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RESEARCH

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Effects of functional strength training on pain, function, and lower extremity biomechanics in patients with patellofemoral pain syndrome: a randomized clinical trial

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Abstract

Background Patellofemoral pain syndrome (PFPS) is a common disorder affecting the lower extremity. This study aimed to compare the effects of functional strength training (FST) and standard strength training (SST) in PFPS patients.

Methods Forty college students (aged 18–30 years) with PFPS and no exercise habits were randomized into FST group ($n=20$) and SST group ($n=20$). FST group underwent six weeks of lower extremity training focused on functional adaptations, whereas SST group focus on lower extremity strength training. Function (Kujala Patellofemoral Scale, KPS), pain (visual analog scale, VAS), peak joint angles of hip, knee, and ankle, along with muscle activation (step-down test) of Vastus medialis, Vastus lateralis, Biceps femoris, Semitendinosus, Gluteus maximus, and Gluteus medius were assessed at baseline and after intervention.

Results FST outperformed SST in pain reduction ($p=0.026$) and function ($p=0.006$) post-intervention. The FST group also showed increased hip flexion ($p<0.001$), gluteus maximus activation ($p<0.001$), and reduced knee valgus ($p=0.032$), while SST group exhibited greater knee flexion ($p=0.008$), and higher activation of the lateral femoral ($p<0.001$) and semitendinosus ($p<0.001$).

Conclusion Interventions focused on functional adaptations result in differential kinematic and muscle activation changes that may result in greater improvements in pain and knee function than lower limb muscle strengthening alone.

Trial registration chictr.org.cn. NO: ChiCTR2400087664. Date 01/08/2024.

Keywords Patellofemoral Pain Syndrome, Exercise Therapy, Strength training, Biomechanics

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Introduction

Patellofemoral pain syndrome (PFPS) is one of the most common disorders affecting the lower extremity [1]. Patients with PFPS are mainly characterized by peripatellar or infrapatellar pain, and the severity of knee pain is exacerbated by functional activities such as jumping, climbing or squatting [2]. In addition to causing pain, patients with PFPS exhibit lower activation of the gluteus maximus and gluteus medius during functional activities [3], leading to excessive adduction angles at the hip joint, in turn, dynamic knee valgus [4]. It has also been found that the quadriceps and hamstrings are less activated in patients with PFPS than in normal patients, which may require excessive flexion of the knee to increase muscle tone and increase the load on the knee joint [5, 6].

The mechanisms that lead to abnormal performance in PFPS patients are still unknown. However, strength training is widely accepted and used as the primary treatment [7]. Several studies have found that strength training of the knee, core and hip muscles in PFPS patients effectively improves pain severity and knee function in PFPS patients [8–10]. Most of these training programs incorporate both the structural and functional orientations of muscles. In the structural approach, the roles of muscles are referenced to enhance those that are weakly activated during functional activities. It's aims to correct the abnormal biomechanical patterns that arise from the functional activities of patients with PFPS [11]. Some scholars propose that weak hip external rotators and abductors contribute to hip over-adduction, thereby emphasizing the importance of strengthening these muscles [12–13]. However, existing research does not entirely support the efficacy of this intervention model. Palmer [14] et al. examined the impact of an isolated hip abductor strengthening program on knee kinematics and found no statistically significant alterations in knee valgus or hip adduction angles [11].

Table 1 Study inclusion and exclusion criteria [17]

Inclusion Criteria	Exclusion Criteria
Aged between 18 and 30 years	History of structural knee injuries such as tendon ligament, meniscus, iliotibial bundle, and goosefoot tendon injuries.
Body mass index (BMI) range from 18.5 to 24.9	Synovitis of the knee, degenerative osteoarthritis of the knee, and history of prior chronic knee pain.
Presence of retro-patellar or peripatellar pain lasting more than 6 weeks	Having referred pain coming from the lumbar spine, hips, ankles or feet
Reproduction of knee pain when performing squats, stairs or other functional activities	Participated in lower limb rehabilitation or systematic exercise training in the last six weeks
Maximum Visual analogue pain score ≥ 3 in the last 2 weeks	History of rheumatoid arthritis of the knee, gout, and other rheumatic conditions of the knee.

Consequently, some scholars have sought to employ functionally oriented interventions aimed at enhancing lower extremity muscle motor control during functional activities in patients with PFPS, ultimately modifying biomechanical patterns [15, 16]. Baldon [10] et al. discovered that stimulating lower extremity stabilization during functional activities through functional stability training improved hip adduction and knee valgus angles in single-leg squats, yielding greater pain relief compared to standard strength training. It remains unclear whether the observed biomechanical changes result from training that enhances functional adaptation, stability in functional movements, or a combination of both. Additionally, it is uncertain whether similar biomechanical changes can be achieved through strength training that primarily focuses on functional adaptations.

The purpose of this study was to compare the effects of functional strength training (FST), which emphasizes functional adaptations, with standard strength training (SST), which primarily focuses on muscle strengthening, on knee pain, functional outcomes, activation of the knee and hip muscle groups, and lower extremity kinematics. We hypothesized that the FST group would demonstrate greater improvements in knee pain, function, as well as different lower-limb kinematics change compared to the SST group.

Methods

Study design and participants

This study was a parallel-group, single-blind randomized clinical trial with an allocation ratio of 1:1. It was approved by the local institutional review board and registered in the Chinese Clinical Trials register as ChiCTR2400087664.

Forty non-exercise-habituated college students aged between 18 and 30 years with PFPS were randomly assigned to either the SST group ($n = 20$) or the FST group ($n = 20$). No exercise habits were defined as engaging in aerobic or physical activity less than twice a week and for no more than 30 min per session.

All participants diagnosed with PFPS were screened for eligibility criteria by three experienced physiotherapists. The inclusion and exclusion criteria are shown in Table 1. All participants provided written informed consent in accordance with guidelines approved by the local ethics committee.

Randomization

Opaque, consecutively numbered envelopes were used for randomization, with assignments based on a random number table generated by SPSS version 26.0 A person who was blinded to the patients' information executed the randomization and communicated the group assignments to the treating physical therapist. Randomization occurred after the baseline assessment. Patients were blinded to their group allocation by ensuring they remained unaware of the exercises performed by the other group, as interventions were delivered separately to members of each treatment group.

Outcome measures

At baseline and the end of the intervention, patients completed the kinematics evaluation, pain intensity, and knee function self-report questionnaires for the affected leg.

A 10-cm visual analog scale (VAS) was utilized, with 0 indicating no pain and 10 representing the worst imaginable pain. The Knee function was assessed using the Kujala Patellofemoral Scale (KPS), which comprises 13 items. A knee is deemed to function normally and painlessly when it achieves a maximum score of 100 [18]. Patients are instructed to rate their worst level of pain as well as their KPS score based on previous week's symptoms.

The kinematic assessment encompassed the muscle activation ratios of the gluteus maximus, gluteus medius, medial femoral, lateral femoral, biceps femoris, and semitendinosus muscles at the moment of initial touchdown during the step-down test, along with the peak angles of the hip, knee, and ankle. This functional test is often referenced in the literature as a means of evaluating the quality of lower extremity movement [19–21].

The procedure of the step-down test: a) After clearing the hair of skin, the electrode pads were placed at the highest point of the targeted muscle belly with 2 cm apart. For all target muscles, electrode placement was based on the SENIAM protocol [22]. The electrode pads related to wires to a myoelectric device (Noraxon, sampling frequency: 1500 Hz). Standardized data were collected for three resisted isometric maximal voluntary contractions (MVC) of the target muscle, each held for 5 s. Based on the Istituti Ortopedici Rizzoli lower limb model used in the biomechanical, 26 circular reflective markers with a diameter of 10 mm were fixed to anatomical landmarks. The specific paste locations included the bilateral anterior superior iliac spine, posterior superior iliac spine, greater trochanter of the femur, medial and lateral condyles of the femur, fibular tuberosity, tibial tuberosity, internal and external malleoli of the fibula, the surface of the second metatarsal, the first metatarsophalangeal joint, the fifth metatarsophalangeal joint, and the heel of the foot. The patient's kinematic data were captured by eight infrared cameras (Qualisys, sampling frequency 100 Hz) placed around the perimeter.

b) The patient stood with his hands on his hips on a step (18 cm height, 30 cm width) and was instructed to perform a step-down from a resting position until the heel touched the force measuring platform (Kistler, sampling frequency 1000 Hz). Subsequently, the patient was to return to the starting position (as illustrated in Fig. 1). The execution time for the step down was standardized to 2.0 ± 0.3 s and was monitored using a digital progressive stopwatch. After three acclimatization trials, each patient completed three trials for data analysis, with a one-minute break between each trial. The experiment was repeated if the patient lost balance during the maneuver or if any evaluation requirements were not met.
c) The static and dynamic models of all patients were repointed using Qualisys Track Manager software, and the required dynamic model was intercepted and imported into Visual 3D software. The kinematic data were selected from the angles of the hip and knee at the moment of initial touchdown (ground reaction force > 10 N) [26] during heel strike. Raw

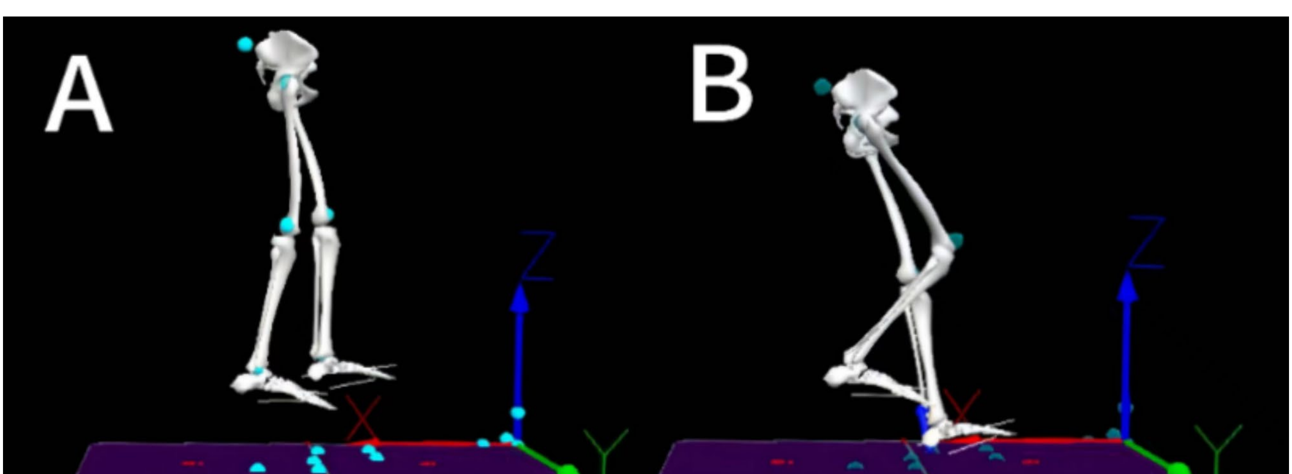

Fig. 1 Patient start (**A**) and end (**B**) position for the step-down test

electromyography data were intercepted from the middle 3s as the patient's standardized MVC and 100ms after the heel strike moment, and Root Mean Square (RMS) was calculated after filtering (10–500 Hz) using surface electromyography signal processing software (MR3.10 Edition).

Interventions

Both groups engaged in three sessions of training at the clinic each week for a duration of six weeks weeks (Fig. 2). An experienced physiotherapist guided the participants through the exercises during each session, providing individual supervision. Each session consisted of 5 min of warm-up (low-intensity running), followed by 40 min of group training, and concluded with 5 min of relaxation (low-intensity walking). Participants were instructed to refrain from additional physical activity throughout the study.

Recent studies have shown that proximal and distal knee muscle exercises are effective in controlling PFPS [8, 17, 23]. Therefore, we chose to train the core, hip and knee muscles of patients with PFPS in two different formats: FST and SST. The FST was similar to that described by Baldon [10] et al., with few modifications.

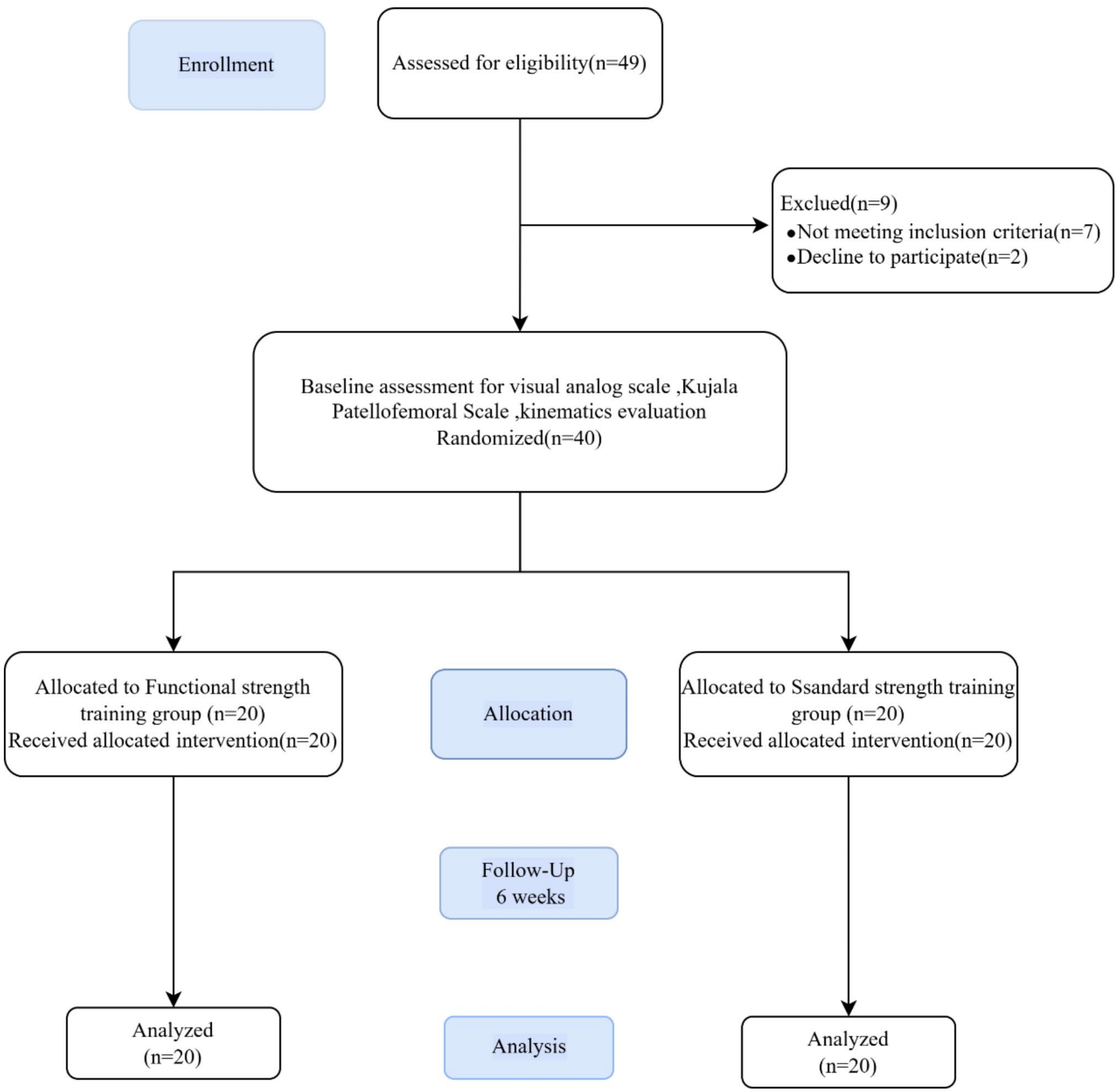

Fig. 2 Flow diagram outlining patient recruitment, group assignment, and outcome assessment

The primary goal of the first two weeks is improving hip and knee muscle motor control in accordance with PFPS patients' daily movement patterns. For the subsequent 4 weeks, the main objectives were to enhance strength of the hip and knee muscles and to continue to improve motor control using weight-bearing activities. Training variables and progression are shown in Appendix 1. The SST is derived from the Clinical Practice Guidelines of British Journal of Sports Medicine [24]and comprises both traditional weight-bearing and non-weight-bearing exercises, with a particular focus on muscle strengthening. Details regarding training variables and progression can be found in Appendix 2.

If necessary, exercises will be tailored to individual situations and abilities. All participants in both groups completed every training session. Throughout the training process, no patients experienced any sports-related injuries, including falls or joint ligament strains.

Sample size calculation and statistical analysis

The sample size was estimated using the primary outcomes (VAS score) from prior PFPS studies [25] .Using a power of 90%, an alpha of 0.05, and a medium effect size (0.5), at least 34 patients were required in total (G*Power software, version 3.1.9.7b was used). Assuming a dropout rate of 20%, we enrolled 20 patients for each group.

Descriptive and statistical analyses were performed using SPSS version 26.0, and the Shapiro-Wilk test and Levene's test were used for normality and chi-square for all data, respectively. Baseline demographics were analyzed using one-way analysis of variance (ANOVA) and Kruskal-Wallish test. To compare within- and between-group differences, the effect of the intervention on the outcome measures was assessed by two-way ANOVA. Results were analyzed using a 2 × 2 ANOVA (2 groups, 2 time points). When significant between-group time interactions were found, a post hoc Bonferroni correction was used to assess the change in each group at the 2 time points.

Table 2 Demographic characteristics of patients

Variable	FST Group	SST Group	P
Male/Female	15/5	16/4	—
Age (y)	21.8 ± 3.8	22.1 ± 3.0	0.68
Height (cm)	172.6 ± 8.7	171.9 ± 7.4	0.85
Weight (kg)	75.1 ± 10.4	72.4 ± 9.8	0.32
Body mass index (kg/m^2)	23.1 ± 1.9	22.5 ± 2.6	0.25
Injured side (right/left)	15/5	14/6	—
Symptom duration, (months)	5.86 ± 1.7	5.40 ± 1.5	0.63

NOTE. Data are presented as mean ± SD or as otherwise noted

Results

Patients

The demographic characteristics of patients are displayed in Table 2. All patients in both groups completed the six weeks of intervention training and completed the post-test.

Self-reported outcomes

A statistically significant difference was observed in pain and KPS scores within the FST group, with a reduction of 66.98% ($P < 0.001$). Similarly, the SST group demonstrated a statistically significant difference in pain and KPS scores, showing a reduction of 39.71% ($P < 0.001$). According to the post hoc Bonferroni correction, a statistically significant difference was found between the FST and SST groups with respect to pain ($P = 0.026$) and KPS scores ($P = 0.006$) (Table 3).

Kinematics

A statistically significant difference was observed in kinematics within the FST group, specifically in hip flexion (14.18% increase, $P = 0.001$) and knee valgus (25.07% decrease, $P < 0.001$). Similarly, within the SST group, a statistically significant difference in knee flexion was noted (7.03% increase, $P = 0.02$). Following the post hoc Bonferroni correction, statistically significant differences were identified between the FST and SST groups regarding hip flexion ($P < 0.001$), knee flexion ($P = 0.008$), and knee valgus ($P = 0.032$) (Table 3).

Lower extremity muscle activation

A statistically significant difference was observed in Gluteus maximus RMS(42.86% increase, $P < 0.001$) within the FST group. A statistically significant difference was observed in Vastus lateralis (28.93% increase, $P < 0.001$) and Semitendinosus activation (34.25% increase, $P < 0.001$) within the SST group. According to the post hoc Bonferroni correction, a statistically significant difference was found between the FST and SST groups with respect to Gluteus maximus ($P < 0.001$), Vastus lateralis ($P < 0.001$) and Semitendinosus activation ($P < 0.001$) (Table 3).

Discussion

Overall, the results of this study indicated that patients with PFPS who participated in a program that included hip and knee muscle strengthening and lower extremity motor control training showed greater improvements in pain and knee function compared to those who participated in exercise therapy focusing solely on muscle strength enhancement. And the two groups of patients demonstrated distinct biomechanical patterns of change.

Table 3 Effect of Training on Pain, knee function

	Baseline	Postintervention	Δ, %	Within-Group Difference, *P*	Between-Group Difference, *P*	$F_{3,76}$	η^2
VAS score(0–10)							
SST	4.76 ± 0.65	2.87 ± 1.03†	39.71↓	<0.001	0.026	37.27	0.651
FST	5.27 ± 1.39	1.74 ± 1.11†‡	66.98↓	<0.001			
KPS score (0-100)							
SST	63.25 ± 6.19	78.44 ± 7.54†	24.02↑	<0.001	0.006	67.99	0.773
FST	61.80 ± 5.50	85.34 ± 6.20†‡	38.09↑	<0.001			
Hip flexion(°)							
SST	48.98 ± 5.00	48.34 ± 5.59	1.31↓	0.946	<0.001	8.99	0.310
FST	49.31 ± 4.97	56.30 ± 4.25†‡	14.18↑	0.001			
Hip adduction (°)							
SST	14.95 ± 3.51	15.66 ± 3.27	4.74↑	0.832	0.801	0.70	0.034
FST	15.88 ± 3.50	16.73 ± 3.97	5.35↑	0.775			
Knee flexion(°)							
SST	67.43 ± 4.78	72.17 ± 4.43†‡	7.03↑	0.020	0.008	4.61	0.187
FST	68.59 ± 4.93	66.95 ± 3.23	2.39↓	0.998			
knee valgus(°)							
SST	17.56 ± 2.83	16.46 ± 2.78	6.26↓	0.820	0.032	6.58	0.248
FST	18.11 ± 3.79	13.57 ± 3.13†‡	25.07↓	<0.001			
Ankle flexion(°)							
SST	31.95 ± 3.93	31.12 ± 6.48	2.60↓	0.882	0.761	0.32	0.016
FST	32.33 ± 3.87	31.54 ± 3.35	2.44↓	0.768			
Vastus medialis(RMS)							
SST	0.99 ± 0.13	1.03 ± 0.17	4.04↑	0.528	0.720	0.46	0.023
FST	0.97 ± 0.12	1.00 ± 0.08	3.09↑	0.661			
Vastus lateralis(RMS)							
SST	1.21 ± 0.20	1.56 ± 0.22†‡	28.93↑	<0.001	<0.001	11.5	0.365
FST	1.27 ± 0.19	1.24 ± 0.17	2.36↓	0.875			
Biceps femoris(RMS)							
SST	0.60 ± 0.09	0.63 ± 0.12	5↑	0.896	0.993	1.17	0.055
FST	0.56 ± 0.11	0.59 ± 0.08	5.36↑	0.857			
Semitendinosus(RMS)							
SST	0.73 ± 0.13	0.98 ± 0.15†‡	34.25↑	<0.001	<0.001	27.45	0.578
FST	0.72 ± 0.10	0.64 ± 0.13	11.11↓	0.305			
Gluteus maximus(RMS)							
SST	0.34 ± 0.08	0.37 ± 0.07	8.82↑	0.792	<0.001	17.27	0.463
FST	0.35 ± 0.08	0.5 ± 0.06†‡	42.86↑	<0.001			
Gluteus medius(RMS)							
SST	0.3 ± 0.08	0.33 ± 0.11	10↑	0.418	0.655	1.00	0.048
FST	0.28 ± 0.08	0.3 ± 0.06	7.14↑	0.536			

Abbreviations: FST, functional stabilization training; SST, standard strength training

NOTE. Data are presented as mean ± SD or as otherwise noted

†Statistically different from baseline ($P < 0.001$)

‡ Statistically significant between-group difference ($P < 0.001$)

↓ indicates decrease and ↑ indicates increase

Effect of FST on pain and KPS scores in patients with PFPS

The results of pain changes as well as KPS scores support the findings of previous studies that in the PFPS patients, a combination of trunk, hip, and knee strengthening exercises, as well as functional training, can have a positive effect on pain and function [10, 25, 26]. The FST group all showed statistically and clinically significant improvements in pain after training, and the mean improvement in VAS was more than the minimum clinically important difference (MCID) of 2 cm [27]. The SST group showed statistically significant but not MCID in pain scores. This change may be attributed to the notable enhancement in hip motor function observed in the FST group, in contrast to the improvement in knee function seen in the SST group. This differential improvement may have contributed to a reduction in knee stress among patients with PFPS, subsequently alleviating knee pain. This may be similar to the mechanism found by previous studies, in which exercise of the hip muscles resulted in better pain improvement than training of the knee muscle groups.

The functional improvements after training in both the FST group and the SST group were statistically and clinically significant. The average improvement in KPS scores in each group was higher than the MCID value of 8 [28], but the score improvement in the FST group was significantly higher than that in the SST group. The difference in self-reported scores between the two groups may be since the FST focuses more on training patients' daily functional activities, while the activities assessed by the KPS are more related to self-perception of functional movements, such as walking and participating in sports activities [29]. Patients in the FST group can better absorb the pressure on the knee joint caused by daily activities, making up for the limitations of SST in functional adaptations.

Effect of FST on kinematics and muscle activation variables in patients with PFPS

This study provides innovative evidence of additional potential clinical benefits of FST. After a 6-week intervention, only the FST group demonstrated increased hip flexion and decreased knee valgus following gluteus maximus activation. These findings are significant, as patients with PFPS typically exhibit underactivation of the gluteus maximus and excessive knee valgus, both of which are believed to increase stress on the Q-angle and patellofemoral joint [30]. In FST training, greater emphasis is placed on hip-knee joint co-mobility through exercises such as forward lunges in front of a mirror and Romanian deadlifts. This approach aims to minimize knee pain, thereby encouraging patients to engage the hip during more substantial activities, which compensates for the limited range of motion in the knee and reduces knee load [31]. Consequently, the hip flexion angle is greater during functional activity testing, accompanied by increased activation of the gluteus maximus. In contrast, the present study found that knee valgus improved in the FST group without a significant increase in gluteus medius activation. This may be attributed to compensatory changes in pelvic and trunk tilt angles that were not assessed in this experiment. Although we emphasized the importance of maintaining an upright trunk during FST training, the exercises targeting the gluteus medius (such as the Side Stand Pelvic Lift and lateral sliding without jumping) did not effectively train the patient's ability to abduct the hip in the frontal plane, focusing instead on horizontal plane movements.

In the SST group training, there was no emphasis on multi-joint coordination, and the focus was solely on muscle strength. During knee training, patients likely engaged the lateral femoral muscles more for contraction, which may have resulted in increased activation of both the lateral femoral muscles and the semitendinosus during the step-down test [2]. Although the SST group trained the gluteus medius and gluteus maximus muscles, the lack of application in functional activities led patients to rely more on the relatively 'strong' quadriceps muscles, particularly the lateral femoral muscles, to perform the step-down test. This reliance resulted in an increased flexion angle of the knee joint. While many scholars consider the enhancement of knee strength and knee flexion angle to be a 'positive indicator' of improvement in PFPS symptoms [32], it has also been suggested that patients with PFPS may attempt to reduce the load on the patellofemoral joint, consequently decreasing the use of the quadriceps muscles and resulting in diminished knee strength and flexion activity [33]. Therefore, in the SST group, there was increased activation of the vastus lateralis and semitendinosus muscles, which may have alleviated the painful symptoms of PFPS without addressing the underlying causes of the condition.

Limitation

The primary limitation of our study pertains to its external validity. Our sample size was relatively small and comprised a homogeneous group of moderately to severely injured individuals, including both male and female non-athletic adults. However, patellofemoral pain syndrome (PFPS) is prevalent among athletes, such as amateur runners, and adolescents. This may limit the generalization of our findings to the PFPS population with exercise habits. Additionally, for safety reasons, we selected subjects with a BMI between 18.5 and 24.9, which may hinder the applicability of our results to overweight populations. Future research is necessary to explore exercise interventions across diverse PFPS populations.

Conclusion

Both FST and SST have the potential to reduce pain (66.98% vs. 39.71%), enhance knee function (38.09% vs. 24.02%), and modify kinematics in patients with PFPS. SST was found to improve knee-dominant movement patterns, whereas FST was more effective in enhancing hip-dominant movement patterns. Notably, FST demonstrated superior efficacy compared to SST in alleviating pain and improving knee function in patients with PFPS. Therefore, FST should be considered when designing exercise therapy for this patient population.

Abbreviations

FST Functional strength training
KPS Kujala Patellofemoral Scale
PFP Patellofemoral pain
VAS Visual analog scale

SST Standard strength training

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05482-z.

Supplementary Material 1

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Author contributions

ZY X, YG, and WZ designed, supervised this study, and were involved in the enrollment and randomization of all participants. ZY X and YG participated in the study design and wrote this manuscript. CS W participated in the exercise instruction, follow-up and outcomes measurements. All authors were involved in the data collection, statistics analysis. HW W and CS W were involved in the revision of this manuscript. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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