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# Adding motor control training to muscle strengthening did not substantially improve the effects on clinical or kinematic outcomes in women with patellofemoral pain: A randomised controlled trial

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ABSTRACT

*Design:* Randomized controlled trial.
*Background:* Patients with Patellofemoral pain (PFP) usually present muscular weakness, pain and impaired motor control. Muscle strengthening is an effective treatment strategy for PFP, but the additional benefits of movement control training remain unknown. Therefore, the aim of this study was to compare the effects of movement control training associated with muscle strengthening, with a conventional program of strengthening alone in women with PFP.
*Methods:* Thirty-four women were randomly assigned to two groups. The Strengthening group (S group) performed 12 sessions to strengthen the knee and hip muscles. The Movement Control & Strengthening group (MC & S group) performed the same exercises and movement control training of the trunk and lower limbs. Effects of the treatment (i.e., between-group differences) were calculated using linear mixed models. Primary outcomes were function and pain intensity after completion of the treatment protocol. Secondary outcomes were; muscle strength and kinematic outcomes during the step down task after 4 weeks of treatment; and function and pain intensity 3 and 6 months after randomization.
*Results:* The MC & S group did not present significantly better function (MD −2.5 points, 95% CI; −10.7–5.5) or pain (MD −0.3 points, 95% CI; −1.7–1.0) at 4 weeks. There was a small difference in favour of the MC & S group for AKPS scores at 3 months (MD −8.5 points; 95% CI; −16.8 to −0.3). No significant between-group differences were observed for the other outcomes.
*Conclusion:* Movement control training was no more effective than the isolated strengthening protocol, in terms of pain, function, muscle strength, or kinematics.

## 1. Introduction

Patellofemoral pain (PFP) is one of the most common knee disorders in clinical practice [1]. PFP affects both young and active individuals [2] and is more common in women than in men [3]. The etiology has been described as multifactorial [4] and as a result, diagnosing and treating PFP have become a clinical challenge [5]. In this context, it has been suggested that proximal factors, such as hip muscle weakness [5,6] and altered movements of the trunk and lower limbs, such as increased ipsilateral trunk lean, contralateral pelvic drop, hip adduction, and internal rotation [5,7,8], besides local factors, such as weak quadriceps [4,5], seem to play an important role in the development of PFP.

Concerning the treatment of PFP, strengthening the knee, hip, and trunk muscles is a well-known method of improving functional capacity and decreasing pain in the short and long term [9–12]. Given the above, it seems plausible that justification for the success of strengthening programs is through correction of the biomechanical alterations [9,10]. However, research demonstrates that, despite the clinical improvement, muscle strengthening alone is not sufficient to change the kinematics of healthy individuals [13,14] or those with PFP [15–17].

In contrast, research investigating the effects of neuromuscular

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training on PFP observed improvement in pain and alterations in the biomechanical behavior [17–19]. However, to date there is little evidence on the effects of the association of proximal and local muscle strengthening with motor control training [20,21]. In this context, to our knowledge, the only clinical trial that addressed these two strategies [21] compared the training of stabilization of movement and trunk, hip, and knee muscular strengthening with stretching and strengthening of the quadriceps, which limited interpretation of the real effect of the addition of movement control training to the proximal and local strengthening program, which is already considered superior to isolated quadriceps strengthening [11,12].

The aim of this study was to determine if adding movement control training to a conventional knee and hip muscle strengthening program would produce better clinical outcomes and improved muscle strength and kinematics compared to strengthening alone in women with PFP. Our hypothesis was that patients receiving movement control training plus conventional strengthening program would present greater improvements in pain, function, and kinematics.

## 2. Methods

### 2.1. Design

This was a 2-arm; parallel randomized controlled trial, with a blinded assessor. The trial was conducted in the Human Motion Analysis Laboratory and physiotherapy clinic of the Nove de Julho University, Brazil. It was approved by the local Ethics Committee and registered on ClinicalTrials.gov (NCT01804608). Patients were recruited between April 2013 and August 2014 from our university community. All patients who agreed to participate signed the consent form.

Firstly, when we registered the trial, we selected the following primary outcome measures (hip adduction and internal rotation range of motion). However, before the trial began, we changed these outcomes to functional capacity and pain intensity as we thought that patient-centered outcomes would be more likely to be selected by patients as important compared to kinematic variables. These changes were amended in the trial registration, following recommendations of the CONSORT statement.

Patients were randomized to the two groups using opaque, sealed, sequentially-numbered envelopes. The envelopes were selected by an individual who was not involved in the recruitment, treatment, or assessment of the patients. The randomization codes were generated using the RAND function of Excel. One of the two therapists, with more than five years of clinical experience, who carried out the treatment, opened the envelopes with the random codes on the first day of treatment. These therapists were not involved in the data collection.

### 2.2. Participants, therapists, and centers

Sample-size calculations were based on the detection of an 8-point difference in the Anterior Knee Pain Scale (AKPS) [22], with an estimated SD of 7.5 points. The alpha level was 0.05 and the statistical power 80%. Therefore, the sample size required (per group) was 15 participants. Allowing for the possibility of a 15% loss to follow up, a total of 34 participants were recruited.

All participants were recruited through flyers posted in the physiotherapy clinic and common areas of the university. Two physiotherapists performed the initial evaluation of the volunteers and if they met the eligibility criteria, they were included in the study. This trial included women aged between 18 and 30 years who had history of anterior knee pain of at least 3 months while performing at least two of the following activities: remaining seated for a prolonged time; going up or down stairs; squatting; running, and jumping [23]. They were also required to score at least 3 points on the Numerical Pain Rating Scale (NPRS) [24]. Individuals were excluded if had history of surgery in the lower limbs, recurrent patellar instability, disorders associated with meniscal and/or ligamentous injuries, as well as cardiac or locomotor disorders that could affect the assessment and treatment.

The same physiotherapists were also responsible for the eligibility screening, assessments at baseline, after treatment, and 3 and 6 months after randomization. Both these individuals were blinded to the treatment allocation. Participants were informed that they would receive one of two different forms of treatment but were unaware of the exercises performed by the other group. Due to the nature of the interventions, it was not possible to blind the physiotherapists who carried out the interventions.

### 2.3. Intervention/control

All patients performed 12 sessions of generic exercises (3 sessions per week, for 4-week period), with interval of at least one day between sessions, which lasted approximately 40 min in the first week and 60 min in the final week. The exercises were performed individually and the sessions were supervised by two physiotherapists with more than 5 years of experience. None of the patient groups performed exercise at home.

Patients in the S group underwent to a set of conventional weight-bearing and non-weight-bearing exercises emphasizing knee extensor, abductor, and lateral rotator hip strengthening (Progression in Table 1). Non-weight-bearing exercises were initiated using ankle weights and elastic bands and progressed to a machine (for quadriceps muscles). The descriptions, figures, and progression of these exercises are reported in the published protocol [25].

Patients in the MC & S group underwent the same strengthening program as the S group, but from the beginning of the treatment were informed about movement control disorders common in women with PFP (ipsilateral trunk lean, contralateral pelvic drop, adduction, and internal rotation of the hip and foot pronation) [5] and were instructed to correct these abnormalities during the execution of the exercises and during daily living activities (Progression in Table 1).

**Table 1**
Treatment protocol performed by the S group and MC & S group.

| S group | Progression |
|---|---|
| Side lying hip abduction[a] | 3 sets of 10 repetitions (1st–4th week) |
| Side lying clam exercise[b] | 3 sets of 10 repetitions (1st–4th week) |
| Seated knee extension (from 90° to 45°) | 3 sets of 10 repetitions (1st–4th week) |
| Squatting (from 0° to 45°) | 3 sets of 10 repetitions (1st–4th week) |
| Lateral band walks[b] | 3 sets of 10 repetitions (2nd–4th weeks) |
| Forward lunge | 3 sets of 10 repetitions (3rd–4th weeks) |
| Pelvic drop in standing | 3 sets of 10 repetitions (3rd–4th weeks) |
| **MC & S group** | **Progression** |
| Same strengthening protocol as the S | 3 sets of 10 repetitions (1st–4th week) |
| Squatting (from 0° to 45°) with elastic band[c] | 3 sets of 10 repetitions (1st–4th week) |
| Single leg stance with extended knee | 3 sets of 20 s (1st week) |
| Lateral band walks[b] | 3 sets of 10 repetitions (2nd–4th weeks) |
| Single leg stance with 30° knee flexion | 3 sets of 30 s (2nd–3rd weeks) |
| Forward lunge with elastic band[c] | 3 sets of 10 repetitions (3rd–4th weeks) |
| Single leg squat (from 0° to 30°) | 3 sets of 10 repetitions (4th week) |

Abbreviations: S group, Strengthening Group; MC & S group, Movement Control & Strengthening Group.
[a] Load is 70% of the 1-repetition maximum.
[b] Maximum resistance that enables 10 repetitions.
[c] Elastic band around the knee.

All weight-bearing exercises in this group were performed in front of a mirror for the purposes of visual feedback. Also involved verbal feedback and different proprioceptive stimuli such as training in single leg balance for each of the lower limbs, which evolved progressively from stable to unstable surface. This was carried out in 3 sets of 20 s in the first week, 30 s in the second week, and 40 s in third week.

The load during training was standardized at 70% of the single maximum repetition [9]. Maximum load was assessed during the first session, revised on a weekly basis, and adjusted when necessary. Exercises using elastic resistance were standardized for the maximum load that each patient could support while completing 15 repetitions of the exercise, assessed on a weekly basis for adaptations. These criteria were based on the protocol described in a previous study [9]. Patients performed 3 sets of each exercise, with 15 repetitions. Resistance was increased as soon as the exercise became easy to execute. If the patient presented increase in anterior knee pain during the exercises, the session was ended.

### 2.4. Outcome measures

Primary outcomes were functional capacity and pain intensity, measured immediately after treatment. The secondary outcomes were muscle strength of the hip and knee muscles and three-dimensional kinematics of the trunk and lower limbs during the step down task, measured after the end of treatment, as well as functional capacity and pain intensity, assessed at 3 and 6 months after randomization. All assessments were conducted on the most painful knee, based on the patient's perception.

### 2.5. Functional capacity

was measured using the AKPS [24], which is a specific questionnaire for anterior knee pain. The score ranges from 0 to 100 points, being higher scores representing "no deficit".

### 2.6. Pain intensity

was measured using the NPRS [24], which ranges from 0 to 10 points, being highers scores representing higher pain [24]. Patients were asked to rate their pain intensity based on the previous forthnight. The Brazilian-Portuguese versions of both the AKPS and NPRS present excellent measurement properties [24].

### 2.7. Muscle strength

Maximum voluntary isometric contraction of the hip abductor and lateral rotator muscles and knee extensor muscles, was measured using a handheld manual dynamometer (Lafayette Instrument Company, Lafayette, IN), as described in a previous study [6]. The strength data, measured in kilograms, were normalized according to the weight of each patient, also measured in kilograms, using the following formula: strength/body weight X 100 [6].

Excellent inter examiner reliability of all the muscle strength data was observed, with Intraclass Correlation Coefficient ($ICC_{2,3}$) ranging from 0.83 to 0.98 and Standard Error of Measurement (SEM) ranging from 0.39 to 0.97.

### 2.8. Kinematics

Trunk and lower limb kinematics were assessed during step down task using the Vicon® system, which involves eight infrared cameras operating at 120 Hz. Twenty-one retro-reflective markers (14 mm) were fixed to specific anatomical points, based on the Plug-in-Gait Model, which served as reference for the motion analysis capture system. The markers were named and saved in C3D format and the joint angles was generated using Vicon Nexus 1.8.3 software. The kinematic data were filtered using a fourth-order zero-lag Butterworth 8-Hz low-pass filter.

To conduct the step down task, the patient was positioned on step with the limb to be tested close to the edge and the non-tested limb suspended (both starting from the same position). The volunteer was asked to squat slowly, for two seconds, until the heel of the non-tested limb touched the ground and then return immediately to the starting position for two seconds. The patients performed the activity 3 times with an interval of one to two minutes between attempts. Prior to execution, the examiner demonstrated the exercise and gave verbal instructions. The height of the step was regulated so that the support leg would achieve to 60° angle of knee flexion at the moment that the contralateral foot touched the ground.

Movement cycle was began at the maximal extension of the knee, passing through maximum flexion and returning to knee extension. After, an optimization procedure was performed with the objective of lowest degree of knee joint angle cross-talk and the highest level of repeatability of hip axial rotation measurements [26,27].

Movement in the frontal, sagittal, and transversal planes of the trunk, pelvis, hip, knee, and ankle was analyzed during the descent phase of the step down task. The variables represented the movement excursions, calculated by subtracting the values acquired, when the knee was at maximum flexion, from those acquired at maximum extension, during the task The angles for trunk and pelvis were generated related to the laboratory coordinate system

Excellent reliability of all the kinematic data was observed for the movements analyzed, with inter examiner Intraclass Correlation Coefficient ($ICC_{2,9}$) ranging from 0.75 to 0.98 and a Standard Error of Measurement (SEM) ranging from 0.28° to 2.40°

### 2.9. Data analysis

Statistical analysis was conducted on an intention-to-treat basis [28]. Histograms were visually inspected to test the normality of the data. The characteristics of the participants were summarized using descriptive statistics. The mean effects of the intervention on the outcomes were calculated using linear mixed models (random intercepts and fixed coefficients), which incorporated terms for treatment, time, and treatment by time interactions. The effect of time was nonlinear, so time was dummy coded and analyzed as a categorical variable. The coefficients of the treatment by time interactions provided estimates of the effects of the exercise intervention. Within-group differences were calculated using paired *t*-tests. The clinical relevance of the results was estimated by calculating effect sizes [29].

## 3. Results

A total of 50 individuals were screened for this study and 16 were excluded for the reasons expressed in Fig. 1. Therefore, 34 patients were treated and assessed after the 4 weeks of intervention (0% loss to post-intervention). All patients from both groups completed the 12 sessions without adverse effects. Two individuals from the MC & S group missed follow-up appointments, one after 3 months and the other after 6 months. One patient in the S group missed the 3-month follow-up (Fig. 1).

Table 2summarizes the demographic characteristics of the participants. There were no significant differences between groups at baseline. Baseline values are displayed in the first column of Tables 3 and 4. The participants had a mean age of 25 years, an average of almost four years of pain, and moderate functional capacity and pain intensity.

### 3.1. Pain and function

The within-group analysis confirmed that patients from both groups exhibited less pain and better function at the end of the intervention as well as at the follow-ups after 3 and 6 months. In the between-group

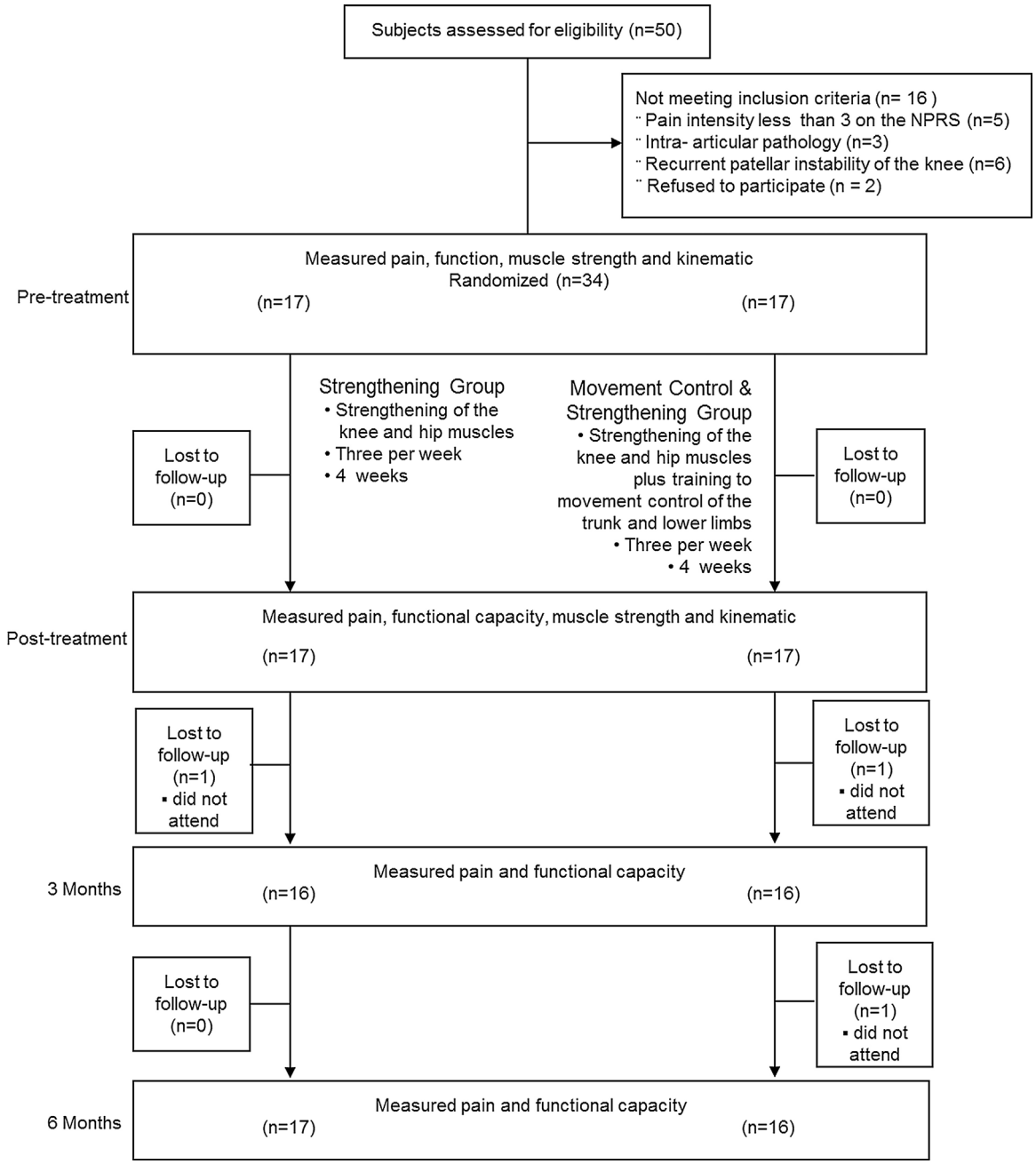


**Fig. 1.** Flow diagram of the study.

**Table 2**
Demographic Data of the S and MC & S groups.[a]

| | S group (n = 17) | MC & S group (n = 17) |
|---|---|---|
| Age, y | 25.3 ± 8.1 | 25.9 ± 5.5 |
| Height, m | 1.59 ± 0.06 | 1.62 ± 0.07 |
| Body Mass, kg | 57.6 ± 5.7 | 57.0 ± 8.9 |
| Body mass index, kg/m2 | 22.79 ± 1.8 | 21.76 ± 2.8 |
| Symptom duration (mo) | 49.3 ± 40.5 | 46.2 ± 33.0 |
| Foot Posture Index | 6.79 ± 1.4 | 6.29 ± 3.6 |

Abbreviations: S group, Strengthening group; MC & S group, Movement Control & Strengthening group.
[a] Values are mean ± SD.

analysis, women in the MC & S group exhibited higher AKPS scores at the 3-month follow-up (mean difference, −8.5 points; 95% confidence interval [CI]: −16.8 to −0.3; P = 0.04) (Table 3).

### 3.2. Muscle strength and kinematics

The within-group analysis showed that patients from both groups exhibited greater strength in all muscles evaluated at the end of the intervention, when compared with the baseline. In addition, in the within-group analysis, no significant difference was found in the kinematic variables of the trunk and lower limbs after the intervention, with the exception of ipsilateral trunk lean in the MC & S group (mean difference, 1.2°; P = 0.02; effect size: 0.72). No between-group differences were observed for these variables at the end of the intervention (Tables 3 and 4).

## 4. Discussion

No previous clinical trial has compared a program that associated hip and knee strengthening and movement control training with an

**Table 3**
Clinical outcomes measures pre-treatment, at 4 weeks, at 3 months and at 6 months post-treatment for subjects in the S (n = 17) and MC & S (n = 17) groups.

| Analysis / Measures | Pre-treatment | 4 we Post-treatment | 3 mo follow-up | 6 mo follow-up |
|---|---|---|---|---|
| Outcomes[a] | | | | |
| NPRS (0–10)[b] | | | | |
| S group | 6.6 ± 1.0 | 2.2 ± 1.6[e] | 3.0 ± 2.4[e] | 2.2 ± 1.6[e] |
| MC & S group | 6.1 ± 1.4 | 2.0 ± 1.7[e] | 1.7 ± 1.6[e] | 1.3 ± 1.8[e] |
| AKPS (0–100)[c] | | | | |
| S group | 67.5 ± 11.3 | 83.7 ± 8.3[e] | 83.3 ± 12.0[e] | 84.8 ± 9.8[e] |
| MC & S group | 67.1 ± 7.6 | 85.8 ± 9.2[e] | 91.4 ± 7.0[d,e,f] | 89.0 ± 8.2[e] |
| Within-group change scores from baseline[a,d] | | | | |
| NPRS (0–10)[b] | | | | |
| S group | | −4.4 ± 1.8 (3.4, 5.3) | −3.5 ± 3.0 (1.9, 5.1) | −4.3 ± 1.7 (3.4, 5.2) |
| MC & S group | | −4.0 ± 1.6 (3.1, 4.9) | −4.3 ± 2.3 (3.0, 5.5) | −4.7 ± 2.3 (3.4, 6.0) |
| AKPS (0–100)[c] | | | | |
| S group | | 16.2 ± 12.8 (−22.7, −9.5) | 16.3 ± 19.5 (−26.7, −5.9) | 17.2 ± 16.8 (−25.9, −8.5) |
| MC & S group | | 18.7 ± 11.5 (−24.6, −12.8) | 24.1 ± 9.4 (−29.8, −15.7) | 21.8 ± 11.3 (−27.8, −15.7) |
| Between-group differences in change scores[d,f,g] | | | | |
| NPRS (0–10)[b] | | | | |
| S group | | −0.3 (−1.7–1.0) | 0.8 (−0.6–2.2) | 0.4 (−0.9–1.8) |
| MC & S group | | | | |
| AKPS (0–100)[c] | | | | |
| S group | | −2.5 (−10.7–5.5) | −8.5 (−16.8 to −0.3) | −4.7 (−12.9–3.5) |
| MC & S group | | | | |

Abbreviations: NPRS, numerical pain rating scale; AKPS, anterior knee pain scale; S group, Strengthening group; MC & S group, Movement Control & Strengthening group.
[a] Values are mean ± SD.
[b] Average pain over the last week. Score from 0 to 10, where 0 is no pain and 10 is the worst imaginable pain.[c]Higher scores on the AKPS represent better function.
[d] Values in parentheses are 95% confidence interval.
[e] Statistically different from pre-treatment (P < 0.05).
[f] Statistically significant between-group difference at this time point (P < 0.05).
[g] MC & S group - S group.

isolated hip and knee strengthening protocol. In general, the results of this study showed that both groups exhibited less pain and better functional capacity at the end of the treatment and that adding movement control training did not provide better clinical or biomechanical outcomes.

Studies suggest that anterior knee pain and functional impairment experienced by women with PFP could be due to the elevated stress levels in the patellofemoral joint, caused by abnormalities in the movements of the trunk and lower limbs, especially excessive internal hip rotation and adduction [30,31]. It is believed that the deficit in dynamic alignment could be correlated with the weakness of the abductors and lateral hip rotators [30]. It seems plausible that reason for successful hip strengthening protocols [9,10,32] may be the correction of misalignment, however some prospective studies did not shown kinematics change after muscle strengthening programs [13–16].

Despite our results having demonstrated significant improvements in the clinical outcomes and improvements in the isometric strength in both groups of the abductors (improvement of 20.7% in the S group; 19% in the MC & S group), lateral hip rotators (18.2% S group; 17% MC & S group) and knee extensors (19.7% S group; 16.2% MC & S group), no relevant kinematics changes during step down task was found within and between groups. There was a reduction in ipsilateral trunk lean in individuals of the MC & S group, however these changes did not influence the pain intensity or functional capacity.

These and the other prospective studies [13–16,33] could indicate that the cause of the PFP may not only be linked to abnormal movements, and the improvement in symptoms may be attributed to gains in strength rather than changes in kinematic behavior. Greater improvement in muscle strength might be able to generate kinematic changes within each group, without affects between groups differeces once both received the same strengthening protocol.

Motor learning is capable of modifying movements using strategies such as the repetition of the movements and the task [34]. Especially in the case of patients with PFP where the nature of the problem is multifactorial, we believe that the addition of training of the movement to the muscle strengthening training could improve kinematics. However, there are still divergences between biomechanical results of studies that performed movement control training [14,18,19,21,35].

The duration of the intervention could be one of the reasons for the inconsistency between the studies, but it was observed that some studies with 2 [18,19] and 4 [36] week of movement training found kinematic differences after treatment, and studies with 5 [14] and 6 [35] weeks did not. This can be explained because those studies with shorter duration trained the evaluated task while the others performed movement training only during the weight bearing exercises, like the current study. These findings might suggest kinematic changes may be dependent on training and evaluated task and could be inserted into clinical practice as treatment strategy, especially those which the patients feel pain,

Although several studies have evaluated different tasks such as running [20], single leg squat [14], drop jump [35] and have not found kinematic changes after movement training, it is possible that task frequently related as painful by subjects with PFP, such as descending stairs, might present different results.

The present study has some limitations. Despite the fact that one of the programs involved movement control training, a deficit in movement control was not considered in the inclusion criteria. The training used in the present study focused on the control of mechanical abnormalities previously described in the literature [5]. It is possible that we may have included women with mild movement disorders and thus, there was little probability of altering these variables. Therefore, the kinematic results provided herein should be analyzed with care.

The intervention period was limited to 4 weeks. Although a significant increase in strength was recorded for all the muscles assessed, and other studies have used treatment protocols of a similar duration to effectively reduce pain and improve functional capacity, [9,10] the duration of the intervention may have affected the kinematic results and the maintenance of the pattern of motion could be a risk for returning the symptoms.

**Table 4**
Effect of Training on Muscle Strength and Lower-Limb and Trunk Kinematics During the Step Down Taks.

| | Groups[a] | | Within-group differences[a,b] | Between-group differences[b,c,e] |
|---|---|---|---|---|
| | Pre-treatment | 4 we Post-treatment | Post-treatment minus Pre-treatment | Post-treatment minus Pre-treatment |
| Muscle Strength, (%BW) | | | | |
| Hip Abductors | | | | 0.3 (−6.2–6.8) |
| S group | 23.2 ± 8.7 | 29.1 ± 8.2[d] | 5.9 ± 8.4 (−10.2, −1.5) | |
| MC & S group | 23.9 ± 9.6 | 29.5 ± 8.2[d] | 5.6 ± 0.2 (−10.8, −0.3) | |
| Hip Lateral Rotators | | | | 0.3 (−2.2–2.9) |
| S group | 11.7 ± 3.5 | 14.3 ± 3.4[d] | 2.6 ± 4.3 (−4.9, −0.3) | |
| MC & S group | 11.2 ± 3.1 | 13.5 ± 2.9[d] | 2.3 ± 3.0 (−3.7, −0.8) | |
| Knee Extensors | | | | 1.8 (−5.7–9.3) |
| S group | 38.1 ± 11.2 | 47.5 ± 7.3[d] | 9.4 ± 11.9 (−15.5, −3.2) | |
| MC & S group | 39.4 ± 14.1 | 47.0 ± 11.1[d] | 7.5 ± 9.5 (−12.5, −2.6) | |
| Trunk Kinematics, (°) | | | | |
| Flexion | | | | 0.08 (−1.1–1.3) |
| S group | 4.0 ± 2.1 | 3.5 ± 1.9 | 0.4 ± 1.8 (−0.4, 1.4) | |
| MC & S group | 3.7 ± 1.3 | 3.1 ± 1.7 | 0.5 ± 1.6 (−0.2, 1.3) | |
| Ipsilateral lean | | | | 0.2 (−1.3–1.6) |
| S group | 5.0 ± 3.7 | 3.9 ± 2.3 | −1.5 ± 4.1 (−3.6, 0.6) | |
| MC & S group | 4.4 ± 1.7 | 3.2 ± 1.6[d] | 1.2 ± 1.9 (0.1, 2.2) | |
| Ipsilateral rotation | | | | 0.6 (−0.9–2.2) |
| S group | 8.5 ± 3.3 | 8.0 ± 2.9 | −1.1 ± 3.2 (−2.7, 0.5) | |
| MC & S group | 8.2 ± 3.9 | 7.1 ± 2.9 | 1.0 ± 2.6 (−0.2, 2.4) | |
| Pelvic Kinematics, (°) | | | | |
| Anterior tilt | | | | −0.6 (−2.3–1.0) |
| S group | 6.2 ± 4.7 | 5.8 ± 3.1 | 0.4 ± 2.5 (−0.8, 1.7) | |
| MC & S group | 4.4 ± 2.0 | 4.6 ± 2.2 | −0.2 ± 2.2 (−1.3, 0.9) | |
| Contralateral lean | | | | −0.2 (−1.4–0.9) |
| S group | 6.7 ± 3.1 | 6.5 ± 3.2 | 0.1 ± 1.4 (−0.5, 0.9) | |
| MC & S group | 7.0 ± 2.6 | 7.1 ± 3.2 | −0.06 ± 1.9 (−1.0, 0.9) | |
| Ipsilateral rotation | | | | 0.8 (−1.1–2.8) |
| S group | 10.2 ± 4.6 | 9.6 ± 4.8 | 0.6 ± 2.2 (−0.5, 1.7) | |
| MC & S group | 9.8 ± 4.9 | 8.3 ± 3.5 | 1.4 ± 3.3 (−0.2, 3.1) | |
| Hip Kinematics, (°) | | | | |
| Flexion | | | | −3.1 (−6.3–0.0) |
| S group | 31.1 ± 8.4 | 29.4 ± 6.6 | 1.7 ± 4.8 (−0.7, 4.2) | |
| MC & S group | 28.8 ± 4.9 | 30.3 ± 5.6 | −1.4 ± 4.2 (−3.6, 0.6) | |
| Adduction | | | | 1.1 (−1.2–3.4) |
| S group | 13.3 ± 5.9 | 13.2 ± 6.7 | 0.1 ± 3.3 (−1.5, 1.8) | |
| MC & S group | 12.6 ± 5.8 | 11.4 ± 5.1 | 1.2 ± 3.3 (−0.4, 2.9) | |
| Internal Rotation | | | | −0.01 (−1.7–1.7) |
| S group | 9.3 ± 3.4 | 9.7 ± 3.6 | −0.4 ± 2.7 (−1.8, 0.9) | |
| MC & S group | 7.9 ± 1.7 | 8.4 ± 1.9 | −0.4 ± 2.3 (−1.6, 0.7) | |
| Knee Kinematics, (°) | | | | |
| Flexion | | | | −2.6 (−6.1–0.9) |
| S group | 54.9 ± 9.6 | 53.0 ± 8.0 | 1.9 ± 5.9 (−1.0, 5.0) | |
| MC & S group | 57.8 ± 3.8 | 58.4 ± 5.4 | −0.6 ± 4.0 (−2.7, 1.4) | |
| Adduction | | | | −0.7 (−2.3–0.8) |
| S group | 4.4 ± 2.0 | 4.2 ± 1.7 | 0.2 ± 2.7 (−1.1, 1.6) | |
| MC & S group | 3.6 ± 1.4 | 4.1 ± 1.8 | −0.4 ± 1.6 (−1.3, 0.3) | |
| Internal Rotation | | | | −1.7 (−4.8–1.3) |
| S group | 18.2 ± 5.1 | 16.1 ± 5.2 | 2.0 ± 4.5 (−0.2, 4.3) | |
| MC & S group | 22.0 ± 4.3 | 21.7 ± 2.4 | 0.3 ± 4.3 (−1.8, 2.5) | |
| Dorsiflexion, (°) | | | | 0.9 (−1.7–2.1) |
| S group | 26.4 ± 6.0 | 25.5 ± 4.6 | 0.9 ± 3.2 (−0.7, 2.5) | |
| MC & S group | 29.6 ± 3.0 | 28.6 ± 3.4 | 1.0 ± 2.3 (−0.1, 2.2) | |

Abbreviations: S, Strengthning Group; MC & S, Movement Control & Strengthning Group; %BW; % Body Weight.
[e]Statistically significant between-group difference at this time point ($P < 0.05$).
[a] Values are mean ± SD. Kinematics values represent movement excursions, which were calculated by subtraction of the values acquired when the knee was flexion maximum from those recorded in the static standing position.
[b] Values in parentheses are 95% confidence interval.
[c] MC & S − S.
[d] Statistically different from baseline ($P < 0.05$).
[e] Between-group differences are adjusted.

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