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Prevention and Rehabilitation

The immediate effect of lumbopelvic manipulation on knee pain, knee position sense, and balance in patients with patellofemoral pain: A randomized controlled trial

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ABSTRACT

Background: Patellofemoral pain (PFP) is a common musculoskeletal disorder. Quadriceps and core muscle neuromuscular control impairments are frequently associated with PFP. Lumbopelvic manipulation (LPM) has been shown to improve quadriceps and core muscle activation and decrease their inhibition, but changes in balance and knee joint position sense (JPS) after this intervention remain unknown.
Objective: To determine whether LPM decreases knee pain and JPS error and increases balance performance in patients with PFP.
Design: Randomized controlled trial.
Setting: Biomechanics laboratory at a rehabilitation science research center.
Methods: Forty-four patients with PFP participated in this study that randomly divided into two equal groups. One group received LPM and the other received sham LPM (positioning with no thrust) in a single session. At baseline and immediately after the intervention, the outcomes of pain using a visual analog scale, balance using the modified star excursion balance test (mSEBT), and JPS at 20° and 60° of knee flexion using a Biodex dynamometer.
Results: There was a statistically significant improvement in pain, balance control (anterior direction) and JPS in the LPM group immediately after the intervention. In addition, we observed significant differences between groups in pain, balance control (anterior direction) and JPS at 60° of knee flexion immediately after the intervention.
Conclusion: A single session of LPM immediately improved balance control, knee JPS, and pain in patients diagnosed with PFP.
Clinical rehabilitation impact: Findings suggest that LPM may be used as a therapeutic tool for immediate improvement of symptoms of PFP. However, more research is needed to determine long term results.

1. Introduction

Patellofemoral pain (PFP) is a common clinical disorder, affecting adults, adolescents, and particularly physically active individuals such as runners or military populations. Its annual prevalence was estimated as 22.7% in the general population and 29.9% in adolescents. PFP has a poor long-term prognosis and usually leads to high levels of disability (Smith et al., 2018).

Previous studies have reported inadequate and decreased quadriceps muscle activity in PFP (Bolgla et al., 2011; Kaya et al., 2011). Therefore, improving quadriceps activity is a major goal in the management of PFP, and there is strong evidence in favor of including quadriceps exercises in rehabilitation programs for these patients (Kooiker et al., 2014).

In weight-bearing positions, different body segments work as a biomechanical chain in which the functions of distal and proximal parts are interrelated. In recent years, some authors have proposed remote factors that may be related to PFP, such as abnormal biomechanics and neuromotor control of the lumbo-pelvic-hip

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complex (core) (Brindle et al., 2003; Cookson, 2003; Dolak et al., 2011; Souza and Powers, 2009). Shirazi et al. reported delayed activity of the gluteus medius and earlier activation of the transverse abdominis, internal oblique, and erector spine muscles in PFP compared to the healthy persons during lateral external perturbation (in appropriate feedback control) (Rojhani Shirazi et al., 2014). Moreover, Biabani et al. found delayed core muscle activity during voluntary tasks such as stair negotiation and heel raising in patients with PFP (inappropriate feedforward control) (Biabanimoghadam et al., 2016). Therefore, in newer rehabilitation programs for PFP, core muscle training in addition to knee exercises has become a focus of interest to improve neuromotor control of the trunk and its biomechanical effects on the knee joint (Motealleh and Nejati, 2019; Earl and Hoch, 2011; Foroughi et al., 2018; Motealleh et al., 2018; Yelvar et al., 2015). Patients with PFP have impaired knee proprioception and balance performance. These patients were found to have less accurate joint position sense (JPS) in comparison to healthy individuals, and patients with unilateral PFP had impaired proprioception in both legs (Baker et al., 2002; Akseki et al., 2008). Moreover, Zazulak et al., in two prospective studies, showed that remote proprioceptive inputs from the trunk and core can predict the risk of knee injury (Zazulak et al 2007a, 2007b). The results of a systematic review showed that proprioceptive training can decrease the risk of knee injury in athletes (Thacker et al., 2003).

Citkar et al. showed that static standing balance is impaired in PFP in comparison to healthy persons (Citaker et al., 2011). Another study showed that dynamic postural control in patients with PFP is impaired, and that these patients had a significantly decreased reach distance in the star excursion balance test (SEBT) compared to a normal group (Arun et al., 2013). Hence, some researchers have tried different rehabilitation techniques to improve knee proprioception or balance (Callaghan et al., 2008; Hazneci et al., 2005; Aminaka and Gribble, 2008; Chevidikunnan et al., 2016).

Considering the importance of both quadriceps and core muscle activity and their relationship to PFP, some authors have tried to increase quadriceps activity with lumbopelvic manipulation (LPM) (Iverson et al., 2008; Motealleh et al., 2016; Suter et al., 1999). They reported that lumbopelvic or spinal manipulation led to better lower extremity performance, together with increased quadriceps and gluteus medius activity in patients with PFP (Suter et al 1999, 2000; Miller et al., 2013; Motealleh et al., 2016). These studies, however, did not evaluate knee joint proprioception or balance performance after LPM.

Given that manipulation can lead to immediate improvements in sensorimotor integration, proprioception (Haavik and Murphy 2012), and quadriceps and gluteus medius muscle activation patterns (Motealleh et al., 2016; Suter et al., 1999), it was decided to test the effect of LPM on knee JPS, balance control, and pain in patients with PFP. It was hypothesized that in patients with PFP, LPM could improve these outcomes by altering common sensory afferent inputs from core and knee muscles or by improving sensorimotor integration.

2. Materials and methods

2.1. Study design and sample size calculation

This study was a randomized placebo-controlled trial. Blocked randomization method with a convenience sample of patients with PFP was used, and subjects were randomly allocated to two groups. The sample size was estimated as at least 44 patients (22 per group) for 80% power and an alpha level of 0.05. Considering a 10% dropout rate, about 49 patients were needed for recruitment. All 49 patients had a diagnosis of PFP and were selected by convenience sampling. From recruited patients, 44 subjects met our inclusion criteria. Given a block size of 4 and the number of 11 blocks, 22 subjects were assigned to the case and control groups at a ratio of 1:1. Randomization was performed with randomizer software and numbered sealed envelopes by an epidemiologist who was unaware of the study groups.

The first group received one session of LPM and the second group received one session of sham LPM with no thrust (sham LPM group). Sample size was calculated based on data for joint angle reproduction error reported by Haavik and Murphy (Haavik and Murphy 2011). The effect size for sample calculation was set at 0.84, and the pooled standard deviation was considered as 0.9. This trial was approved by the Medical Ethics Committee ofShiraz University of Medical Sciences (Registration No. CT-92-6512 and IRCT2013061213651N1), and all participants signed a written informed consent form before the study began.

2.2. Participants

Patients with PFP were referred to our rehabilitation center by an orthopedist. All participants were screened for inclusion and exclusion criteria by a physiotherapist, and 44 patients who met the inclusion/exclusion criteria participated in the study. The participants reported their pain on a 10-cm visual analog scale (VAS) after complementing three basic functional tasks (double leg squat, step-up, and step-down with a 25-cm step). Patients were included if they were between 18 and 40 years old and had: a) a history and clinical evidence of unilateral PFP in the preceding 3 months; b) an average Kujala Questionnaire (Negahban et al., 2012) score between 45 and 80 before the study; c) an average pain level between 3 and 8 on the VAS before the study; d) a complaint of non-traumatic retropatellaror anterior knee pain during least in two of the following activities: stair ascent, stair descent, prolonged sitting, kneeling, squatting, or isometric quadriceps contraction. Patients were excluded if they had: a) prior spine or lower extremity surgery; b) signs or symptoms of lumbosacral spine pathology, myelopathy, lumbar radiculopathy, or nerve compression; c) any neurologic disease such as diabetic neuropathy or multiple sclerosis. Other exclusion criteria were d) pregnancy; e) females in their menstrual cycle (pain, balance, muscular activity and function may be influenced by the menstrual cycle) (Craft, 2007; Hapidou and Rollman, 1998; Rhudy and Bartley, 2010; Samani et al., 2019); f) current use of non-steroidalanti-inflammatory drugs or corticosteroids; g) current treatment for their knee or lumbopelvic pain; h) any contraindication for manipulation such as hypermobility or Ehlers–Danlos syndrome(Baker et al., 2002; Balci et al., 2009; Cowan et al., 2002; Iverson et al., 2008; Tumia and Maffulli 2002). Five patients who did not meet the eligibility criteria were screened out of our study (Fig. 1).

2.3. Outcome variables

Primary outcome measure in this study was knee JPS, and the secondary outcome measures were balance performance and pain.

2.3.1. Knee JPS measurement

In all patients JPS was measured with a Biodex isokinetic dynamometer system(Biodex, Multi-joint System 4 Pro, Shirley, NY, USA), which has been shown to be valid and reliable in previous studies(Tankevicius et al., 2013; Drouin et al., 2004). Each participant sat on the apparatus with her or his trunk supported and inclined backwards at an angle of 85° from the vertical, the hips at 85 degrees of flexion, and the knees at 90 degrees of flexion. The seat position and dynamometer axis were adjusted with the knee axis of rotation, and the pad of the lever arm was positioned on the

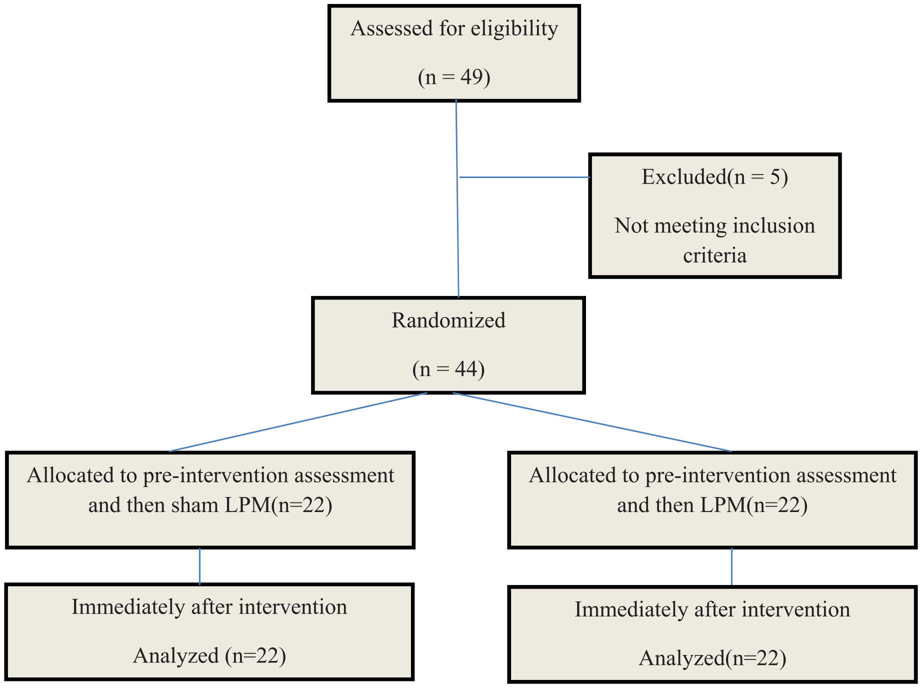

Fig. 1. Flow of participants through the trial.

proximal portion of the lateral malleolus (Fonseca et al., 2005). The protocol for JPS measurement consisted of active positioning followed by active repositioning at a predetermined angle (20° and 60 degrees of flexion) (Callaghan et al., 2008). All participants were blindfolded during the test. Patients actively extended their knees and moved the lever arm from the starting position (90 degrees of flexion) toward one of the target angles. The test order for target angles (20° or 60°) was selected randomly. When the target angle was reached, the dynamometer held the knee in position for 5s and the participant was instructed to concentrate on knee joint position. Then the knee was passively returned to the starting position by the Biodex system at a predetermined angular velocity of 10° per second. Immediately after the knee returned to the starting position, we asked the patient to actively reproduce the perceived target angle and push the stop bottom to lock the dynamometer in place when he or she believed the target position had been reached. The difference between the target and replicated angles was recorded as the absolute error. The test was repeated three times and the mean score of all three trials was considered for analysis(Peixoto et al., 2011) (Fig. 2).

Fig. 2. Joint position sense assessment.

2.3.2. *Balance Performance measurement*

Balance was evaluated with the modified star excursion balance test (mSEBT), which measures dynamic balance during stance leg balance while the contralateral leg reaches in the anterior, posteromedial and posterolateral directions (Plisky et al., 2009; Alnahdi et al., 2015). The participant stood without footwear on the involved leg, with his or her heel at the center of the Y and great toe facing forward. Patients held this position while they performed maximum reaches with their free leg in each reach direction, and then returned to the start position. Participants were instructed to reach as far as possible without lifting their stance foot from the center of the Y. Each test was performed three times and the longest reach in each direction was used for analysis. Reach direction was randomized, and the reach distance in each direction was normalized to leg length (cm) measured from the anterior superior iliac spine to the medial malleolus in supine position. Prior to the main test, each participant was asked to do a standard test of six practice trials for familiarization. After a 5-min rest, the participants began the main test (Plisky et al., 2009).

2.3.3. *Pain measurement*

A 10-cm VAS was used to determine pain level after three functional tests. In this scale, zero indicated no pain and 10

Fig. 3. Lumbopelvic manipulation.

Table 1
Participants' demographics and pre-intervention characteristics (Means ± SD).

Demographic data	LPM[a] group (n = 22)	Sham LPM group (n = 22)
Age (y)	23.18 ± 4.19	24.13 ± 4.17
Height (cm)	166 ± 7.00	168 ± 8.00
Weight (kg)	60.68 ± 8.21	62.18 ± 8.00
BMI[b] (kg/cm^2)	21.88 ± 1.83	21.92 ± 1.70
Kujala score	69.46 ± 5.73	67.65 ± 8.43
Pain (VAS)	5.54 ± 1.18	5.68 ± 1.12
JPS[c] $_{20°}$	5.62 ± 2.12	5.45 ± 3.08
JPS$_{60°}$	6.58 ± 3.21	5.91 ± 2.54
Anterior D[d]	67.09 ± 7.01	66.59 ± 7.09
Post-Lat D	70.45 ± 6.91	70.95 ± 7.24
Post-Med D	71.04 ± 7.16	71.81 ± 6.89

[a] Lumbopelvic Manipulation.
[b] Body Mass Idex.
[c] Joint Position Sense.
[d] Direction.

indicated the worst imaginable pain. This type of scale has been shown to be valid and reliable for subjective pain measurement (Hjermstad et al., 2011). Pain was assessed with the VAS after the participant completed three basic functional tasks (double leg squat, step-up and step-down with a 25-cm step). During the double leg squat test, the angle of knee flexion at which the patient reported pain was measured with a goniometer and recorded. Patient-reported pain was also recorded when they performed the test to the same angle after the intervention (Miller et al., 2013).

2.3.4. Procedures

Initially the participants' demographic characteristics were recorded, and then pain, knee JPS and balance performance were evaluated. After a 5-min rest, the participant entered the intervention phase. Patients in the LPM group lay supine on a manipulation table and the therapist stood contralateral to the side to be manipulated (contralateral to the affected knee). The participant was side-bent passively towards and rotated away from the selected side. Then a quick thrust in a posterior, inferior and lateral direction was applied through the anterior superior iliac spine on the side of the involved knee (Motealleh et al., 2016) (Fig. 3). The applied technique was a general LPM which was done at the same side of the involved knee. This manipulation was applied regardless of the presence or absence of sacroiliac joint or lumbopelvic dysfunction (Grindstaff et al 2009, 2012; Miller et al., 2013). Patients in the sham LPM group received the same intervention except that no thrust was applied. Immediately after the intervention we re-evaluated the outcome measures in the same way as reported above. All tests and measurements were done by the same therapist in the same quiet environment.

2.3.5. Statistical analysis

All statistical analyses were done with SPSS version15.0 (SPSS, Chicago, IL, USA), for a significance level of $\alpha < 0.05$. The Kolmogorov–Smirnoff test showed normal distribution of our data. Paired sample t-tests were used to investigate within-group differences, and independent t-tests were used to determine between-group differences.

3. Results

The demographic and pre-intervention characteristics of the patients are shown in the Table 1. The results of independent t-tests showed that there were no statistically significant differences between the two groups in age, weight, height, body mass index, Kujala Questionnaire score, pain, knee JPS error or mSEBT scores in different directions before the intervention.

3.1. Knee JPS

The results showed a statistically significant reduction in JPS errors immediately after the intervention in the LPM group ($P_{20°} = 0.03$, $P_{60°} < 0.001$). As shown in Table 2, there were no significant improvement in JPS errors immediately after the intervention in the sham LPM group ($P_{20°} = 0.35$, $P_{60°} = 0.58$). Our results also showed a significant difference between groups in changes in JPS error at 60 degrees of knee flexion immediately after the intervention ($T_{60°} = 4.79$, $P_{60°} = 0.001$).

3.2. Balance performance

Our results showed a significant increase in excursion distance in the anterior direction immediately after the intervention in the LPM group (T = -3.26, P = 0.04). There was no significant change in the excursion distance in any direction in the sham LPM group immediately after the intervention. As shown in Table 3, there was a significant difference between groups in excursion distance in the anterior direction immediately after the intervention (T = 3.66, P = 0.001).

3.3. Pain

Data analysis with the paired *t*-test revealed a statistically significant decrease in pain immediately after the intervention in the LPM group (T = 5.69, P < 0.001). As shown in Table 2, there was no significant reduction in pain immediately after intervention in the sham LPM group (T = −0.14, P = 0.88). The results of independent t-tests disclosed a significant difference between groups in VAS score change immediately after the intervention (T = −3.51, P < 0.001), as shown in Table 3.

4. Discussion

4.1. Manipulation and pain

In this study knee pain decreased immediately after LPM, whereas no significant change was seen in the sham LPM group. The mean pain decrease in the manipulation group was about 1.34 points. These findings are in line with results reported by Crowell et al. and Motealleh et al. (Crowell and Wofford 2012; Motealleh et al., 2016)Decreased knee pain following LPM might be explained by the activity of descending inhibitory pathways of pain control, which are able to selectively modulate C-fiber nociceptive

Table 2
Within-group changes in pain, JPS and balance control.

variables		LPM* group (n = 22)					Sham LPM* group (n = 22)				
		Mean ± SD	P value	(95% C.I)[b]	T	ES[c]	Mean ± SD	P value	(95% C.I)[b]	T	ES[c]
Pain	Before	5.54 ± 1.18	<0.001[a]	0.083–1.79	5.69	0.96	5.68 ± 1.12	0.88	−0.69 ± 0.60	−0.14	0.03
	After	4.20 ± 1.54					5.72 ± 1.27				
JPS$^{\Delta}_{20^\circ}$	Before	5.62 ± 2.12	0.03[a]	0.04–0.94	2.31	0.23	5.45 ± 3.08	0.35	−0.17 − 0.49	0.94	0.05
	After	5.12 ± 2.16					5.30 ± 2.83				
JPS$^{\Delta}_{60^\circ}$	Before	6.58 ± 3.21	<0.001[a]	1.28–2.90	5.35	0.74	5.91 ± 2.54	0.58	−0.66 − 0.38	−0.55	0.05
	After	4.48 ± 2.40					6.05 ± 2.96				
Anterior D[£]	Before	67.09 ± 7.01	0.004[a]	−3.72 − 0.82	−3.26	0.31	66.59 ± 7.09	0.10	−0.16 − 1.71	1.71	0.10
	After	69.22 ± 7.39					65.81 ± 7.85				
Post-Lat D[£]	Before	70.45 ± 6.91	0.16	−1.50 − 0.28	−1.40	0.09	70.95 ± 7.24	0.73	-.90 − 1.26	0.34	0.02
	After	71.09 ± 7.20					70.77 ± 7.53				
Post-Med D[£]	Before	71.04 ± 7.16	0.53	−1.37 − 0.73	−0.62	0.04	71.81 ± 6.89	0.15	−0.16 − 0.98	01.48	0.04
	After	71.40 ± 7.37					71.36 ± 6.75				

[a]Significant recovery compared to baseline values in the same group, paired *t*-test.
[b]Confidence intervals reported in relation to baseline.
[c]Effect size.
*Lumbopelvic Manipulation.
[¥]Body Mass Idex.
[Δ]Joint Position Sense.
[£]Direction.

Table 3
Between-group differences in pain, JPS and balance performance.

Variables		LPM* group (n = 22)	Sham LPM* group (n = 22)	T	P value	ES[c]
		Mean ± SD	Mean ± SD			
Pain	AI	1.31 ± 1.08	−0.04 ± 1.46	−3.51	0.001[a]	1.05
JPS$^{\Delta}_{20^\circ}$	AI	−0.49 ± 1.00	−0.14 ± 1.18	1.32	0.19	0.40
JPS$^{\Delta}_{60^\circ}$	AI	−2.09 ± 1.83	0.14 ± 1.18	4.79	<0.001[a]	1.44
Anterior D[£]	AI	−2.27 ± 3.26	0.77 ± 2.11	3.66	0.001[a]	1.10
Post-Lat D[£]	AI	−0.63 ± 2.08	0.18 ± 2.44	1.19	0.23	0.35
Post-Med D[£]	AI	−0.31 ± 2.37	0.40 ± 1.29	1.25	0.21	0.37

[a]Significant recovery compared to between-group, independent *t*-test.
[c]Effect size.
*Lumbopelvic Manipulation.
[Δ]Joint Position Sense.
[£]Direction.

signals and increase the pain threshold (Skyba et al., 2003). The decreased pain after LPM is mediated by the release of neurotransmitters such as serotonin and noradrenalin in these pathways (Skyba et al., 2003). Another mechanism that may contribute to improved knee pain after LPM is related to the extra-segmental effects of manipulation. Some studies suggested that mobilization has both segmental and extra-segmental hypoalgesic and sympatho-excitatory effects (Bialosky et al., 2009; Lascurain-Aguirrebeña et al., 2016; Schmid et al., 2008). Manipulation (i.e. grade V mobilization) might affect the knee pain via descending inhibitory pathways. Hypoalgesia associated with spinal manipulation has been shown in many studies (Bialosky et al., 2008; Randoll et al., 2017), and is thought to be associated with decreased temporal summation vs. any local anatomical effects. In addition, decreased pain following LPM may be related to the activity of the neuroendocrine system. Sampath et al. found that a neuroendocrine-related responseled to decreased salivary cortisol concentration immediately after spinal manipulation (Sampath et al., 2017).In addition, salivary cortisol concentration was shown to be correlated with the level of stress, which in turn can affect the threshold and perception of clinical pain (Choi et al., 2012).Accordingly, improved knee pain following LPM in the present study may be related to an altered neuroendocrine response, which would modulate the pain threshold and perception by decreasing stress. However, the level of stress before and after the intervention in this study was not measured. In addition, the lumbopelvic region and knee joint share some common sensory and motor innervations via divisions of the L2–S3 segments (Gardner 1948; Lippert 2006).Consequently, any modulation in lumbopelvic afferent signals due to LPM might also have led to decreased knee pain.

4.1.1. Manipulation and JPS

The results showed that immediately after LPM, knee JPS error at 20° and 60° decreased significantly. However, no significant change was seen in the sham LPM group. The mean decrease in JPS error was 0.5° at20° and 2.1° at 60° in the LPM group, which was statistically different from the sham LPM group. Our results are in line with the findings of Haavik and Murphy, who reported improved elbow JPS after cervical manipulation in asymptomatic people with a history of subclinical neck pain (Haavik and Murphy, 2011).

Improved knee JPS following LPM may be explained by modified knee joint afferent inputs. According to previous studies, manipulation can increase sensory afferent inputs (Bennell et al., 2003; Lephart et al., 1997),activate mechanoreceptors, and free nerve endings in and around the manipulated joint (Grindstaff et al., 2009; Sung et al., 2005; Suter et al., 2005).As noted above, common sensory innervations exist between the lumbopelvic region and knee joint via divisions of the L2–S3 segments (Gardner 1948; Lippert 2006). Consequently, any modulation in lumbopelvic afferent inputs following LPM may modulate knee joint afferent inputs and thus lead to improved JPS. It should be noted that improved JPS after LPM cannot be explained by reduced knee pain, because previous studies have shown that knee pain intensity is not correlated with proprioception (Baker et al., 2002; Bennell et al., 2003).

4.2. Manipulation and balance performance

The results showed significant within-group and between-group differences in mSEBT in the anterior direction after LPM. Previous studies reported that patients with PFP have difficulty with balance in the anterior direction in the SEBT, because this direction is more challenging for quadriceps muscle activity (Goto et al., 2017; Earl and Hertel 2001). Our finding may be explained by three different mechanisms: decreased knee pain, improved proprioception, or increased muscular activity following LPM. An earlier study showed a direct correlation between proprioceptive sense and balance (Wang et al., 2016).In the present study, decreased JPS error after LPM may explain the improved balance performance. According to Farazdaghi et al., immediately after lumbosacral manipulation, the frequency of the trembling component of the center of pressure increases, which indicates increased muscular activity to control postural balance (Farazdaghi et al., 2017).In addition, Citaker et al. found a correlation between lower extremity muscle strength and balance performance in patients with PFP (Citaker et al., 2011).In this regard our results are in line with the findings of other studies which showed increased gluteus medius, quadriceps and vasti muscle activity after LPM in patients with PFP (Suter et al., 1999; Motealleh et al., 2016). Moreover, decreased knee pain following LPM might lead to increased synchronization of the knee muscle motor units (Mellor and Hodges 2005),which in turn may improve balance performance. However, Grindstaffet al. reported that interventions directed at the lumbopelvic region had no immediate effect on quadriceps force output or activation (Grindstaff et al., 2012).

A limitation of this study was related to a blinding issue. All outcome measures, i.e. pain intensity, JPS and balance performance, were evaluated by the same therapist who performed the intervention, and this might create a source of bias. Because the present study evaluated only the immediate effects of LPM, lack of follow up is a limitation of this study and further studies are advisable to assess the long-term effects of manipulation. Moreover, we recorded only knee JPS but not trunk position sense. Hence we are not sure whether the improvements in pain and balance performance were related to changes in trunk position sense, knee position sense, or both following manipulation.

5. Conclusions

Lumbopelvic manipulation may have a positive role in rehabilitation for patients with PFP. This intervention may reduce knee pain, improve balance performance and decrease knee JPS error. Further studies with follow up are needed for understanding the long term benefit of LPM for PFP.

Trial registry

This trial was approved by the Medical Ethics Committee of Shiraz University of Medical Sciences (Registration No. CT-92-6512 and IRCT2013061213651N1).

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Declaration of competing interest

The authors state no conflict of interest.

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