Research Paper

Effects of Weight-bearing Exercise on a Mini-trampoline, and Foot-ankle Therapeutic Exercise Program on Foot-ankle Functionality in People With Diabetic Peripheral Neuropathy

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ABSTRACT

Purpose: This study aims to investigate and compare the efficacy of two training programs of weight-bearing on a mini-trampoline, and ankle exercise therapy on foot-ankle functionality in people with peripheral neuropathy.

Methods: The present research is a clinical trial study that has been conducted using two intervention groups and one control group. The statistical population of this study includes 48 women living in Tehran City, Iran with type 2 diabetes and moderate or severe neuropathy. The Michigan neuropathy screening instrument (MNSI) and foot health status questionnaire (FHSQ-BR) were used to collect data. The first experimental group performed mini-trampoline exercises, while the second group performed ankle therapeutic exercises at home for eight weeks. Data were analyzed using analysis of covariance (ANOVA) and correlated t-test.

Results: The findings showed that mini-trampoline exercise and ankle exercise therapy had a significant effect on relieving foot pain ($P<0.05$), as well as improving foot functionality ($P<0.05$) and overall foot health ($P<0.05$) in both intervention groups compared to the control group. Also, the results showed that ankle exercise therapy was more effective than mini-trampoline exercise in two variables of foot pain and foot functionality ($P<0.05$). Both training programs showed significant effects on the ankle range of motion ($P<0.05$), while, no significant difference was observed between the two intervention groups for the range of motion of the ankle ($P<0.05$). Moreover, mini-trampoline exercise and ankle exercise therapy revealed a significant effect on the range of motion of the metatarsophalangeal joints compared to the control group ($P<0.05$). In the range of motion of dorsiflexion of the right foot, mini-trampoline exercises were more effective than therapeutic exercises, while regarding the variable of dorsiflexion of the left foot, the effectiveness of ankle training intervention was more than trampoline ($P<0.05$). Both trampoline exercise and ankle therapeutic exercise interventions had a significant effect on ankle strength, but no difference was observed in plantar flexion strength of the right foot between the two

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intervention groups. However, the mini-trampoline intervention was more effective than the ankle exercise therapy intervention for the three variables of the hallux dorsiflexion strength of the hallux and plantar flexion strength of the left foot (P<0.05). Both training interventions were effective on the variable of right and left hallux flexion strength (P<0.05). The efficacy of none of the two interventions on the right and left hallux extension strength was confirmed; the effectiveness of both interventions on the right and left hallux flexion strength was similar and no significant difference was observed (P>0.05). No significant difference was found in the control group after 8 weeks for the relevant variables (P>0.05).

Conclusion: Exercises on the mini-trampoline and ankle therapeutic exercises at home can be effective in improving patients' quality of life as a simple, affordable, low-risk, and quick-improvement treatment program that focuses on the use of segmental exercises for foot functionality.

Highlights

• The result showed that foot-ankle therapeutic exercise program plays a significant role in reducing musculoskeletal dysfunctions in diabetic peripheral neuropathy patients.

• Weight-bearing exercise on a mini-trampoline showed significant effect on overall foot health in people with diabetic peripheral neuropathy.

• Ankle exercise therapy was more effective than mini-trampoline exercise in two variables of foot pain and foot functionality.

• Ankle range of motion, first metatarsophalangeal joint range of motion, ankle strength and hallux strength showed significant changes in patients with diabetic peripheral neuropathy.

• No significant changes was observed for the hallux extension/flexion strength variables in two weight-bearing exercise on a Mini-trampoline, and foot-ankle therapeutic exercise program in people with diabetic peripheral neuropathy.

• We recommend therapeutic exercise programs for foot health and enhance quality of life in diabetic peripheral neuropathy patients.

Plain Language Summary

Diabetic peripheral neuropathy is a common diabetes complication that affects 40-50% of diabetics, causing severe pain, one or both feet numbness, foot ulcers, and an increased risk of having their foot amputated at the ankle or below knee level. Exercise therapy, including mini-trampoline workouts and an ankle rehabilitation exercise program, are discussed in this study which can lead to improved sole mobility, ankle, and toe spectrum of movements, and foot muscle strength.

1. Introduction

Diabetes is the most common endocrine disease, one of the leading causes of death in most countries, and unquestionably one of the most pressing health issues in the world today [1-3]. Diabetes causes a broad spectrum of complications. The most common long-term complication of this disease is peripheral neuropathy. According to the national diabetes information center, more than 50% of those with diabetes have some form of neuropathy, even if they have no symptoms. Diabetic peripheral neuropathy (DPN) is a neurological disorder that affects the sensitivity and excitability of the nerves of the feet and hands [4, 5] resulting in a stabbing or burning sensation, numbness, and tingling in lower limbs [6-8]. Foot disorders are the main problem related to diabetic neuropathy, leading to a significant deal of pain and social costs for patients [9, 10]. Numbness in one or both feet is frequently the early symptom. Therefore, people with DPN are more likely to develop foot ulcers and are at a higher risk of having their foot amputated at the ankle or below knee level [11].

DPN also causes musculoskeletal dysfunction due to sensory-motor disorders which include changes in the joints surrounding the tissues, as well as a decrease in function and strength of feet due to atrophy of the inner lower foot muscles. Furthermore, it causes decreased mobility of the ankle and the first metatarsophalangeal joint, which can result in high plantar pressure under the metatarsal heads and loss of function of the toes, particularly the big toe. These effects are the primary contributors to the formation of deformities and high pressures on the soles of the feet, which affect the stability of foot dynamics and cause changes in the biomechanics of walking, such as a reduction in walking speed and ankle dorsi and plantar flexion, as well as a decrease in torque force around the ankle joint, a delay in muscle activation in the legs and thighs, and an increase in torque force in the hip joint [7]. As a result of these changes, patients with DPN typically exhibit more disturbance in posture and walking, along with difficulties performing daily activities [12, 13].

A growing body of evidence supports the impact of exercise on neuropathy management. Exercise improves glucose control and increases insulin sensitivity throughout the body. It lowers circulating fat levels, stimulating angiogenesis and increasing perfusion, physical performance, and balance, and lowering depression, anxiety, and the risk of falling in DNP patients [14]. Strength, stretching, balance, and resistance training programs have been shown to improve muscle strength, endurance, and flexibility, and can lead to increased range of motion (ROM) and muscle strength [15-19].

Proper foot and ankle exercises are among the other appropriate exercises investigated in this study. On the one hand, these exercises have beneficial results in reducing negative factors of diabetic foot pathogenesis and may lead to increased nerve speed of the lower limbs and muscle strengthening, improved ROM of the ankle, redistributed sole and plantar pressure during walking, and as a result, a better physiological pattern. More positive effects, such as increased skin sensitivity and intraepidermal nerve fiber density can be achieved by performing appropriate ankle exercises in diabetic patients, which can delay the usual process of DPN, skin damage, and wounding [20].

On the other hand, increased weight-bearing activities can result in increased pressure on the soles of the feet and, as a result, foot ulcers. Therefore, the American Diabetes Association advises people with diabetic neuropathy to exercise properly and to limit activities that require bearing body weight. Trampoline exercise has recently been shown to improve balance control in the elderly [21], as well as athletic performance, rehabilitation, injury recovery, and foot function in athletes with ankle instability [22].

Exercises on the mini-trampoline and ankle therapeutic exercises at home can be effective in improving patients' quality of life as a simple, affordable, low-risk, and quick-improvement treatment program that focuses on the use of segmental exercises for foot function. However, to our knowledge, no earlier study has been conducted to evaluate the effects of a foot and ankle treatment program capable of personalizing special foot treatment exercises at home aimed at preventing and treating musculoskeletal defects and complications in patients with diabetic neuropathy. Therefore, more research in this field is required to strengthen the level of evidence based on the use of specific ankle therapeutic exercises to reduce risk factors and prevent further complications.

Thus, this study aims to examine whether providing appropriate solutions based on therapeutic strategies for musculoskeletal abnormalities related to DPN, including self-care instructions and home exercises (ankle therapeutic exercises and weight-bearing exercises on a mini-trampoline), can improve the health and performance of the foot and ankle ROM.

2. Materials and Methods

The current study is a clinical trial study with two experimental groups and one control group. The statistical population of this study includes 48 women who suffered from type 2 diabetes for at least 7 years with an average age of 50 to 65 years and a history of moderate or severe peripheral neuropathy with decreased sensation in the feet that had been previously diagnosed by a medical doctor. The sample size was estimated using G Power software. The software was programmed with the assumption of a large effect size (80%), at a level of 5% error probability and 95% power. The total sample size calculated by the software for three groups was 48 people with 16 subjects in each group. This study was conducted at the Parsian diabetes clinic in Tehran.

After receiving informed consent, volunteers who met the eligibility criteria were randomly assigned into two intervention groups and one control group. During the exercise intervention period, all three groups received foot care training and medical team recommendations, which included, foot hygiene, daily washing and careful drying of the feet, especially between the toes, use of non-elastic and seamless socks, trimming the nails in a square shape, preventing unsupervised removal of calluses or blisters, not wearing shoes or slippers without socks, and seeking medical attention if problems with the feet are discovered. During the study, subjects in all three groups did not receive any other concurrent care, such as physiotherapy, acupuncture, or any other non-conventional medical intervention. Cramping, moderate to severe pain, fatigue, dizziness, fear, or any condition that exposed the patient to discomfort were all reasons for stopping the session.

To validate the training protocols, all participants underwent two measurement sessions (before and after the intervention) to measure the flexion and extension angles of the first metatarsophalangeal joint with a goniometer, the ROM of the ankle with an electro goniometer, and the isometric strength of the foot with a hand-held dynamometer. The researcher performed all measurements in the presence of a medical doctor and physiotherapist.

Research instruments

All participants completed the Brazilian version of the Michigan neuropathy screening instrument (MNSI) questionnaire to determine the presence of DPN. In this research, the Brazilian-Portuguese version of the foot health status questionnaire (FHSQ-BR) was used to assess foot health [23, 24]. Flexion and extension angles (first) ([metatarsophalangeal joints] MTPJ) were measured with a goniometer using the dynamic ROM measurement method. For analysis, the mean values of three maximum flexion and maximum extension records were calculated [14]. An electro-goniometer (model DSI [Danesh Salar Iranian]) with a measurement accuracy of 1 degree was used to evaluate the ROM of the ankle flexion and extension, and the mean scores of three records of maximum flexion and maximum extension were calculated for analysis [23, 24]. The strength peak muscle force (kg) was measured by a maximum isometric voluntary contraction in ankle dorsi and plantar flexion and hallux dorsi and plantar flexion using a hand-held push-pull dynamometer. Each muscle group should be tested with a 3-5 s contraction. Three repetitions were performed for each foot muscle group, with a minimum of 10 s of rest between each, and the mean scores of three measurements were used for data analysis [25, 26].

Exercise protocols

The first experimental group exercised on a mini-trampoline at home [14]. The mini-trampoline training program consisted of four levels of progression over eight weeks. The participants were instructed to perform each exercise with 10 repetitions for two weeks, at least three times per week, and hold the position for up to 10 s in static exercises. The exercise program was performed daily in three sets with 5-minute rest intervals between them. To warm up and cool down, participants were asked to stretch quadriceps, hamstrings, biceps, and soleus muscles. Each muscle was stretched 3 times with a 20 s rest between each. In addition, the participants were asked to wear appropriate footwear and inspect their feet after the exercises. Discontinuation criteria for each session included cramping, moderate to severe pain, fatigue, dizziness, or any condition that exposed the patient to any discomfort [14].

The ankle exercise-therapy program was carried out by the second experimental group. This program included exercises to strengthen the internal and external foot and ankle muscles [27]. Six exercises were performed, four exercises for the inner foot muscles and two exercises for the outer foot and ankle muscles. Exercises were done using tools, such as cotton ball, pencils, balls, and chairs. The interphalangeal, metatarsophalangeal, and ankle joints were targeted in this protocol, with emphasis on the following muscle groups, medial plantar side (abductor hallucis, flexor hallucis brevis, and adductor hallucis), lateral plantar side (abductor digiti minimi, flexor digiti minimi, and opponens digiti minimi), median plantar side (flexor digitorum brevis, quadratus plantar, lumbrical muscle, plantar interosseous muscle, and dorsal interosseous muscle) and dorsal plantar side (extensor digitorum brevis, and extensor hallucis brevis). Foot exercises were performed first in a sitting position and one set of 30 repetitions, then in a standing position and standing on one foot if the exercise was very simple for the patient. In addition, after completing the exercises, the patient could complete a table indicating the perceived exertion using a Likert scale. If the exertion scale was between 0 and 5, the individual should progress to the next stage of the exercise for the next session (e.g. from sitting to standing or using a different tool). If the exertion scale was between 6 and 8, the exercise volume and intensity level should be maintained. If the exertion level was between 9 and 10, the number of repetitions should be reduced or the position should be modified (for example, switching from a standing position to a sitting one). This program was followed by the participants for eight weeks, three times a week and a total of twenty-four sessions.

Statistical analysis

The analysis of the covariance (ANCOVA) test was used to assess the efficacy of mini-trampoline exercise and ankle exercise therapy and interventions. The pre-test score of the groups was considered as a covariance or control variable in this test, and its effect was neutralized. The post-hoc comparison test of Bonferroni was also used to compare the post-test of three groups. The pre and post-test times for each group's mean scores were compared separately using a paired or paired t-test. SPSS software, version 27 was used to analyze the data.

3. Results

Table 1 presents the characteristics of the current research participants, including age, height, weight, body mass index, history of diabetes, duration of neuropathy, and hemoglobin A1c (HBA1C) (P>0.05).

Table 2 presents the results of ANCOVA used to investigate and compare the effectiveness of both mini-trampoline exercise and ankle exercise therapy interventions on foot mobility.

The results of ANCOVA revealed that mini-trampoline exercise and therapeutic exercise interventions were significantly effective on plantar mobility at a confidence

Table 1. Descriptive statistics of research participants (n=16)

Indication	Groups	Mean±SD	P
Age (y)	Control	57±5.26	0.47
	Mini-trampoline	56.93±4.12	
	Exercise therapy	58.75±4.62	
Height (m)	Control	1.64±0.40	0.11
	Mini-trampoline	1.67±0.5	
	Exercise-therapy	1.65±0.4	
Weight (kg)	Control	59.18±4.53	0.54
	Mini-trampoline	60.06±5.11	
	Exercise-therapy	60.87±3.07	
Body mass index (kg/m²)	Control	21.94±2.16	0.74
	Mini-trampoline	22.2±2.19	
	Exercise-therapy	21.7±0.98	
History of diabetes (y)	Control	8.43±1.36	0.18
	Mini-trampoline	9.37±1.89	
	Exercise-therapy	8.56±1.31	
DPN	Control	4±0.69	0.18
	Mini-trampoline	4.06±0.77	
	Exercise-therapy	4.2±0.94	
HBA1c	Control	8.37±0.8	0.71
	Mini-trampoline	8.5±0.96	
	Exercise-therapy	8.37±0.77	

DPN: Diabetic peripheral neuropathy; HBA1c: Hemoglobin A1c.

PHYSICAL TREATMENTS

Table 2. Comparing the effectiveness of both mini-trampoline exercise and ankle exercise therapy on foot functionality with ANCOVA and post hoc test

Variables	Groups	Mean±SD		T-test	ANCOVA		
		Pre-test	Post-test	P	F	P	η²
Foot pain	Control	40.12±9.81	40.43±10.49	0.064	42.93	0.000	0.66
	Mini-trampoline	43.06±4.31	50.06±5.29[b]	0.000			
	Exercise-therapy	38.75±9.78	47.81±10.16[a*]	0.000			
Foot functionality	Control	43.18±8.68	44.62±5.08	0.071	32.98	0.000	0.60
	Mini-trampoline	47.12±8.17	58±7.52[b]	0.001			
	Exercise-therapy	43.31±6.03	59.65±7.97[a]	0.001			
General foot health	Control	51.81±8.17	52.50±8.56	0.140	29.54	0.000	0.57
	Mini-trampoline	48.75±11.46	53.06±11.11	0.001			
	Exercise-therapy	48.56±12.43	52.50±12.09	0.001			

[a, b]Effectiveness of the two intervention methods, [a] A more effective intervention at 95% confidence. PHYSICAL TREATMENTS

ANCOVA: Analysis of covariance.

level of at least 95% (P<0.05) (Table 2). Also, the paired t-test results revealed a difference between the pre-test and post-test mean scores in the two intervention groups for all variables listed in Table 2 (P<0.05), but no significant difference was found in the control group between the pre-test and post-test mean scores (P>0.05). Post hoc Bonferroni test showed that therapeutic exercise intervention was more effective than mini-trampoline intervention regarding two variables of foot pain and foot functionality (P<0.05).

Table 3. Comparing the efficacy of interventions on ankle range of motion with ANCOVA and the post hoc test

Variables	Groups	Mean±SD		T-test	ANCOVA		
		Pre-test	Post-test	P	F	P	η²
Dorsiflexion ROM of the right foot	Control	9.50±1.75	9.75±1.69	0.161	36.35	0.000	0.62
	Mini-trampoline	9.87±1.99	12.12±1.98	0.000			
	Exercise-therapy	10.25±2.23	12.50±2.06	0.000			
Dorsiflexion ROM of the left foot	Control	9.62±2.12	9.87±2.02	0.209	30.02	0.000	0.57
	Mini-trampoline	10.06±1.87	11.75±1.48	0.000			
	Exercise-therapy	10.18±2.04	12.50±1.75	0.000			
Plantar flexion ROM of the right foot	Control	31.81±2.94	32.31±2.75	0.052	42.25	0.000	0.65
	Mini-trampoline	32.87±3.46	35.56±2.87	0.000			
	Exercise-therapy	34.06±2.67	37.37±2.27	0.000			
Plantar flexion ROM of the left foot	Control	31.93±2.74	32.31±2.75	0.009	30.99	0.000	0.58
	Mini-trampoline	33.06±3.25	35.62±2.75	0.000			
	Exercise-therapy	33.68±2.93	37.06±3.12	0.000			

ROM: Range of motion; ANCOVA: Analysis of variance. PHYSICAL TREATMENTS

Table 4. Comparing the effectiveness of interventions on the range of motion of the first metatarsophalangeal joint based on analysis of covariance and post hoc test

Variables	Groups	Mean±SD		T-test	ANCOVA		
		Pre-test	Post-test	P	F	P	η²
Dorsiflexion ROM of the right foot	Control	24.50±2.98	24.87±2.89	0.079	56.73	0.000	0.72
	Mini-trampoline	24.12±3.99	49.3±75.26[a]	0.000			
	Exercise-therapy	23.50±75.3	27.62±3.09[b]	0.000			
Dorsiflexion ROM of the left foot	Control	24.25±2.88	24.25±2.8	0.104	58.21	0.000	0.72
	Mini-trampoline	24.06±3.82	26.75±3.85[b]	0.000			
	Exercise-therapy	23.50±3.57	27.18±3.54[a]	0.000			
Plantar flexion ROM of the right foot	Control	35.50±1.21	35.65±1.19	0.178	20.77	0.000	0.48
	Mini-trampoline	35.12±3.80	36.87±1.2	0.000			
	Exercise-therapy	35.25±1	37±1.03	0.000			
Plantar flexion ROM of the left foot	Control	35.56±1.26	35.75±1.23	0.332	44.25	0.000	0.66
	Mini-trampoline	35.25±0.77	37.31±0.87	0.000			
	Exercise-therapy	35.31±0.87	37.50±1.03	0.000			

[a, b]Effectiveness of the two intervention methods, [a] A more effective intervention at 95% confidence. PHYSICAL TREATMENTS

Abbreviations: ROM: range of motion; ANCOVA: analysis of variance.

Table 3 presents the results of ANCOVA used to investigate and compare the effectiveness of mini-trampoline interventions and ankle exercise therapy on ankle range of motion.

The results of ANCOVA demonstrated that mini-trampoline and ankle exercise therapy interventions were significantly effective on the ankle range of motion at the 95% confidence level (P<0.05) (Table 3). Furthermore, the paired t-test results revealed a difference between the pre-test and post-test mean scores in the two intervention groups for all variables mentioned in Table 3 (P<0.05), while no significant difference was observed between the pre and post-test mean scores in the control group (P>0.05). The post hoc Bonferroni test showed no difference in the effectiveness of the two interventions on ankle range of motion (P<0.05).

Table 4 presents the results of ANCOVA used to investigate and compare the effectiveness of mini-trampoline interventions and ankle exercise therapy on the range of motion of the first metatarsal joint.

The results of ANCOVA revealed that, at a confidence level of at least 95%, both mini-trampoline and ankle therapeutic exercise interventions were effective on the first metatarsophalangeal joint's range of motion (P<0.05) (Table 4). In addition, the paired t-test results showed a difference between the pre and post-test mean scores in the two intervention groups for all variables listed in Table 4 (P<0.05). However, no significant difference was observed between the pre-test and post-test mean sores in the control group (P>0.05). The Bonferroni's post hoc test revealed that the mini-trampoline intervention was more effective than the ankle therapeutic exercise regarding the variables of dorsiflexion ROM of the both right and left foot (P<0.05).

Table 5 presents the results of ANCOVA to investigate and compare the effectiveness of mini-trampoline exercise and ankle exercise therapy interventions regarding the range of ankle strength.

The results of ANCOVA showed that at the confidence level of at least 95%, two mini-trampoline interventions and ankle therapeutic exercise were significantly effective on ankle strength variables (P<0.05) (Table 5). Also, the results of the paired t-test showed a difference between the pre-test and post-test mean scores in both intervention groups in all the variables listed in Table 5 (P<0.05). In the control group, the pre-test and post-test mean values were not significantly different except for one variable (Dorsiflexion strength of the left foot)

Table 5. Comparing the effectiveness of ankle strength interventions with ANCOVA and the post hoc test

Variables	Groups	Mean±SD		T-test	ANCOVA		
		Pre-test	Post-test	P	F	P	η^2
Dorsiflexion strength of the right foot	Control	5.58±1.98	5.28±1.85	0.109	34.47	0.000	0.61
	Mini-trampoline	6.24±1.56	7.91±1.57[a]	0.000			
	Exercise-therapy	5.56±1.67	6.58±1.43[b]	0.000			
Dorsiflexion strength of the left foot	Control	5.82±2.07	6.23±2.08	0.002	20.24	0.000	0.47
	Mini-trampoline	6.34±1.52	8.28±1.51[a]	0.000			
	Exercise-therapy	5.83±1.46	6.96±1.48[b]	0.000			
Plantar flexion strength of the right foot	Control	9.22±1.96	9.47±2.15	0.068	13.25	0.000	0.37
	Mini-trampoline	10.65±1.62	12.76±1.72	0.001			
	Exercise-therapy	9.73±2.08	11.09±2.30	0.001			
Plantar flexion strength of the left foot	Control	9.27±1.99	9.53±1.98	0.054	26.38	0.000	0.54
	Mini-trampoline	10.51±1.73	12.8±1.72[a]	0.000			
	Exercise-therapy	9.73±1.96	11.07±2.1[b]	0.000			

[a, b]Effectiveness of the two intervention methods, [a] A more effective intervention at 95% confidence.

PHYSICAL TREATMENTS

ANCOVA: Analysis of variance.

(P>0.05). The post hoc Bonferroni test showed no difference between the two intervention groups in the plantar flexion strength of the right foot, but in the three variables of the dorsiflexion strength of the right and left foot and the plantar flexion strength of the left foot, the mini-trampoline intervention was more effective than the ankle exercise therapy intervention (P<0.05).

Table 6 presents the results of ANCOVA to investigate and compare the effectiveness of mini-trampoline exercise and ankle exercise therapy interventions on the strength of the hallux.

The results of ANCOVA showed that at the confidence level of at least 95%, both mini-trampoline exercise and ankle therapeutic exercise interventions were significantly effective on the two variables of the hallux strength (P<0.05) (Table 6). The efficacy of any of the two interventions for right and left hallux extension strength was not confirmed (P>0.05). The paired t-test results revealed a difference in both intervention groups' pre and post-test mean scores in the right and left hallux flexion strength (P<0.05). However, no significant difference was observed between the pre and post-test mean scores in the control group (P>0.05). Post hoc Bonferroni test showed that the effectiveness of both interventions on the strength variables of the hallux was similar and no significant difference was observed (P>0.05).

4. Discussion

The findings showed that weight-bearing exercises on the mini-trampoline and ankle exercise therapy program in the interventional groups compared to the control group resulted in a significant improvement in foot sole mobility, ankle ROM, first metatarsophalangeal joint ROM, isometric strength of ankle dorsiflexion and plantarflexion and hallux dorsiflexion and plantarflexion. These results were consistent with the results of studies conducted by other researches [14, 24, 29, 30].

Kanchanasamut et al. (2017) investigated the effect of a weight-bearing exercise program on a mini-trampoline on foot mobility, plantar pressure, and sensation in diabetic foot neuropathy. This study included 24 patients with diabetic neuropathy in one control and two experimental groups. The control group only received the foot care program, while the experimental group participated in exercises for eight weeks. The results showed that weight-bearing exercises for eight weeks improve the perception of vibration [14].

Table 6. Comparing the effectiveness of mini-trampoline exercise and ankle exercise therapy interventions on the strength of the hallux strength based on ANCOVA and post hoc bonferroni test

Variables	Groups	Mean±SD		T-test	ANCOVA		
		Pre-test	Post-test	P	F	P	η^2
Strength of the right hallux flexors	Control	4.04±1.27	4.18±1.49	0.109	14.35	0.000	0.39
	Mini-trampoline	3.39±0.77	4.02±0.71	0.000			
	Exercise-therapy	3.16±0.66	3.94±0.65	0.000			
Strength of the left hallux flexors	Control	3.47±1.10	3.57±1.12	0.432	14.84	0.000	0.40
	Mini-trampoline	2.89±0.78	3.58±0.85	0.000			
	Exercise-therapy	2.94±6.65	3.89±0.62	0.000			
Strength of the right hallux extensors	Control	2.52±1.10	2.89±1.18	0.000	2.23	0.188	0.09
	Mini-trampoline	2.19±0.85	2.82±0.83	0.000			
	Exercise-therapy	2.43±0.90	2.99±0.88	0.000			
Strength of the left hallux extensors	Control	2.71±0.95	2.95±0.98	0.000	2.52	0.092	0.1
	Mini-trampoline	2.47±0.84	2.94±0.96	0.000			
	Exercise-therapy	2.91±1.03	3.40±1.04	0.000			

ANCOVA: Analysis of variance.

PHYSICAL TREATMENTS

Sartor et al. (2014) analyzed the effect of functional, strengthening, and stretching exercises on foot function in patients with diabetic neuropathy. A total of 55 patients with diabetic neuropathy participated in this research. The control group received medication, as well as medical care, and foot care instructions, and the experimental group performed exercises for 12 weeks. The results revealed changes in the rocking motion of the foot during walking, improved distribution of plantar pressure, and better functional status of the ankle [28].

The study entitled “exercise therapy improves plantar pressure distribution in patients with diabetic peripheral neuropathy” conducted by Fayed et al. (2016) included forty women with DPN. The control group received treatment and medical care, while the experimental group received medical treatment as well as physiotherapy interventions and stretching, strengthening, balance, and walking exercises. The findings demonstrated that physiotherapy intervention can significantly prevent the occurrence of diabetic ulcers in patients with diabetic neuropathy. The outstanding changes in this study were supported by pressure distribution, peak plantar pressure, and foot contact area [29].

Cerrahoglu et al. (2016) evaluated the effect of ROM and plantar pressure on diabetic patients with and without neuropathy on foot care exercises. The study included 76 diabetic patients, and the exercise groups followed their respective training programs for four weeks. The findings demonstrated that a home exercise program can be an effective preventive method to improve ROM in the foot joints and plantar pressure distribution in diabetic patients, regardless of the presence or absence of neuropathy [30].

All previous studies have shown that exercise programs and treatment protocols are effective in improving musculoskeletal health, balance, preventing further complications, and increasing patients’ independence in performing daily activities. However, the mentioned exercises typically target larger joints and lower limb muscles, with a primary focus on walking training, whereas both protocols in the current study target musculoskeletal defects of distal and smaller joints and muscles, as well as intrinsic and extrinsic muscles which are the most damaged in neuropathic patients and their functions and biomechanics are affected under dynamic conditions. In neuropathy patients, movement disorders in the distal muscles are seen with a 15%-20% decrease in the maximum ankle isokinetic moment, as well as atrophy of the inner foot muscles. In addition, the greater the plantar overload under the corresponding part during walking, the lower the lateral mobility of the forefoot in the first metatarsophalangeal joint, inversion, and eversion of the subtalar joint. As a result, the target of the relevant exercise protocols in the present study was the interphalangeal, metatarsophalangeal, ankle joints, and muscle groups on the medial plantar side, lateral plantar side, median plantar side, and dorsal plantar side, which resulted in increased mechanical properties of the calcaneal tendon, reduced foot fat, increased isometric muscle strength of the toes and hallux, increased the ankle extensor torque and strength, increased the ROM of the ankle in the sagittal plane, increased the conduction speed of the peroneal motor nerve and the sural sensory nerve, reduced plantar numbness, expanded peripheral microvasculature and changed vascular function, as well as improved sensory and motor afferent function [14, 15, 17, 18, 20]. As a result, mini-trampoline and ankle therapeutic exercises can be used as a simple, affordable, low-risk, and quick-improvement treatment program that focuses on the integration of peripheral strengthening using segmental exercises for foot function, which improves diabetic patient's quality of life.

5. Conclusion

According to the findings, the exercise protocols used in this study, which were completely focused on the musculoskeletal dysfunction caused by DPN, can be effective in reducing musculoskeletal dysfunctions caused by this problem, and included in patients' daily activities as a self-care strategy to minimize the harmful consequences of DPN.

Study limitations

The small sample size and short-term follow-up of the exercise program's effects were the study's main shortcomings. It is suggested that further comparative studies using exercise routines and a larger sample size should be conducted to evaluate their impact on the management of DPN. Furthermore, given the paucity of studies designing exercise programs such as mini-trampoline and ankle therapy exercise programs to prevent and control diabetes in women with peripheral neuropathy, it is recommended to conduct more research in this area.

Ethical Considerations

Compliance with ethical guidelines

The Research Ethics Committee of the Institute of Sports Sciences approved all research processes and methods in terms of ethical considerations (Code: IR.SSRI.REC 1400.1311). Also, written informed consent was obtained from all participants.

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Authors' contributions

Conceptualization, methodology, resources, visualization, original data preparation and analysis, writing- original draft, review and editing: Ashraf Ansari; Supervision: Mohammad Karimizadeh Ardakani and Mahdieh Akoochakian

Conflict of interest

The authors declared no conflict of interest.

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