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TITLE PAGE

SHORT FOOT EXERCISES HAVE ADDITIONAL EFFECTS ON KNEE PAIN, FOOT BIOMECHANICS, AND LOWER EXTREMITY MUSCLES STRENGTH IN PATIENTS WITH PATELLOFEMORAL PAIN

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ABSTRACT

BACKGROUND:

Patellofemoral pain (PFP) was reported as a common knee problem. And the foot posture in a relaxed stance was reported as distal factors of PFP. However, the effects of short foot exercise (SFE) on the knee and functional factors have not yet been investigated in patients with PFP.

OBJECTIVE:

This study aimed to investigate the additional effects of SFE on knee pain, foot biomechanics, and lower extremity muscle strength in patients with PFP following under the standard exercise program.

METHODS:

Thirty patients with *'weak and pronated'* foot subgroup of PFP were randomized to a control group (ConG,*n=15*) and a short foot exercise group (SFEG,*n=15*) with concealed allocation and blinded to the group assignment. The program of ConG consisted of hip and knee strengthening and stretching exercises. SFEG program consisted of additional SFE. Both groups performed the supervised training protocol two times per week for 6 weeks. Assessment measures were pain visual analog scale (pVAS), Kujala patellofemoral score (KPS), navicular drop test (NDT), rearfoot angle (RA), foot posture index (FPI), and strength tests of lower extremity muscles.

RESULTS :

Both groups displayed decreases in pVAS scores, but it was only significant in favor of SFEG. NDT, RA, and FPI scores decreased in SFEG whereas they increased in ConG. There was a significant group-by-time interaction effect in hip extensor strength and between-group difference was found significant in favor of SFEG.

CONCLUSIONS:

An intervention program consisting of additional SFE had positive effects on knee pain, navicular position, and rearfoot posture. An increase in the strength of the hip extensors may also be associated with improved stabilization by SFE.

Key words

Patellofemoral Pain; Short Foot Exercises; Foot Core; Foot Posture.

1. INTRODUCTION

Patellofemoral pain (PFP) is characterized by increased retropatellar or peripatellar pain with activity. The prevalence of patellofemoral pain reported as 22.7% in the general population (1). The etiology of PFP is widely accepted to be multifactorial, with proximal, local, and distal factors. Distal factors such as excessive and prolonged pronation of the rearfoot and increased navicular drop values in relaxed stance have been reported as important (2).

Unfortunately, it has been reported that despite the high prevalence and positive short-term treatment outcomes 80% of individuals who completed a rehabilitation program for PFP still reported pain, and 74% had reduced their physical activity at a 5-year follow-up (3-6). The international consensus considering the high failure rate for treatment of PFP suggests that a paradigm shift towards identifying PFP subgroups and delivering stratified care is required (2, 7, 8). Recently Selfe *et al.* have taken the first step towards this by identifying 3 distinct subgroups of patients with PFP one of these was *''Weak and Pronated''* partially defined by having a score of Foot Posture Index (FPI) of >6, however, they did not conduct any intervention or investigate patient outcomes (9). Studies on the effects of foot pronation on PFP have been limited to the recommendation of foot orthoses. Mills et al. reported that orthoses provided greater improvements in anterior knee pain compared to a wait-and-see approach (10). Collins et al. reported that foot orthoses are superior to flat inserts according to participants' overall perception, but they do not improve outcomes when added to physiotherapy (4).

Besides that current rehabilitation approaches adopt the view that centers the patient and is based on the patient's active participation. At this point, foot orthoses remain passive methods and there is a need to investigate exercise therapies such as the Short Foot Exercise (SFE) - Foot Core Paradigm in PFP to assess whether they are capable of improving foot biomechanics and reducing knee pain (11).

Limited numbers of studies have demonstrated that SFE is effective in strengthening the biomechanical structure of the foot (12-15). The pathomechanical effects of prolonged and increased rearfoot pronation and increased navicular drop measures on knee joint have been emphasized, according to the results of previous studies, it can be considered that SFE may also be effective in knee problems such as PFP.

The aim of this study was to investigate the additional effects of SFE on knee pain, foot biomechanics, and muscle strength in patients with PFP following under the standard exercise program.

2. MATERIAL AND METHODS

A randomized controlled parallel-group trial was performed in the outpatient clinic of Hacettepe University Faculty of Physical Therapy and Rehabilitation. Diagnosis of PFP (based on 2016 PFP consensus) was made by an orthopedic surgeon and patients who consulted for physiotherapy were recruited for this study between April and September 2017 (16).

Inclusion criteria were with no gender limitation being 25 to 55 years of age; having complaints of continuing knee pain (for at least six months and without trauma) in the bilateral pre-/retropatellar area, pain provoked by at least one activity from prolonged sitting, squatting, kneeling, or stair climbing and classifying as moderate (3.5-6.4) and severe (≥6.5) according to pain-Visual Analogue Scale (pVAS), (17) and categorizing as *''weak and pronated''* foot which defined by having a score from FPI of >6 according to Selfe *et al.* (9) . Patients were excluded if they had a history of previous knee surgery, trauma, patellar dislocation or subluxation, tendinitis or bursitis, any other non-surgical interventions in the previous 6 months if they had intra-articular problems; involvement of ligaments or meniscus; knee pain or joint effusion due to rheumatic diseases and pregnancy, pain or tenderness of plantar fascia and foot or history of plantar fasciitis (18-20).

All patients read and signed an informed consent form approved by Hacettepe University Non-interventional Clinical

Research Ethics Board (Number: GO17/168-17) prior to participation. The trial was registered on clinicaltrials.gov (ID: NCT03099512).

2.1. Sample Size Analysis

A sample size calculation *(GPower 3.1.9.2)* based on the average knee pain while prolonged sitting, ascending and descending stairs (the more complained of all) (using *α: .05, β: .20 (power: 80%)*) was conducted from a pilot study (pVAS scores of prolonged sitting; with mean (standart deviation (SD))= -2.12 (2.85) in short foot exercise group (SFEG) and .66 (2.16) in control group (ConG), ascending stairs; with mean (SD)= -3.75(2.43) in SFEG and 2.16 (2.74) in ConG, descending stairs; with mean (SD)= 2.62 (2.44) in SFEG and 2.16 (2.85) in ConG). Based on the results, 22 patients with PFP were needed to adequately power the study for variables of interest.

Therefore, to allow for potential dropouts (expected as %25) 30 patients were recruited for the study. In total, 45 patients were assessed for eligibility. Thirty-five of them randomized and at the end of intervention 30 participants had completed the study (Figure 1).

2.2.Randomization and blinding

In this study, concealed allocation was conducted and patients with PFP were divided into 2 groups with *Random*

Allocation Software (version 1.0) in a single block format. Randomization was performed after the baseline assessment, and the patients were blinded to group allocation by ensuring that they were unaware of the exercises performed by the other group. To maintain the blinding, the intervention sessions were delivered separately to members of each treatment group.

[Figure1 near here]

2.3. Outcome Measures

Participants were assessed at baseline and at the end of the 6-week intervention. The initial clinical examination (baseline) consisted of observation and palpation of the knee joint, patella, and peripatellar soft tissue. All assessments were performed by the same physiotherapist who had at least 2 years of experience in these procedures.

Participants' self-report of pain intensity was assessed by using pVAS, with the minimal clinically important difference being ≥2 cm (21, 22). Participants were asked to rate their response based on the average knee pain, which located around or behind the patella while performing walking, prolonged sitting, climbing stairs, squatting activities, and nocturnal pain during the previous week. Besides pain intensity, other common symptoms were investigated with the Kujala Patellofemoral Scale (KPS) , with the minimal clinically important difference being 10 to 13 points (23). The KPS is a 13-item self-reported questionnaire the maximum possible score of 100 indicates a normal, painless and fully functioning knee.

Navicular drop (ND) was assessed to determine the flexibility of the medial longitudinal arch (MLA) and the position of the navicular bone in both feet (14).The participant's knee was stabilized while nonweightbearing (sitting) (NWB) and the subtalar joint neutral position (STJN) was manually determined. In this position, the navicular tuberosity was marked and the floor-distance was measured with a digital caliper *(Neiko 01408A, Neiko Tools USA)*. Subsequently, all procedures (except STJN) were repeated in symmetrical bilateral weightbearing (standing) (WB) and the differences between the two measures were noted for both feet as *Navicular drop test (NDT)* score.

Rearfoot angle (RA) was measured to determine the position of the rear foot (calcaneal eversion/inversion) and noted as the angle between distal midline of the Achilles tendon and the midline of the calcaneus. A standard universal goniometer was used and rearfoot angle measurements were repeated in both NWB and WB positions.

The *six item-Foot Posture Index (FPI)* with good inter item reliability *(Cronbach's α = 0.83)* was used to evaluate foot posture. Items include: talar head palpation, curves above and below the lateral malleoli, calcaneal inversion/eversion, talonavicular bulging, MLA, rearfoot abduction/adduction. Each item is scored between -2 (supinated) and +2 (pronated) and 0 for neutral position (total score between -12 (highly supinated) and +12 (highly pronated)) (24).

Isometric strength of hip extensors and abductors, knee flexor and extensors, ankle dorsi (DF) and plantar flexors (PF), flexor hallucis longus (FHL) muscles were quantified by using a hand-held dynamometry-*Laffayette Manual Muscle Tester (Laffeyette Instrument, 47903, USA)*. All measurements were performed in standard clinical muscle test positions and the *make test* method was applied and, to avoid the effect of examiner's strength and stabilize the dynamometer a strap was used to hold dynamometer(25, 26). The center of the force pad on the dynamometer was placed approximately midpoint of the area between two neighbour joints *(for instance, the force pad was placed at the midline of the femur for hip extensors*). Participants held the contractions for 5 seconds, and 3 trials were performed with a 30 seconds rest between each trial (27) mean strength values were recorded in Newton (N).

2.4. Intervention

Participants from both groups performed the training protocol two times per week for 6 weeks, with at least one day between intervention sessions. All individual sessions were supervised by the same physiotherapist and performed as one set (containing 10 repetitions per exercise) once a day. Sessions on the other days were performed as a home program according to the same protocols. And, no medication was prescribed as part of their treatment.

Control Group (ConG). The treatment program consisted of hip and knee strengthening and stretching exercises, considered as standard exercise therapy approach (Appendix).

Short Foot Exercise Group (SFEG). The SFEG physiotherapy program was similar to ConG. Additionally; participants in SFEG performed short foot exercises (SFE). SFE is described as targeting isolated contraction of the plantar intrinsic muscles. The foot is 'shortened' by using the intrinsic plantar muscles to pull the metatarsal heads towards the calcaneus (when the metatarsal heads on the ground and the toes neither flexed nor extended) as the MLA is elevated (28). For progression; SFE is performed from sitting to bipedal, to unipedal-with minimal support and to unipedal-without support (Appendix).

To exclude the confounding effects, the patients were asked not to change their shoes and not use orthoses during the treatment. Appropriately designed orthoses were recommended for severe cases who completed the intervention program and were in need.

2.5. Statistical Analyses

Statistical analyses were performed using the *"Statistical Processing for The Social Sciences Software (SPSS 22.0 Inc., Chicago, Illinois)"*. The variables were investigated using *Shapiro-Wilk's test* to determine the normality. Data for variables were reported as mean (X), standard deviation (SD) and 95% confidence interval (95%CI). Outcome measures were compared before and after the treatment using a two-way (group-by-time) mixed-model analysis of variance (ANOVA), with time (baseline and postintervention) as the repeated measure. Partial Eta-squared was cited as a measure of effect size (29). When significant group-by-time interactions were found, the main effects of time and group were reported and also planned pairwise comparisons with *paired samples t-test* was used to determine whether the ConG or SFEG group had changed over time, and the *independent samples t-test* was used to determine between-group differences. Because data were normally distributed parametric tests were used. In the absence of a significant interaction term, the main effects of time and group were reported only. For all analyses, the alpha level was set at .05.

3. RESULTS

The demographic characteristics of the groups were similar and summarized in at Table.1. No adverse effects were reported but 5 patients dropped out due to other reasons (Figure.1). The tenderness of lateral retinaculum has been palpated in all participants and 24 (80%) of all with tenderness along the medial patellar facet; 27 (90%) participants with the tenderness of distal to the dorsal patellar tendon, indicating patellar tendinopathy; 3 (10%) participants with tenderness either side and proximal pole of the patella, indicating quadriceps tendon and peripatellar soft tissues inflammation. And also mild swelling was observed in 3 (10%) of all participants.

[Table.1 near here]

There was a significant group-by-time interaction for the average knee pain around or behind patella while prolonged sitting, ascending stairs, squatting activities and nocturnal pain values *(respectively $p=.002$; effect size (ES): .291, $p=.007$; ES: .235, $p=.041$; ES: .141, $p=.027$; ES: .164)*. This means that groups were changed over time but in different ways. The main effect of time for all were significant, in other words the groups did change over time and both groups were getting less pain *(respectively $p=.001$; ES: .335, $p<.001$; ES: .541, $p< .001$; ES: .443, $p=.027$; ES: .164)*. No significant main effect of group was found *(respectively $p=.547$; ES: .013, $p=.873$; ES: .001, $p=.546$; ES: .013, $p=.439$; ES: .022)*. The group-by-time interaction term for the average knee pain around or behind patella while descending stairs values was near the threshold of statistical significance *(*$p=.051$*; ES: .129)*, but there was a significant main effect of time *(*$p<.001$*; ES: .496)*. And no significant main effect of group was found *(*$p=.461$*; ES: .020)*.

The group-by-time interaction and the main effect of group for the average knee pain around or behind patella while walking did not meet the significance threshold *(respectively* $p=.131$*; ES: .080,* $p=.124$*; ES: .083)*. However a significant main effect of time was found *(*$p=.008$*; ES: .225)*. No statistically significant group-by-time interaction and main effect of group was observed for KPS *(respectively* $p=.601$*; ES: 010,* $p=.836$*; ES: .002)* but main effect of time was significant *(*$p<.001$*; ES: .502)*. This means that both groups had similar changes for the average knee pain while walking and KPS values (Table 2).

pVAS scores decreased in both groups but planned pairwise comparisons (between-group differences) showed that a significant difference in terms of prolonged sitting, ascending and descending stairs, squatting activities and nocturnal pain between the 2 groups *(*$p=.02$*,* $p=.007$*,* $p=.05$*,* $p=.041$*,* $p=.027$*)* (Table 2).

[Table.2 near here]

A significant group-by-time interaction was found for right side NDT *(right p=.007; ES: .230), RA-NWB (right p=.034; ES: .151, left p=.001; ES: .348, and WB (right p=.004; ES: .257, left p<.001; ES: .424)* and FPI *(right and left p<.001; right ES: .534, left ES: .547)*. This means that groups were changed over time but in different ways. The group-by-time interaction term for the left side NDT was near the threshold of statistical significance *(p=.054; ES: .126)*. The main effect of time for all were significant, in other words the groups did change over time and both groups' foot posture changed (*NDT right p=.013; ES: .201, left p=.017; ES: .064, RA-NWB right p=.014; ES: .075, left p=.001; ES: .348, and WB right and left p<.001; right ES: .420, left ES: . 424, FPI right and left p<.001; right ES: .534, left ES: .547)*. And no significant main effect of group was found *(NDT right p=.307; ES:.037, left p=.228; ES:.228, RA-NWB right p=.218; ES:.054, left p=.416; ES:.024, and WB right p=.600; ES: .023, left p=.336; ES:.033, FPI right p=.241; ES: .049 and left p=.400; ES:0.025).*

NDT, RA, and FPI scores decreased in SFEG whereas they increased in ConG. Planned pairwise comparisons (between-group differences) showed that a significant difference in terms of all parameters between the 2 groups *(NDT right p=.007, left p=.054; RA-NWB right p=.040, left p=.001; RA-WB right p=.004, left p<.001; FPI right and left p<.001)* (Table 3). These indicate that the participants in the SFEG had more and statistically significant improvements compared to the participants in the ConG after the interventions.

[Table.3 near here]

Hip muscles (extensors and abductors) group: Statistically significant group-by-time interaction effect was observed for hip extensors *(right p=.028; ES: .161, left p=.037; ES: .280)*, however no statistically significant group-by-time interaction effect was observed for hip abductors *(right p=.298; ES: .0.039, left p= .727; ES: .004),* suggesting that both groups had similar changes. For the main effect of time significant improvements in both groups were observed. This means that the groups did change over time and both groups gained strength *(p<.001; extensors; right ES:.0,572, left ES:.490, abductors; right ES:.344, left ES:.399)*. No significant main effect of group was found *(extensors; right p=.172; ES:.065, left p=.241; ES:.049, abductors; right p=.875; ES:.001, left p=.958; ES:.000).*

As there was a significant group-by-time interaction effect in the extensors a planned pairwise comparison was performed, between-group difference was found significant in favor of SFEG *(right p=.028, left p=.037)* (Table 4).

[Table.4 near here]

Knee muscle group: There were no significant group-by-time interactions for the knee musculature *(flexors right p=.741; ES:.004, left p=.299; ES:.038 and extensors right p=.466; ES:.020, left p=.347; ES:.033)*. This showed that both groups had similar changes. No significant main effect of group was found *(flexors right p=.458; ES: .020, left p=.889; ES: .001 and extensors right p=.368; ES: .030, left p=.374; ES:.029).* However a significant main effect of time was found *(flexors and extensors right p<.001; flexors right ES: .397, left ES: .531 and extensors right ES: .437)* except left side extensors *(p=.078; ES:.111)* (Table 4).

Ankle muscle group and FHL: The group-by-time interaction and the main effect of group for the ankle muscle group and FHL did not meet the significance threshold *(DF right p=.936; ES:.000, left p= .365; ES:.029, PF right p=.178; ES:.064, left p=.777; ES:.003, FHL right p=.758; ES:.003, left p=.267; ES:.045, DF right p=.400; ES:.025, left p=.184; ES:.062, PF right p=.414; ES:.024, left p=.518; ES:.015, FHL right p=.809; ES:.002, left p=.273; ES: .044)*. The results suggest that both groups had similar changes. No significant main effect of time was found for FHL *(right p=.075; ES:.109, left p=.875; ES:.001)*. However for the main effect of time, significant improvements were observed in ankle musculature strength *(DF right p=.001; ES:.324, left p<.001; ES:.472, PF right p<.001; ES:.395, left p=.002; ES:.002)* (Table 4).

4. DISCUSSION

The overall aim of this study was to investigate the efficiency of SFE. Specifically, we focused on the knee pain, foot biomechanics, and muscle strength in patients with *'weak and pronated'* foot subgroup of PFP. The results of this study show that patients with *'weak and pronated'* foot subgroup of PFP who performed SFE in addition to hip and knee strengthening and stretching exercises experienced greater knee pain reduction and clinically higher functional improvements compared to patients who performed only hip and knee strengthening and stretching exercises. The result of this study demonstrated that SFE has significant effects on foot biomechanics and knee pain.

Our results are similar to others that have found improvements in pVAS and KPS (30, 31). pVAS scores decreased in both groups but it was significantly in SFEG's favor. And improvements in all pain related domains for SFEG were approximately ≥2 cm which was indicated as minimal clinical important difference (32). Although there is no difference between overall scores in KPS, in more detail, we observed that KPS-climbing stairs, squatting, prolonged sitting and walking scores were clinically higher in the SFEG.

The findings of the current study indicate that a significant improvement occurred in the ND and RA values in the SFEG. However, in the ConG, a slight increase in the ND and RA values was recorded and this indicated an increased tendency to pronated foot posture. At this point, although the baseline values of the two groups seem to be different to consider the laterality of the NDT and RA, the difference in baseline values due to random allocation of the patients into the groups. Although the baseline values of the patients randomly included in the SFEG show lower MLA and more pronated rearfoot posture than ConG, both groups remained within the norm values.

As a result, findings from this study can be interpreted as progressive SFE, in addition to hip and knee strengthening exercise is effective in increasing the activity of the foot intrinsic muscles and reducing foot pronation by providing arch control in patients with *'weak and pronated'* foot subgroup of PFP.

The main mechanism of arch control is the 'Windlass mechanism'. The winding of the plantar fascia around the metatarsal heads, via dorsiflexion during the propulsive phase, elevates the MLA and as a result, the foot forms a rigid lever arm (33). In this way, the plantar flexor torque is transferred to the ground effectively. Intrinsic muscles are thought to affect this active mechanism (33).

Although it was beyond the scope of this study, consistent with Nguyen and Boiling (34), the ND- subtalar joint-knee valgus connection was also demonstrated and an exercise approach was suggested.

Another noteworthy finding of the current study was an improvement in foot pronation assessed with FPI in SFEG. With these results add to the findings of current study, it was concluded that SFE should be taken into consideration to maintain foot posture. Although there is a consensus that foot orthoses are effective only in patients with PFP with excessive pronation, foot orthoses are commonly demonstrated as first treatment option for foot pronation in PFP (35-37). In addition, FPI was demonstrated as a useful assessment for foot posture and orthoses (36). This indicates patients with PFP who may benefit from orthoses will have scores of 10 points and over defined as *'highly pronated'* according to FPI. In line with Selfe et al., in this study, patients were defined as *'pronated'* (in the range of 6-7 points) according to the FPI (38). Therefore the results of this study also offers preliminary evidence to suggest that as part of a stratified care approach SFE may be a useful targeted intervention to use for the weak and pronated foot group of patients with PFP.

Muscle strength imbalance is stated as one of the most important factors to predispose PFP. In particular, knee and hip extensor, hip abductor muscles weakness has been emphasized in previous studies (39-41). It is reported that the weakness of hip and knee muscles could increase femoral adduction and medial rotation, leading to excessive knee dynamic valgus during functional activities (42). Also the inhibition of the load response ability results in the greater transmission of shock to the supporting foot structures and acceleration of the lower extremity pronation (43, 44). In other words, the weakness of the hip and knee muscles can lead to poor shock absorption and decreased pronation control. Furthermore, previous reports show that this lack of control could result in dynamic postural balance instability (40). Current literature indicates increased muscle strength and improvements after various exercise treatments (isometric, isotonic or isokinetic) (35). However, the foot, which is the distal-end element of the lower extremity kinematics, foot biomechanics, foot muscles training and their effects remain relatively unclear.

Similar to literature, the strength of all tested lower extremity muscle groups increased in both groups after exercise programs (45, 46). However, in more detail, it was generally observed that the muscle strength in SFEG increased slightly more. In particular, we believe that the increase in strength of the hip extensors may have occurred due to the additional support of the SFE to postural stability. This additional support is explained with the sensory contributions of the foot intrinsic muscles via neural subsystem according to the concept of foot core system (47-49). This sensory contribution is believed due to the stimulation of proprioceptors on the sole. As a result of the increasing afferent input to the spinal cord, voluntary muscle activation was enhanced and the standing stability was improved (50).

On the other hand, it has been known that muscle strength affects posture, posture also affects muscle strength and is an important component of maximum gain in strength training (51). We believe that the combination of these two, may explain the difference in the strength of the hip extensors in SFEG. In other words, foot posture improved via the SFE may have lead gaining more from strengthening exercises in the SFEG by providing the alignment of the entire lower extremity posture.

4.1. Study Limitations

These results of this study need to be considered in the context of several limitations. First of all, SFE is an exercise protocol based on intrinsic muscle training and the most prominent marker of effective treatment will be recording the intrinsic muscles activity. Because of the limited evaluation methods in the literature and the need for special devices, we could not include this evaluation in our study.

Secondly, this study seems like as gender-specific study because of the high proportion of the female participants (more than %80). But it was reported that females were 2-3 times more likely develop PFP compared with males (52). As a result, female participants were included in higher proportion compared with males.

The clinical picture of PFP emphasizes the importance of dynamic situations compared to static positions. Unfortunately only static evaluations could be included in this study. However, if we could obtain data on plantar pressure distribution dynamically, we believe that the improvements with SFE could be more objectively expressed.

To our knowledge, this is the first study investigate the use of SFE in patients with PFP. In the current study, the improvement observed in terms of knee pain in both groups, revealed that exercise contributes to PFP rehabilitation. However we believe that the results support the use of SFE as an important component of a stratified care approach for the rehabilitation of PFP patients with a FPI in the region of 6/7. The findings indicate that SFE will positively influence navicular position, rearfoot posture and valgus stress on the knee. Although it was away from the primary purposes, FPI should be considered as an evaluation in patients with PFP in terms of concordance with NDT and RA. And also the results of this study suggest that the increase in strength of the hip extensor muscles may also be due to the additional support to the stabilization with SFE. Further research about SFE in patients with PFP is warranted to clarify the long-term effects of SFE, training during dynamic activities and performance.

5. ACKNOWLEDGEMENTS

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7. TABLES

Table 1. The demographic characteristics of the groups

	ConG (n=15) X (SD) (Min/Max)	**SFEG (n=15) X (SD) (Min/Max)**	***p***

Age (years)	43.60 (7.76) (25/52)	39.60 (8.87) (25/55)	0.199
Height (cm)	165.14 (7.59) (153/182)	167.66 (12.15) (150/192)	0.693
Weight (kg)	68.36 (10.66) (54/86.5)	71.34 (16.25) (47.7/99)	0.760
BMI (kg/m^2)	25.09 (3.77) (19.13/32.56)	25.36 (5.19) (18.25/34.18)	0.896

*__BMI:__ Body Mass Index, __ConG:__ Control Group, __SFEG:__ Short Foot Exercise Group, __X:__ Mean, SD: Standard deviation, __Min.:__ Minimum value, __Max.:__ Maximum value, * p<0.05.*

Table 2. Pain intensity before and after treatment

Outcome/Time	ConG (n=15) X (SD) (95% CI)	SFEG (n=15) X (SD) (95% CI)	Between- group differences X (95%CI)
Walking pain			

Baseline	4.13±3.22 (2.34, 5.92)	3.66±2.28 (2.39, 4.93)	
6th week	3.46±2.99 (1.80, 5.12)	1.40±1.54 (0.54, 2.25)	1.60 (-0.50, 3.70)
Within-group change	0.66±3.49 (-1.27, 2.60)	2.26±1.90 (1.21, 3.32)	
Sitting pain			
Baseline	3.13±3.13 (1.39, 4.87)	4.93±2.46 (3.56, 6.29)	
6th week	3.00±3.22 (1.21, 4.78)	2.33±1.87 (1.29, 3.37)	2.46 (0.97, 3.95)
Within-group change	0.13 ±1.95 (-0.95, 1.21)	2.60± 2.02 (1.47, 3.72)	
Stair-up pain			
Baseline	4.46±2.87 (2.87, 6.05)	5.80±2.11 (4.63, 6.96)	
6th week	3.30±2.38 (1.97, 4.62)	2.20±1.52 (1.35, 3.04)	2.43 (0.73, 4.13)
Within-group change	1.16±2.21 (-0.06, 2.39)	3.60±2.32 (2.31, 4.88)	
Stair-down pain			
Baseline	4.86±3.02 (3.19, 6.53)	5.06±1.75 (4.09, 6.03)	
6th week	3.63±3.00 (1.97, 5.29)	2.26±1.22 (1.58, 2.94)	1.56 (-0.006, 3.13)
Within-group change	1.23±2.09 (0.07, 2.39)	2.80±2.11 (1.63, 3.96)	
Squatting pain			
Baseline	5.20±3.23 (3.40, 6.99)	6.73±2.28 (5.46, 7.99)	
6th week	4.00±3.25 (2.19, 5.80)	3.53±1.76 (2.55, 4.51)	2.00 (0.08, 3.91)
Within-group change	1.20±3.05 (-0.49, 2.89)	3.20±1.93 (2.12, 4.27)	
Nocturnal pain			
Baseline	1.80±2.65 (0.33, 3.26)	3.60±3.35 (1.74, 5.45)	
6th week	1.80±2.65 (0.33, 3.26)	1.33±1.83 (0.31, 2.35)	2.26 (0.28, 4.25)
Within-group change	0.00±2.56 (-1.41, 1.41)	2.26±2.73 (0.75, 3.78)	
Kujala Patellofemoral Scale			
Baseline	63.86±10.07 (58.28,69.44)	62.06±14.16 (54.22,69.91)	
6th week	72.60±12.14 (65.87,79.32)	72.73±11.39 (66.42,79.04)	1.93 (-5.55, 9.41)
Within-group change	-8.73±8.13 (-13.23, -4.22)	-10.66±11.57 (-17.07, -4.25)	

***Walking pain:** pain after 30 minute walking, **Sitting pain:** pain after 1 hour sitting, **Stair-up pain:** pain at ascending stairs, **Stair-down pain:** pain at descending stairs, **Squatting pain**: pain while squatting, **ConG**: Control Group, **SFEG:** Short Foot Exercise Group, **X:** Mean, **SD:** Standard deviation, **CI:** Confidence of Interval.*

Table 3. Navicular drop test, rear foot angle values and foot posture index scores before and after treatment

	ConG (n=15) X±SD (95% CI)	SFEG (n=15) X±SD (95% CI)	Between-group differences X (95%CI)
NDT (mm)			
Right side			
Baseline	8.61±3.12 (6.88, 10.34)	11.19±3.48 (9.26, 13.12)	-3.10 (-5.30, -0.90)
6th week	8.74±2.65 (7.27, 10.21)	8.21±2.95 (6.58, 9.84)	
Within-group change	-0.12±3.45 (-2.04, 1.78)	2.97±2.30 (1.69, 4.25)	
Left side			
Baseline	8.35±4.43 (5.90, 10.81)	11.29±4.23 (8.94, 13.64)	-2.60 (-5.25, 0.47)
6th week	8.76±4.22 (6.42, 11.10)	9.09±3.13 (7.35, 10.83)	
Within-group change	-0.40±2.73 (-1.91, 1.11)	2.19±4.19 (0.12, 4.52)	
RA (NWB) (degree)			
Right side			
Baseline	2.53±5.28 (-0.39, 5.46)	1.40±6.34 (-2.11, 4.91)	2.46 (0.12, 4.80)
6th week	2.93±5.31 (-0.007, 5.87)	-0.66±4.32 (-3.05, 1.72)	
Within-group change	-0.40±1.18 (-1.05, 0.25)	2.06±4.11 (-0.21, 4.34)	
Left side			
Baseline	2.13±5.44 (-0.88, 5.15)	4.86±4.74 (2.23, 7.49)	2.73 (1.26, 4.20)
6th week	2.13±5.13 (-0.71, 4.97)	2.13±2.66 (0.65, 3.61)	
Within-group change	0.00±1.25 (-0.69, 0.69)	2.73±2.43 (1.38, 4.08)	
RA (WB) (degree)			
Right side			
Baseline	8.60±1.80 (7.60, 9.59)	7.33±3.43 (5.43, 9.23)	-2.40 (-3.97, -0.82)
6th week	8.06±1.86 (7.03, 9.10)	4.40±2.64 (2.93, 5.86)	
Within-group change	0.53±1.45 (-0.27, 1.34)	2.93±2.60 (1.49, 4.37)	
Left side			
Baseline	7.93±3.30 (6.10, 9.76)	9.00±3.22 (7.21, 10.78)	-4.13 (-5.99, -2.27)
6th week	7.93±2.34 (6.63, 9.23)	4.86±3.27 (3.05, 6.67)	
Within-group change	0.00±2.03 (-1.12, 1.12)	4.13±2.87 (2.54, 5.72)	
FPI			
Right side			
Baseline	6.53±3.77 (4.44, 8.63)	6.13±3.04 (4.45, 7.82)	-2.13 (-2.94, -1.32)
6th week	6.53±3.77 (4.44, 8.63)	4.00±2.87 (2.41, 5.59)	
Within-group change	-	2.13±1.45 (1.32, 2.94)	
Left side			
Baseline	6.73±3.88 (4.58, 8.88)	7.00±2.03 (5.87, 8.12)	
6th week	6.73±3.88 (4.58, 8.88)	4.53±2.32 (3.24, 5.82)	-2.46 (-3.37, -1.55)
Within-group change	-	2.46±1.64 (1.55, 3.37)	

NDT: *Navicular Drop Test,* ***RA:*** *Rear foot Angle****, NWB:*** *Non-weight Bearing Position (sitting),* ***WB****: Weight Bearing Position (standing),* ***FPI:*** *Foot Posture Index,* ***ConG:*** *Control Group,* ***SFEG:*** *Short Foot Exercise Group****, X:*** *Mean,* ***SD:*** *Standard deviation,* ***CI:*** *Confidence of Interval,* ***negative (-):*** *Varus for rear foot angle,* ***positive (+):*** *Valgus for rear foot angle.*

Table 4. Lower extremity muscle strength before and after treatment.

Muscle Strength (N)/Time	ConG (n=15) X±SD (95% CI)	SFEG (n=15) X±SD (95% CI)	Between-group differences X (95%CI)
Hip Joint Abduction			
Right Side			
Baseline	35.40±5.19 (32.46, 38.24)	34.71±6.27 (30.89, 38.54)	
6th week	38.44±4.31 (35.99, 40.89)	39.52±4.70 (36.67, 42.36)	-2.35 (-6.89, 2.18)
Within-group change	-3.06±5.68 (-6.17, 0.11)	-5.39±6.27 (-8.92, -1.86)	
Left Side			
Baseline	31.96±4.70 (29.32, 34.51)	32.65±5.58 (29.22, 36.08)	
6th week	35.99±4.51(33.44, 38.44)	36.77±3.92 (34.32, 39.22)	-0.71 (-4.88, 3.44)
Within-group change	-4.02±4.41 (-6.47, -1.47)	-4.70±6.47 (-8.33, -1.07)	
Hip Joint Extension			
Right Side			
Baseline	33.63±3.92 (31.47, 35.79)	34.22±3.53 (32.06, 36.38)	
6th week	36.57±4.41 (34.12, 39.03)	40.50±4.31 (37.85, 43.14)	-3.60 (-6.80, -0.41)
Within-group change	-2.94±3.53 (-4.90, -0.98)	-6.57±4.80 (-9.21, -3.82)	
Left Side			
Baseline	32.55±4.80 (29.81, 35.20)	34.12±6.47 (30.20, 38.04)	
6th week	37.26±4.90 (34.51, 40.01)	40.10±4.60 (37.26, 42.95)	-1.98 (-6.53, 2.55)
Within-group change	-4.70±4.70 (-7.35, -2.05)	-6.66±7.06 (-10.68, -2.74)	
Knee Joint Flexion			
Right Side			
Baseline	33.34±5.78(30.10, 36.48)	35.69±4.02(33.24, 38.14)	
6th week	37.95±7.25 (33.93, 41.97)	40.59±5.88 (37.06, 44.12)	-0.78 (-5.57, 4.01)
Within-group change	-4.60±7.15 (-8.53, -0.58)	-5.39±5.49 (-8.43, -2.35)	
Left Side			
Baseline	32.65±5.88 (29.32, 35.89)	35.20±5.00 (32.16, 38.24)	
6th week	39.03±5.00 (36.18, 41.87)	39.22±6.37 (35.30, 43.05)	2.02 (-1.89, 5.94)
Within-group change	-6.37±5.88 (-9.61, -3.13)	-4.31±4.41 (-6.86, -1.86)	
Knee Joint Extension			
Baseline	25.00±2.54 (23.63, 26.47)	25.49±3.23 (23.53, 27.55)	
6th week	27.36±2.35 (25.98, 28.63)	28.83±2.94 (27.06, 30.69)	-0.88 (-3.35, 1.57)
Within-group change	-2.25±2.74 (-3.88, -0.68)	-3.13±3.53 (-5.19, -1.07)	
Left Side			
Baseline	24.81±4.60 (22.26, 27.36)	24.90±3.72 (22.65, 27.16)	-7.04 (-22.06, 8.06)

6th week	28.04±4.11 (25.69, 30.40)	35.79±29.81 (17.75, 53.83)	
Within-group change	-3.13±3.04 (-4.90, -1.47)	-10.19±28.34 (-26.57, 6.08)	
Ankle Dorsi Flexion			
Right Side			
Baseline	22.65±4.02 (20.39, 24.90)	23.33±2.64 (21.77, 25.00)	
6th week	24.71±3.43 (22.75, 26.67)	25.69±2.94 (23.83, 27.45)	0.09 (-2.47, 2.28)
Within-group change	-2.05±3.53 (-4.02, -0.07)	-2.15±2.64 (-3.62, -0.68)	
Left Side			
Baseline	22.75±2.45 (21.37, 24.12)	24.12±2.54 (22.65, 25.69)	
6th week	25.39±2.05 (24.22, 26.57)	25.98±2.15 (24.61, 27.26)	0.83 (-1.01, 2.69)
Within-group change	-2.64±2.74 (-4.21, -1.07)	-1.76±2.05 (-3.02, -0.67)	
Ankle Plantar Flexion			
Right Side			
Baseline	30.59±5.78 (27.36, 33.83)	30.10±5.29 (26.87, 33.34)	
6th week	33.53±5.78 (30.30, 36.67)	31.67±4.90 (28.63, 34.61)	1.41 (-0.67, 3.51)
Within-group change	-2.84±2.84 (-4.51, -1.27)	-1.47±2.64 (-2.96, 0.004)	
Left Side			
Baseline	26.08±5.88 (22.84, 29.41)	25.49±4.02 (22.94, 27.94)	
6th week	29.22±6.57 (25.59, 32.85)	28.24±3.62 (25.98, 30.49)	0.47 (-2.89, 3.83)
Within-group change	-3.04±5.00 (-5.88, -0.28)	-2.54±3.82 (-4.70, -0.50)	
FlexorHallucis Longus			
Right Side			
Baseline	21.57±2.25 (20.29, 22.84)	21.77±2.05 (20.49, 23.04)	
6th week	22.26±2.74 (20.69, 23.83)	23.04±2.25 (21.57, 24.41)	-0.27 (-2.13, 1.56)
Within-group change	-0.68±2.25 (-1.96, -0.59)	1.27±2.61 (-2.35, 0.47)	
Left Side			
Baseline	25.10±14.41 (17.06, 33.14)	20.69±2.25 (19.31, 22.06)	
6th week	22.35±2.94 (20.79, 24.02)	22.84±2.05 (21.57, 24.12)	-4.77 (-13.42, 3.86)
Within-group change	2.64±15.49(-5.78, 11.27)	-2.04±2.96 (-3.76, -0.33)	

***N:** Newton, **ConG:** Control Group, **SFEG:** Short Foot Exercise Group) **X:** Mean, **SD:** Standard deviation, **CI:** Confidence of Interval.*

8. FIGURE CAPTIONS

Figure.1. CONSORT Flow Chart *(Abbreviations: ConG; Control group, SFEG; Short Foot Exercise Group)*

9. FIGURES