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Original Article

Effect of a home-based stretching exercise on multi-segmental foot motion and clinical outcomes in patients with plantar fasciitis

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Abstract

Objectives: This study aimed to investigate the effect of a home-based stretching exercise on multi-segmental foot motion and clinical outcomes in patients with plantar fasciitis (PF). **Methods**: A single group pre- and post-test design was conducted for this study in 20 patients with PF. They had the self home-based stretching program of calf muscle for 3 weeks. They were assessed for the multi-segmental foot motion (degree) and clinical outcomes which included the plantar fascia pain/disability scale (PFPS) (score), muscle length (degree) of gastrocnemius and soleus, and muscle strength (kg) of ankle dorsiflexors, plantarflexors, invertors, evertors, great toe flexors, and lesser toe flexors. **Results**: There were no significant differences ($p>0.05$) in multi-segmental foot motion and muscle length after exercise. Significant improvements ($p<0.05$) were found in PFPS and muscle strength of ankle plantarflexors, invertors, evertors, great toe flexors, and lesser toe flexors after exercise. **Conclusions**: A home-based stretching exercise was an effective program for reducing pain, enhancing muscle strength for both extrinsic and intrinsic foot muscles in patients with PF.

Keywords: Fasciitis, Plantar, Exercise, Motion, Signs and Symptoms

Introduction

Plantar fasciitis (PF) is the most common cause of heel pain in adults and affects more than one million individuals each year in the United States[1]. There are several factors involving the development of PF. Reduction of the ankle dorsiflexion angle accompanying with calf muscle tightness was suggested to be one of the implicating factors of PF development[2,3]. The most common symptoms of PF is pain at the inferior heel region and difficulty in walking. Patients often have particular severe pain at the first few steps in the morning or after a long period of non-weight bearing activities such as sitting or lying. And this pain will appear again after having a period of weight-bearing[3,4]. When PF has developed into a chronic condition, it may affect the patient's quality of life including poorer foot-specific quality of life and general health, limited physical activities, more socially isolated, and lack of energy to participate the activities[5,6].

The calf muscle tightness is the major cause of biomechanical alteration in PF. It will lead to the increased tensile force on the plantar fascia during the stance phase of gait[2]. Excessive pronation and overcompensation at the first metatarsal phalangeal joint are also the factors contributing to the increased stress at the insertion of plantar fascia and developing to PF[7]. From the study of Chang et al in 2014[8], they found a greater total medial forefoot plantarflexion/dorsiflexion, greater total hindfoot inversion/eversion motion, and greater maximum metatarsophalangeal joint dorsiflexion during the stance phase of gait in PF group when compared to the healthy individuals. In a recent study performed by Bovonsunthonchai et al in 2019[9], under the walking speed was controlled and compared data to healthy, individuals with PF had significant reductions in dorsiflexion and inversion angles for the forefoot relative to hindfoot segments. When plantarflexion angle of the forefoot relative to hindfoot segments and dorsiflexion and inversion angles of the hindfoot relative to tibia segments tended to increase.

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These multi-segment foot motion alterations can create a functional deficit and either cause or contribute to the obvious clinical symptoms or other impairments in patients with PF. So, evaluation and treatment of PF should be concerned about these alterations. Discovering the treatment that able to recover normal movement and function may be a sustainable method to alleviate clinical symptoms for patients with PF[10].

Treatments for PF can be classified into surgical and nonsurgical methods. However, surgery may have multiple residual complications such as pain, flatfoot deformity, medial calcaneal nerve damage, and plantar tender scar[11]. There are several nonsurgical treatments for PF such as shoe modification, prefabricated and custom insertion, stretching exercise, physical therapy, nonsteroidal anti-inflammatory medication, cortisone injection, night splint, cast application, and modality[12,13]. Among these nonsurgical methods, a study reported that stretching exercise was the most effective treatment. It was a low-cost method and can improve not only pain but also the overall functional impairment of the foot and ankle[14].

Based on the previous findings, stretching exercise showed the best results in a long term when compared to the other treatments such as customed orthotics, night splints insertion, extracorporeal shock wave, ultrasound, iontophoresis, low dye taping, anti-inflammatory medication, corticosteroid, botulinum toxin, and platelet-rich plasma injections. Another advantage was patients able to practice on their own in any places and a low-cost technique. Furthermore, it was found that the simultaneous stretching of the Achilles tendon and plantar fascia provided the double improvement for pain and ankle dorsiflexion than the stretching exercise of the Achilles tendon alone[15]. A randomized controlled study[16] that compared the effect of stretching and strengthening exercise programs for 8 weeks on pain and gait in individuals with PF. Both groups of the intervention had the improvement in pain and several gait variables over the period of training but no difference between groups effect was found.

Obviously, stretching exercise provides beneficial effects to improve clinical symptoms in patients with PF. However, the exact biomechanical alterations that act as the cause of functional limitation and relation with other clinical outcomes still unknown. Adjustment of the foot motion after stretching exercise may help the health professions to obtain more understanding of the biomechanical mechanism and its effect for patients with PF. So, the aim of the study was to investigate the effect of gastrocnemius and soleus muscles and plantar fascia stretching on the foot motion and clinical outcomes in patients with PF. We hypothesized that there would be a significant reduction in the multi-segmental foot motion, significant improvement of all clinical outcomes including the decreased plantar fasciitis pain/disability scale (PFPS) and increased muscle length and muscle strength of lower extremity after performed a home-based exercise in patients with PF.

Materials and methods

Design and ethical approved statement

A single group pre- and post-test design was conducted in this study. Prior to participating in the study, participants were informed about the study details and signed the informed consent which was approved by the institutional ethical committee (COA no: MU-CIRB 2019/018.2801). The study conformed to the Declaration of Helsinki guideline.

Participants

Inclusion criteria for the participants included the age between 40-65 years, duration of clinical symptoms ≥1 month, resting visual analogue scale for pain (VAS-pain) ≤4 points, limited active talocrural joint dorsiflexion, tightness of Achilles tendon and negative tarsal tunnel test. Exclusion criteria were history of neuromuscular disorder, lower extremity surgery, systemic disease, rheumatoid arthritis, ankylosing spondylitis, Reiter's syndrome, generalized osteoarthrosis, tingling or numbness at the foot, inflammation sign at the ankle, flatfoot deformity, heel pain that is not consistent with proximal PF, peripheral vessel disease, and receive other physical therapy, treatment and/or medication during participating in the study.

Fifty-four participants were recruited from social media and poster details posted on the board at Physical Therapy Center, Faculty of Physical Therapy, Mahidol University, Thailand. After screening, 26 patients with PF were enrolled in the study. During the study, there were the patients withdrew from the study due to pain at the knee (n=1), lumbar (n=1), hospital admission from urethritis (n=1). Some participants unable to complete a whole protocol due to personal reasons (n=2) and lost to follow up (n=1). Therefore, 20 patients with PF completed overall protocol of the study (Figure 1).

Participants were recorded for the demographic data including the age, weight, height, gender, onset, and worst pain scale of the painful side or more severity of pain side (assessing by the PFPS), participants rated their pain scale in a range of number from 1 to 100, according to pain level which is a more number represents more pain severity), symptomatic side of PF (unilateral or bilateral), and physical activity level by a short form of the International Physical Activity Questionnaire (IPAQ)[17]. It was categorized into low, moderate, and high physical activity levels according to the activity and intensity performed over the past 7 days.

Data collection protocol

The multi-segment foot motion

For the multi-segmental foot motion, it was assessed for two times at before and after 3 weeks of exercise. The data were collected by using the 3D motion analysis system (Vicon™ Oxford, UK), consisted of 10 high-speed cameras (Vantage series) and 2 force plates (AMTI-OR67, Advance Mechanical Technologies Inc., USA) which placed on the middle part of the walkway. To obtain the valid data,

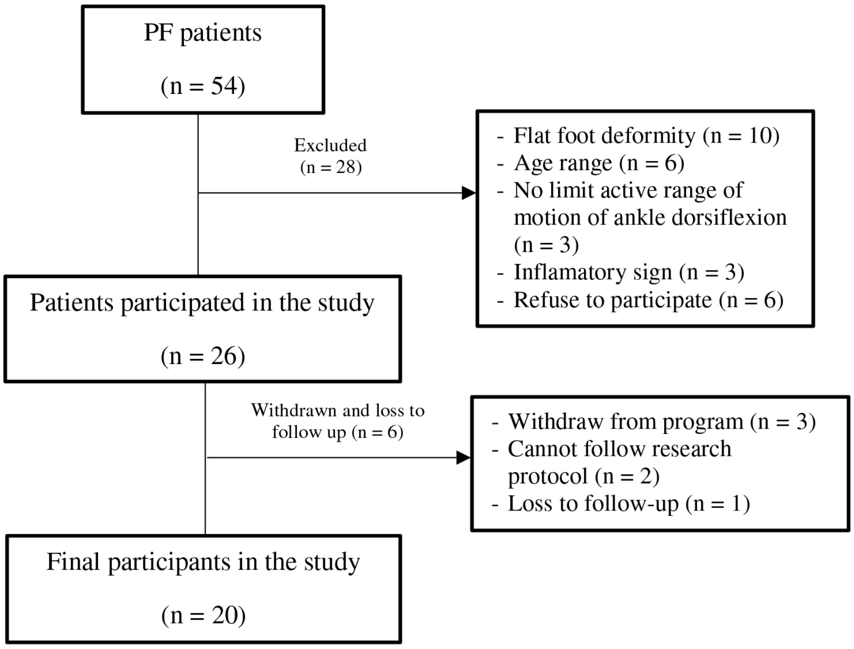

Figure 1. Flowchart of the study.

system and participant calibrations were performed before data collection. The set of 42 markers (9 mm) following the Oxford foot combination with PIG model was used. The Oxford foot model has been proved to be valid in both normal and pathological conditions and has been used in all age groups[18]. Good reliability (ICC ≥0.83) was found for hindfoot and forefoot angles in all planes of movement[19].

Participants walked with their barefoot along the 8 m walkway. They were asked to walk with their natural speed for consecutive 5 trials. To obtain reliable results but avoiding more pain or injury, participants were allowed to practice 2-3 trials until they walk naturally and consistency before the real 5 walking trials. The multi-segmental foot motion was collected at a frequency of 100 Hz and the force data was collected at 1,000 Hz.

For data processing, the multi-segmental foot motion was selected in the middle part of the walkway and gait events were identified by force plates and foot markers. Data were filtered using the fourth-order Butterworth low pass method with cut-off frequencies of 6 Hz for motion and for 15 Hz for force. All data of multi-segmental foot motion were processed using the Nexus software. The averaged successful data of 3 trials from 5 trials of walking were used in the analysis.

Multi-segmental foot motion (degree) including: 1) total forefoot plantarflexion and dorsiflexion was the relative motion between forefoot and hindfoot segments during affected foot touch the ground in stance phase, 2) total hindfoot inversion and eversion was the angle that calculated from the relative motion between hindfoot and tibia during affected foot touch the ground in stance phase, and 3) total hallux flexion and extension was the angle that calculated from the relative motion between hallux and forefoot during affected foot touch the ground from midstance to push-off.

Clinical outcomes

All clinical outcomes were assessed four times including before, after 1 week, after 2 weeks, and after 3 weeks of exercise. Clinical outcomes were measured for PFPS, muscle length, and muscle strength. For the patients who had bilateral symptoms, the more painful side data of foot motion and clinical outcomes were selected in the analysis.

PFPS (score) is a self-questionnaire to report the impact of PF on pain, mobility, and function. There are 19 items dividing into 2 subcategories consist of pain description and mobility/function. The participants have to score each question on a scale from 0 (never) to 3 (always) that best describes their foot symptoms. The pain sub-category consists of 8 items and measures foot pain description. The mobility and function subcategory consists of 7 items and measures difficulty in performing various functional activities, emotion and daily lifestyle. The total score of this questionnaire is 100 scores and a higher score indicates greater pain or disability.

Muscle length (degree) for gastrocnemius and soleus muscles were assessed by the wall stretch test with a digital inclinometer measurement. Participants were instructed to lunge forward with knee extension and slight knee flexion (around 30° knee flexion) for measuring the lengths of gastrocnemius and soleus muscles, respectively. The assessor placed a digital inclinometer on the tibia tuberosity landmark of the affected leg to measure the ankle dorsiflexion angle[20],

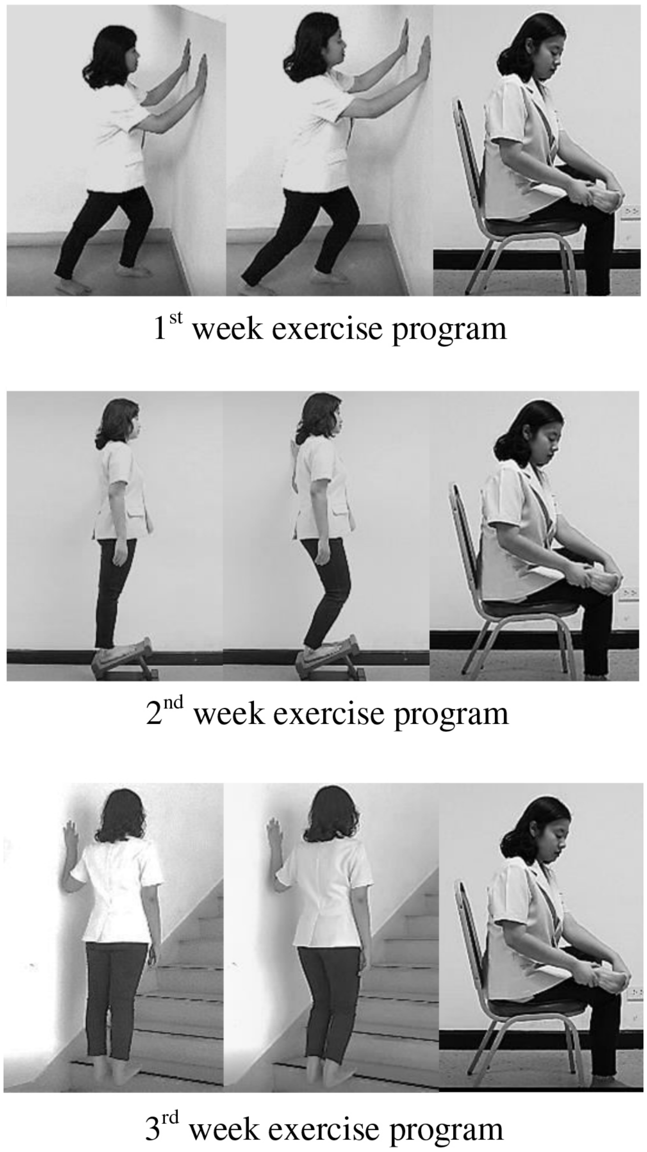

Figure 2. Exercise program protocol.

which the lesser degree of angle indicates more tightness of the muscle. Averaged data from three assessment trials were used in further analysis. The intra-tester reliability of muscle length test was performed from an investigator in this study. Excellent reliability was found for both gastrocnemius and soleus muscles (ICC=0.981 and 0.949, p=0.001).

Muscle strength (kg) of six muscle groups including: 1) ankle plantarflexors, 2) ankle dorsiflexors, 3) ankle invertors, 4) ankle evertors, 5) great toe flexors, and 6) lesser toe flexors were collected by a hand-held dynamometer. Averaged data of two trials from three trials of assessment were used in further analysis. The investigator practised how to use the tool to measure the strength and tested for reliability. There was excellent intra-tester reliability for all outcome muscles (ICC=0.807-0.913, p=0.001).

Table 1. Exercise progression.

Progression step	Directions	Set	Tension
Slightly tightness	Static stretching Stretch 20-30 sec: Rest 10 sec	10	≤5
Moderate tightness	Static stretching Stretch 20-30 sec: Rest 10 sec	10	6-7
Most tightness	Static stretching Stretch 20-30 sec: Rest 10 sec	10	≥8

Exercise program

The exercise program was a home-based stretching exercise for calf and plantar fascia that allowed the patients to perform by themselves and was progressed by week (Figure 2). To ensure the patients able to follow the program properly, a physiotherapist taught the exercise program until they remembered and able to exercise by their own accurately. They received both handbook and video clip of the exercise that can be opened and followed via smartphone. In addition, the researcher reminded them to follow the exercise twice a week by Line chat or telephone. Participants were re-checked and were assigned more progressively of exercise for two times (after 5th day and 10th day of the intervention program).

The programs consisted of the gastrocnemius, soleus, and plantar fascia stretching exercise. Duration for each stretching exercise was 20-30 sec, resting between exercises for 10 sec, and stretching each exercise for 10 sets. They spent a total time for the exercise around 20 minutes per day, 5 days per week over the duration of 3 weeks.

Exercise progression

Progression of stretching exercise was adjusted individually to prevent injury and effectiveness of the exercise program following the tension as demonstrated in Table 1. The criteria of tightness step depended on tension score that rated by participants individually during performed stretching exercise with a physiotherapist. The tension score was rated over the range level of 1 to 10 score, with a higher score indicated a higher tension level. If participants had tension score at ≤5, 6-7, >8, they performed the exercise with the feeling instruction of slight, moderate, and most tightness, respectively. Muscle length was re-assessed every week before progressing the next step of the exercise.

Statistical analyses

All data were analyzed using the SPSS software Version 23.0 (SPSS Inc, Chicago, IL, USA). The significant difference was set at p<0.05 for all comparisons. The Kolmogorov Smirnov Goodness of Fit test was used to assess the distribution of the data and the data demonstrated normal distribution. So, the Paired t-test was used to compare

Table 2. Demographic data of the participants.

Variables	(n, % or mean±SD)
Amount (n)	20
Age (years)	57.30±6.44
Weight (kg)	64.83±17.71
Height (cm)	159.78±9.84
Body mass index (kg/m^2)	25.05±4.16
Gender	
Male (n, %)	6, 30
Female (n, %)	14, 70
Onset of the last recent plantar fasciitis (months)	
1-3 months (n, %)	5, 25
3-6 months (n, %)	2, 10
6-9 months (n, %)	1, 5
12 months up (n, %)	12, 60
Worst pain (score)	57.04±20.12
Symptomatic side of plantar fasciitis	
Unilateral (n, %)	8, 40
Bilateral (n, %)	12, 60
Physical activity level	
High (n, %)	11, 55
Moderate (n, %)	1, 5
Low (n, %)	8, 40
SD (standard deviation)	

Table 3. Comparison of the multi-segmental foot motion between before exercise and after 3 weeks of exercise.

Variables	Before exercise (mean ± SD)	After 3 weeks of exercise (mean ± SD)	p-value*
Total forefoot plantarflexion and dorsiflexion	13.57±4.25	14.85±3.76	0.115
Total hindfoot inversion and eversion	13.41±3.23	11.88±3.03	0.081
Total hallux flexion and extension	22.65±9.55	24.17±8.33	0.432
** Significant difference tested by the Paired t-test at p<0.05. SD (standard deviation).*			

the multi-segmental foot data between before and after 3 weeks of exercise. The repeated measure for ANOVA was used to compare the PFPS, muscle strength, and muscle length among before, after 1 week, 2 weeks, and 3 weeks of exercise. If data showed a significant difference, a pairwise comparison with Bonferroni post hoc analysis at $p<0.05/3$ or $p<0.017$ was used to find a pair of difference.

Sample size calculation

The sample size was estimated from our own pilot study (n=5) on the variable of total hindfoot inversion and eversion between before and after 3 weeks of exercise which was the primary outcome of this study. By using the G*Power software Version 3.1.9.2 with the function to compare the difference between two dependent means: Matched pairs test and the alpha error probability of 0.05 and power of 0.95 were set. The number of total sample size was 15. Due to this study had follow-up session, drop out of 20% was included and the total sample size was 19. Hence, the number of participants that recruiting in this study probably sufficient to answer the research question.

Results

Demographic data

Table 2 shows the demographic data of the participants. Twenty patients with PF participated in the study and all of them completed a whole protocol of the study. Their averaged age, weight, height, and BMI were 57.30±6.44 years, 64.83±17.71 kg, 159.78±9.84 cm, and 25.05±4.16 kg/m^2, respectively.

Table 4. Comparison of clinical outcomes among before, after 1 week, after 2 weeks, and after 3 weeks of exercise and pairwise comparison test.

Variables	Before exercise (mean± SD)	After 1 week (mean± SD)	After 2 weeks (mean± SD)	After 3 weeks (mean± SD)	Repeated measure ANOVA (p-value*)	Pairwise comparison (p-value**): Before and after 1 week	Before and after 2 weeks	Before and after 3 weeks	After 1 week and 2 weeks	After 1 week and 3 weeks	After 2 weeks and 3 weeks
Plantar fasciitis pain/disability scale (score)	38.36±11.91	31.17±6.80	27.24±7.00	25.37±8.60	**<0.001**	0.021	**<0.001**	**<0.001**	**0.007**	**0.004**	0.687
Muscle length (degree)											
Gastrocnemius	57.82±5.94	57.65±6.02	55.07±5.40	56.60±8.18	0.298	n/a	n/a	n/a	n/a	n/a	n/a
Soleus	46.45±7.27	46.02±7.22	44.73±8.27	45.44±7.69	0.517	n/a	n/a	n/a	n/a	n/a	n/a
Muscle strength (kg)											
Ankle dorsiflexors	15.55±3.96	15.40±4.27	16.67±4.47	16.51±4.02	**0.031**	1.000	0.249	0.645	0.068	0.482	1.000
Ankle plantarflexors	23.62±4.38	24.05±4.20	26.04±4.29	26.10±4.08	**<0.001**	1.000	0.097	0.061	**0.005**	**0.004**	1.000
Ankle invertors	9.88±2.27	11.10±3.09	11.89±2.77	11.42±2.03	**<0.001**	0.118	**0.005**	**0.008**	0.449	1.000	1.000
Ankle evertors	9.15±2.16	10.83±1.92	11.82±2.48	12.41±2.65	**<0.001**	**0.006**	**0.001**	**<0.001**	0.291	0.022	0.858
Great toe flexors	7.90±2.99	8.48±3.43	10.59±4.14	11.25±2.65	**<0.001**	1.000	**0.011**	**<0.001**	**0.011**	**<0.001**	1.000
Less toe flexors	7.63±2.86	9.15±2.95	10.91±2.71	11.41±3.04	**<0.001**	0.054	**<0.001**	**<0.001**	0.028	**0.005**	1.000

**Significant difference testing by the repeated measure for ANOVA at p <0.05. **Significant difference testing by the Pairwise comparison with Bonferroni adjustment at p <0.017. SD (standard deviation); n/a (not assessment).*

The multi-segmental foot motion

Table 3 shows the comparison of the multi-segmental foot motion between before and after 3 weeks of exercise. There were no significant differences (p>0.05) in all testing variables.

Clinical outcomes

Table 4 shows the comparison of clinical outcomes including PFPS, muscle length, and muscle strength among before, after 1 week, after 2 weeks, and after 3 weeks of exercise as well as the pairwise comparison test. The repeated measures ANOVA revealed significant differences in PFPS ($F_{3,57}$=21.534, p <0.001) and muscles strengths. For muscle strength, significant differences were found in ankle dorsiflexors ($F_{3,57}$=3.18, p=0.031), plantarflexors ($F_{3,57}$=6.944, p<0.001), invertors ($F_{3,57}$=7.134, p<0.001), evertors ($F_{3,57}$=17.343, p<0.001), great toe flexors ($F_{3,57}$=12.722, p<0.001), and lesser toe flexors ($F_{3,57}$= 19.154, p<0.001). Whereas, muscle length of gastrocnemius and soleus showed no differences (p>0.05).

The pairwise comparison test demonstrated significant differences (p<0.017) between various pairs of duration in both PFPS and muscle strengths.

Discussion

Effect of a home-based stretching exercise on the multi-segmental foot motion

There were no significant differences (p>0.05) in all multi-segmental foot motion variables between before and after 3 weeks of exercise. For the total hindfoot inversion and eversion, this may be due to the large variation of the data causing by the different walking patterns among individuals. The result was consistent with the previous study[21] that found no significant difference in the total hindfoot movement during running on treadmill recorded by film between non-injury and

PF runners. However, the result of our study showed a decrease in total hindfoot inversion and eversion between before and after 3 weeks of exercise for 1.53 degrees. This agreeing with the previous observational study of Chang et al. in 2014[8], that compared the multi-segmental foot motion between patients with PF and normal healthy and found that total hindfoot inversion and eversion was significantly greater in patients with PF. So, we expected to observe the decrease in this angle after 3 weeks of exercise. The alteration of total hindfoot inversion and eversion may be influenced by a home-based stretching exercise program that emphasized on progressive stretching of gastrocnemius and soleus muscles combined with plantar fascia stretching. It was known that a greater degree of foot pronation induced the increase of stress and strain and could inhibit the tissue healing process on the plantar fascia[22]. Excessive pronation may potentially act as a compensatory response to gastrocnemius and soleus muscles tightness, tend to flatten the arch of foot, which stresses the plantar fascia[10]. After 3 weeks of exercise, tightness of gastrocnemius muscle was decreased. In addition, the effect of plantar fascia stretching exercise may enhance the recreation of windlass mechanism[23]. So, It may reduce foot pronation and may lead the arch of foot had more stabilization as shown in the improvement of muscle strength around the foot that control the stability of hindfoot inversion and eversion during walking.

When comparing the total forefoot plantarflexion and dorsiflexion and total hallux flexion and extension between before and after 3 weeks of exercise, the results showed no significant difference. There were the increased forefoot plantarflexion and dorsiflexion and hallux flexion and extension for 1.27 and 1.52 degrees, respectively. This was opposite to the expectation, it may be caused by the difference of used model and protocol of analysis. Our study used total forefoot plantarflexion and dorsiflexion and total hallux flexion and extension. While the previous study used total medial forefoot plantarflexion and dorsiflexion and peak first metatarsal phalangeal joint dorsiflexion as the representative of forefoot and hallux motion[8]. However, the most important reason underlying this finding was that the exact of biomechanical alteration was still unknown and had conflicted. For the related variables that determined by Wearing et al. in 2007[18], they found no difference in the total range of calcaneal-first metatarsal angle of the symptomatic limb in patients with PF when compare with the symptomatic limb. For a related variable to total hallux flexion and extension of our study, Wearing et al. in 2004[24] found the symptomatic limb of patients with plantar heel pain had limited maximum metatarsophalangeal joint dorsiflexion. While Chang et al. study in 2014[8] found greater maximum metatarsophalangeal joint dorsiflexion in patients with plantar heel pain when compared with the healthy group. In addition, the exercise program in this study emphasized only on gastrocnemius and soleus muscles stretching exercise, which was closer to the hindfoot segment than the forefoot or hallux segments.

Hence, it can conclude that a home-based stretching exercise effect on multi-segmental foot motion variables was still unclear because there was only a tendency of reduced total hindfoot inversion and eversion motion when the forefoot plantarflexion and dorsiflexion and hallux flexion and extension were not different.

Effect of a home-based stretching exercise on the plantar fasciitis pain/disability scale (PFPS)

PFPS showed significant improvement in all pairwise comparisons among before, after 1 week, after 2 weeks, and after 3 weeks of exercise excepts for between after 2 weeks and after 3 weeks of exercise. This may come from the effect of exercise program that emphasized the progressive stretching for gastrocnemius and soleus muscles combined with plantar fascia stretching. Increasing of tensional force in the Achilles tendon may result in the increased transmission of force in the plantar fascia during the stance phase of gait, causing the development of PF[2]. This also affected the functions, clinical symptoms, and quality of life in patients with PF. After 3 weeks of exercise, decreased gastrocnemius and soleus muscles tightness occurred and causing the improvement of pain, foot function, and mobility that observed by the improvement of PFPS score. The result agreed with the previous studies[15,24,25], that found the improvement of pain and function after stretching exercise in patients with PF. However, there was no difference in PFPS between after 2 weeks and after 3 weeks of exercise, but the score still continuous declined from 27.24 to 25.37. This may come from the exercise program was progressed with the exercised eccentrically on the step over the 3rd week of duration. So, it was a combination effect of stretching and strengthening for gastrocnemius and soleus muscles.

Effect of a home-based stretching exercise on muscle length

For the muscle length of gastrocnemius and soleus, although the results showed no significant differences among different testing times. But we found the tendency of slight improvement of this outcome after exercise. This differed from the results of previous study[15] that showed the explicitly increase in muscle length after stretching exercise. The difference in exercise program was probably the main reason for this difference. In our study, stretching exercise was progressively over the week. Reduced degree assessing from a digital inclinometer demonstrated the increased muscle length was observed over weeks. We found the maximum score of muscle length in week 2 and it increased slightly at the last week of exercise for both gastrocnemius and soleus muscles. This may relate with the stretching types that used the inclined wooden block during week 2 and stretching on the step at week 3. However, only increasing of 2.75 and 1.72 degrees was observed for the gastrocnemius and soleus in our study. While the previous study[15], reported the increase of muscle length of 3.4 and 3.6 degrees for gastrocnemius and soleus in the PF group who received the Achilles tendon and plantar fascia stretching. The difference in the amount of improvement of muscle length between studies may relate to demographic data that affect tissue property and recovering process. Most of the participants in our study had the onset of last recent PF more than 12 months when previous study[15] had up to 8.5 months only. It is well known that mechanical and neural factors influence the response to stretching. Although the increase in muscle length from stretching exercise is the main results of a reduction in passive stiffness of the muscle-tendon unit, however, this also causes by the neural mechanisms. The neural mechanism is the change in afferents on the muscle motoneuron, which controls by central nervous system[26]. When the clinical onset was longer, this may difficult to change muscle length due to neural mechanism adaptation. Besides, this is also influenced by gender and age differences between studies. The contractile elements capacity can be varied according to the earlier mentioned factors[27].

Effect of a home-based stretching exercise on muscle strength

In this study, the extrinsic foot muscles including ankle dorsiflexors, plantarflexors, invertors, and evertors showed significant improvement ($p<0.05$) among before, after 1 week, after 2 weeks, and after 3 weeks of exercise. However, there was no change ($p>0.017$) when testing with the Bonferroni post hoc adjustment analysis for the ankle dorsiflexors. But the other muscles showed significant differences ($p<0.017$) for all pairwise comparisons. The increased muscle strength in the present study may partly due to the increased flexibility of muscle and plantar fascia obtained from the stretching exercise. According to the stretch-induced strength loss theory from Nelson et al. in 2001[28], they stated that when muscle length is in the shortened position for a long duration, sarcomere become in the shorter length. This is not a proper length to generate muscle contraction, so, it generates only minimal isometric tension. It can be implied that stretching exercise increases the muscle-tendon unit compliance, thereby, allowing a greater sarcomere shortening during the isometric contraction. The previous study[29] investigated muscle performance during maximal isometric contraction on the stiffness of tendinous structure, suggested that compliance of muscle, tendon or aponeurosis associated with force exertion during isometric force assessment. From mechanism during performing the maximal isometric contraction, the muscle fibres are shortened from connective tissue compliance, and increasing compliance of muscle, tendon or aponeurosis result in a rightward shift on the force-velocity curve.

As a result of stretching exercise for calf muscle and plantar fascia, it is likely to be related with the increased muscle strength of all testing muscles, except for the ankle dorsiflexors. This may be due to the ankle dorsiflexors has only one and small muscle to do the action of ankle dorsiflexion movement, causing it has lesser influence from the effect of stretching exercise than other extrinsic foot muscles in this study.

There are several muscles that act as the longitudinal arch support[30]. Thordarson et al in 1995[31], demonstrated an elevation of the longitudinal arch in cadaveric feet when passive tension was imposed on the tendons of the tibialis posterior, flexor digitorum longus, flexor hallucis longus, and peroneus longus. Therefore, the function of these muscles during walking was to help in stabilization of the longitudinal arch during the stance phase of gait[32]. The extrinsic muscles including the tibialis anterior, soleus, gastrocnemius, peroneus longus, peroneus brevis, and extensor digitorum longus. During walking, gastrocnemius and soleus muscles initially control the sagittal plane forward rotation of the shank and absorption force during push-off. For peroneus longus, it is the strongest hindfoot evertor. For peroneus brevis, it is working together with peroneus longus to stabilize the ankle in the frontal plane of movement. Peroneus brevis plays a role as dynamic evertor, by co-contraction in the early stance with tibialis anterior, and stabilize a whole foot by limiting inversion. For extensor digitorum longus, it plays a role as eccentric control of hindfoot and toes plantarflexion at heel contact, concentric toe dorsiflexion at toe-off, and also co-contraction with tibialis anterior to stabilize the ankle joint[33]. Kibler et al in 1991[34], compared the strength of ankle dorsiflexors and ankle plantarflexors in patients with PF to the ones without PF group, they found that there were significant deficits of lower extremity muscle strengths in patients with PF. Patients with PF had muscle weakness, which diminishes the dynamic arch function to decrease ground reaction forces and to stabilize the longitudinal arch of the foot[35]. Then, this is compensated by the increase of additional stress on plantar fascia which is the passive support structure of the foot. Hence, improvement of these muscles strength after exercise in our study support the effectiveness of a home-based stretching exercise on enhancing foot muscles in patients with PF.

Limitation

The study may limit by no control group, so, this may be difficult in the interpretation. In addition, a long term effect of the exercise program was not evaluated in this study. Further study should focus more on other kinematic and kinetic variables and other types of exercise to obtain more improvement in the clinical outcomes.

Conclusion

The findings of this study showed that a home-based stretching exercise was an effective program for reducing pain, enhancing function and muscle strengths of both extrinsic and intrinsic foot muscles in patients with PF. Therapists can apply this exercise for patients with PF to improve their impairment including pain, function, and muscle strength.

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Authors' contributions

Hataitip Boonchum: Data collection, Data analysis & interpretation, Manuscript drafting, Manuscript revision. Sunee Bovonsunthonchai: Conception and design, Data analysis & interpretation, Manuscript drafting, Manuscript revision, Correspondence. Komsak Sinsurin: Conception and design. Wanlop Kunanusornchai: Conception and design .

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