completion of antimicrobial therapy (8,9). The observed pain reduction may be explained by the multimodal nature of PNF, which provides controlled afferent input, graded movement exposure, joint positioning, and sensory-motor retraining. These mechanisms may help normalize movement-related pain responses and improve patient confidence during functional tasks. Similar benefits have been reported in studies using physiotherapeutic protocols for leprosy-related nerve injury and neuropathic pain, although the present trial strengthens the evidence by directly comparing a structured PNF-based approach with conventional physiotherapy (8,9).

The findings are also supported by evidence from other neuropathic and rehabilitation populations. PNF-based and progressive resistance interventions have shown favorable effects on strength, balance, and functional independence in patients with diabetic neuropathy, suggesting that structured proprioceptive and resistance-based training may be useful in peripheral neuropathies characterized by impaired sensorimotor control (7). Similarly, earlier work in leprosy sequelae reported that PNF-based stretching improved range of motion and functional mobility compared with passive static stretching, supporting the potential applicability of PNF in this population (10). The present study extends these findings by evaluating a broader PNF-based physiotherapy program and by demonstrating benefits across motor, disability, and pain outcomes.

From a clinical and public health perspective, these results support the integration of PNF-based rehabilitation into leprosy care pathways, particularly in endemic and resource-limited settings where disability prevention is a major priority. PNF requires therapist training but does not depend on expensive equipment, making it potentially feasible for district-level rehabilitation units, leprosy centers, and community-based physiotherapy services. The reduction in disability and pain is especially meaningful because both outcomes influence independence, social participation, treatment adherence, and stigma. By improving functional capacity, PNF-based rehabilitation may contribute to long-term disability prevention and improved quality of life among leprosy-affected individuals.

Several limitations should be considered when interpreting these findings. Although the study was conducted across multiple specialized centers in Karachi, the urban setting may limit generalizability to rural areas where access to trained physiotherapists and structured rehabilitation may differ. Participant and therapist blinding was not feasible because of the nature of physiotherapy interventions, although blinded outcome assessment was used to reduce detection bias. The 12-week follow-up period provides evidence of short-term effectiveness but does not establish whether improvements are sustained over six months or longer. In addition, functional mobility and quality-of-life outcomes were included in the protocol but were not fully reported in the available results, and future publications should include complete reporting of all prespecified outcomes, effect sizes, confidence intervals, adherence data, and long-term follow-up. Future trials should also evaluate cost-effectiveness, rural implementation, therapist training fidelity, and subgroup responses according to nerve involvement, disability grade, and duration of neuropathy.

CONCLUSION

This randomized controlled trial found that a 12-week PNF-based physiotherapy program was more effective than conventional physiotherapy in improving motor strength, reducing leprosy-specific disability, and decreasing neuropathic pain among patients with leprosy-related peripheral neuropathy. The findings suggest that PNF offers a clinically meaningful rehabilitation strategy by combining proprioceptive stimulation, neuromuscular facilitation, progressive resistance, and functional task integration. Incorporating PNF-based protocols into leprosy rehabilitation services may improve functional independence, reduce pain-related limitations, and support disability prevention, although

longer follow-up studies with complete functional mobility and quality-of-life reporting are needed to confirm durability and implementation feasibility.

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