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The effect of additional strengthening of hip abductor and lateral rotator muscles in patellofemoral pain syndrome: a randomized controlled pilot study

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Objectives: To study the effect of additional strengthening of hip abductor and lateral rotator muscles in a strengthening quadriceps exercise rehabilitation programme for patients with the patellofemoral pain syndrome.
Design: Randomized controlled pilot trial.
Setting: Clinical setting with home programme.
Participants: Fourteen patients with patellofemoral pain syndrome.
Intervention: The subjects were randomly assigned to the intervention group (strengthening of quadriceps plus strengthening of hip abductor and lateral rotator muscles) or to the control group (strengthening of quadriceps). Both groups participated in a six-week home exercise protocol.
Main outcome measures: The perceived pain symptoms, isokinetic eccentric knee extensor, hip abductor and lateral rotator torques and the gluteus medius electromyographic activity were assessed before and after treatment. Parametric and non-parametric tests were used to compare the groups before and after treatment with $\alpha = 0.05$.
Results: Only the intervention group improved perceived pain symptoms during functional activities ($P = 0.02$–0.04) and also increased their gluteus medius electromyographic activity during isometric voluntary contraction ($P = 0.03$). Eccentric knee extensors torque increased in both groups ($P = 0.04$ and $P = 0.02$). There was no statistically significant difference in the hip muscles torque in either group.
Conclusion: Supplementation of strengthening of hip abductor and lateral rotator muscles in a strengthening quadriceps exercise programme provided additional benefits with respect to the perceived pain symptoms during functional activities in patients with patellofemoral pain syndrome after six weeks of treatment.

Introduction

Patellofemoral pain syndrome is one of the commonest knee pain syndromes seen in the physical therapy outpatient clinic.[1,2] The reported incidence in the clinical setting ranges from 21 to 40%.

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Patellofemoral-related problems occur twice as often in females as in males.[3] The aetiology of this condition remains unknown, although many intrinsic and extrinsic factors have been suggested.[4,5] Thus a variety of conservative treatments have been suggested, including quadriceps strengthening, patellar taping, stretching and biofeedback.[6–9] Nevertheless, no single intervention has been shown to be the most effective and the results of these treatment approaches have been mixed.[10]

Recently, various authors have suggested an association between hip muscle weakness or motor control impairment and the patellofemoral pain syndrome.[11–14] Poor hip control may lead to abnormal patellar tracking, increasing patellofemoral joint stress and causing wear on the articular cartilage.[15] Especially poor eccentric hip abductors and lateral rotators muscles control can result in femoral adduction and medial rotation during weight-bearing activities, leading to a predisposition to lateral patellar tracking as the femur medially rotates underneath the patella.[16,17] With this in mind, a possible treatment for the patellofemoral pain syndrome could include optimizing hip abductors and lateral rotators muscle function to control these femur motions and prevent or reduce greater lateral forces acting on the patella. It is also desirable to preserve or increase the trunk and pelvis musculature, since a lack of control of these musculatures may cause excessive anterior pelvic tilt, which may lead to femoral medial rotation.[18]

Mascal *et al.*[19] reported on two patients with patellofemoral pain who were treated with exercises focused on the recruitment and endurance training of the hip, pelvis and trunk musculature. After 14 weeks of treatment, both patients experienced significant improvement in their pain symptoms, function and in force production by the gluteus medius and gluteus maximus muscles. Tyler *et al.*[20] treated 35 patients with patellofemoral pain syndrome over six weeks. The treatment programme emphasized hip strength and flexibility exercises. The authors reported successful results associated with improvements in hip flexion strength combined with iliotibial band and iliopsoas flexibility. Boling *et al.*[21] studied the effects of a six-week rehabilitation programme consisting of strengthening the quadriceps and hip abductor musculature on pain symptoms and functionality and on quadriceps and gluteus medius electromyographic activities during a step-down task. There were improvements in the pain symptoms and functionality, but not in the gluteus medius activity.

Considering the above, there are few studies focused on the role of the hip musculature in the treatment of the patellofemoral pain syndrome. No study has compared a rehabilitation protocol focused on strengthening of the hip abductors and lateral rotators musculature with a strengthening of quadriceps treatment approach, to evaluate if there is some additional benefit. Although the hip abductors and lateral rotators muscles act eccentrically to prevent femur adduction and medial rotation during weight-bearing functional activity, no study has evaluated eccentric hip muscle torque in patients with patellofemoral pain.[17] Therefore, the purpose of this study was to investigate the effects of strengthening and functional training of the transversus abdominis, hip abductors and lateral rotators muscles in addition to a quadriceps strengthening rehabilitation protocol, on the perceived pain symptoms; knee extensor, hip abductor and hip lateral rotator eccentric torques; and the gluteus medius electromyographic activity.

Method

This study used a prospective, single-blinded, randomized controlled design to compare two interventions. Participants were 14 patients (10 women and 4 men) who had been clinically diagnosed with patellofemoral pain syndrome and referred for physical therapy treatment. The subjects were 17–40 years of age (mean 23.6, SD 5.9 years). The inclusion criteria were anterior or retropatellar knee pain during at least three of the following activities: ascending/descending stairs, squatting, running, kneeling, hopping/jumping and prolonged sitting; the insidious onset of these symptoms being unrelated to a traumatic incident and persistent for at least four weeks; and the presence of pain on palpation of the patellar facets, on stepping down from a 25-cm step, or during a double-legged squat.[6,22]

The participants were excluded if they showed signs or symptoms of any of the following: meniscal or other intra-articular pathologic conditions; cruciate or collateral ligament involvement; tenderness over the patellar tendon, iliotibial band, or pes anserinus tendons; sign of patellar apprehension; Osgood–Schlatter or Sinding–Larsen–Johansson syndromes; hip or lumbar referred pain; a history of patellar dislocation; evidence of knee joint effusion; or previous surgery on the patellofemoral joint.[6]

The local ethics committee for human investigation approved the procedures employed in the study and all the subjects gave their written informed consent prior to participation.

Procedure

After baseline assessment, participants blindly drew one of 14 preprinted cards in opaque sealed envelopes from a box (seven labelled 'intervention group' and seven labelled 'control group') and were placed in the intervention or control group in accordance with the card drawn. The principal investigator remained blind to treatment allocation until all baseline assessment had been completed. After this point, blinding of the principal investigator was not feasible. Although the principal investigator was present at all outcome measurements, two blind assessors conducted the assessments to minimize any communication between the participant and the researcher that might interfere with the results. Participants were blind to treatment allocation; both groups received therapeutic exercises as intervention in individual sessions. There were five women and two men in each group.

Outcome measurements

Before the start of their rehabilitation programme and after six weeks of training, all the patients were evaluated with respect to several outcome measurements. The affected or most affected lower extremity of each patient was used for data collection.[12]

Patients rated their worst and usual pain in the last week on a 10-cm visual analogue scale, based on a previous study that demonstrated this procedure to be reliable, valid and responsive in assessing the outcome in persons with patellofemoral pain.[23] Pain and discomfort during stair-climbing, descending stair, squatting and prolonged sitting were also documented on a 10-cm visual analogue scale, with 0 indicating no pain and 10 indicating extremely intense pain.

The eccentric knee extensor, hip abductor and hip lateral rotator torques measurements were performed using the isokinetic dynamometer (Biodex Multi-Joint System 2, Biodex Medical Inc., New York, USA).

Eccentric knee extensor peak torque was measured with the subjects in the seated position according to the instructions accompanying the instrument. The knee was forced by the dynamometer to move through the range of motion from 20 to 90 degrees (0 degree straight leg).

Hip abductor eccentric peak torque was measured in the side-lying position with the non-tested hip and knee flexed and fixed with straps. The axis was aligned with the intersection point of the posterior superior iliac spine and the greater trochanter. The lever arm of the dynamometer was attached 5 cm above the superior patella border with straps. The range of motion of the test was from 0 (neutral position) to 30 degrees of hip abduction.[24]

Hip lateral rotator peak torque was measured in the seated position with the hip and knee flexed at 90 degrees. The axis was aligned with the centre of the patella. The range of motion of the test was from 0 (neutral position) to 30 degrees of lateral hip rotation.[25]

The subjects performed two sets of five repetitions of knee flexion/extension, hip adduction/abduction and hip lateral/medial rotation with their maximal eccentric voluntary effort. The movements were performed at an angular speed of 30 degrees per second with peak torque collected and normalized against their body mass. Electromyographic data were collected during the eccentric hip abductor torque measurement. Before testing, the skin was shaved, abraded and cleaned with alcohol. Bipolar Ag/AgCl surface electrodes (Meditrace TM 100, Mansfield, Canada) were placed one-half of the distance between the iliac crest and the greater trochanter,[26] and also midway between the anterior and posterior superior iliac spines[27] over the muscle belly of the gluteus medius. Surface electrodes, placed parallel to the gluteus medius muscle fibres, measured 30 mm in diameter and had an interelectrode distance of 30 mm. The reference electrode was positioned around the ankle.

Electromyographic signals were obtained using an eight-channel module (EMG System do Brasil LTDA), consisting of a signal conditioner with a bandpass filter with cut-off frequencies at 20–500 Hz, an amplifier gain of $\times 1000$ and a common mode rejection ratio >120 dB. The data then underwent an analogue-to-digital conversion (12 bits) with a sampling frequency of an anti-aliasing of 8.0 kHz and an input range of 5 mV. The raw electromyographic data were analysed with a Matlab custom programme (Mathworks, Natick, MA, USA).

All EMG files were pre-filtered with a 101st-order FIR (finite impulse response) bandpass filter with a 20–500 Hz passband. The envelope was estimated from a full-wave rectified filtered signal using a lowpass 101st-order FIR filter with a cut-off frequency of 15 Hz and a Hamming window.

Muscle onset was determined when the electromyographic activity increased above the threshold by at least two standard deviations above the electromyography data for a resting interval of 200 ms, and remained above this threshold for at least 25 ms. The muscle was considered off when it fell below this threshold for more than 50 ms.[22] The onset of the gluteus medius and the duration were determined using the procedures described above. The magnitude of the muscle activity was computed from the area under the linear envelope for the duration of muscular activity during: maximal isometric voluntary contraction, eccentric contraction, and also eccentric contraction expressed as a percentage of the maximum voluntary isometric contraction during 1 second, which was performed prior to the isokinetic eccentric hip abductor torque assessment.[14]

Therapeutic intervention

The exercise protocol for the control group consisted of patellar mobilization, stretching of the quadriceps, gastrocnemius, iliotibial band and hamstrings and open and closed kinetic chain exercises for quadriceps strengthening. The intervention group received the same exercise protocol as the control group as well as additional time for strengthening and functional training exercises focused on the transversus abdominis muscle, hip abductors and lateral rotator muscles. All the patients performed the rehabilitation exercises once a week under the supervision of the principal investigator and four times a week at home, for a total of five sessions a week for six weeks. To facilitate programme compliance, patients were given an exercise log with a detailed description and demonstrative figure of each exercise to be completed during the week. The participants were also oriented to log any and all complaints or difficulties during home exercises in the exercise log. If there was any doubt or difficulty during the home exercise, the participant was oriented to make contact with the principal investigator to clarify the issue. Appendix 1 provides a detailed description of the rehabilitation programme.

Data analysis

The data were initially analysed with respect to their statistical distribution using the Shapiro Wilks W test. The demographic data and initial assessment results were compared using the t-test with the Statistical Package for the Social Science version 10.0 software (SPSS Inc, Chicago, IL, USA). With respect to the parametric data, the t-test for paired samples was used to compare the results of the assessment before and after treatment. With respect to the non-parametric data, the Wilcoxon signed rank test was used for the comparisons mentioned above. The independent t-test for parametric data or the Mann–Whitney U-test for non-parametric data were used to analyse between groups. The alpha level was set at 0.05.

Results

Twenty-four participants were assessed for eligibility for entry to the study. Fourteen participants were included and randomized to receive treatment (Figure 1). All the participants completed the rehabilitation protocol and assessment sessions.

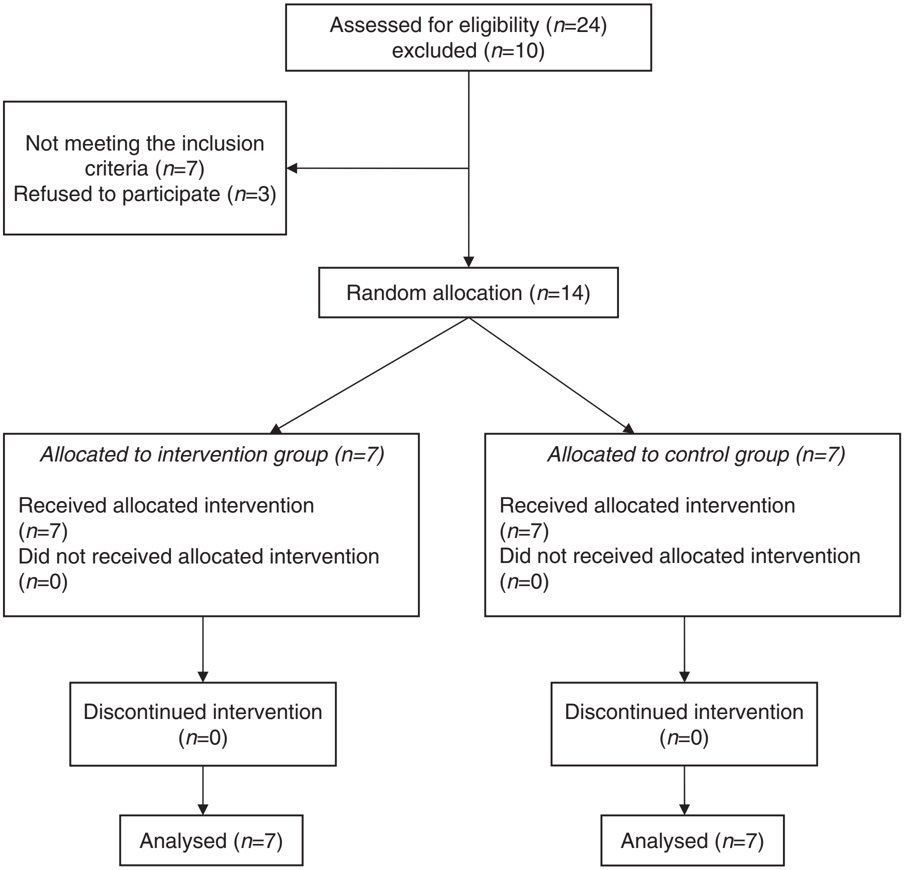

Figure 1 Participant flow diagram.

There were no complaints of adverse effects due to the exercise programmes from either group.

The assessment baseline comparability showed no significant differences between the participants in the two groups with respect to their demographic characteristics, visual analogue scale, isokinetic dynamometry or gluteus medius electromyographic signal ($P > 0.05$). No significant difference in the prestudy duration of the symptoms was observed between the two groups ($P = 0.80$).

The results of the pain assessment were obtained using six visual analogue scales (Table 1). The intervention group showed a significant difference ($P < 0.05$) between the baseline and final assessments for all the visual analogue scales, except for prolonged sitting. No significant differences between the two evaluation periods could be detected for any of the visual analogue scales in the control group.

The eccentric isokinetic knee extensor peak torque improved significantly between the baseline and final assessments for both the intervention group and control groups ($P = 0.04$ and $P = 0.02$, respectively). No significant difference could be observed for hip abductor and hip lateral rotator eccentric peak torque after six weeks of treatment for either group ($P > 0.05$) (Table 2).

The statistical analysis of the intervention group showed a significant increase in the gluteus medius electromyographic signal during maximal isometric voluntary contraction after six weeks of treatment ($P = 0.03$). No significant differences were observed in the control group ($P > 0.05$) (Table 3).

Discussion

After six weeks of treatment, the intervention group improved their perceived pain symptoms, knee extension torque and gluteus medius electromyographic activity during maximal isometric contraction. In contrast, the control group improved only eccentric knee extension torque.

There were significant improvements in the intervention group after treatment with respect to their worst, usual perceived pain as well as reduced pain during functional dynamic activities, and no improvement in the control group. There was no improvement of perceived pain symptoms during prolonged sitting in either group. It should be noted that since the intervention group rehabilitation protocol also focused on trunk, pelvis and hip muscle recruitment, one would have expected these patients to have better hip motor control during the exercises and weight-bearing functional activities.[19] The lower extremity kinematics were expected to improve during functional activities, because movement patterns were executed more correctly and thus reduced the stress on the patellofemoral joint and, consequently, decreased pain symptoms. Although we did not evaluate gait or step-down kinematics, our exercise protocol was very similar to that of Mascal *et al.*,[19] who had reported improvements in the kinematic analysis during a step-down manoeuvre, including a

Table 1 Mean and standard deviation (SD) of the worst pain and the usual pain last week and pain assessment during stair-climbing, descending stair, squatting and prolonged sitting for both groups

Visual analogue scale (cm)	Baseline	Final	Mean change	*P*-value
Intervention group ($n=7$)				
Usual pain	3.8 ± 2.1	1.1 ± 1.2	–3.6 ± 2.6	0.03*
Worst pain	5.0 ± 2.1	1.4 ± 1.3	–2.6 ± 2.5	0.03*
Stair-climbing	3.5 ± 3.7	0.4 ± 0.6	–3.0 ± 3.2	0.04*
Descending stair	4.5 ± 3.1	0.3 ± 0.4	–4.1 ± 2.9	0.03*
Squatting	5.7 ± 3.2	0.4 ± 0.6	–5.4 ± 3.0	0.02*
Prolonged sitting	2.9 ± 3.2	1.1 ± 1.6	–1.9 ± 2.9	0.14
Control group ($n=7$)				
Usual pain	4.7 ± 2.6	4.0 ± 2.6	–1.5 ± 2.8	0.31
Worst pain	5.5 ± 1.5	3.4 ± 1.9	–1.3 ± 3.9	0.20
Stair-climbing	5.0 ± 3.4	2.6 ± 2.8	–2.4 ± 3.6	0.13
Descending stair	4.7 ± 3.3	2.0 ± 2.4	–2.8 ± 2.7	0.43
Squatting	4.8 ± 3.0	3.0 ± 3.1	–1.8 ± 2.6	0.12
Prolonged sitting	5.2 ± 2.8	2.9 ± 3.1	–2.3 ± 3.1	0.09

*Statistically significant difference with $P<0.05$.

Table 3 Mean and standard deviation (SD) of the gluteus medius electromyographic signal during maximal isometric voluntary contraction (MIVC), eccentric contraction (EC) and EC expressed as a percentage of MIVC (EC/MIVC)

Variable	Baseline	Final	Mean change	*P*-value
Intervention group ($n=7$)				
MIVC	51.7 ± 29.5	127.8 ± 145.6	76.1 ± 128.7	0.03*
EC	57.6 ± 46.6	96.4 ± 122.9	38.8 ± 74.7	0.24
EC/MIVC	119.4 ± 87.9	71.4 ± 20.7	–8.0 ± 88.6	0.50
Control group ($n=7$)				
MIVC	72.3 ± 42.7	57.0 ± 36.6	2.3 ± 37.5	0.31
EC	72.3 ± 50.2	74.6 ± 74.0	–1.6 ± 35.0	0.31
EC/MIVC	96.9 ± 28.2	114.5 ± 53.5	17.6 ± 69.1	0.73

*Statistically significant difference with $P<0.05$.

Table 2 Mean and standard deviation (SD) for knee extensor, hip abductor and hip lateral rotator isokinetic eccentric peak torque per body mass (Nm/kg)

Peak torque per body mass (Nm/Kg)	Baseline	Final	Mean change	*P*-value
Intervention group ($n=7$)				
Knee extensor	264.9 ± 84.8	318.9 ± 96.8	54.1 ± 53.5	0.04*
Hip abductor	89.1 ± 29.5	102.2 ± 19.8	13.1 ± 23.4	0.18
Hip lateral rotator	55.5 ± 14.6	59.4 ± 18.9	3.9 ± 6.8	0.15
Control group ($n=7$)				
Knee extensor	283.6 ± 45.0	301.9 ± 63.4	18.4 ± 21.8	0.02*
Hip abductor	114.6 ± 32.1	120.4 ± 30.4	5.8 ± 20.2	0.31
Hip lateral rotator	60.4 ± 16.5	62.9 ± 24.9	2.5 ± 13.5	0.61

*Statistically significant difference with $P<0.05$.

reduction in the adduction/medial rotation of the stance limb, that could decrease the dynamic Q angle, and thereby reduce the amount of lateral force acting on the patella.[15,16] Although previous studies have reported a strong correlation between restoration of quadriceps muscle strength and improvement in pain and functional outcome,[28] both groups had similar knee extensor torque improvements[29] in the present study. Thus, we speculate that improved motor control motion had an important role in the improvement of pain symptoms found in the intervention group patients, as there had been no difference between the groups in the eccentric knee extensor torque gain and pain reduction was observed during dynamic functional weight-bearing activities.

Recent studies have reported significant impairments in hip abduction and lateral rotation strength which suggest that strengthening exercises for these hip muscles could be an important factor in managing patellofemoral pain.[11,13,30] Therefore, the objective of this study was to verify the clinical effect of adding strengthening and functional training exercises that focus on these two muscle groups. However, this study did not address whether either muscle group was a greater contributor to clinical improvement than the other. After six weeks of treatment, pain symptoms in the intervention group improved without statistically increasing the eccentric hip abductor and hip lateral rotator muscle torque. Mascal *et al.*[19] reported pain symptom improvement after 14 weeks of treatment associated with increases in the gluteus medius and gluteus maximus isometric muscle force production and improved motor control of hip motion during functional weight-bearing activities. Tyler *et al.*[20] demonstrated improvement in hip abductor muscle strength after six weeks of treatment, but this data was not related to a successful outcome. In contrast to the studies by Mascal *et al.*[19] and Tyler *et al.*,[20] our study evaluated eccentric hip abductor and lateral rotator muscle torque because we believe this to be a more functional evaluation, since during weight-bearing functional activities the hip abductor and lateral rotator muscles must contract eccentrically to prevent femur adduction and medial rotation.[17] Although our hip muscle-strengthening exercises were very similar to the Mascal *et al.*[19] exercise protocol, our patients underwent a much shorter treatment period which may account for the differences in the torque gain results. One should also consider that a lack of statistically significant difference may not always mean a lack of clinical significance. While our study did not show pain symptom improvement to be associated with a statistical significant increase in eccentric hip muscle torque, we do suggest two possible reasons for this result. First, statistical significance in hip muscle torque was not attained because of the small sample size of our study; and second, although pain symptom improvement was not associated with torque gains, it may still be related to better motor control of hip motion during the functional activities.

Previous research has reported conflicting results between subjects with patellofemoral pain syndrome and healthy subjects[14,21] for the timing characteristics of the gluteus medius activation pattern during ascent and descent of stairs. No study has simultaneously evaluated eccentric hip abductor muscle torque and gluteus medius electromyographic activity in patients with patellofemoral pain syndrome. The addition of strengthening and functional training of hip abductor and lateral rotator muscles improved clinical symptoms in patellofemoral patients and was associated with an increase in the gluteus medius electromyographic activity during maximal isometric voluntary contraction. Strength training is recognized for producing marked adaptations in both the muscular and nervous systems, and the use of surface electromyographic techniques has revealed that strength gains in the early phase of a training regimen are associated with an increase in the amplitude of electromyographic activity.[31,32] Eccentric contractions appear to involve a different electromyographic activation scheme in comparison to isometric and concentric contractions.[31,32] Our results agree with the specificity principle of training, because the greater part of the hip abductor muscle exercise used in our rehabilitation protocol involved isometric contractions, and explains the significant difference in gluteus medius electromyographic activity during isometric contraction.

On the basis of our results, we believe that strengthening and functional training of hip abductor and lateral rotator muscles play an important role in patellofemoral treatment and should be considered when treating these patients. The intervention protocol used was able to improve pain symptoms during functional activities, which we believe was the most important clinical result to the patient, within a short period of time and more efficiently than the conventional approach based on the strengthening of quadriceps alone. Thus, the additional time spent on the hip abductor and lateral rotator muscles is a worthwhile approach to patellofemoral pain treatment. More studies are necessary to elucidate the mechanism of pain improvement associated with this approach and to establish the best exercise protocol.

One limitation of this study was the absence of a control group of patellofemoral patients who received no treatment, but this type of study was considered unethical. In addition, since the patients with patellofemoral pain that took part in this study suffered from chronic pain (mean of 40 months), we believe that the improvements were the result of the rehabilitation protocol used and not of any natural improvement that could have occurred during the study.

Also, the present study did not include a controlled follow-up period, so no conclusions can be drawn about the long-term benefits of the treatment.

It cannot be ignored that a larger sample size could have altered some of the results of the study; and therefore further research is required before definite conclusions can be drawn.

Further research should include a greater sample size and a follow-up period. It is also important to study the influence of other pelvic or hip muscles in the development and treatment of patellofemoral pain and other treatment protocols, including the eccentric training of hip musculature.

In conclusion, this study demonstrated that a six-week home exercise programme based on quadriceps strengthening supplemented by strengthening and functional training focused on the transversus abdominis muscle, hip abductors and lateral rotators muscles provided additional benefits with respect to the pain perceived symptoms during functional activities in patients with patellofemoral pain syndrome. Quadriceps torque gains can only partly explain the decrease in pain symptoms, since both groups increased eccentric knee extension torque. The better results for the intervention group with respect to pain and function were associated with changes in the gluteus medius electromyographic activity, but statistically significant increases in eccentric hip abduction and lateral rotation torque were not essential for clinical improvement.

Clinical messages

- The addition of strengthening of hip abductor and lateral rotator muscles in patellofemoral pain treatment improves the pain symptoms during functional activities and the gluteus medius electromyography activity during isometric contraction.

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Appendix 1 – Control group (CG) and intervention group (IG) patellofemoral rehabilitation guidelines

Control group

Activity	Duration
Stretches (all exercise sessions)	
Sitting hamstring stretch	3 repetitions/30-second hold
Sitting patellar mobilization	
Standing quadriceps stretch	
Standing calf stretch	
Standing iliotibial band stretch	
Weeks 1 and 2 exercises	
Isometric quadriceps contractions while sitting with 90° of knee flexion	2 sets of 10 repetitions/ 10-second hold
Straight-leg raise in supine position	3 sets of 10 repetitions
Mini squats to 40° of knee flexion	4 sets of 10 repetitions
Weeks 3 and 4 exercises	
Wall slides (0–60° of knee flexion)	3 sets of 10 repetitions
Steps-up and steps-down from a 20-cm step	3 sets of 5 repetitions
Forward lunges (0–45° of knee flexion)	3 sets of 10 repetitions
Weeks 5 and 6 exercises, as for weeks 3 and 4 plus:	
Balance exercises: unilateral stance on the floor and on an air-filled disc, with opened and closed eyes	3 sets of 30-second hold each exercise
Progressive walking or running programme	

Intervention group[a]

Activity	Duration
Weeks 1 and 2 exercises[b]	
Transversus abdominis muscle contraction in the quadruped position	2 sets of 15 repetitions/ 10-second hold
Isometric combined hip abduction–lateral rotation in side-lying with the hips and knees slightly flexed elastic resistance	2 sets of 15 repetitions/ 10-second hold
Side-lying isometric hip abduction with extended knee	2 sets of 15 repetitions/ 10-second hold
Isometric combined hip abduction–lateral rotation in the quadruped position	2 sets of 15 repetitions/ 10-second hold
Weeks 3 and 4 exercises[b]	
Pelvic drop exercise on a 20-cm step	2 sets of 15 repetitions/ 10-second hold
Upper extremity extension of the contralateral arm with elastic resistance performed in a single-leg stance	3 sets of 10 repetitions
Rotation of the body in the direction of the contralateral side, holding an elastic resistance with the ipsilateral arm while maintaining the lower extremity static	2 sets of 15 repetitions/ 10-second hold
Weeks 5 and 6 exercises, as for weeks 3 and 4b	
Additional elastic resistance around the affected leg in the forward lunges to encourage lateral rotation and abduction of the hip	

[a]The patients were asked to maintain the tranversus abdominis muscle contraction and alignment of the pelvis during all the exercises.
[b]In addition to the control group exercises.