

Effect of Foot Muscle Energy Technique on Plantar Pressure in Patients with Diabetic Neuropathy: A Randomised Controlled Trial

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ABSTRACT

Introduction: Diabetic Peripheral Neuropathy (DPN) is a common complication of diabetes mellitus, often leading to altered plantar pressure, foot dysfunction, and increased risk of foot ulcers. Physiotherapy interventions such as Muscle Energy Technique (MET) and conventional strengthening and mobility exercises may improve foot biomechanics and functional outcomes in these patients.

Aim: To evaluate the effect of Foot MET compared with strengthening and mobility exercises, both combined with sensory integration training, on plantar pressure distribution and foot function in patients with moderate DPN.

Materials and Methods: An open-label randomised controlled trial was conducted in the Department of Physiotherapy at Dr. Prabhakar Kore Hospital and Medical Research Centre, Belagavi, Karnataka, India, from July 2025 to December 2025, on 24 participants aged 50-75 years diagnosed with moderate DPN. Participants were randomly allocated into two groups: Group-A received MET with sensory integration, and Group-B received strengthening and mobility exercises with sensory

integration. Interventions were administered three times weekly for four weeks. Data normality was assessed using the Shapiro-Wilk test. Within-group and between-group comparisons were performed using the Wilcoxon's signed-rank test and Mann-Whitney U test, respectively. Effect size was calculated using standardised correlation coefficient (r).

Results: Both groups demonstrated statistically significant improvements in plantar pressure distribution, pain, disability, activity limitation, and total Foot Function Index (FFI) scores post-intervention ($p < 0.001$). Effect sizes were larger in Group-A, indicating a greater magnitude of improvement. Between-group analysis showed that MET resulted in significantly better plantar pressure redistribution, pain reduction, and overall foot function compared with strengthening and mobility exercises.

Conclusion: Both MET and strengthening and mobility exercises with sensory integration effectively improved plantar pressure and foot function in patients with DPN. MET demonstrated superior outcomes and may be considered an effective physiotherapy intervention to enhance foot biomechanics and functional performance in individuals with diabetic neuropathy.

Keywords: Diabetic neuropathies, Exercise therapy, Foot diseases, Pressure ulcer prevention, Proprioception

INTRODUCTION

The DPN is one of the most common and debilitating complications of Diabetes Mellitus, first described by Gowers WR in the late nineteenth century, and continues to represent a major global health burden [1]. DPN affects the sensory and motor nerves of the lower limbs and has been reported to affect a significant proportion of individuals with diabetes worldwide [2,3]. Individuals with DPN commonly experience numbness, burning sensation, muscle weakness, impaired proprioception, and balance deficits, which gradually interfere with mobility and daily activities [4,5]. The underlying pathophysiology involves complex cellular and metabolic mechanisms including oxidative stress, mitochondrial dysfunction, and impaired axonal repair, which contribute to progressive nerve damage [6,7]. Progressive sensory loss and weakness of the intrinsic foot muscles alter normal foot biomechanics and plantar pressure distribution during standing and walking [8]. Increased plantar pressure, particularly over the forefoot and midfoot regions, is considered a major contributing factor for callus formation, foot ulceration, gait abnormalities, and lower-limb complications in individuals with diabetes [9-12]. Therefore, early assessment and management of plantar pressure abnormalities are important in preventing diabetic foot complications and improving functional mobility [13,14].

Physiotherapy interventions are commonly used in the management of DPN to improve balance, gait, proprioception, muscle strength, and foot function. Conventional rehabilitation approaches such as

strengthening exercises, mobility training, balance training, and sensory integration techniques have shown beneficial effects in improving postural stability and reducing functional impairment in individuals with diabetic neuropathy [15,16]. However, despite these interventions, abnormal plantar loading and altered foot biomechanics remain major concerns in individuals with DPN, particularly in those with modifiable risk factors such as smoking and dyslipidaemia [17,18].

The MET has gained attention as a manual therapy intervention for improving muscle flexibility, joint mobility, neuromuscular activation, and proprioceptive facilitation. MET involves voluntary isometric contraction performed against therapist resistance followed by relaxation and stretching of the targeted muscle [19]. Previous studies investigating MET in musculoskeletal conditions such as hamstring tightness, plantar fasciitis, chronic low back pain, neck pain, and ankle dysfunction have reported improvements in flexibility, pain reduction, range of motion, gait mechanics, balance, and functional mobility. Smith M and Fryer G demonstrated significant improvement in hamstring extensibility following MET intervention [19], while Joshi TM et al., reported better flexibility outcomes using post-isometric relaxation techniques [20]. Patil V and Heggannavar A also demonstrated improved functional outcomes with prolonged MET application in musculoskeletal conditions [21]. These findings suggest that MET may help improve abnormal biomechanical loading patterns and functional impairments associated with DPN.

Despite these reported benefits, limited literature is available regarding the application of Foot MET in individuals with DPN. Most previous studies involving DPN have primarily focused on strengthening exercises, balance training, gait rehabilitation, electrical stimulation, or management of diabetic foot ulcers [13,14]. The commonly studied outcomes in these interventions include balance, pain intensity, muscle strength, and quality of life measures, while very few studies have objectively evaluated plantar pressure redistribution, which is considered an important biomechanical factor contributing to ulcer formation in diabetic neuropathy [9]. Additionally, limited evidence exists regarding the combined effect of MET and sensory integration training on plantar pressure distribution and foot function in individuals with DPN [10,15]. Therefore, the present study was undertaken to compare the effects of foot MET and strengthening and mobility exercises on plantar pressure distribution and foot function in individuals with moderate DPN.

MATERIALS AND METHODS

The present study was an open-label randomised controlled trial was conducted in the Outpatient Department of Physiotherapy at Dr. Prabhakar Kore Hospital and Medical Research Centre, Belagavi, Karnataka, India, from July 2025 to December 2025. Ethical approval was obtained from the Institutional Research and Ethics Committee of KLE Academy of Higher Education and Research (K.A.H.E.R) Institute of Physiotherapy (Approval No: KIPT/2025/08/01959). The trial was prospectively registered with the Clinical Trials Registry of India (CTRI/2025/09/095451). Written informed consent was obtained from all participants prior to enrollment, and confidentiality of participant data was maintained.

Inclusion and Exclusion criteria: Participants aged 50-75 years diagnosed with Type 2 diabetes mellitus for at least 10 years and moderate DPN according to the Toronto Clinical Scoring System (score 9-11) were included in the study [11]. Participants were required to demonstrate altered plantar pressure distribution without active foot ulcers and be able to walk independently [10,14]. Participants with severe neuropathy, severe foot deformity, recent lower limb surgery or fractures, history of amputation, or neurological and musculoskeletal disorders affecting mobility were excluded from the study [11,13].

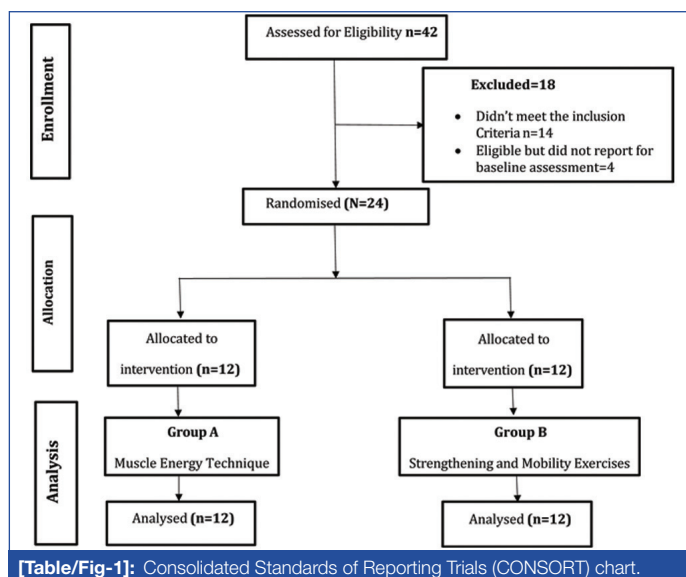
Sample size: Sample size was calculated using the formula for comparison of paired means based on the paired t-test method at a 5% level of significance, 80% power, and two-tailed analysis. Based on the calculated values, 12 participants per group were required, totaling 24 participants. Considering an anticipated dropout rate of 15%, a total of 42 participants were initially screened according to the predefined inclusion and exclusion criteria. Out of the 42 participants screened, 18 participants were excluded as they did not satisfy the inclusion criteria or were unwilling to participate in the study.

Eligible participants were randomly assigned into two groups using the closed-envelope techniques to ensure unbiased group allocation. Prior to enrolment, 24 opaque envelopes were prepared, with 12 randomly designated Group-A and 12 Group-B, and thoroughly shuffled. Each participant sequentially drew one envelope at the time of enrolment, ensuring that group assignment remained concealed until after enrollment was confirmed.

Group-A (n=12) received MET with sensory integration training, while Group-B (n=12) received strengthening and mobility exercises with sensory integration training. Baseline demographic details and outcome measures were recorded prior to intervention [Table/Fig-1].

Study Procedure

Prior to recruitment, the purpose and procedures of the study were clearly explained to all potential participants. Individuals willing to participate were provided with an informed consent form, and written consent was obtained before enrollment. Participants diagnosed with moderate DPN were screened according to the predefined inclusion

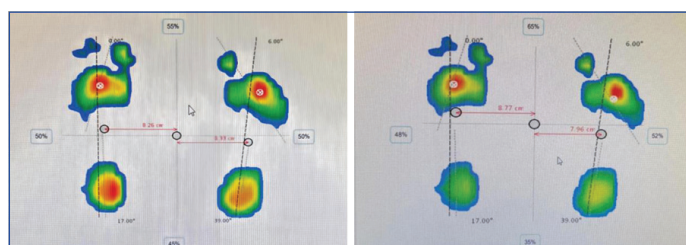


and exclusion criteria. Baseline demographic details including age, gender, duration of diabetes, Body Mass Index (BMI), and medical history were recorded using a standardised assessment form.

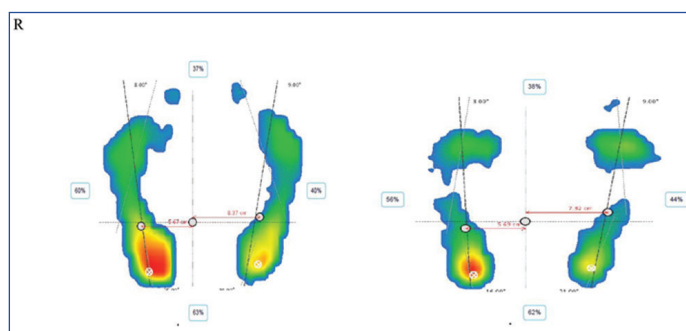
Baseline assessment of plantar pressure distribution and foot-related functional status was conducted before initiation of the intervention and repeated after completion of the four-week treatment protocol.

Outcome Measures

Plantar pressure distribution: Plantar pressure distribution was assessed using the KODEYS FootWork® Néo Plantar Pressure System, which records pressure distribution across different regions of the plantar surface during weight-bearing activities. The system provides quantitative analysis of regional plantar loading patterns and pressure distribution abnormalities associated with DPN [Table/Fig 2,3].



[Table/Fig-2]: Plantar Pressure System- Pre (Left) and Post (Right) in Group-A.



[Table/Fig-3]: Plantar Pressure System-Pre (Left) and Post (Right) in Group-B.

Foot Function Index (FFI): Foot-related functional status was assessed using the 17-item Italian Foot Function Index (17-IFFI), a self-reported questionnaire used to evaluate the impact of foot pathology on pain, disability, and activity limitation [22]. The questionnaire comprises three subscales: pain (5 items), disability (9 items), and activity limitation (3 items). Each item is scored on a numerical rating scale from 0 to 10, and subscale and total scores are expressed as a percentage, calculated as the sum of item scores divided by the maximum possible score for applicable items.

Higher scores indicate greater impairment in foot function, with 0% representing no pain or functional limitation and 100% representing maximum pain and functional disability [22].

Intervention protocol: Participants in both groups received intervention three times per week for four weeks, with each treatment session lasting approximately 30-40 minutes [13,15].

Group-A – Muscle Energy Technique (MET) with sensory integration: Participants in Group-A received MET targeting the gastrocnemius, soleus, tibialis anterior, tibialis posterior, peroneal muscles, and intrinsic foot muscles. Gentle isometric contractions were performed against therapist resistance for 7-10 seconds, followed by relaxation and passive stretching [19,20]. Each contraction was repeated 3-5 times according to participant comfort [19].

Following MET, sensory integration training was administered, including tactile stimulation using a soft brush, vibration stimulation using a handheld vibration device, and balance activities such as standing with feet together, tandem standing, and multidirectional weight shifting to improve proprioceptive input and postural control [15,16].

Group-B – Strengthening and mobility exercises with sensory integration: Participants in Group-B received strengthening and mobility exercises for the foot and ankle along with sensory integration training. Exercises included towel toe curls, marble pick-up exercises, ankle dorsiflexion and plantarflexion using resistance bands, and seated heel raises performed for 15 repetitions in two sets [13,14].

Sensory integration training similar to Group-A was also provided, including plantar brushing stimulation, vibration stimulation, and balance activities to improve proprioception and sensory feedback [15,16]. Each session additionally included 5-10 minutes of warm-up and cool-down exercises.

STATISTICAL ANALYSIS

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) software version 23.0. Normality of data distribution was assessed using the Shapiro-Wilk test, which is appropriate for sample sizes less than 50. The results indicated that the data did not follow a normal distribution ($p < 0.05$) for the majority of outcome variables. Therefore, non parametric statistical tests were employed for all analyses. Within-group comparisons of pre- and post-intervention scores for plantar pressure distribution and FFI were performed using the Wilcoxon's Signed-Rank test. Between-group comparisons of post-intervention scores between Group-A (Foot MET with sensory integration) and Group-B (strengthening and mobility exercises with sensory integration) were performed using the Mann-Whitney U test. Effect size was calculated using standardised correlation coefficient (r). All tests were two-tailed, and the level of statistical significance was set at $p < 0.05$ with a 95% Confidence Interval.

RESULTS

A total of 24 participants with DPN were randomised to Group-A (Foot MET with sensory integration) or Group-B (strengthening and mobility exercises with sensory integration). Plantar pressure and foot function (FFI) were assessed at baseline and after four weeks of intervention to determine within-group and between-group treatment effects.

Group-A and Group-B were comparable in age distribution, gender, weight, height, BMI, Toronto Clinical Neuropathy Score, Glycated Haemoglobin (HbA1c) and duration of diabetes (all $p > 0.05$), confirming baseline homogeneity between groups [Table/Fig-4].

Both groups showed statistically significant pre- to post-intervention improvements across all outcome measures- plantar pressure, pain, disability, activity limitation, and total FFI score (all $p < 0.001$)- with large effect sizes ($r = 0.87-0.90$) in both groups. The magnitude of improvement was consistently greater in Group-A across all five outcomes [Table/Fig-5].

Variables	Category	Group-A (n=12) n (%)	Group-B (n=12) n (%)	Total (n=24) n (%)	p-value
Age group (years)	50-55	3 (25%)	3 (25%)	6 (25%)	1.000
	56-60	3 (25%)	3 (25%)	6 (25%)	
	61-65	3 (25%)	3 (25%)	6 (25%)	
	66-70	2 (17%)	2 (17%)	4 (17%)	
	71-75	1 (8%)	1 (8%)	2 (8%)	
Gender	Male	7 (58%)	6 (50%)	13 (54%)	0.682
	Female	5 (42%)	6 (50%)	11 (46%)	
Weight (kg)	60-65	4 (33%)	4 (33%)	8 (33%)	1.000
	66-70	3 (25%)	3 (25%)	6 (25%)	
	71-75	3 (25%)	3 (25%)	6 (25%)	
	76-80	2 (17%)	2 (17%)	4 (17%)	
Height (cm)	160-162	3 (25%)	3 (25%)	6 (25%)	1.000
	163-165	4 (33%)	4 (33%)	8 (33%)	
	166-168	5 (42%)	5 (42%)	10 (42%)	
BMI (kg/m ²)	Normal (18.5-24.9)	5 (42%)	5 (42%)	10 (42%)	1.000
	Overweight (25-29.9)	7 (58%)	7 (58%)	14 (58%)	
Toronto Clinical Neuropathy Score	Score 9	4 (33%)	4 (33%)	8 (33%)	0.881
	Score 10	5 (42%)	4 (33%)	9 (38%)	
	Score 11	3 (25%)	4 (33%)	7 (29%)	
HbA1c (%)	6.5-7.0	3 (25%)	3 (25%)	6 (25%)	1.000
	7.1-8.0	5 (42%)	5 (42%)	10 (42%)	
	8.1-9.0	4 (33%)	4 (33%)	8 (33%)	
Duration of Diabetes (years)	10 years	4 (33%)	4 (33%)	8 (33%)	1.000
	11-12 years	5 (42%)	5 (42%)	10 (42%)	
	13-15 years	3 (25%)	3 (25%)	6 (25%)	

[Table/Fig-4]: Baseline demographic characteristics of participants.

The ANCOVA was performed on the primary outcome (plantar pressure), adjusting for baseline values. The between-group difference remained statistically significant after adjustment (adjusted mean: Group-A 0.815, Group-B 0.663; $F(1,21)=112.74$, $p < 0.001$), confirming that Group-A (Foot MET) showed significantly greater improvement in plantar pressure distribution compared with Group-B, independent of baseline differences.

At baseline, the groups were comparable for plantar pressure ($p = 0.259$) but differed significantly on pain, disability, activity limitation, and total FFI score, with Group-A scoring higher on all four ($p \leq 0.002$). Post-intervention, Group-A showed significantly greater improvement than Group-B in plantar pressure, pain, activity limitation, and total FFI score (all $p < 0.05$); disability improvement was also significantly greater in Group-A ($p < 0.001$), though the post-test between-group comparison for disability alone did not reach significance ($p = 0.089$) [Table/Fig-6].

DISCUSSION

The present study evaluated the effectiveness of Foot MET combined with sensory integration training compared with strengthening and mobility exercises combined with sensory integration on plantar pressure distribution and foot function in individuals with moderate DPN. Significant improvements were observed in plantar pressure distribution and FFI scores following the intervention period in both groups. However, greater improvement was observed in the MET group, suggesting that interventions targeting joint mobility, proprioception, and neuromuscular control may provide additional benefits in improving foot biomechanics and functional ability in individuals with DPN [2,3].

The improvement in plantar pressure distribution observed in the present study suggests a more balanced redistribution of

Outcome Measure	Group	Pre Mean±SD	Post Mean±SD	Mean Difference	SD Difference	Effect Size (r)	z-value	p-value
Plantar Pressure	Group-A	0.48±0.18	0.81±0.04	0.34	0.19	0.88	3.063	<0.001
	Group-B	0.52±0.05	0.67±0.03	0.14	0.02	0.89	3.078	<0.001
Pain Scale	Group-A	49.83±3.33	25.25±3.49	24.58	6.60	0.89	3.074	<0.001
	Group-B	43.67±3.28	31.83±5.97	11.83	5.57	0.90	3.108	<0.001
Disability Scale	Group-A	42.50±2.97	24.42±3.75	18.08	6.39	0.87	3.010	<0.001
	Group-B	37.00±2.17	28.67±4.74	8.33	4.74	0.90	3.108	<0.001
Activity Limitation	Group-A	21.42±1.31	11.25±1.71	10.17	2.69	0.89	3.088	<0.001
	Group-B	18.92±1.44	13.92±2.61	5.00	3.33	0.90	3.133	<0.001
Total FFI	Group-A	66.47± 4.08	35.83±5.22	30.64	8.98	0.88	3.034	<0.001
	Group-B	58.58±3.87	43.77±7.72	14.80	7.83	0.88	3.050	<0.001

[Table/Fig-5]: Within-group pre–post comparison.

Outcome Measure	Time Frame	Group A Mean±SD	Group-B Mean±SD	z-value	p-value	Effect Size
Plantar Pressure	Pre	0.48±0.18	0.52±0.05	1.128	0.259	0.23
	Post	0.81±0.04	0.67±0.03	4.108	<0.001*	0.84
	Diff	0.34±0.19	0.14±0.02	3.478	<0.001*	0.71
Pain Scale	Pre	49.83±3.33	43.67±3.28	3.463	<0.001*	0.71
	Post	25.25±3.49	31.83±5.97	2.817	0.005*	0.58
	Diff	24.58±6.60	11.83±5.57	3.306	<0.001*	0.67
Disability Scale	Pre	42.50±2.97	37.00±2.17	3.414	<0.001*	0.70
	Post	24.42±3.75	28.67±4.74	1.702	0.089	0.35
	Diff	18.08±6.39	8.33±4.74	3.203	<0.001*	0.65
Activity Limitation	Pre	21.42±1.31	18.92±1.44	3.087	0.002*	0.63
	Post	11.25±1.71	13.92±2.61	2.242	0.025*	0.46
	Diff	10.17±2.69	5.00±3.33	2.882	0.004*	0.59
Total FFI	Pre	66.47±4.08	58.58±3.87	3.238	0.001*	0.66
	Post	35.83±5.22	43.77±7.72	2.204	0.027*	0.45
	Diff	30.64±8.98	14.80±7.83	2.936	0.005*	0.60

[Table/Fig-6]: Between-group comparison at pre and post-test.

mechanical load across the plantar surface during weight-bearing activities. Abnormal plantar loading is considered one of the major biomechanical contributors to callus formation and diabetic foot ulceration in individuals with neuropathy. Previous studies by Mueller MJ et al, and Fernando ME et al., reported that individuals with DPN demonstrate altered gait mechanics, increased plantar pressure, and abnormal loading patterns that increase the risk of ulcer development [4,13]. Similarly, Rao S et al., demonstrated that reduced foot and ankle mobility significantly influences plantar loading during gait in individuals with diabetes [23]. The findings of the present study are consistent with these studies and indicate that improving foot and ankle mobility, intrinsic muscle flexibility, and neuromuscular coordination may help achieve more effective plantar pressure redistribution.

Significant improvement was also observed in FFI scores following intervention, indicating reduction in foot-related pain, disability, and activity limitation. These findings suggest improvement in functional mobility and performance of daily activities. Similar findings were reported by Allet L et al., who demonstrated that structured rehabilitation programs improved gait performance, walking ability, and balance in individuals with diabetic neuropathy [15]. Menz HB et al., also reported that DPN is associated with impaired walking stability and sensorimotor dysfunction, which negatively affect functional independence and increase fall risk [16,24]. The functional improvements observed in the present study may therefore be attributed to enhanced proprioceptive feedback, improved postural control, better muscle activation, and improved movement coordination following physiotherapy intervention.

An important aspect of the present study was the inclusion of Foot MET as part of the rehabilitation protocol. MET is a manual therapy

technique involving voluntary isometric contraction followed by relaxation and stretching, which helps improve muscle extensibility, joint mobility, and neuromuscular activation. Previous studies investigating MET in conditions such as hamstring tightness, plantar fasciitis, chronic low back pain, and ankle dysfunction have demonstrated improvements in flexibility, range of motion, pain reduction, balance, and gait mechanics. Smith M and Fryer G reported significant improvement in hamstring extensibility following MET intervention [19], while Joshi TM et al., demonstrated beneficial effects of post-isometric relaxation techniques on muscle flexibility [20]. Patil V and Heggannavar A also reported improved functional outcomes with prolonged MET application in musculoskeletal conditions [21]. The neurophysiological basis of these effects may relate to altered pain processing and neuropathic mechanisms in peripheral nerves [25,26]. Although these studies mainly focused on pain, flexibility, and mobility outcomes, their findings support the neuromuscular and biomechanical effects of MET observed in the present study.

The beneficial effects observed following MET intervention may be explained through both neurophysiological and biomechanical mechanisms. MET is believed to facilitate post-isometric relaxation, reduce muscle spindle excitability, and improve muscle flexibility and joint mobility. Repeated isometric contractions may also enhance proprioceptive input, improve circulation, and facilitate motor activation, thereby promoting more efficient movement patterns during gait and weight-bearing activities. In addition, sensory integration training may have contributed to improved balance, postural stability, and proprioceptive awareness, which are commonly impaired in DPN [5,16]. Together, these effects may have contributed to improved plantar pressure redistribution and better functional outcomes observed in the present study.

Despite the growing use of physiotherapy interventions in diabetic neuropathy, most previous studies have primarily focused on balance training, strengthening exercises, gait rehabilitation, electrical stimulation, or management of diabetic foot ulcers [13,15]. Commonly assessed outcomes in these studies include balance, muscle strength, gait parameters, pain, and quality of life, while limited studies have objectively evaluated plantar pressure redistribution as an outcome measure [8,9]. Furthermore, limited literature is available regarding the use of Foot MET in individuals with DPN before the development of foot ulcers, and current international guidelines continue to emphasise the importance of early biomechanical intervention in this population [14,27]. A major novelty of the present study lies in the objective evaluation of plantar pressure distribution using the KODEYS FootWork® Néo system along with assessment of foot-related functional status through the FFI [22]. Another important aspect of the study is the comparison of Foot MET combined with sensory integration training against conventional strengthening and mobility exercises in individuals with moderate DPN before ulcer development. By addressing these gaps, the present study provides preliminary evidence supporting the role of Foot MET in improving plantar pressure distribution and foot function in individuals with DPN [2,3,28].

Limitation(s)

The present study did not include long-term follow-up; therefore, the sustainability of treatment effects could not be determined. The study was conducted in a single institutional setting, which may limit external validity. Blinding of participants and therapists was not feasible due to the nature of the intervention, which may have introduced performance bias. Despite randomisation, baseline differences were observed between groups in the primary outcome measure, which may have influenced interpretation of between-group treatment effect. Additionally, only individuals with moderate DPN were included, limiting generalisation of the findings to severe neuropathy.

Future studies should include larger sample sizes and longer follow-up periods to evaluate long-term outcomes. Additional outcome measures such as gait analysis, balance assessment, nerve conduction studies, and quality of life assessments may provide a more comprehensive understanding of treatment effectiveness.

CONCLUSION(S)

Both MET and strengthening and mobility exercises combined with sensory integration training were effective in improving plantar pressure distribution and foot function in individuals with DPN. Significant improvements were observed in plantar pressure redistribution and FFI scores following intervention in both groups. However, greater improvement was observed in the MET group, suggesting superior effectiveness in improving foot biomechanics and functional ability. The findings of the present study indicate that interventions targeting proprioception, mobility, and neuromuscular control may play an important role in the rehabilitation of DPN. Early physiotherapy intervention may help reduce abnormal plantar loading and improve functional mobility before the development of diabetic foot complications. Therefore, Foot MET may be considered a useful adjunct in the physiotherapy management of individuals with moderate DPN.

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