

## Combined Open and Closed Kinetic Chain Exercises for Patellofemoral Pain Syndrome: A Randomized Controlled Trial

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**Abstract:** Patellofemoral pain syndrome (PFPS) is a common ailment of the knee. Both open and closed kinetic chain exercises are effective in strengthening of the quadriceps muscle. It has been suggested that these exercises are used jointly in the management of PFPS, but no study to date has evaluated the effect of combined open and closed kinetic chain exercises on PFPS. The present randomized controlled trial aimed to evaluate six weeks of combined open and closed kinetic chain exercises on PFPS patients. For this purpose, 28 patients with PFPS (10 males and 18 females) were assigned to exercise and control groups randomly. Exercise group performed combined open and closed kinetic chain exercises for six weeks. Subjective symptoms, functional performance, knee flexion during stair ascent and descent by the patients were assessed before and after the 6-week exercise program. Results of the study indicated that after six weeks, pain decreased significantly and Anterior Knee Pain Scale (AKPS), knee flexion during stair ascent and descent and single leg hop increased significantly in the exercise group. But control group demonstrated significant increase in pain and significant decrease in knee flexion during stair ascent and descent and single leg hop. It is concluded that a combined open and closed kinetic chain exercise program will result in improved subjective and clinical outcomes in the patients with patellofemoral pain syndrome.

**Key words:** Open kinetic chain exercises % Closed kinetic chain exercises % Patellofemoral pain syndrome

### INTRODUCTION

Patellofemoral pain syndrome (PFPS) which is also known as anterior knee pain in the literature is the most common ailment of the knee in athlete and non-athlete youth and adults [1]. Incidence of this problem was reported to be 7% to 15%, most often involving the women and the youth. It seems, however, about one out of every four persons suffers from this syndrome in common population [2]. Main symptom of this condition is diffuse retropatellar and peripatellar pain with no specific pathology, which is exacerbated while activities such as stair ascent and descent, prolonged sitting, squatting, kneeling, running and jumping [3]. In the patients with this syndrome, muscular function decreases [4]. Furthermore, due to decreased range of motion of the knee, kinematics of gait changes in activities of daily living, e.g. stair ascent and descent [5, 6]. Generally, the patient may experience some degrees of functional disability as a result of pain and decreased function of the knee [7].

There are a lot of theories regarding pathogenesis of PFPS, including muscle imbalance among the quadriceps and hamstrings, tensor fascia lata and gluteus medius, vastus medialis and vastus lateralis [3, 8], malalignment of lower extremities [9], overuse injuries [10], ligament and cartilage injuries of the knee [11] and hormonal factors [12]. Muscle imbalance between vastus medialis and vastus lateralis and patella maltracking in trochlea groove of femur and lateral patellar motion is the theory mostly accepted by the authors [1, 3, 8, 13-15]. Lateral patellar motion results in change in pressure distribution on the articular surfaces and also concentration and increased stress on lateral facet of patella, which in turn leads to patellar pain and PFPS [8].

Some PTPS patients are managed well by conservative and nonoperative treatments and most therapists believe that the syndrome should be first treated in nonoperative and conservative manner [8, 16]. The authors suggested various conservative treatments to manage PFPS. Strengthening of the quadriceps by focusing on retraining of the vastus medialis oblique,

which stabilizes the patella in trochlea groove, is the most commonly used and highly accepted procedure in management of patellofemoral pain syndrome, known as "Golden Standard" [8, 9, 16-19]. Evidence supports exercise therapy in management of PFPS [20, 21].

Open kinetic chain exercises are the traditional method of strengthening the quadriceps muscle, which have been used since past years, but closed kinetic chain exercises are remarkably used during recent years [22]. One of the reasons to use closed kinetic chain exercises is that they are similar to activities of daily living, i.e. they are functional [23, 24]. On the other hand, low stress is imposed on patellofemoral joint in closed as compared to open kinetic chain exercises [25-27].

The studies comparing the effect of closed and open kinetic chain exercises on PFPS found no remarkable difference between them. Hence, combined open and closed kinetic chain exercises in management of PFPS were suggested [1, 3, 28-30]. However, in review of the literature, there was no study that evaluated the effect of combined open and closed kinetic chain exercises on PFPS. The present study aimed to evaluate the effect of six weeks of combined open and closed kinetic chain exercises on pain status and functional indices of the PFPS patients through a randomized controlled trial.

## MATERIALS AND METHODS

**Study Population:** 28 patients with PFPS, as diagnosed by an orthopedic surgeon, had included in the study after they met the requirements of inclusion criteria by providing a consent form. Inclusion criteria included a) Symptoms of PSFS for at least 6 months, b) having pain between 3 to 6 in Visual Analogue Scale (VAS), c) having knee pain at least in two activities among stair ascent and descent, prolonged sitting with the knees flexed, squatting over 90 degrees, running, jumping and kneeling and d) experiencing pain in one of the following clinical tests: i) pain during apprehension test, ii) pain or tenderness during compression test, iii) pain during resisted extension of knee in 90° flexion, iv) pain during resistance is applied on superior border of patella during isometric contraction of the quadriceps.

Exclusion criteria included a) a history of knee surgery or arthritis, b) a history of dislocation or subluxation, c) referral pain from spinal cord or nerve roots, d) ligament rupture, e) articular capsule or meniscus injury and f) tendon and muscle ruptures in lower extremity.

**Group Assignment:** Each patient was assigned a number according to the time of inclusion in the study. Then, through an online randomizer program (<http://www.randomizer.org>), the patients were categorized by their gender into exercise group (mean age of 25.7±2.6 years, mean height of 168.0±8.6 cm, mean weight of 63.7±12.5 kg) and control group (mean age of 26.8±2.3 years, mean height of 162.9±8.5 cm, mean weight of 59.6±10.8 kg), each group including 9 females and 5 males. Randomization was performed by an outsider.

**Testing Procedure:** All study subjects were tested before randomization and after six weeks of exercise program by a similar procedure.

**Disability (Anterior Knee Pain Scale):** In order to evaluate function of the patient, a standard scale defined by Kujala *et al.* was used [31]. This questionnaire is specifically designed for the patients with anterior knee pain syndrome and assesses the knee status by evaluating the knee pain during stair ascent, squatting, running, jumping, prolonged sitting with the knees flexed, limp while walking, knee swelling, atrophy of the quadriceps muscle, decreased range of motion of knee and needed support in walking. This questionnaire includes 13 questions and the scores range from 0 to 100, where 100 indicating the highest efficiency of the knee and 0 indicating the highest disability. Validity of this questionnaire was provided by Kujala *et al.* and its reliability was reported to be 0.96 [31].

**Pain:** Knee pain during stair ascent and descent was assessed by Visual Analogue Scale (VAS) that includes a horizontal line with the length of 100 mm, on which 0 mm indicates "no pain" and 100 mm indicates "intolerable pain". Validity and reliability of this scale were reported to be very high in measurement of pain [32].

**Functional Performance (Single Leg Hop Test):** To evaluate muscular function of lower extremity, single leg hop test was used, which is a useful functional test in evaluation of strength, power and kinesthesia of lower extremity [33]. This test is used in research and clinical settings to assess the progress in a training program or rehabilitation of the lower extremity [34]. Typically, this test is performed at the intervals of 4 to 6 weeks in order to monitor progress of the subject [34]. Reliability of this test was reported to be 0.92 in healthy subjects [35], but its reliability has not been reported in PTPS patients.

Thus, before the present study, reliability of this test was evaluated in 11 PFPS patients at the interval of four weeks and ICC was 0.91. In order to perform the test, a 2-meter standard tape measure was secured to the floor and scaled in centimeter. The subject stood behind the start point with the toes lined at the tape measure's zero point with the arms kept crossed on the chest. Subjects were instructed to hop as far as possible. The point touched by his/her heel was marked on the ground and the distance was measured. Each subject performed three repetitions and the average was recorded.

**Stance-Phase Knee Flexion:** Studies indicated that PFPS patients flexed their knees less than healthy subjects in activities like stair ascent and descent imposing more stress on knee and they reduced the knee pain by decreasing patellofemoral joint load [36, 37]. Increased knee flexion during stair ascent and descent may indicate improvement of the PFPS patients [6]. In the present study, therefore, knee flexion at heel strike while stair ascent and descent was measured before and after the exercise program [6].

In order to measure knee flexion, a Biometric Electrogoniometer, SG-150, the UK, was used. The electrogoniometer had two end blocks that were attached, one on shaft of femur in line with greater trochanter and the other on shaft of fibula in line with lateral malleolus [38].

Before stair-stepping task, a footswitch synchronized with the electrogoniometer was placed inside the heel of the shoes of the subjects so that "heel strike" in stair-stepping task was marked on the electrogoniometer diagram. In this study, the custom-made stairs of 20 cm in height and 80 cm in width were used for stair-stepping task (Fig. 1). This test consisted of ascending two stairs and then descending two stairs. Stepping was performed at fixed rate of 96 steps/min as controlled by metronome [39, 40].

The subject stood 1.5m away from the platform and stepped at a controlled rate and ascended two steps and then descended two steps (Fig. 2). Before the main test, each subject practiced the test at least for 5 times. Finally, the subjects performed stair-stepping task for 5 times with 30 seconds of rest intervals. Knee flexion was recorded in these repetitions and their mean value was calculated [41].

**Exercise Intervention:** After the testing procedures, the subjects of exercise group were instructed to perform the exercises. Control group was asked to



Fig. 1: Custom-made stair platform



Fig. 2: The ascent phase of the stair-stepping task

continue their activities of daily living. Exercise program included three exercise sessions per week for six weeks (Table 1). At the beginning of each exercise session, the patients performed warm-up by stationary bicycle for five minutes. At each exercise session, five exercises were performed. Exercises 1 to 4 which were used to strengthen the quadriceps and especially vastus medialis oblique were performed during all six weeks, but exercises 5 and 6 were performed intermittently within three weeks. Exercise program is provided in Table 1.

**Statistical Analysis:** Independent t test was used to compare variables among study groups in pretest and posttest and paired t test was used to compare pretest and posttest variables within study groups. Effect size (Cohen's d) of combined open and closed kinetic chain exercises was measured for each

Table 1: Exercise program

Exercise	Type	Duration
1 Semi squat with hip adduction and internal rotation	CKC <sup>1</sup>	3 × 15 repetitions; 10-second hold
2 Quadriceps isometric in supine position	OKC <sup>2</sup>	3 × 15 repetitions; 10-second hold
3 Terminal knee extension with elastic band	CKC	3 × 15 repetitions; 10-second hold
4 Terminal knee extension in supine position	OKC	3 × 15 repetitions; 10-second hold
5 Adductor squeeze in crook lying (squeeze the ball) (odd weeks)	CKC	3 × 15 repetitions; 10-second hold
6 Hip adduction in lateral decubitus position (even weeks)	OKC	3 × 15 repetitions; 10-second hold

<sup>1</sup> Closed kinetic chain, <sup>2</sup> Open kinetic chain

significant difference of within-group variables. Effect size of 0.2 to 0.5 was considered as small, 0.5 to 0.8 as moderate and higher than 0.8 as large. All statistical analyses were performed by SPSS software, Version 18, at significance level of  $\alpha = 0.05$ .

### RESULTS

There was no significant difference in age, height and weight between two study groups ( $p > 0.05$ ) (Table 2). Also, no significant difference was found between study variables before the beginning of six weeks of exercise program ( $p > 0.05$ ) (Table 2).

Results of paired t test indicated that after six weeks, single leg hop test, knee flexion during stair ascent and

descent and anterior knee pain scale (Kujala Score) increased significantly ( $P < 0.05$ ) and pain during stair ascent and descent decreased significantly ( $P < 0.05$ ) in combined open and closed kinetic chain exercise group (combined exercise group) (Table 3). Unlike combined exercise group, no improvement was observed in control group after six weeks. Single leg hop, knee flexion during stair ascent and pain during stair ascent and descent increased significantly ( $P > 0.05$ ) (Table 3).

Comparison of control and exercise groups after six weeks indicated that pain during stair ascent, with large effect size (large ES -6.44; 95% CI -8.25 to -4.63) and pain during stair descent with large effect size (large ES -6.32; 95% CI -8.13 to -4.50) were significantly lower in combined exercise group than group control ( $P < 0.05$ ).

Table 2: Baseline characteristics of the exercise and control groups

	Exercise group Mean (SD)	Control group Mean (SD)	t	P
Age (yr)	25.7 (2.6)	26.8 (2.3)	-1.2	0.22
Height (cm)	168.0 (8.6)	162.9 (8.5)	1.5	0.12
Weight (kg)	63.7 (12.5)	59.6 (10.8)	0.94	0.35
VAS while Ascending	49.8 (5.2)	51.3 (4.7)	-0.8	0.43
VAS while Descending	51.3 (5.5)	50.2 (3.9)	0.58	0.56
Knee flexion while Ascending (°)	64.0 (9.1)	64.8 (7.2)	-0.25	0.80
Knee flexion while Descending (°)	12.5 (2.5)	12.7 (2.9)	-0.2	0.84
Single leg hop (cm)	92.8 (19.6)	98.3 (20.2)	-0.7	0.47
AKPS (Kujala)	65.2 (7.1)	61.5 (8.3)	0.4	0.22

Table 3: outcome measures of subjects in exercise and control groups in pretest and posttest

	Group	Pretest Mean (SD)	Posttest Mean (SD)	t	P
Pain while ascending (VAS)	Exercise	49.8 (5.2)	19.6 (4.8)	16.3	0.00*
	Control	51.3 (4.7)	54.4 (5.9)	-2.4	0.02*
Pain while descending (VAS)	Exercise	51.3 (5.5)	19.8 (3.6)	22.1	0.00*
	Control	50.2 (3.9)	54.2 (6.8)	-2.4	0.02*
Knee flexion while ascending (°)	Exercise	64.0 (9.1)	69.3 (7.0)	-9.9	0.00*
	Control	64.8 (7.2)	63.2 (7.0)	5.0	0.00*
Knee flexion while descending (°)	Exercise	12.5 (2.5)	15.0 (2.0)	-5.5	0.00*
	Control	12.7 (2.9)	12.3 (3.3)	1.0	0.31
Single leg hop (cm)	Exercise	92.8 (19.6)	109.9 (18.1)	-14.9	0.00*
	Control	98.3 (20.2)	95.3 (17.4)	1.2	0.02*
AKPS (Kujala)	Exercise	65.2 (7.1)	85.8 (7.0)	-21.5	0.00*
	Control	61.5 (8.3)	59.6 (6.4)	1.3	0.20

\*  $P < 0.05$

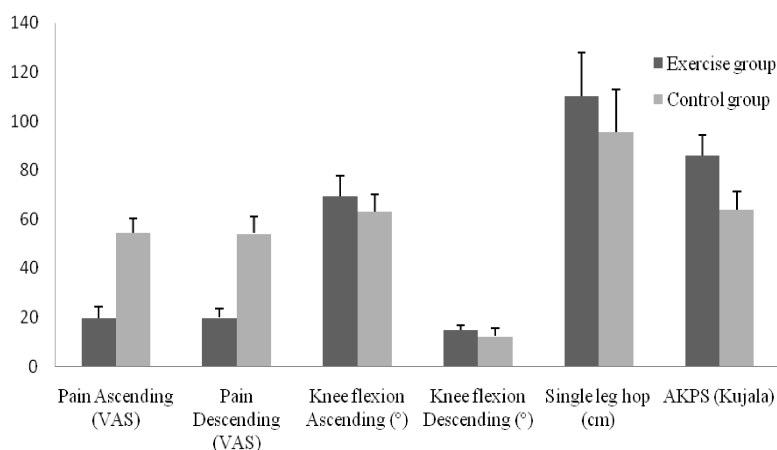


Fig. 3: differences in outcome measures between exercise and control groups after six weeks

Furthermore, knee flexion during stair ascent with large effect size (large ES 0.80; 95% CI 0.03 to 1.57), knee flexion during stair descent with large effect size (large ES 0.98; 95% CI 0.20 to 1.77), single leg hop with large effect size (large ES 0.82; 95% CI 0.5 to 1.59) and anterior knee pain scale with large effect size (large ES 3.90; 95% CI 2.64 to 5.16) were significantly higher in combined exercise group than control group ( $P < 0.05$ ) (Fig. 3).

## DISCUSSION

This study indicated that six weeks of combined open and closed kinetic chain exercises were effective in the management of PFPS. After six weeks, in combined exercise group, pain during stair ascent and descent decreased significantly and knee flexion during stair ascent and descent, anterior knee pain scale and single leg hop increased significantly. But in control group, pain during stair ascent increased significantly and knee flexion during stair ascent and single leg hop decreased significantly, which indicates aggravation of the status of the subjects in control group.

Since there was no single standard measure to evaluate the outcome of exercise programs in PFPS [42], several outcome measures were used in this study. The effect size of pain during stair ascent and descent, knee flexion during stair ascent and descent, single leg hop and anterior knee pain scale were all large ( $ES > 0.8$ ). These results support using combined open and closed kinetic chain exercises for decreasing pain and improving function of the PFPS patients.

Imbalance between the vastus lateralis and vastus medialis oblique muscles is closely related to patella maltracking and PFPS [43]. Dysfunctions in motor control are largely managed by retraining of vasti muscles, especially vastus medialis oblique [8, 44].

In this study, therefore, combined exercises focused on selective strengthening of vastus medialis oblique, which leads to correction of patella maltracking. By restoration of patella malalignment, decreased pain and improved function are expected, as evidenced by this study.

The present study is one of the first studies that used knee flexion during walking as an outcome measure in evaluation of the effect of the exercise program in management of PFPS. After six weeks of combined open and closed kinetic chain exercises, there was a  $5^\circ$  increase in knee flexion during stair ascent and  $2.5^\circ$  during stair descent while it decreased in control group after six weeks. Furthermore, knee flexion during stair ascent and descent was significantly higher in combined exercise group than control group after six weeks. Crossley *et al.* (2005) also indicated that six weeks of physiotherapy program could increase knee flexion during stair ascent and descent in the patients with PFPS [6]. According to Crossley *et al.*, improvements in the neuromotor control of the vasti muscles may affect patellar tracking and the process leading to improved function of the subject during gait [6].

Single leg hop also increased significantly in combined exercise group after six weeks of exercise program, but it decreased significantly in the control group. In addition, after six weeks, single leg hop was significantly higher in combined exercise group than in control group. Hop tests are used for evaluation of functional performance in both rehabilitation programs and sport field [45]. Functional performance tests such as single leg hop are unbiased for measurement of functional ability [46]. Improved single leg hop in combined exercise group was indicative of improved function of lower extremity and effectiveness of exercises in performance of the patients with PFPS.

Open and closed kinetic chain exercises have been used as treatment protocols in management of PFPS [8, 47, 48]. Some studies compared the effects of open and closed kinetic chain exercises in management of this syndrome. Herrington and Al-Sherhi (2007) and Witvrouw *et al.* (2000, 2004) concluded that both open and closed kinetic chain exercises were equally effective in management of this syndrome and suggested to use both exercises jointly in treatment of PFPS [28, 29, 49]. As we know, the present study is the first randomized controlled trial that evaluates the effect of combined open and closed kinetic chain exercises in management of PFPS. Results of the present study are in compliance with the previous studies indicating the efficacy of both open and closed kinetic chain exercises in management of PFPS.

### CONCLUSION

Results of this randomized controlled trial indicates that six weeks of combined open and closed kinetic chain exercises will result in improved function and decreased pain of the patients with PFPS. Considering the results of this study, it is recommended to use combined open and closed kinetic chain exercises as suggested by the previous authors.

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