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Examining the efficacy of short foot exercises as an effective stand-alone treatment for mechanical low back pain associated with foot overpronation

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Abstract.
BACKGROUND: Abnormal foot mechanics in foot over-pronation has an identified relationship with mechanical low back pain (MLBP).
OBJECTIVE: To explore the use of short foot exercises (SFEs) as a standalone treatment for MLBP with foot over-pronation.
METHODS: Forty-six patients with MLBP (PwMLBP) presenting with and foot over-pronation were analyzed. They were randomized into the SFE (short foot exercise), SFE plus traditional physical therapy treatment (SFE+TPT), and control (CG) groups. Functional disability and pain level were measured using the Oswestry Disability Index (ODI) and visual analog scale (VAS), respectively. Ultrasonography measured the cross-sectional area (CSA) of the abductor hallucis (AbdH) muscle. The foot posture and navicular drop (ND) were investigated using the foot posture index-6 (FPI) score and ND test, respectively.
RESULTS: The CSA of the AbdH and VAS scores improved significantly ($p < 0.001$) between the groups, more in the SFE+TPT group than in the SFE group ($p < 0.001$). The ND, FPI, and ODI measures improved significantly among the groups ($p < 0.001$), with no significant difference ($p > 0.002$) between the SFE and SFE+TPT groups. The CG did not show significant differences in the outcome measures ($p > 0.002$). Based on the effect size, SFEs significantly improved all the variables of interest ($d > 1$).
CONCLUSION: SFEs, with or without TPT may offer an effective treatment for PwMLBP with foot over-pronation.

Keywords: Mechanical low back pain, foot overpronation, short foot exercises, navicular drop, abductor hallucis muscle

1. Introduction

Mechanical low back pain (MLBP) is one of the most frequent complaints worlwide. Approximately 60–80% of the general population experiences MLBP at least once in their lives [1]. MLBP is a musculoskeletal back pain that does not include nerve root encroachment or devastating spinal diseases. Its prevalence is profoundly evident in young and active adults and is usually caused by acute traumatic issues as well as additive trauma [2].

Ankle and foot disorders could be recognized as one of the possible etiologies for low back pain (LBP) due to a defect in the kinetic chain that connects the foot with the back. Therapists in rehabilitation fields should shed light on ankle and foot problems, especially when the traditional treatment of LBP fails [3]. Impairment in foot mechanics and functions, such as low-arched and

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pronated feet have been considered as precipitating factors for developing LBP [4]. The predominance of foot pronation occurs in youth by 48% to 78% [5], while in adults it ranges from 2% to 23% [6]. The hallmark of foot overpronation is the loss or decrease of the medial longitudinal arch (MLA) and is concurrent with diminished ankle dorsiflexion, heel valgus, mild subtalar joint subluxation, forefoot supination, and displacement of the calcaneus laterally. Any disorders that occur in the MLA, such as pes planus and foot overpronation, may contribute to the increased reaction force from the ground to the feet, which consequently predisposes patients to complications such as knee and hip pain, sacroiliac pain, and even LBP [7].

In addition, based on the anatomy trains model, the transfer of energy goes through direct fascial connections that link the muscular structures inside the fascial system. These are four anatomy trains: the superficial back and front lines, the lateral line, and the spiral line. Abnormalities in the MLA or plantar surface of the foot, which consists of the superficial back line, could participate in many foot problems and, as a result, may affect the upper part of the anatomy trains causing tightness of the hamstring muscle, hyperextension of the knee joint, decreased lumbar lordosis and increased cervical lordosis [8].

Furthermore, foot overpronation causes excessive medial rotation of the tibia and hip, tilting of the pelvis anteriorly, and ipsilateral pelvic drop. These changes can lead to mechanical problems in the lower back, resulting in LBP [9]. Abnormal foot mechanics occurring in foot overpronation have an identified relationship with LBP because of increased vertical ground reaction forces, loading rates, diminished ankle dorsiflexion, and increased navicular drop (ND) [10]. A previous study concluded that the ground reaction force (GRF) components were elevated in patients LBP with a pronated foot, as compared to those having only a pronated foot without LBP. The study stated that the increased GRF components in the foot induced a compressive load on the lumbar discs [11]. Many biomechanical problems found in the lower back could have resulted from the overpronated foot; however, without notable effects on the functional level of LBP patients [12].

It was found that weakness of the intrinsic foot muscles leads to the development of foot overpronation measured by ND. The overpronated foot requires either specific passive treatment (orthotics) or active treatment (strength training) [13]. Strength training (short-foot exercises) for intrinsic foot muscles helps to regain the average height of the medial longitudinal arch of the foot and correct ND [14]. A recent study revealed that 6-weeks of short-foot exercises could correct foot overpronation in terms of reduction of pain and ND [15]. Short foot exercises augment the MLA by connecting the head of the first metatarsal bone to the heel without causing excessive toe extension. Additionally, short-foot exercises activate the abductor hallucis muscle, which in turn maintains navicular stability [16]. Little is known about the direct effect of strengthening exercises of short foot exercises (SFEs) in treating MLBP associated with foot overpronation. We hypothesized that SFEs could be used as a standalone treatment in patients experiencing MLBP with foot overpronation. Therefore, the present study investigated whether SFEs can improve MLBP associated with foot overpronation in terms of decreasing MLBP, improving the functional disabilities and the cross-sectional area (CSA) of the abductor hallucis (AbdH) muscle, changing the foot posture, and reducing ND.

2. Methods

2.1. Participants

A total of 76 men, aged between 35 and 60 years, experiencing MLBP [17] with foot overpronation, were referred by an orthopedic specialist. The patients were recruited from Prince Sattam Bin Abdulaziz University Hospital and King Khalid Hospital, Saudi Arabia. They were allocated and randomized into three groups: a control group (CG), short foot exercise group (SFE), and short foot exercises plus traditional physical therapy treatment group (SFE+TPT).

Participants were included in the study with the following inclusion criteria: (1) pain in the lower back for more than 3 months and scored more than 3 on the visual analog scale (VAS), (2) ND $>$ 10 mm at least one foot, and (3) foot posture index (FPI-6) rated from $+10$ to $+12$ at least one foot. Exclusion criteria were: (1) history of surgery, herniated disc, and traumatic injuries in the spine; (2) history of the spine's rheumatoid arthritis and/or inflammatory diseases; (3) musculoskeletal injuries such as ankle sprain, cruciate ligament deficit, and meniscal problems, (4) history of neurological disorders or previous surgeries in the ankle and foot regions; and (5) any disease that interfered with a patient's sensation, such as diabetes.

The estimated sample size was based on the calculated effect size in a previous study [23], giving ($d = 0.50$) and a probability of 0.05. The G*power 3.0.10

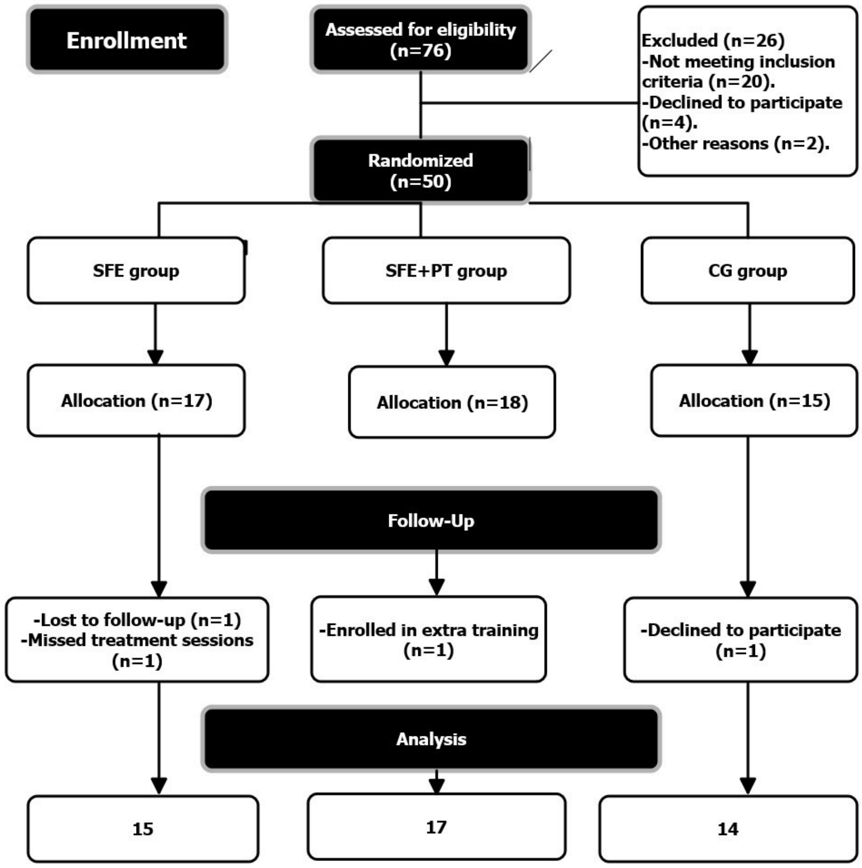

Fig. 1. Flowchart of patient's dropouts and withdrawals.

software (University of Dusseldorf, Dusseldorf, Germany) was used, and the power of analysis was set at a 80% chance of correctly rejecting the null hypothesis of no difference with entire 42 participants as a sample size. We raised the sample size to 50 participants in anticipation of nearly 20% of the participants' exclusion and dropout.

2.2. *Study design*

This was a randomized, triple-blind controlled trial, following the CONSORT guidelines, conducted between July 2020 and February 2021 with concealed allocation. The study was conducted at the physiotherapy outpatient clinic of the College of Applied Medical Sciences, Prince Sattam Bin Abdulaziz University, Saudi Arabia. Before beginning of the study, details and procedures were described to all participants following the ethics of the Declaration of Helsinki. All patients agreed to participate in the study after signing the consent form. Ethical approval for this study was granted by the Research Ethics Committee (No. RHPT/021/016) of the Health and Rehabilitation Sciences Department, College of Applied Medical Sciences, Prince Sattam Bin Abdulaziz University, Saudi Arabia.

2.3. *Randomization*

Seventy-six MLBP patients were eligible for the study, considering the inclusion criteria. Subsequently, each patient was assigned a number. An assistant researcher, who was not included in the study, performed the randomization process using non-transparent envelopes. Fifty envelopes were arranged, and each patient chose an enclosed envelope to determine whether the patient was allocated randomly to the SFE group ($n = 15$), SFE+TPT group ($n = 17$), and CG group ($n = 14$). The patients' dropouts and withdrawals are shown in Fig. 1.

2.4. *Study plan*

Patients in the SFE and SFE+TPT groups underwent SFEs, while patients in the SFE+TPT group underwent

SFEs in addition to the TPT. However, the CG group completed the non-biomechanical exercises. The outcome measures of interest were measured at the beginning of the study and after 6 weeks of treatment intervention. Home program exercises were not advised to patients to prevent the variability of the delivered exercises and standardize the procedures.

2.5. Assessment procedures

2.5.1. Functional disabilities

The ODI was used to evaluate the functional disability status of patients with MLBP. The questionnaire consisted of 10 questions and six statements for each question. The statement was scored 0 if the patient chose the first statement and scored five if the last statement was checked. If all 10 questions or sections were answered, the overall score was calculated as follows: (gained score/5 $\times$ possible questions answered) $\times$ 100. The lower the total score, the lower the degree of disability, whereas the higher the total score, the higher the degree of disability [18].

2.5.2. Pain score

The MLBP was evaluated using the VAS for pain, which was self-assessed by the patient. The patient expressed his level of pain on the VAS, by placing a perpendicular line at the point that described the pain intensity [19].

2.5.3. Cross-sectional area of AbdH muscle

The AbdH muscle was insonated using an HI Vision Avius ultrasound unit (Hitachi) connected to a L12-5 MHz, 50 mm broadband linear array ultrasound probe. The patient was placed in the supine position. The patient's knees were in full extension, while the ankle joint was positioned at 90 degrees, and the plantar surface of the foot was rested on a platform to maintain the ankle in a fixed and stable position. Behind the navicular tuberosity, at approximately 1 cm, the ultrasound probe measured the CSA of the AbdH muscle along the muscle borders using a manual tracing technique. To reduce any possible changes in muscle morphology, the probe pressure was maintained at minimum during imaging. The imaging procedures were repeated three times, and the average score was used for the analysis [20,21].

2.5.4. The FPI-6

The FPI-6 was used to provide a complete and multi-aspect assessment of the foot. The FPI-6 evaluates specific anatomical parts of the forefoot and rearfoot as follows: (i) head of talus palpation, (ii) curvature of the superior and inferior lateral malleolus, (iii) deviation of the calcaneus to inversion/eversion, (iv) bulging of the talonavicular joint, (v) curvature status of the MLA, and (vi) the state of the forefoot and rearfoot in terms of abduction/adduction.

Each patient was screened for six index parts, and the score ranged from -2 to $+2$ for each part. Then, the overall score was calculated and categorized as follows: (i) increased foot supination from -12 to -5, (ii) slight foot supination from -4 to -1, (iii) a neutral foot from 0 to $+5$, (iv) slight foot pronation from $+6$ to $+9$, and (v) increased foot pronation from $+10$ to $+12$ [22].

2.5.5. The ND test

At the beginning of the test, a pen dot with a fat marker was placed on the tuberosity of the navicular bone while the patient was sitting (unloaded). The distance from the navicular tuberosity to the ground was measured in millimeters and marked on a piece of paper. The patient was then instructed to stand (loaded), and the distance from the navicular tuberosity to the ground was again identified on the same paper. The difference between the two marks on the piece of paper was calculated. This process was repeated three times, and the average was used for the analysis. A difference $>$ 10 mm was considered as foot overpronation [23].

2.6. Treatment procedures

2.6.1. SFEs

The SFEs were performed in two stages, each lasting for 3 weeks. First, the patient shortened the foot in the anterior-posterior direction, approximating the head of the metatarsals to the heel, avoiding toes flexion. The patient was placed in a seated position, without loading and was asked to notice an increase in the MLA while performing the exercise. The second stage included an increased level of difficulty using balance loading of three support points (heads of first and second metatarsals and calcaneus). The patient performed the exercises in three different positions: sitting, standing, and half-squat [24]. The exercise in each stage was repeated for 30 repetitions; each repetition lasted for 30-s interrupted with a rest period of rest of 10 s [25]. The SFEs was done daily for 6 weeks. At least two sessions per week were supervised by one of the authors. The patient was kept barefoot while performing the exercises. Both feet received the SFEs in the same session, even if the patient had a unilateral occurrence. However, the examination of outcome measures (ND, FPI-6 score, and the CSA of the AbdH muscle) was obtained from the affected foot only.

2.6.2. The TPT

In the SFE+TPT group, the patients conducted a 20-min aerobic walking exercise designed at 50% of the heart rate reserve. The aerobic walking was performed twice per week for six weeks [26]. Thereafter, the patients were asked to perform static stretching of the hamstring and calf muscles, in addition to stretching of the plantar fascia on both sides. The stretching time lasted for 60-s/time × 5 times. Transecutaneous electrical nerve stimulation (TENS) (Chattanooga Group Inc., Hixson, TN, USA) was applied to the lumbar area through two channels. The TENS current was delivered in biphasic mode, 90 Hz, 100 ms pulse width, for 20-min. The intensity was increased gradually according to patient tolerance. Then, three types of massages (effleurage, petrissage, kneading, rhythmic pressures, and rolling) were chosen and applied to the lumbar area for 15-min [27]. The patients received traditional physical therapy (except aerobic walking training) three sessions per week for 6 weeks.

2.6.3. Non-biomechanical exercises

Non-biomechanical exercises are designed for non-therapeutic effects that cannot induce a substantial change in foot mechanics. These exercises consist of dorsiflexion and plantarflexion of the metatarsophalangeal and ankle joints without resistance, in the unloading position, with the ankle and knee joints at 90 degrees and at full extension, respectively. The non-biomechanical exercises were conducted for 30-s for each exercise, alternating with a 10-s rest between sets, five sets daily, for 6 weeks.

2.7. Outcome measures

The functional disabilities and pain level of MLBP patients were measured using the Oswestry Disability Index (ODI) questionnaire and VAS, respectively. Ultrasonography was used to estimate the changes in the CSA of the AbdH muscle (mm^2). The type of foot posture and ND were investigated using the FPI-6 scale scores and ND test (mm), respectively.

2.8. Statistical analysis

All statistical analyses were computed using the IBM SPSS (Statistical Package for Social Sciences (SPSS), Version 23, Chicago, IL). All data are represented as mean ± standard deviation, and 95% confidence intervals (CIs) are also given. The Shapiro-Wilk test confirmed the normal distribution of the data. For basic and demographic data, one-way analysis variance (ANOVA), the Kruskal-Wallis test, and the Chi-square test were used to assess the homogeneity of the pre-test scores for continuous, categorical, and nonparametric variables, respectively, among the three groups. A one-way between-subjects ANOVA was conducted to compare the effect of SFEs on variables of interest in MLBP with foot overpronation among the SFE, SFE+TPT, and CG groups. A paired t-test was used to explore the changes in dependent variables within each group. The effect size (Cohen's d) was used to recognize the magnitude of the effectiveness of SFEs, with the aim of detecting the ability of SFEs alone in treating MLBP with foot overpronation. To avoid type-one error resulting from multiple comparisons, the relative changes in the variables of interest were corrected using the Bonferroni correction (corrected $P < 0.002$).

3. Results

3.1. Basic and demographic characteristics

Forty-six patients were analyzed, but 66 feet were investigated (SFE: 22 feet; SFE+TPT: 24 feet; CG: 20 feet). All patients' basic and demographic characteristics were homogeneous with no significant differences between the three groups (Table 1).

3.2. Changes in ND, the FPI-6 score, and the CSA of AbdH muscle pre- to post-treatment

A paired t-test revealed that the SFEs in the SFE group, in addition to the combined effect of SFEs and TPT, in the SFE+TPT group, had a highly significant effect on ND ($p < 0.001$), while in the CG group, there was a minor reduction in ND which was not significant ($p = 0.06$). The ND test results differences among the three groups due to the exercise intervention are shown in Table 2. The treatment intervention improved the ND test result among the three groups, F (2, 63) = 30.06, $p < 0.001$, $\eta^2 = 0.488$. The ND test result in the SFE and SFE+TPT groups improved significantly compared to the CG ($p < 0.001$). However, the ND test result did not change significantly between the SFE and SFE + PT groups ($p = 0.927$).

The FPI-6 score improved significantly in the SFE and SFE+TPT groups ($p < 0.001$), while in the CG, the FPI-6 score did not change significantly ($p = 0.428$)

Table 1
Demographic characteristics of all participants

	SFE ($n = 15$)	SFE+TPT ($N = 17$)	CG ($N = 14$)	p
	Mean ± SD (CI 95%)			
Age, years*	50.28 ± 8.28 (45.5–55.07)	47.42 ± 7.10 (43.32–51.52)	47.64 ± 7.76 (43.16–52.12)	0.546
Height, cm*	174 ± 5.21 (171.84–177.86)	175.5 ± 5 (172.61–178.38)	176.28 ± 6.10 (172.75–179.81)	0.750
Weight, Kg*	80.92 ± 3.98 (78.62–83.23)	82 ± 6.28 (78.36–85.63)	81.5 ± 5.88 (78.10–84.89)	0.857
BMI, (Kg/m^2)*	27.27 ± 1.48 (26.42–28.14)	27.71 ± 1.63 (26.76–28.65)	28.07 ± 1.63 (27.12–29.011)	0.334
	Median (Q_1–Q_3)			
Q angle, degrees**	13.5 (12.5–15)	13.5 (12.5–15)	13 (12–14)	0.567
No. of previous P.T sessions within 6 months**	18 (12–30)	24 (6–24)	6 (12–36)	0.852
	No. (%)			
Distribution of unilateral/bilateral occurrence***				
Unilateral	8 (53.3%)	10 (58.8%)	8 (57.1%)	0.951
Bilateral	7 (46.7%)	7 (41.2%)	6 (42.9%)	
Symptoms' duration of MLBP***				
More than 6 months	11 (73.3%)	13 (76.5%)	9 (64.3%)	0.744
More than 2 years	4 (26.7%)	4 (23.5%)	5 (35.7%)	
Episodes of inner side foot pain***				
1 time/week	2 (13.3%)	4 (23.5%)	1 (7.1%)	0.458
2–5 times/week	8 (53.3%)	10 (58.9%)	11 (78.6%)	
> 7 times /week	5 (33.4%)	3 (17.6%)	2 (14.3%)	
Included in regular exercises within 6 months***				
Yes	3 (20%)	2 (11.8%)	2 (14.3%)	0.806
No	12 (80%)	15 (88.2%)	12 (85.7%)	

BMI: Body mass index; Q angle: Quadriceps angle; CI: Confidence interval; Q1: 25thquartile; Q3: 75thquartile; *: Nonsignificant difference between groups (One-way ANOVA test); **: Nonsignificant difference between groups (Kruskal-Wallis test); ***: Nonsignificant difference between groups (Chi-Square test).

Table 2
Changes of ND, FPI, and CSA of AbdH pre- to post-treatment intervention among three groups

	SFE ($n = 15$, 22 feet) Mean ± SD (CI 95%)		SFE+TPT ($n = 17$, 24 feet) Mean ± SD (CI 95%)		CG ($n = 14$, 20 feet) Mean ± SD (CI 95%)		p
	Pre	Post	Pre	Post	Pre	Post	
ND, mm	12.55 ± 1.4 (12.05–13.34)	10.09 ± 1.06* (9.72–10.67)	13.25 ± 1.18 (12.75–13.84)	9.88 ± 1.26* (9.39–10.60)	12.75 ± 1.16 (12.20–13.29)	12.5 ± 1.31** (10.88–13.11)	< 0.001†
FPI	11.18 ± 0.79 (10.76–11.53)	6.73 ± 0.93* (6.29–7.20)	11.04 ± 0.90 (10.57–1142)	6.38 ± 1.40* (5.79–7.1)	11.3 ± 0.86 (10.89–11.7)	11.2 ± 0.76** (10.84–11.55)	< 0.001†
CSA of AbdH, mm^2	216.63 ± 17.15 (208.01–224.58)	233.5 ± 11.59* (228.23–239.56)	220.79 ± 21.68 (213.94–233.45)	256.75 ± 17.59* (246.23–262.86)	211.55 ± 21.5 (201.48–221.61)	212.45 ± 20.33** (211.76–229.43)	< 0.001†

ND: Navicular drop test; FPI: Foot posture index; CSA: Cross-sectional area; AbdH: Abductor Hallucis; CI: Confidence interval; †: significant difference between groups of post-tests (One-way between-subjects ANOVA test); *: significant difference between pre- to post -test (Paired t-test); **: non-significant difference between pre- to post-test (Paired t-test).

(Table 2). The treatment intervention significantly improved the FPI-6 score among the three groups, F (2, 63) = 127,22, $p < 0.001$, $\eta^2 = 0.802$. However, the Bonferroni test revealed that the SFE and SFE+TPT groups did not show a significant improvement ($p = 0.836$), but they differed significantly on comparison with the CG group ($p < 0.001$).

Regarding the CSA of the AbdH muscle, patients in the SFE+TPT group showed an increased CSA ($p < 0.001$), more than that in the SFE group ($p = 0.001$). However, there was no significant difference in the CSA of the AbdH muscle in the CG group ($p = 0.216$). In a comparison among the three groups, the CSA of the AbdH muscle increased significantly as (F (2, 63) = 28.15, $p < 0.001$, $\eta^2 = 0.472$ (Table 2). The second group, the SFE+TPT group, differed significantly from the SFE and CG groups ($p < 0.001$), whereas, based on Bonferroni correction, the SFE group did not show

Table 3
Changes of VAS and ODI pre- to post-treatment intervention among three groups

	SFE (n = 15, 22 feet) Mean ± SD (CI 95%)		SFE+TPT (n = 17, 24 feet) Mean ± SD (CI 95%)		CG (n = 14, 20 feet) Mean ± SD (CI 95%)		p
	Pre	Post	Pre	Post	Pre	Post	
VAS	7.40 ± 0.90 (6.94–7.75)	4.9 ± 1.3* (4.16–5.33)	7.04 ± 1.6 (6.33–7.76)	2.87 ± 0.89* (2.5–3.39)	6.9 ± 1.61 (6.14–7.65)	6.7 ± 1.4** (6.03–7.36)	< 0.001†
ODI, %	34.45 ± 4.55 (31.96–36.33)	26.31 ± 4.08* (24.34–28.35)	33.29 ± 24.37 (31.01–35.48)	24.37 ± 4.42* (22.64–26.95)	33.95 ± 4.94 (31.63–36.26)	33.35 ± 4.81** (31.09–35.60)	< 0.001†

VAS: Visual analogue scale; ODI: Oswestry disability index; CI: Confidence interval; †: significant difference between groups of post-tests (One-way between-subjects ANOVA test); *: significant difference between pre- to post -test (Paired t-test); **: non-significant difference between pre- to post-test (Paired t-test).

a significant increase in CSA of the AbdH muscle, as compared to the CG group ($p = 0.038$).

3.3. Changes in the VAS and ODI scores pre- to post-treatment

The pain scores changed significantly among the three groups (F (2, 63) = 54.7, $p < 0.001$, $\eta^2 = 0.635$), as shown in Table 3. Based on Bonferroni pairwise comparisons, all groups differed significantly from each other ($p < 0.001$), indicating that the patients in the SFE+TPT group had the lowest pain score. Within-group analysis revealed that the pain scores decreased significantly in both the SFE and SFE+TPT groups ($p < 0.001$), with superior improvement in the SFE+TPT group (2.87 ± 0.89) than in the SFE group (4.9 ± 1.3). However, there was no significant decrease in the pain score in the CG group.

As for the ODI scores, the results revealed that there were significant improvements in patients' functional abilities among the three groups, F (2, 63) = 24, $p < 0.001$, $\eta^2 = 0.432$, as outlined in Table 3. The ODI scores were profoundly reduced in both the SFE and SFE+TPT groups, but without significant differences ($p = 0.429$) between the two groups. Nevertheless, the ODI score in the CG group differed significantly ($p < 0.001$) compared to that in the SFE and SFE+TPT groups, as patients in the CG group did not show improvement in functional abilities. The paired t-test confirmed that the ODI scores in the SFE and SFE+TPT groups were significantly reduced ($p < 0.001$), unlike the CG group, where there was no significant reduction in ODI ($p = 0.573$).

3.4. The effect of SFEs alone on dependent variables, inferred by the effect size values

The magnitude of significant differences in the variables of interest resulted from SFEs is presented in Fig. 2. It is to be noted that the effect size for all variables of interest was above 1, which means that SFEs could have a positive impact on correcting foot overpronation and reducing mechanical LBP.

4. Discussion

This study aimed to determine the influence of SFEs on patients with MLBP and foot overpronation that is, we intended to determine whether the SFEs could have a noticeable effect on MLBP in addition to its impact on the correction of foot overpronation. Our study reports significant differences in ND and the FPI-6 and ODI scores among the three groups. The ND and the FPI-6, and ODI scores improved significantly in the SFE and SFE+TPT groups, but there were no significant difference between the SFE and SFE+TPT groups. In addition, there were significant differences among the three groups in terms of pain (VAS scores) and the CSA of the AbdH muscle, with a statistically significant difference between the SFE and SFE+TPT groups. However, no significant differences were found in the CG group regarding the five variables of interest.

Abnormal morphological structures in pronated feet induce stretched and weakened intrinsic foot muscles by lengthening these muscles behind the resting physiological length. Furthermore, the adverse effect of these abnormal alignments in foot overpronation interrupts the length-tension relationship of intrinsic muscles, consequently decreasing intrinsic muscles' ability to generate sufficient force [28]. Overpronation of the feet probably induces biomechanical changes in the lower limbs due to the internal rotation of the hip joint [29]. In addition, long-lasting foot overpronation leads to an increase in the exposure of the medial line of the foot to excess pressure, which negatively affects the lumbopelvic region during static and dynamic activities. These disorders of the lumbopelvic region may cause atrophy

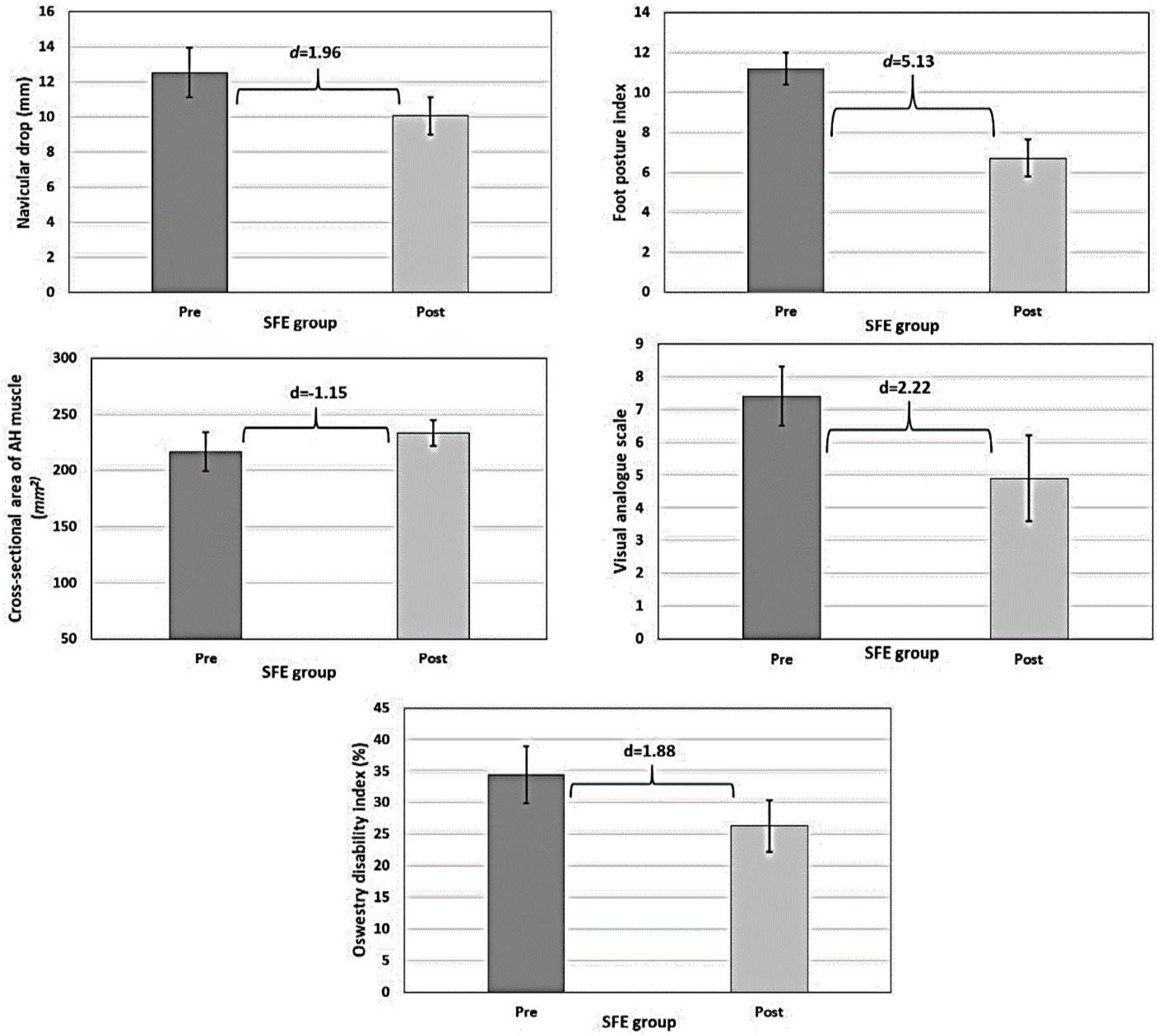

Fig. 2. Effect sizes of significant intervention of SFEs; d: Cohen's d; SFEs: Short foot exercises; AH: Abductor Hallucis muscle.

of the lumbopelvic muscles indirectly [30]. Therefore, ankle and foot exercises could have an apparent effect on the direct correction of foot problems and thus work to improve MLBP indirectly.

The results of the present study indicate that patients in the SFE+TPT group had a more significant increase in the CSA of the AbdH muscle ($p < 0.001$) than their SFE counterparts ($p = 0.001$). This difference may be due to the inclusion of aerobic walking in the former group [31]. A previous study showed that, SFEs with neuromuscular electrical stimulation (NEMS) increased AbdH activity in participants with flexible flatfoot and lower MLA than SFEs alone. However, the results of this previous study ae inconsistent with those of our study, as the SFEs with NEMS and SFEs alone did not show significant differences in increasing CSA of the AbdH and navicular height [32]. This result was probably due to the period of the previous study (4 weeks). Furthermore, the current study shows a decreased mean reduction of MLBP in the SFE+TPT group (VAS: 2.87) compared to the SFE group (VAS: 4.9). Despite a reduction in pain in both groups, TENS application could have a role in pain alleviation [33], in addition to massage therapy [34] more in the SFE+TPT group than in the SFE group.

According to the integrated kinetic chain paradigm, the myofascial chains transfer loads through muscular pathways, which are connected together, because when the load is applied, the musculoskeletal system demands to become stiff [35]. In this context, Sulowska-Daszyk et al. stated that SFEs could enhance the muscle extensibility of the upper body [36]. Notably, in a previous study, the authors revealed that the tibia was the most adjusting mediator segment in the kinematic chain reaction that occurs during posture alignment and intervention of foot overpronation. It was found that the tibia has a significant influence on pelvic adjustment (change of 2–3 degrees measured at the pelvis) in approximately 40% of cases [37].

Based on the effect size results, it is evident that the SFEs had the ability to improve overpronated feet and reduce MLBP, where all values of the effect size scored above 1. The results of the present study suggest that the application of SFEs for patients experiencing MLBP with foot overpronation might improve muscle strength and power in proximal segments, based on the kinematic chains.

It is well known that the AbdH is a dynamic supporter of the MLA of the foot, helping the peroneus longus muscle to decrease the arch flattening at heel strike and raise the arch to commence the toe-off phase of the gait [38]. The results of the current study show that the SFEs had the ability to significantly increase the thickness of the AbdH muscle, but with a higher percentage in the SFE+TPT group than in the SFE group. Based on the effect size results, the SFEs significantly increased the CSA of the AbdH muscle (effect size = 1.15), correcting and treating foot overpronation. This is in agreement with a previous study which stated that the SFEs improved the electrical activity of the AbdH muscle while descending stairs in patients with pronated feet, reflected in the reduction of pain in patellofemoral pain syndrome [39].

Abe et al. reported a correlation between the strength of the short foot muscles and physical performance in terms of walking speed in healthy volunteers [40]. In the current study, the SFE+TPT and SFE groups significantly improved the MLA by decreasing the ND values (25.4%, 19.6%, respectively). A previous study similar to the showed that SFEs had a statistically significant effect in terms of reducing the ND test by approximately 32.5% and improving the MLA of the foot [41].

Since ND is considered a determinant of the medial longitudinal arch status, the ND value contributes an essential part of shock absorption and energy transfer during motion [42]. Moreover, Kendall et al. reported in a previous study that the shock forces elicited during running were transferred to the lumbar region higher in subjects with pronated feet than in supinated feet [43]. The present study reported that the SFEs corrected ND significantly in the SFE (effect size = 1.96) and SFE+TPT groups, accompanied by improved MLBP and functional abilities. This improvement might arise from regaining shock absorption and energy transfer as normally as possible. Also, correcting foot pronation to the normal value was a helpful mechanism, providing proper shock absorption and ground contact [44]. Moreover, by correcting ND to low values, the degree of internal tibial rotation could be neutralized. It was further reported that ND scores correlated significantly with increased internal tibial rotation and substantially affected the shin and knee joint during running [45].

In the current study, SFEs had a significant effect on correcting foot overpronation as well as reducing MLBP and enhancing functional abilities, as measured by the ODI. The observed results might support that the correction of foot pronation indirectly decreased the anterior pelvic tilt and subsequently LBP. There was a strong correlation between anterior pelvic tilt and the aggravation of LBP [46]. In addition, previous studies suggested that treating foot pronation by the application of foot orthosis could regain the normal alignment of the tibia and femur and improve the properties of the lower limb joints, consequently decreasing the spinal load and LBP [47,48].

The FPI-6 score was the most important variable of interest that improved because of SFEs in the current study. The FPI-6 score decreased significantly in both the SFE (effect size = 5.13) and SFE+TPT groups, without a significant difference ($p = 0.836$). The FPI-6 score was improved considerably in the SFE+TPT (42.2%) and SFE groups (39.8%) after therapeutic intervention. Sulowska et al. reported that the SFE improved significantly ($p = 0.017$) the inversion/eversion of the calcaneus, one of the FPI-6 parameters, which indicated a slight change in foot pronation to become an almost neutral foot in adult long-distance runners [24].

The results of the current study show that while decreased pain level (the VAS score) was evident in both the SFE+TPT and SFE groups (59.2% and 33.8%, respectively), it occurred more in favor of SFE+TPT. In addition, the functional disabilities of MLBP patients improved significantly more in the SFE+TPT than in the SFE group (26.8% and 23.6%, respectively). These results indicate that the SFEs induced significant correction of foot overpronation, leading to improvement of pain (effect size = 2.22) and functional disabilities (effect size = 1.88) in MLBP. It is possible to explain this point of results with what Yi stated, that is, the subtalar pronation and calcaneal eversion occur during foot pronation, causing internal rotation of the hip joint, backward femoral head, and posterior alignment of the pelvis, putting the trunk in a forward position and pelvic anteversion [49]. Since there is a significant association between larger anteversion of the pelvic angle and LBP participants [50], this improvement of MLBP and functional disabilities in the present study might be due to the correction of pelvic anteversion in the MLBP patients.

4.1. Limitations

The current study is limited by several factors, which may be controlled in future studies. First, it was conducted on a limited sample size, which needed follow-up investigations. Second, the entire sample selection consisted of males, which was done to prevent the discrepancy of the AbdH muscle size between females and males and possible incorrect explanation of results, but this might affect the generalizability. Third, we did not measure the effect of the SFEs on leg length discrepancy, which might have a role in correcting foot overpronation, especially in cases of unilateral occurrence that correlated with LBP [51].

5. Conclusion

Based on the clinical findings of the current study, SFEs is effective in the treatment of MLBP patients with foot overpronation. The SFEs may be considered as a standalone treatment in improving the pain and functional disabilities in patients with MLBP, in addition to correcting ND, the FPI-6 score, and the CSA of AbdH muscle in the overpronated foot.

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Ethical considerations

Before beginning of the study, details and procedures were described to all participants following the ethics of the Declaration of Helsinki. All patients agreed to participate in the study after signing the consent form. Ethical approval for this study was granted by the Research Ethics Committee (No. RHPT/021/016) of the Health and Rehabilitation Sciences Department, College of Applied Medical Sciences, Prince Sattam Bin Abdulaziz University, Saudi Arabia.

Conflict of interest

There was no potential conflict of interest in this article.

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