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Trunk postural control during unstable sitting differs between patients with patellofemoral pain syndrome and healthy people: A cross-sectional study

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ABSTRACT

Background: Patellofemoral pain syndrome (PFPS) is a common orthopedic problem with a high prevalence among young women. Patients with PFPS have altered trunk muscle activity, impaired postural control and greater displacement of the center of pressure (COP) while standing. Training in unstable sitting, by putting more emphasis on trunk sensory receptors, may improve trunk proprioception by minimizing the role of the lower extremities. The aim of this study was to compare trunk postural control in healthy persons and in patients with PFPS.
Methods: Twenty-one women diagnosed with PFPS and 21 healthy women volunteered to participate in this cross-sectional study. The participants were asked to maintain trunk postural balance on an unstable sitting device, and COP indices of trunk postural control were compared between groups.
Results: All COP indices (e.g., mean anterior–posterior and lateral COP displacement, mean COP velocity and mean area of COP displacement) were significantly increased in participants with PFPS in comparison to healthy controls ($P < 0.001$). The effect sizes of all the indices were greater than 0.80.
Conclusions: Trunk postural control is impaired in patients with PFPS, and this finding has clinical implications for rehabilitation in patients with PFPS. Adding seated postural control training to conventional physical therapy management in patients with PFPS may have beneficial effects by emphasizing trunk proprioception while minimizing the role of the lower extremities.

1. Introduction

Patellofemoral pain syndrome (PFPS) is one of the most common orthopedic complaints that motivate referrals to physiotherapy clinics [1,2]. This syndrome has been called an orthopedic 'enigma' [3]. It is often seen in active young people, and its incidence in women is approximately twice as high as in males [4]. The symptoms are aggravated by prolonged sitting, stair climbing and squatting, which may lead to decreased quality of life [5,6]. Despite the high prevalence of PFPS, its underlying cause and therefore its gold standard treatment remain unclear [1,7–10].

This syndrome appears to be multifactorial, and factors such as larger quadriceps angle, larger sulcus angle, larger patellar tilt, quadriceps weakness, muscle imbalance, and patellar maltracking have been proposed as possible causes [7,11]. Some researchers found associations between the prevalence of PFPS and proximal factors such as abnormal trunk kinematics, aberrant core muscle

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activity and poor core stability [12–15]. Among factors far from the knee, neuromuscular control impairment in the hip, pelvis and trunk can be considered as contributing factors to developing PFPS [16]. Deficits in trunk neuromuscular control can compromise dynamic stability of the knee [17].

Core stability is the ability of the lumbo-pelvic-hip complex to prevent collapse of the spinal column and return it to equilibrium following perturbations [15]. Some researchers have suggested that deficits in core neuromuscular control may lead to postural instability in response to external or internal perturbations. Loss of stability may be related to lower extremity problems such as PFPS [18–20]. Zazulak et al. demonstrated that trunk repositioning errors and the amount of trunk displacement after a sudden perturbation were significantly greater in female athletes with knee injuries than in female athletes without injuries after three years of follow-up [20]. They concluded that trunk proprioceptive and sensory inputs are impaired in these patients. Motealleh et al. reported that during stair negotiation, trunk muscle electromyography (EMG) showed delayed onset in patients with PFPS in comparison to healthy individuals [21]. This study indicated that feed-forward control mechanisms of trunk muscles were impaired in patients with PFPS. Rojhani et al. showed that patients with PFPS had earlier trunk (transverse abdominis/internal oblique and erector spinae) EMG onsets in response to sudden unexpected perturbation compared to healthy persons [22]. This finding indicates that the feedback control mechanism of trunk muscles is impaired. The results of these two studies show that trunk control (feed-forward and feedback mechanisms) which are task dependent are impaired in patients with PFPS. As these two control mechanisms are involved in postural control, patients with PFPS may have problems with their postural control [23].

Previous studies have shown impaired postural control and greater displacement of the center of pressure (COP) in patients with PFPS during standing [24–26]. Because earlier studies investigated standing postural control, they were unable to clarify whether trunk postural control was impaired in patients with PFPS or not. The unstable sitting balance paradigm makes it possible to focus on trunk postural control while minimizing the contributions of the lower extremities. Understanding the differences between trunk postural control in healthy persons and patients with PFPS may lead to more effective preventive or treatment strategies. Accordingly, the aim of this study was to compare trunk postural control during unstable sitting in patients with PFPS and healthy people. We hypothesized that trunk postural control during unstable sitting would be impaired in patients with PFPS compared to healthy control group. If this hypothesis were supported, training on unstable surfaces might help to improve sensorimotor control of the trunk.

2. Material and methods

2.1. Participants

This was a cross-sectional study conducted between August 2014 and February 2015 at the Research Center of Rehabilitation Sciences, Shiraz University of Medical Sciences. Women who were eligible based on the inclusion and exclusion criteria participated in the study (Table 1). Prior to participation, each person was informed about the study protocol and signed an informed consent form. The sample size was calculated based on a pilot study. Considering a 30% dropout rate, 0.05 error and a power of 80%, for an effect size of 0.80 and a 1:1 allocation ratio, 21 participants were assigned to each group. The primary outcome of the present study was mean COP velocity, which is considered the most informative stability parameter [27]. Mean COP velocity is calculated as $\sum Vd/n$ where Vd is the displacement velocity and n is the number of times velocity displacement was calculated. Healthy young people have lower mean velocity than older patients and those with neurological diseases or disorders. Increased mean velocity indicates an inability to anticipate body position changes effectively [28].

As secondary outcome measures, we used other COP stability parameters. Anterior–posterior displacement was calculated as the absolute value of $y_{max} - y_{min}$ where y is the anterior–posterior direction of displacement. Surface area was defined as the

Table 1
Inclusion and exclusion criteria of the participants.

	Inclusion criteria	Exclusion criteria
PFPS group	1. Women 18–40 years old 2. Unilateral anterior knee pain for at least 4 months that was unrelated to trauma and was provoked by at least two of the following activities: running, jumping, prolonged sitting, kneeling, step up/down, squatting 3. Positive Clark test 4. Pain on palpation of medial and lateral facets of the patella 5. Anterior knee pain for the previous 4 months 6. An average pain level of at least 3 on a VAS in the preceding month 7. Functional level of 50–80 on the Persian version of the Kujala Questionnaire	1. Traumatic arthritis or acute knee trauma 2. Knee osteochondral deficits such as Sinding Larsen Johansson Syndrome or Osgood–Schlatter syndrome 3. Patellar instability 4. Meniscus and ligament pathology 5. Plica syndrome 6. Disk herniation and spinal referred pain 7. History of fracture or surgery involving the trunk, pelvis or lower extremity 8. Significant deformities of the spine or lower limbs 9. Pain or pathology in the lumbo-pelvic-hip complex 10. Evidence of neurological disorders 11. Evidence of any metabolic diseases such as rheumatoid arthritis and diabetes 12. Pregnancy 13. Regular participation in sports at least 2 h per day, three times per week 14. BMI <18.5 kg/m^2 or >25 kg/m^2
Control group	Age, sex, and BMI were matched to the PFPS group	Same as PFPS group

BMI, body mass index; PFPS, patellofemoral pain syndrome.

surface contained within a closed curve that included all recorded COPs [27]. Greater COP displacement is interpreted as greater instability [27].

Forty-two women aged 18–40 years (21 patients with PFPS, 21 healthy women) participated in this cross-sectional study. Regarding ethical considerations, the present study was based on the criteria of the local ethics committee, which were consistent with the standards of the Helsinki Declaration (ethics committee approval number 92-6524). The inclusion and exclusion criteria were similar to prior studies (Table 1) [22,29,30]. Women diagnosed with PFPS by an orthopedist and referred to our rehabilitation research center were selected with a convenience sampling method. The diagnosis was reconfirmed by detailed clinical history and careful clinical examination [4,22] (Table 1). The healthy volunteers were matched with the patients for age, height and weight using a frequency matching method [31].

2.2. Instruments

To evaluate core postural control, we used a force platform (Kistler, Model 9286A, Winterthur, Zurich, Switzerland) combined with a specially designed unstable sitting device [32]. This device consisted of a seat equipped with an adjustable footrest and a wooden hemisphere 30 cm in diameter which was mounted under the bottom of the seat. The footrest was used to prevent any lower body movement and to prevent the effects of the lower extremities from influencing postural control measurements (Figure 1) [32]. The unstable sitting device was placed on a wooden base (30 × 50 × 70 cm), which was located on the force platform. This base transferred changes in COP from the unstable seat to the force platform. For this purpose, the base was designed with a base of support (30 × 50) smaller than the area of the force platform.

We used a guard rail to ensure the safety of participants during the unstable sitting balance test (Figure 1). To capture and record the COP coordinates, the platform sampling rate was set at 100 Hz.

2.3. Procedures

Initially, all participants completed a 10-point visual analog scale (VAS) and the Persian version of the Kujala Questionnaire [33] to determine pain and functional level, respectively. For postural control measurements, the participant sat on the unstable device and the footrest was adjusted so that her knees and ankles were in 90° of flexion. Then she was asked to cross her arms over her chest and maintain her balance on the unstable seat while looking straight ahead.

Before data collection, each participant was allowed two minutes of practice; subsequently, the test started and was repeated for five trials. Each trial lasted seven seconds [32] as it seemed to be a suitable duration to achieve steady state without leading to fatigue. It is worth mentioning that, practically during the design of the study, we observed that maintaining balance on such an unstable surface is difficult and our subjects were able to maintain their balance for about five to 10 s. Thus, we selected the mean value of this range which was approximately seven seconds. A 30-second rest was allowed between sequential trials. Coordinates

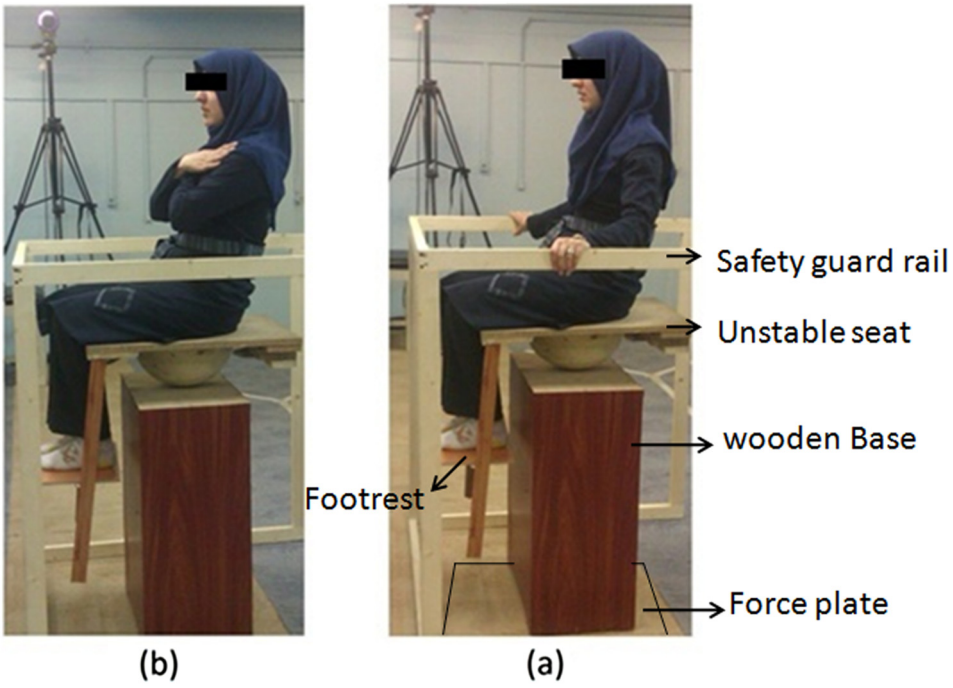

Figure 1. Participant on the unstable sitting device (a) before the test and (b) during the test.

for the COP data were recorded continuously with Qualisys Track Manager Platform software (Qualisys Company, Goteborg, Sweden). The data were analyzed with Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA). Postural control was analyzed with the COP derivatives mean anterior–posterior displacement, mean medial–lateral displacement, mean velocity of displacement, and area of displacement. The average of all the trials was engaged in the final analysis.

2.4. Statistical analysis

Statistical Package for Social Science (SPSS) software version 19.0 (IBM Corporation, Armonk, NY, USA) was used for all statistical analyses. Normality of the data was checked with the Kolmogorov–Smirnov test, and *t*-tests for independent samples were used for between-group comparisons. The effect size of COP trajectory parameters was calculated with Cohen's *d* [34].

3. Results

There were no statistically significant differences between the case and control groups in any demographic characteristics (Table 2). The results of between-group comparisons of COP parameters including mean COP velocity, mean anterior–posterior displacement, mean medial–lateral displacement, and area of displacement are summarized in Table 3. As shown, COP parameters were significantly greater in patients with PFPS in comparison to the healthy control group ($P < 0.001$). This was in agreement with our hypothesis showing impaired trunk postural stability in patients with PFPS during unstable sitting. The COP parameters had large effect sizes based on Cohen's suggestion [34].

4. Discussion

The purpose of this study was to compare trunk postural control between women with PFPS and a healthy matched control group during unstable sitting. Our results showed statistically significant differences in COP parameters between groups during unstable sitting. Women with PFPS had greater COP velocity, greater COP anterior–posterior and lateral displacement, and greater surface area of displacement.

A potential explanatory mechanism for our results may be impaired trunk muscle strength. Trunk muscle strength supports the mechanical stabilization of the spine, and the distribution and delivery of translational, compressive and shearing forces to and from the rest of the body [35]. Reduced core muscle strength has been associated with an increased risk of knee injury [12]. Women with PFPS were found to have weaker core muscles (hip abductors and external rotators) than the healthy control group [36]. In addition, Cowan and colleagues showed that trunk lateral flexors were weaker in women with PFPS compared to an asymptomatic control group [37]. Meira and Brumitt found a link between hip muscle strength and the position of the hip joint and PFPS [38]. However, Rathleff et al. deduced from their systematic review that decreased hip muscle strength might be a result of PFPS rather than a cause [39]. Chevidikunnan et al. found that adding a core muscle strengthening exercise program to conventional physical therapy management improved dynamic balance in patients with PFPS [35]. In the present study, decreased core muscle strength may have led to increased COP velocity, displacement and surface area in women with PFPS compared to the healthy control group.

Altered motor control and recruitment patterns in core muscles are another probable mechanism that may explain our findings. Little research has investigated the recruitment patterns of core muscles in patients with PFPS. Rojhani et al. evaluated core muscle recruitment patterns in response to an unexpected perturbation [22] and found that recruitment patterns were completely different in women with PFPS vs. healthy women. In the latter, the transversus abdominis, internal oblique and gluteus maximus (GM) were activated first, and the erector spinae responded significantly later, whereas in the PFPS group, the GM was activated later than the trunk muscles. Biabanimoghadam et al. found different core muscle recruitment patterns in patients with PFPS and

Table 2
Demographic characteristics, pain and disability scores of the case and control groups.

	Group	n	Mean ± SD	*P*
Age (years)	Case	21	23.19 ± 3.56	0.47
	Control	21	23.57 ± 3.35	
Height (cm)	Case	21	161.50 ± 3.94	0.67
	Control	21	162.00 ± 4.24	
Weight (kg)	Case	21	56.56 ± 5.89	0.68
	Control	21	56.84 ± 6.30	
BMI (kg/m^2)	Case	21	21.66 ± 1.82	0.66
	Control	21	21.63 ± 1.91	
Pain (VAS)	Case	21	4.71 ± 1.34	–
	Control	21	NA	
Kujala score	Case	21	73.09 ± 5.80	–
	Control	21	NA	

BMI, body mass index; NA, not applicable; SD, standard deviation; VAS, visual analog scale.

Table 3
Comparison of COP parameters between the case and control groups.

	PFPS* (Mean ± SD)	Control (Mean ± SD)	95% CI Lower limit, upper limit	*P*	Cohen's *d*
Mean velocity (mm/s)	51.18 ± 22.36	26.72 ± 5.08	14.08, 34.83	<0.001	1.50
Anterior–posterior displacement (mm)	26.04 ± 11.48	9.35 ± 4.02	11.32, 22.05	<0.001	1.94
Medial–lateral displacement (mm)	25.47 ± 12.40	9.70 ± 3.70	10.06, 21.48	<0.001	1.72
Area of displacement (mm^2)	564.60 ± 263.70	186.38 ± 68.04	255.18, 501.27	<0.001	1.96

CI, confidence interval; *PFPS, patellofemoral pain syndrome; SD, standard deviation.

healthy participants during voluntary heel raise [40]. The recruitment pattern in core muscles was altered during both voluntary tasks and unexpected perturbation. Hence, impaired stability due to altered neuromuscular control in core muscles may have induced changes in COP parameters. It can be inferred that both feedback and feedforward control mechanisms of core stability are impaired in patients with PFPS. Preuss et al. showed that maintaining balance on an unstable seat required a combined feedforward–feedback strategy [41].

Regardless of the probable cause and effect relationship between motor control of core muscles and the incidence of PFPS, trunk postural control is impaired in patients with PFPS. Preuss et al. observed that mean EMG activity levels were lower in persons with good balance. This suggests that core stability relies on appropriate neuromuscular control [41]. Moreover, accurate proprioceptive inputs play an important role in neuromuscular control. Currently there is scant evidence of impaired trunk proprioception in patients with knee injuries. Zazulak et al. evaluated core proprioception in 227 college athletes and prospectively investigated knee injuries including ligament, meniscal and patellofemoral lesions over a three-year period [20]. They concluded that impaired core proprioception can predict the risk of knee injury [20]. Reduced core proprioception can alter dynamic stability of the knee, and these alterations may in turn explain the increased risk of knee injury during athletic activities. Because a proprioception deficit was shown in active and passive proprioceptive repositioning of the trunk, fusimotor activity and sensory feedback from muscle spindles are assumed to be diminished [20]. However, no study to date has evaluated trunk proprioception in patients with PFPS, and future studies are warranted to investigate this relationship. Regarding the importance of impaired trunk proprioception in the incidence of knee pathologies, inclusive trunk proprioception training programs such as unstable sitting might be offered as an additional option for treatment that may supplement more functional multi-joint closed-chain tasks. Also, it might be appropriate for individuals with severe pain early on during rehabilitation who are unable to tolerate standing tasks but would still benefit from trunk rehabilitation.

The large effect sizes observed in the evaluated variables might be interpreted as the clinical difference in trunk postural control between patients with PFPS and healthy control group.

4.1. Suggestions for future study

In this study, we showed that trunk postural control was impaired in patients with PFPS during unstable sitting. Future prospective interventional studies are warranted to observe the added beneficial value of the unstable sitting in the rehabilitation program of patients with PFPS. Due to the setup of our study, it is not clear that the deficit in unstable sitting postural control in patients with PFPS is related to the impairment of sensory receptors, motor actuators or both in the trunk region. Future studies are warranted to determine the contribution of sensory receptors and motor actuators in patients with PFPS. If this can be determined, more emphasis could be put on proprioception training, motor training or both depending on the underlying mechanism.

It is worth noting that this approach of evaluation is impairment based. Future activity-based interventions are required to improve the teamwork on the musculoskeletal system to improve motor control.

Another potentially informative type of study could be designed to evaluate the function of sensory receptors in trunk muscles in patients with PFPS, given that sensory receptors in the trunk region play an important role in optimal postural control. Furthermore, we recommend prospective evaluations of trunk postural control to identify factors that may predict the potential risk of PFPS. We did not measure the strength of muscles involved in trunk postural control. Future studies are thus warranted to evaluate the correlation between trunk muscle strength and trunk postural control.

4.2. Limitations

There are anatomical, biomechanical, and hormonal differences between women and men that might lead to an increased incidence and prevalence of PFPS in women [42], thus only women were recruited as participants in this study. Accordingly, the results of this study cannot be generalized to all patients with PFPS. We do not know whether any of our participants had experience with seated balancing (e.g., sitting on an exercise ball) which may have affected the results. The constrained position of extremities which are considered as inherent postural reactions could be another limitation of our study which might have affected the obtained results. Another limitation of our study was the lack of EMG recordings from trunk muscles. Therefore, EMG studies during this task are advisable to identify motor deficits which might be due to trunk muscle dysfunction in patients with PFPS. It is worth noting that due to the cross-sectional nature of this study, we cannot claim a causal relationship between

trunk postural control and the development of PFPS. Future longitudinal studies are required to determine the possible cause and effect relationships between these factors.

5. Conclusions

Trunk COP velocity, surface area, and anterior–posterior and mediolateral excursion were greater in women with PFPS compared to healthy women, indicating impaired postural control during unstable sitting. This can be attributed to impaired muscle strength, altered motor control and recruitment patterns, and deficits in trunk muscle proprioception. Our finding has clinical implications for the rehabilitation of patients with PFPS. Designing rehabilitation programs that focus on trunk postural control with sensorimotor perturbation training, e.g. exercising on an unstable sitting device with various levels of difficulty, may be effective in the management of patients with PFPS.

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Conflict of interest

The authors have no conflicts of interest to declare.

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