

EFFECTS OF FOOT INTRINSIC EXERCISES AND ANKLE MOBILITY EXERCISES ON FOOT PRESSURE AMONG PARTICIPANTS WITH DIABETIC PERIPHERAL NEUROPATHY: A PROSPECTIVE RANDOMIZED CONTROLLED STUDY

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ABSTRACT

Objective

This study compared the effects of regular foot care, foot intrinsic muscle exercises, and ankle mobility exercises on dynamic forefoot pressure (DFFP) and hindfoot pressure (DHFP), strength, and ankle dorsi flexion range of motion in diabetic peripheral neuropathy patients (DPN).

Materials and methods

Two hundred individuals who were clinically diagnosed with DPN who complied with the inclusion and exclusion criteria were enrolled for this study. The participants were allocated into two groups (100 in each). Group I received standard foot care as per International Working Group on Diabetic Foot guidelines, while Group II underwent foot intrinsic muscle strengthening and ankle mobility exercises, along with usual foot care over eight weeks. The primary outcome measures dynamic forefoot & hind foot pressures were measured by insole pressure sensors, and the secondary outcome measures Foot intrinsic muscle strength (FIMS) and Ankle dorsiflexion range of motion (ADROM) were measured by the Enhanced paper grip test and Universal goniometer, respectively. The measurement was taken before and after 8 weeks of treatment. These scores were recorded and analysed using paired and unpaired t-tests.

Results

The intragroup difference observed in both groups was statistically significant ($p < 0.001$). The mean value analysis reveals that, regarding between-group analysis of all the dependent variables, regular foot care along with foot intrinsic muscle strengthening exercise and ankle mobility exercise was more effective than regular foot care alone in positively improving DFFP and DHFP, the power of foot intrinsic muscle and ankle dorsiflexion movement among DPN patients ($p < 0.001$).

Conclusion

In DPN patients, the management of DFFP and DHFP, FIMS, and ADROM is more effective when regular foot care is combined with foot intrinsic muscle strengthening exercise and ankle mobility exercise than when regular foot care is performed alone.

Keywords

Ankle dorsiflexion, Diabetic peripheral neuropathy, Foot intrinsic muscle strengthening exercise, Goniometer, Paper grip test

INTRODUCTION

Diabetic peripheral neuropathy (DPN), a prevalent neurological condition, has evolved into symmetric, time-dependent sensori-motor polyneuropathy¹. Long-term hyperglycemia and cardiovascular risk factors alter metabolism and microvessels, causing this disease. Neuron conduction test abnormalities, typically asymptomatic, are the earliest sign of this illness². DPN patients benefit from aerobic, strength, and balance exercises. It is recommended to do these exercises three times a week for eight weeks for 30–60 minutes. Specialised exercise programs, such as range of motion (ROM) exercises, muscular strengthening, and gait training, have been demonstrated to improve walking patterns in DPN patients^{3, 4}.

Forefoot and hindfoot pressures play a crucial role in walking and running biomechanics, influenced by foot alignment, gait, and footwear⁵. A study⁶ indicated that while heel pressure is

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constant, forefoot pressure varies significantly with eversion angles, particularly at higher hindfoot angles. DPN can lead to nerve injury, causing symptoms like numbness that hinder pressure detection, increasing the risk of diabetic foot ulcers due to elevated plantar pressures. The anatomy of the longitudinal arch, defined by the navicular bone and arch height index, is important for foot function; exercises targeting the intrinsic foot muscles (IFM) can mitigate running injuries related to arch instability⁷. Additionally, conditions like pes cavus and pes planus are associated with neuropathy and affect plantar pressure. Age-related changes also impact gait, which further influences plantar pressures⁸. Intrinsic foot muscle strengthening exercises are workouts that target and strengthen the intrinsic muscles of the foot. These foot-only muscles are vital to foot health. They aid toe movement but not ankle movement. These exercises stabilise the foot during motion, support the arch, and reduce plantar fasciitis symptoms⁹.

Ankle joint, muscles, and tendons are stretched through ankle mobility exercises. These exercises aim to increase the range of motion during workouts and daily life. The joints and muscles are trained for unexpected motions, protecting the ankle and preventing injury. These exercises are great for athletes and individuals with stiff or weak ankles¹⁰. Ankle mobility exercises (AME) in warm-up and cool-down routines could boost range of motion, improve workout performance, minimise muscular cramps, and improve fitness¹¹.

Foot pressure sensing platforms measure static load interaction between the foot and its supporting surface. A piezoelectric transducer or force-sensing resistor (FSR) sensor changes voltage or resistance when pressure is applied to this electrical device¹². The platform usually has a flat, durable matrix of pressure-sensing units implanted in the floor. It is used in health monitoring, sports performance assessment, injury prevention, footwear development, and disease diagnosis. These platforms provide crucial knowledge into the pressure contact between the plantar surface of the foot and the shoe sole, advancing biological and sports research¹³.

The Enhanced Paper Grip Test (EPGT) quantitatively assesses toe grip strength by measuring the force required to pull a card from under the participants' feet, providing a more thorough evaluation of foot muscle strength compared to traditional binary tests. This is vital for identifying individuals at risk of falls due to lower limb muscle weakness, as hallux grip strength is

correlated with overall foot and ankle muscle function and balance¹⁴. Additionally, the role of goniometers in physical therapy is highlighted, as they measure joint range of motion using fixed and adjustable arms aligned with the examined joint. Furthermore, diabetic peripheral neuropathy symptoms vary from none to complete foot numbness, emphasising the importance of early treatment due to the condition's prevalence¹⁵. This study compares the effects of regular foot care, foot intrinsic muscle exercises, and ankle mobility exercises on dynamic forefoot and hindfoot pressure, strength, and ankle dorsiflexion range of motion in diabetic peripheral neuropathy patients.

MATERIALS AND METHODS

The study was a one-year prospective, open-label, control and experimental design with pre- and post-tests in a tertiary care facility. The sample size was calculated using G Power 3.1 to achieve 90% power and 5% alpha error. Sample size estimations yielded 172 samples (each group 86) to achieve a significant between-group effect size with 95% confidence interval and 90% power at the 0.05 significance level. Considering the likelihood of 15% dropout rates ($n = 26$), 198 participants ($n = 99$ in each group) were needed to generate clinically meaningful between-group differences in both primary outcomes. The trial included 200 people, 100 in each group, since we sought a larger sample size than expected. After obtaining informed consent, 200 people with diabetic peripheral neuropathy were chosen based on the inclusion and exclusion criteria established.

A website called www.random.org generated 200 random numbers, which were split into 40 blocks of five. Allocation ratios and random number generation were carried out by an independent researcher who was not involved with the study facility.

The opaque envelope with group identification numbers concealed each five random number blocks separately. Roman letter I denoted group I, which received regular foot care. Group II was assigned Roman letter II for regular foot care, foot intrinsic muscle strengthening, and ankle mobility activities. The independent researcher who concealed the random numbers sent the research supervisor all 40 blocks in a large brown envelope. The investigator executed the respective treatments among 200 participants, who were equally distributed between two groups with a 1:1 allocation.

Men and women with type I or type II diabetes

mellitus who were clinically diagnosed with peripheral neuropathy with a Neuropathy disability score of 3 to 5 (Mild neuropathic), unilateral or more severe side, aged 40 to 70 years, and able to perform the exercises and visit the study setting at least three times per week for eight weeks were included. PEOD, structural foot skeleton deformities, poor balance and abnormal gait patterns, foot size below 7 and above 9, any lower limb musculoskeletal deformity, and chronic systemic illness due to untreated diabetes, like hyperkeratosis on feet, previous ulceration, retinopathy, nephropathy, etc., were excluded.

Both groups were informed about regular foot care, foot intrinsic muscle strengthening exercise, and ankle mobility exercises and their therapeutic and adverse effects before the therapies. All participants were instructed to disclose to the researcher if they felt significant pain or discomfort during treatment. All participants were assured they might stop therapy if they felt extreme pain or discomfort. Insole pressure sensors (Line Pro) assessed dynamic forefoot and hindfoot pressures, and EPGT and UG assessed FIMS and ADFROM. The measurement was obtained before and after 8 weeks of treatment.

Measurement of dynamic forefoot pressure (DFFP) & dynamic hind foot pressure (DHFP) by using insole pressure sensors

An in-sole foot pressure sensor from Linepro Controls Pvt. Ltd. dynamically measured forefoot and hindfoot pressure. This Linepro device uses a shoe-mounted electronic footbed with printed electronics for monitoring foot pressure. It has eight FSR: one in the toe, three in the metatarsals, one in the midfoot, and three in the heel. Foot sole pressure is examined to determine dispersion. Patients were forced to wear proper shoes and walk on a stiff floor. Microcontrollers processed the subject's foot pressure and sent it to a connected computer system in kilopascals. For foot sizes 7, 8, and 9, we used three insole fitting methods. The subjects received instructions to walk after fitting the insole sensor to their shoes.

Measurement of Foot intrinsic muscle strength by using the enhanced paper grip test

EPGT measured intrinsic foot muscular strength. This was done by connecting a digital dynamometer to the card being pulled. The test was done on a level, hard gait training floor.

Participants must remove their shoes and socks and sit on a stable armrest-free seat before the test. The plantar portion of each hallux was cleaned with a damp cloth. An established protocol was followed during skin drying. The card was placed under the hallux after desiccation. To ensure uniform card-floor contact, a standard A4 paper was placed to the floor under the subject's feet. As the examiner started the dynamometer to measure the highest pulling force, people were instructed to hold the card. Participants were told not to lift or slip their heels during the assessment. After fully removing the card from behind the hallux, the measurement ended. The card's greatest kilogram pulling force during testing was considered after it was removed. An introductory trial was followed by three EPGTs on each foot with at least 30 seconds of break. The average of these three measures was used by the EPGT to determine the final measurement for each foot.

Measurement of ankle dorsiflexion range of motion by using a goniometer

Subject position: Supine lying position with fully extended legs.

Therapist position: Therapist standing lateral to the ankle joint.

Position of axis: Lateral malleolus.

Position of the stationary arm: The stationary arm's position is extending in the direction of the fibular head.

Position of movable arm: The movable arm should be aligned with the long axis of the fifth metatarsal.

Procedure: Once the mobile arm was positioned by the examiner, the angle was documented. Subsequently, the subject was instructed to dorsiflex his ankle to the maximum extent possible, and this angle was also recorded.

Treatment Procedure

Those in group I received regular foot treatment. International Working Group on the Diabetic Foot recommendations advised regular foot care. Group II received routine foot care, foot intrinsic muscle strengthening, and ankle mobility exercises. Interventions were given for 8 weeks.

Foot intrinsic muscle strengthening exercises

The participant was taught to actively contract their foot by pulling the ball to the heel. This raises the foot arch, generating a dome and engaging arch-regulating

muscles. They must stay arched for 5 seconds. Allow the foot to return to its relaxed state. Consider this movement sequence a repetition. It should be done in three sets of 12-rep with a two-minute break. Perform this workout three times a week for eight weeks. Toes must stay grounded while raising the arch and not curling during the workout. As they get better, individuals can do the exercise standing and then in a single-limb stance.

Ankle mobility exercises

The ankle alphabet:

Moving the ankle and using the great toe as a “pen” to draw the alphabet one letter at a time while sitting on the chair with the heel edge on the floor was instructed. The subject must repeat the alphabet (A-Z) twice in three sessions per week for eight weeks.

Seated heel rise:

Participants sat with their affected feet flat. They told them to raise the heel as high as possible with the toes on the ground and then lower it. The person must do two sets of 10–15 repetitions three times a week for eight weeks.

Seated toe rise:

Participants are advised to elevate their toes as far as possible while keeping their heel on the ground, then drop them to the floor while sitting with the affected foot on the ground. The person must do two sets of 10–15 repetitions three times a week for eight weeks.

Calf stretching

The individual must face a wall with their hands on the wall at shoulder height. Place the affected foot behind the unaffected foot and keep the back leg heel on the ground. Ask the participant to lean forward against a wall until the calf stretches, hold for 30 seconds, and repeat. The participant must execute two sets of ten repetitions twice per session, three times per week, for eight weeks.

RESULTS

In DPN patients, DFFP ratings are significantly lower after regular foot care (291.06 ± 2.69) than the pretest values (298.71 ± 2.81). Similarly, the pretest (298.33 ± 2.9) and post-test values (261.6 ± 2.77) of the regular foot care combined with foot intrinsic muscle strengthening and ankle mobility exercise were statistically significant ($p < 0.001$). The intergroup

comparison of post-test findings also revealed a statistically significant difference ($p < 0.001$) (Table 1).

Table 2 illustrates that the DPN patients' DHFP scores improve considerably after regular foot care and regular foot care combined with foot intrinsic muscle strengthening exercise and ankle mobility exercise. The intragroup comparison of the pretest and post-test values of group I were 215.62 ± 2.88 and 212.65 ± 2.37 , respectively, and that of group II was 215.87 ± 3.03 and 199.89 ± 2.83 , respectively. This intragroup difference observed in both groups was found to be statistically significant. The intergroup comparison of posttest findings also revealed a statistically significant difference ($p < 0.001$)

Further, the foot intrinsic muscle strength scores improve considerably after regular foot care (1.926 ± 0.55), as well as regular foot care combined with foot intrinsic muscle strengthening and ankle mobility exercise (2.672 ± 0.63) (Table 3). The intergroup comparison of post-test findings revealed a statistically significant difference ($p < 0.001$). The pretest values of group I and group II were 1.164 ± 0.48 and 1.215 ± 0.51 , respectively. The intragroup comparison of the pretest and post-test values of groups I and II were found to be statistically significant ($p < 0.001$).

Similarly, the ankle dorsiflexion ROM scores improve considerably after regular foot care, as well as regular foot care combined with foot intrinsic muscle strengthening and ankle mobility exercise (Table 4). The pretest values of group I and group II were 8.69 ± 2.65 and 8.82 ± 2.73 , respectively. The post-test values of group I and group II were 13.67 ± 2.11 and 17.22 ± 2.84 , respectively. The intragroup comparison of the pretest and post-test values of groups I and II were found to be statistically significant ($p < 0.001$). The intergroup comparison of post-test findings revealed a statistically significant difference ($p < 0.001$).

DISCUSSION

The study examined the effects of regular foot care (Group I) and regular foot care combined with foot intrinsic muscle strengthening and ankle mobility exercises (Group II) on dynamic forefoot and hindfoot pressure in patients with diabetic peripheral neuropathy using insole pressure sensors [7–9]. To maintain homogeneity, patients with poor balance and abnormal gait patterns were carefully identified and excluded from the study [10]. Additionally, three types of insole



fittings corresponding to foot sizes 7, 8, and 9, which are common among adult Indians, were used.

Foot pressure has been strongly associated with diabetic peripheral neuropathy (DPN) [11–13]. Previous research by Unver et al. [16] conducted in a biomechanics laboratory demonstrated that short-foot exercises significantly improved outcomes in patients with pes planus over a six-week period. The study reported reductions in pain, disability, Foot Posture Index, and navicular drop scores, along with increased maximal plantar force in the midfoot region. In contrast, the sham exercise group did not show significant improvements. Overall, short-foot exercises effectively reduced disability, foot pronation, and foot pain while enhancing medial midfoot plantar pressure. Similarly, Shin et al. [17] reported that foot-strengthening exercises combined with functional insoles improved joint angles and plantar pressure distribution in elderly women more effectively than exercises alone. Although reductions in peak plantar pressures were not completely achieved, improved plantar pressure distribution across the foot was observed. These interventions were suggested to enhance muscle activation, gait performance, and joint stability. Monteiro et al. [18] further demonstrated that a 12-week foot–ankle exercise program in patients with DPN resulted in increased hip extension during push-off, elevation of plantar arches, and improved plantar pressure distribution during walking compared with standard care.

Research indicates that foot intrinsic muscle strength and morphology deteriorate with ageing [19]. Reduced foot intrinsic muscle strength in older adults is associated with impaired postural stability and an increased risk of falls [19,20]. A study published in the *Clinical Interventions in Aging* journal found that older adults aged 60–75 years had significantly lower foot muscle strength, including reduced doming ability and diminished toe and ankle muscle strength [20]. These findings emphasise the importance of incorporating intrinsic foot muscle exercises into geriatric rehabilitation programs to preserve or improve foot function and stability. Such exercises have been

shown to improve balance, reduce self-perceived disability, decrease navicular bone drop, and improve Foot Posture Index scores, although pain reduction may not always be significant [20,21]. Furthermore, foot intrinsic muscle exercises can improve outcomes related to lower extremity injuries by enhancing strength, balance, motor performance, sensory function, and subjective assessments of pain and disability in clinical populations [21,22].

Okamura et al. [21] observed that short-foot exercises improved foot alignment and reduced walking time in individuals with pes planus, indicating enhanced windlass mechanism function. Backman et al. [22] discussed how limitations in ankle dorsiflexion can contribute to lower extremity injuries and compensatory movement patterns, potentially leading to conditions such as plantar fasciitis. Macklin et al. [23] reported that calf muscle stretching significantly improved ankle dorsiflexion range and dynamic plantar pressures. During the present study, challenges were encountered while teaching short-foot exercises to elderly participants; these difficulties were addressed by simplifying instructions and incorporating visual aids for better understanding and performance [24,25].

The study had several limitations, including a short study duration and the inability to perform long-term follow-up assessments [26]. Only individuals between 40 and 70 years of age were included in the study. Future longitudinal studies using similar variables are recommended [26,27]. Additionally, more advanced pressure-measuring technologies may be utilised in future investigations for enhanced accuracy and analysis [27].

CONCLUSION

In DPN patients, the management of dynamic forefoot and hindfoot pressures, foot intrinsic muscle strength, and ankle dorsiflexion range of motion is more effective when regular foot care is combined with foot intrinsic muscle strengthening exercise and ankle mobility exercise than when regular foot care is performed alone.

Table 1: Comparison of mean values of DFFP among group I and group II subjects

	Group I	Group II	Mean difference	Unpaired t-test	p-value
Pre test	298.71±2.81	298.33±2.9	0.38	0.94	0.35
Post test	291.06±2.69	261.6±2.77	29.46	76.30	<0.001**
Mean difference	7.65	36.73			
Paired t-test	19.66	91.59			
p-value	<0.001**	<0.001**			

Table 2: Mean difference value of DHFP among group I and group II subjects

	Group I	Group II	Mean difference	Unpaired t-test	p-value
Pre test	215.62±2.88	215.87±3.03	-0.25	-0.60	0.55
Post test	212.65±2.37	199.89±2.83	12.76	34.57	<0.001**
Mean difference	2.97	15.98			
Paired t-test	7.96	38.54			
p-value	<0.001**	<0.001**			

Table 3: Mean difference of FIMS among group I and group II subjects

	Group I	Group II	Mean difference	Unpaired t-test	p-value
Pre test	1.164±0.48	1.215±0.51	-0.05	-0.73	0.47
Post test	1.926±0.55	2.672±0.63	-0.75	-8.92	<0.001**
Mean difference	-0.76	-1.46			
Paired t-test	-10.44	17.97			
p-value	<0.001**	<0.001**			

Table 4: Mean difference values of ADROM across group I and group II subjects

	Group I	Group II	Mean difference	Unpaired t-test	p-value
Pre test	8.69±2.65	8.82±2.73	-0.13	-0.34	0.73
Post test	13.67±2.11	17.22±2.84	-3.55	-10.03	<0.001**
Mean difference	-4.98	-8.4			
Paired t-test	-14.7	-21.32			
p-value	<0.001**	<0.001**			

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