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RESEARCH REPORT

Efficacy of proprioceptive neuromuscular facilitation techniques versus traditional prosthetic training for improving ambulatory function in transtibial amputees

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KEYWORDS
functional abilities;
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Abstract The objective of this randomized controlled trial was to evaluate the efficacy of proprioceptive neuromuscular facilitation (PNF) techniques in comparison to traditional prosthetic training (TPT) in improving ambulatory function in transtibial amputees. Thirty study participants (19 men and 11 women) with unilateral transtibial amputation participated in the study. They were randomly allocated to either the traditional training group (i.e., TPT) ($n = 15$) or the PNF training group ($n = 15$). The treatment in the TPT group consisted of weight-bearing, weight-shifting, balance, and gait exercises for 30 minutes daily for 10 treatment sessions. In the PNF group, the same activities were performed by employing PNF principles and techniques. The outcome measures were gait parameters (e.g., stride width, step length, and stride length) and the Locomotor Capabilities Index (LCI). The between-group comparisons at the end of the trial showed that the PNF group showed significant improvement in gait parameters and in the LCI, compared to the TPT group ($p < 0.05$). The results of the study suggested that prosthetic training based on proprioceptive feedback is more effective than the traditional prosthetic programme in improving ambulatory function.

Introduction

Lower limb amputation accounts for 91.7% of traumatic amputations, with men being at a significantly higher risk than women. In the United States, approximately 1.7 million people are living with an amputation and

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approximately 135,000 new amputation cases occur yearly [1]. The majority (53%) of amputation cases are classified as a transtibial or below-knee amputation, in which there is a loss of one or both legs below the level of the knee [2].

Walking with a prosthetic limb is the primary goal of rehabilitation after a lower limb amputation. With a well-planned physical therapy programme, amputees can walk in a pattern that approximates the normal gait [3–5]. The desire of amputees to perform more vigorous indoor and outdoor activities and sports has posed more challenges to rehabilitation practitioners in their quest to maximize the functional capacity of their clients. Strength, balance, and gait training have become an integral part of the rehabilitation protocol, which can be achieved through traditional prosthetic training or through proprioceptive neuromuscular facilitation techniques.

Proprioceptive neuromuscular facilitation (PNF) is an integrated approach that treats an individual as a whole person, rather than merely focusing on a body segment. [6]. The basic facilitation procedure provides a mean for therapists to help an amputee gain efficient motor control that are necessary for proper ambulation. It is believed that PNF provides efficient treatment of multiple joints or muscles through functional movement patterns [6]. Gailey and Clark [4] suggested that the neuromuscular facilitation system may effectively achieve static standing, weight bearing steadiness and dynamic walking, and weight shifting stability for amputees. Yigiter et al [7] proposed that the difficulties arising from inadequate awareness of functional tasks because of the loss of the limb segment could be taught and restored more easily with proprioceptive feedback. Yigiter et al [7] furthermore reported that, in patients with transfemoral amputation, prosthetic training based on proprioceptive feedback more effectively improved weight bearing and gait in comparison to a traditional programme. However, these training methods have not been compared among patients with transtibial amputation. The goal of this study was to compare the efficacy of traditional prosthetic training with that of proprioceptive neuromuscular facilitation (PNF) techniques in enhancing gait function in patients with transtibial amputation.

Methods

Study design

This was a randomized controlled trial designed to evaluate the efficacy of PNF techniques, compared to traditional prosthetic training, in improving ambulatory function in transtibial amputees.

Participants

The criteria for inclusion were lack of muscle contractures or lack of limitations in the joint range of motion; absence of other limb segments; first-time prosthetic user; and a minimum stump length of one-third of the tibial length. Amputees were excluded if they had a history of vascular disease, hypertension, phantom pain, neuroma, cardiac disease, and gross deformities of stump such as tightness, contracture, or deformity (more than 5 degrees of malalignment). The Institutional Ethics Committee of the National Institute for the Orthopedically Handicapped (Kolkata, India) approved the study. All study participants provided written consent.

Randomisation

The study participants were first screened in accordance with the inclusion and exclusion criteria. They were then allocated by computer-generated randomisation to the PNF group or the traditional prosthetic training (TPT) group.

Intervention

Group 1 (PNF Group)

The amputees received 2 weeks of preprosthetic phase training and prosthetic phase training. The 1st week consisted of the preprosthetic phase, which included strengthening of the lower limbs. All muscles of amputated and sound limbs underwent resistance training. The muscles trained included the hip flexors, extensors, abductors, adductors, knee flexors and extensors, irrespective of the muscle strength. One set of 10 repetitions of movement in each plane was performed while using sandbags to provide resistance. The total duration of each session was typically 30 minutes. The second week consisted of the prosthetic phase, which included muscle strengthening, weight bearing, weight shifting, balance exercises and gait training. The amputees performed one set of 10 repetitions of movement in each plane. The total duration of each session was typically 30 minutes. All aforementioned trainings were based on PNF principles and techniques. The initial prosthetic training was performed by using parallel bars. The four main techniques were *resistance, approximation*, *slow reversal*, and *rhythmic stabilisation* [6].

Approximation is gentle compression of the joint surface by manual compression or weight bearing; it stimulates co-contraction of agonist and antagonist muscle to enhance dynamic stability and postural control. The first approximation occurs at, or just after, heel strike to promote weight acceptance.

To approximate, the heel (i.e., carpal ridge) of each hand was placed on the anterior crest of the ilium and above the anterior superior iliac spine (ASIS). The fingers pointed down and back in the direction of the force. The individual's pelvis remained in a slight posterior tilt. The direction of the approximation force should go through the ischial tuberosities towards the heels. Approximation was sharply applied to the participants and maintained whilst adding resistance.

The participant stood with the weight on the sound leg and the involved leg placed forward. The therapist stood in the diagonal stride position in front of or in back of the individual's involved leg. The therapist placed his or her right foot forward in front of the individual's back foot. The therapist's weight was placed on his or her forward foot. Approximation and resistance were used to stabilize the individual on the involved leg. Diagonal resistance was applied as the individual's weight shifted from the back leg to the front leg. The therapist may use his or her body weight to apply resistance.

The therapist and patient stepped with the same leg. When standing behind the patient, the therapist's fingers were on the amputee's iliac crest. The hands and forearms formed a line that pointed down through the ischial tuberosities towards the amputee's heels. The therapist's forearms pressed against the patient's gluteal muscles. Standing behind was advantageous if the client was taller than the therapist; if the therapist wanted to use his or her own body weight to pull down and back on the amputee's pelvis for approximation, stretch, and resistance; or if the therapist wanted to give the patient an unobstructed view forward. The amount of resistance applied during dynamic concentric muscle contraction was the greatest amount of resistance possible that still allowed the client to move smoothly through the available range. Weight acceptance was performed by combining approximation through the pelvis on the strong side with stabilising resistance at the pelvis, and by combining approximation through the pelvis on the weak side with stabilising resistance at the pelvis.

Slow reversal involves changing an active motion from one direction (i.e., agonist) to the opposite direction (i.e., antagonist) without a pause or relaxation. The therapist resisted the patient's movement in one direction, usually the stronger or better direction. As the end of the desired range of motion approached, the therapist reversed the grip on the distal portion of the moving segment and gave a command for the individual to prepare for a change of direction. At the end of the desired movement, the therapist gave an action command to reverse direction without relaxation, and the therapist provided resistance to the new motion. Weight shifting was performed both as both a pre-requisite to stepping and as an exercise of the lower extremity itself. Exaggerated weight shift forward or laterally exercised hip hyperextension and lateral motions and knee stability. This activity was initiated by stabilizing the patient on one leg. The therapist provided resistance as the individual shifted weight to the other leg.

Rhythmic stabilisation is the alternating isometric contraction against resistance with no motion; it is designed to promote stability through co-contraction of the proximal stabilising musculature of trunk, shoulder, and pelvic girdle regions of body. It is performed in the weight bearing position to incorporate joint approximation into the procedure, hence further facilitating the contraction.

A static balance exercise was administered. The therapist provided resistance in the antagonistic direction and asked the patient to maintain his or her balance. During these activities, the patient resisted the therapist by performing muscle co-contractions.

Pelvic patterns are believed to facilitate weight-bearing motions of the legs. The pelvis should not move further into an anterior or posterior tilt during this exercise. These exercises can be performed with the patient standing or supine. Anterior elevation, anterior depression, posterior elevation, and posterior depression were performed with 10 repetitions daily with the patient lying on the side.

Group 2 (TPT Group)

The participants in this group were treated with traditional prosthetic training consisting of a preprosthetic phase and a prosthetic phase. The preprosthetic phase consisted of muscle strengthening exercises, just as in the PNF group. The prosthetic phase, however, consisted of weight bearing on the prosthetic limb, weight shifting, balance exercises, and gait training. The treatment focus was initially on having the amputees learn to shift their weight towards the side of the prosthesis. This began with the patient standing in the parallel bars. Forward—backward and sideways weight shifting exercises were administered so that amputees could experience the orientation of their centre of mass over the base of support. To promote increased weight bearing on the prosthesis, single limb loading and weight shifting exercises were administered whilst the sound limb was advanced. The amputee also learned side stepping and stepping forward and backward with the sound and prosthetic limbs. The therapists used none of the PNF principles and techniques (e.g., manual contact, verbal command, vision, and timing for emphasis, resistance, approximation, and stretch). Each treatment session lasted typically 30 minutes.

Outcome measurement

The measured gait parameters included stride width, step length, stride length, and the Locomotor Capabilities Index (LCI) [8,9]. A baseline reading was obtained at the end of 1st week (i.e. at the end of the preprosthetic training) and a post-test reading was obtained at the end of the 2nd week (i.e. at the end of the trial). Clients were asked to walk on a 6-m walkway at a self-selected comfortable speed. The stride width was the distance between the centres of the two heels. The stride length was the distance between two successive foot prints of the same foot. The step length was the distance between two successive foot prints: amputated-to-sound-heel and sound-to-amputated heel. Six footprints consisting of three successive right and left footprints were analysed. Three measurements of the stride width and three measurements of the step length and stride length on the amputated side and on the sound side were averaged for statistical analysis. Footprints were obtained on paper with ink applied on an amputee's shoe soles, and markers were used to mark the measuring points.

The LCI [8,9] is a self-administered scale that is composed of 14 questions on different locomotor activities, which were selected primarily from the locomotor disabilities classification of the World Health Organization. Each item was rated on a four-level ordinal scale (0—3 points). The scale ranged from "not able" to "able to accomplish the activity alone", which indicated the degree of perceived independence in performing each of the 14 activities whilst wearing the prosthesis. Higher scores reflect greater locomotor capability with the prosthesis and less dependence on external assistance. The index can be divided into two 7-item subscales that covered basic and advanced items, respectively. The LCI has good internal consistency (Cronbach $\alpha = 0.95$), and intra-rater reliability (kappa values for the item scores = 0.58—1.000).

Statistical analysis

An intention to treat analysis was performed by using SPSS 15.0 Software (SPSS Inc., Chicago, IL, USA). Shapiro-Wilk tests were completed to assess whether the dependent variable conformed to a normal distribution (and thus whether parametric testing could be undertaken). The results of the Shapiro-Wilk test indeed suggested that the dependent variable was normally distributed ($p > 0.05$). An independent *t* test was used to compare the client characteristics for continuous data (e.g., height, weight, body mass index, age) and the Chi-square test was used to compare the categorical data (e.g., the proportion of men and women). An independent *t* test was also used to analyse gait parameters (i.e., stride width, stride length, step length) and the LCI of the two groups at baseline and after treatment. The level of significance was adjusted to less than 0.025 by using the Bonferroni correction (0.05/2 comparisons).

Results

Forty clients were assessed for eligibility. Seven clients did not satisfy the inclusion criteria and three refused to participate. Thirty participants (19 men, 11 women) with a mean age of 39 years were enrolled in the study. Fifteen participants were randomly allocated to the PNF group and the other 15 participants were allocated to the TPT group (see the CONSORT flowchart in Fig. 1). Table 1 details the demographic data of the study population. Independent *t* test analysis revealed no statistically significant differences between the two groups in any of the demographic (Table 1) and outcome variables (Table 2).

A between-group analysis of the gait parameters was performed by using independent *t* tests (Table 2). At the end of the trial, both groups had an improvement in the stride width. The mean improvement in the PNF group and TPT group was 14.73 cm and 5.67 cm, respectively. The stride width at post-test revealed a statistically significant between-group difference ($p < 0.025$). The PNF group tended to have a greater improvement in stride length and step length, but no significant between-group difference in these parameters was present at the end of the trial ($p > 0.025$). The LCI showed a significant between-group difference after the treatment period ($p < 0.025$), with the PNF group demonstrating more improvement.

Discussion

This study compared the efficacy of the PNF programme with that of the TPT programme in improving ambulatory function in transtibial amputees. The results showed that

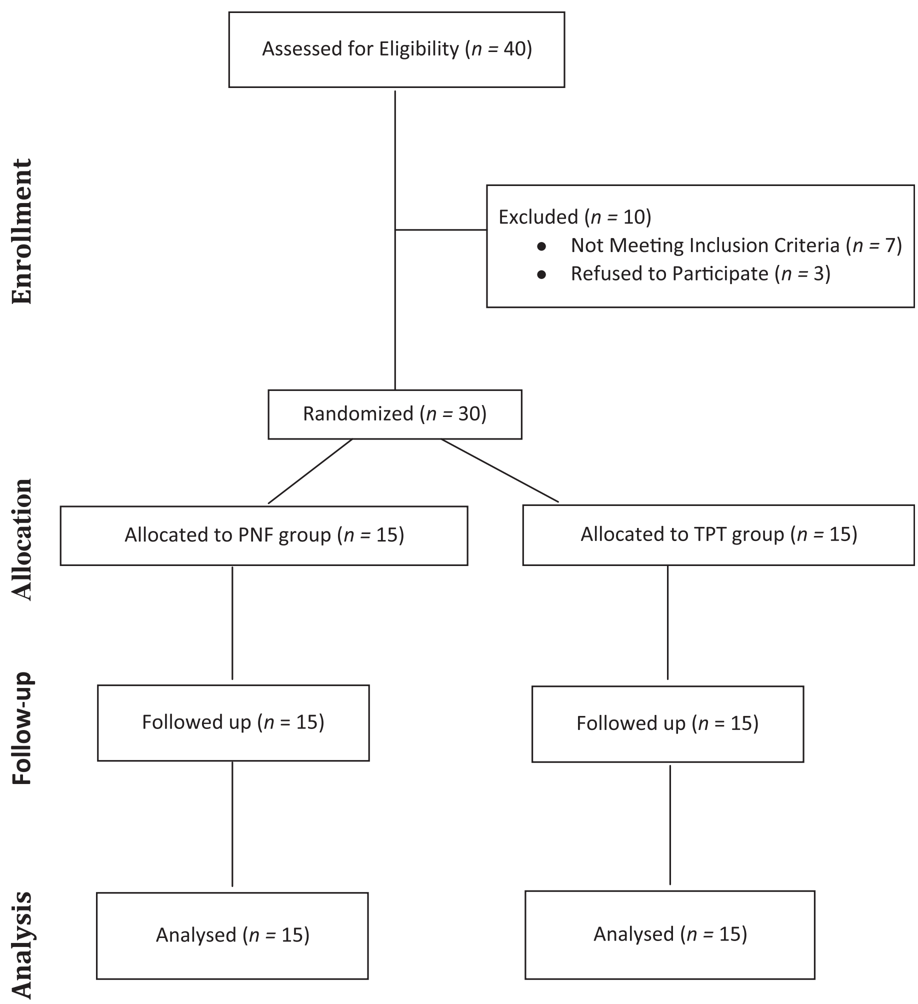

Figure 1 CONSORT diagram showing the flow of the study participants through each stage of the randomized trial. PNF = proprioceptive neuromuscular facilitation; TPT = traditional prosthetic training.

Table 1 Comparison of client characteristics

	PNF Group [mean (SD)], $N = 15$	TPT Group [mean (SD)], $N = 15$	p*
Age (y)	40.27 (5.08)	38.40 (5.73)	0.456
Sex (men/women)	10/05	09/06	0.865
Weight (kg)	64.25 (5.61)	63.86 (4.55)	0.435
Height (cm)	154.36 (4.42)	154.56 (3.66)	0.723
BMI (kg/m^2)	27.10 (1.37)	26.94 (2.05)	0.676

BMI = body mass index; N = number; SD = standard deviation.
*Independent t test (for continuous data) or Chi-square test (for categorical data).

the PNF programme was more effective than traditional prosthetic training in improving gait function in this patient population.

Normal gait is characterized by almost identical movements of both lower limbs with only small differences in kinematic and kinetic parameters. Isakov et al [10] showed that the symmetry of gait can be measured by different methods and can be reflected through various gait parameters.

Changes in stride width

At the beginning of the treatment period, the stride width in both groups was greater than normal. Individuals with a unilateral transtibial amputation lose this specific form of sensory feedback from one of their limbs, resulting in a decreased ability to maintain and regulate body movements. This led Viton et al [11] to suggest that amputees need to be more cautious when experiencing body disequilibrium since the loss of lower limb musculature and sensory feedback around the ankle joint makes re-adjusting to slight errors more difficult.

After the training period, both groups showed improvement in the stride width, but a significantly greater improvement occurred in favour of the PNF group (24% [PNF group] vs. 14% [TPT group]). A perceptible difference can be deduced on the basis that an individual initially may be apprehensive in bearing weight and have a wide base of support to maintain balance. Stride width after training was nearly normal with repeated practice and with improved balance, weight bearing and weight shifting. Slow reversal helps an amputee change an active motion from one direction (i.e., agonist) to the opposite direction (i.e., antagonist) without a pause or relaxation. Slow reversal may also help increase the active range of motion and strength, coordination, endurance, and help make changing the direction of motion more easy. In the therapy regimen of the PNF group, this was one of the techniques added that may have led to the better outcomes.

Changes in stride length and step length

Our study showed that the PNF group improved more than the TPT group in stride length (19.7% vs. 7.3%, respectively) and in step length (21.3% vs. 12.9%, respectively), but the results did not quite reach statistical significance ($p = 0.046$ and $p = 0.042$, respectively). This may be because of the reduced statistical power. Significant results may have been obtained if a larger sample had been used. Summers et al [12] found that unilateral transtibial amputees tend to favour the intact limb during an upright stance. Similarly, Yigiter et al [7] found that individuals with transtibial amputation often could not maintain an equal step length because of inadequate weight bearing and greater use of the intact limb. Maintenance of equal step and stride length is a difficult part of gait training in transtibial amputees. The uneven step and stride length are usually related to inadequate weight bearing through the prosthetic limb [4].

Trueblood et al [13] were unable to show an improvement in the gait speed of 20 individuals after one session of treatment consisting of four sets of five repetitions of resisted PNF pelvic motion; however, stance stability and limb advancement of the involved lower extremity improved.

Previous studies that have examined the effect of PNF on stride length and gait speed in other populations report mixed results. Wang [14] stated that the improvement in gait speed (e.g., reduced task completion time) obtained

Table 2 Comparison of outcome measurements between the two treatment groups

	PNF Group, $N = 15$		TPT Group, $N = 15$		Between-group Comparison p	
	Pre	Post	Pre	Post	Pre	Post
Stride width (cm)	14.5 ± 2.9	11.0 ± 1.8	15.1 ± 3.0	12.9 ± 2.4	0.625	0.025*
Stride length (cm)	78.8 ± 15.1	93.5 ± 14.7	76.7 ± 15.2	82.4 ± 14.5	0.712	0.046
Step length (cm)	40.5 ± 8.7	49.1 ± 9.0	37.5 ± 8.3	42.4 ± 8.0	0.351	0.042
LCI	40.3 ± 3.8	47.9 ± 4.0	38.6 ± 3.4	43.7 ± 3.0	0.165	0.006*

LCI = Locomotor Capabilities Index; N = number; PNF = proprioceptive neuromuscular facilitation; TPT = traditional prosthetic training.
*Indicates a significant between-group difference, based on the independent t test ($p \leq 0.025$).

with PNF treatment was positively related to many spatiotemporal gait parameters and with improvement in other muscular characteristics and functional activities among patients with hemiplegia. Mirek et al [15] showed that the clients with Parkinson's disease had a better rhythm of gait with PNF-based training. However stride length and duration of single limb support did not change significantly.

Changes in the Locomotor Capabilities Index

The LCI score in the PNF group increased by 18.7% after training, which was significantly more than the improvement obtained in the TPT group (13.3%). Kawahira et al [16] were able to show that a rehabilitation programme consisting chiefly of the PNF technique led to improvement in voluntary movement of the hemiplegic lower limb. David et al [17] found that improvement in walking speed enhanced an individual's ability to negotiate real-world overground environments (e.g., steps, obstacles, and uneven surfaces) and to walk independently and confidently.

What factors may explain the better outcomes in the PNF group? Loofbourrow and Gellhorn [18] showed that when a muscle contraction is resisted, the muscle's response to cortical stimulation increases. Active muscle tension produced by resistance is an effective proprioceptive facilitation. The magnitude of the facilitation is related directly to the amount of resistance. Proprioceptive reflexes from the contracting muscle increase the response of synergists at the neighbouring joints. This facilitation can spread in the proximal-to-distal direction and in the distal-to-proximal direction. Antagonists of the facilitated muscles are usually inhibited. If the muscle activity in the agonists becomes intense, there may also be activity in the antagonistic muscle groups (i.e., co-contraction) [6].

Resistance to balance and motion is most effective when it occurs in the diagonal direction. The direction of motion can be controlled by standing in the chosen diagonal. Resisted gait activities are an exaggeration of normal motion. When strong motions are resisted during standing and walking, irradiation will facilitate the contraction of the weaker muscles of the trunk and lower extremity. Large amplitude body motions are resisted during weight shifting. Resistance to large-amplitude motions helps the individuals to gain the strength and skills needed to stand and walk functionally approximation through the pelvis during stance and stretch reflex to the pelvis during swing facilitate the muscles of the lower extremity and trunk. When pelvic motion and stability are facilitated, the leg can function more efficiently [6].

In this study, the authors assumed that auditory stimulation or verbal commands have the added beneficial effect of improving all spatial parameters of gait. The tone of a therapist's voice influences the quality of an individual's response. Buchwald [6] stated that a tone of moderate intensity evokes gamma motor neuron activity and a loud tone can alter alpha motor neuron activity. Strong, sharp commands stimulate a stress situation and are used when maximal stimulation of motor response is required. The volume at which a therapist speaks a command can affect the strength of an individual's muscle contractions [19]; help the client control and correct the position and motion that influence the head and body motion; provide an avenue of communication; and help to ensure cooperative interaction. Visual stimuli assist in the commencement and coordination of movement. Visual stimuli should be monitored to ensure that the client is tracking in the direction of the movement. Thus, the significant differences in the improvement of the PNF group can be justified on the basis of the aforementioned theories and on past studies on PNF-based gait training. Proprioceptive neuromuscular facilitation focuses on movements that resemble the activities of daily living such as walking; it therefore may lead to better carryover of training effects [6].

Limitations

A major limitation of this study was the small sample size of only 30 clients. The reduced statistical power may partly explain the nonsignificant results in this study. In this study, only the exoskeletal patellar tendon-bearing prosthesis with a solid-ankle cushion-heel foot and cuff suspension was available. The results may not be generalizable to patients wearing other types of prostheses. Further study of patients with different types of prostheses is recommended to examine the efficacy of the two treatment approaches. Additionally, the long-term effect of the treatment was not examined. Finally, the evaluators' knowledge of the group allocation of the study participants may have reduced the validity of the measurements and results. A double-blinded study would have improved the validity of the measurements and results.

Conclusion

The results of this study showed that PNF exercises are more effective in improving stride width and the LCI in patients with transtibial amputation. Further double-blinded randomized controlled trials with larger sample sizes are required to further investigate the efficacy of these two programs on ambulatory function, activities of daily living and societal participation in this patient population.

Conflicts of interest

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

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