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Effects of pain exacerbation on postural control in women with patellofemoral pain during single leg squat: a cross-sectional study

Ali Yalfani[1*], Fatemeh Ahadi[1] and Mohamadreza Ahmadi[1]

Abstract

Background The center of pressure (COP) excursion parameters are recognized as risk factors for the etiology and development of patellofemoral pain (PFP). The purpose of the present study measures the effect of pain exacerbation on COP excursion, and the correlation between pain intensity and COP excursion in women with PFP during single leg squat (SLS).

Methods Sixty patients with PFP participated in this cross-sectional study. The outcome measures were included pain intensity and COP excursion which evaluated in pre and post pain exacerbation during SLS. The COP parameters were evaluated during single leg squat in 60° of knee flexion. A paired t-test and MANOVA was used to compare pain intensity and COP excursion between the two conditions, respectively. Furthermore, A Pearson's correlation matrix was used to examine the relationship between pain intensity with COP excursion.

Results Statistical analysis showed that pain intensity ($t = -16.655$, $p < 0.001$) and COP excursion (Wilks' Lambda $= 0.225$, $p < 0.001$) with medium effect size increased after PFJ loading. In addition, an excellent positive correlation was observed between increased in pain intensity and COP excursion ($P < 0.001$, $r > 0.80$).

Conclusion After PFJ loading, women with PFP presented increases in the pain intensity, COP excursions, and sway velocity. In addition, there was an association between the increase in pain intensity and COP excursions. Clinicians aiming to improve postural control of patients with PFP could use kinesio taping as a short-term intervention and balance training to improvements in postural control at medium and long-term. Furthermore, emphasizing psychological factors to reducing kinesiophobia can be useful to restoring proper movement pattern, reducing pain and improving symptoms.

Keywords Patellofemoral pain, Postural balance, Loading, Center of pressure

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Background

Patellofemoral pain (PFP) defined as pain in the retropatellar or peripatellar region [1, 2]. This orthopedic condition is aggravated by the patellofemoral joint (PFJ) loading [3, 4]. The prevalence of PFP in the general population and professional athletes has been reported as 22.7% and 35.7%, respectively [5]. It has been shown PFP is more common in females aged 18 to 35 years with an estimated prevalence being 13% [6, 7]. Researchers speculate there are many biomechanical and anatomical alignment factors that may lead to the increased incidence of PFP in females compared with males. These factors include increased Q-angle, increased dynamic knee valgus, reduced lower extremity muscle strength, increased hip internal rotation, hip adduction moment, and knee abduction moment, and decreased knee flexion angle [8]. Despite the high prevalence, the PFP etiology is unknown [6]. However, growing body of research suggests psychological factors (e.g. kinesiophobia) have play a more important role in self-reported pain, function, and disability and have greater influence on movement impairments in women with PFP [9, 10]. Importantly, change behavior due to kinesiophobia in patients with PFP may change kinematics and lead to detrimental effects at the PFJ [9, 10].

Postural control involves a complex integration of visual, vestibular and somatosensory systems based on reflex actions occurring to postural stability [11, 12]. The center of pressure (COP) path assessment is the most common technique for balance assessment, which represents the average absolute pressure exerted by the body on the ground [11]. The changes of COP parameters are recognized as risk factors for the etiology and development of PFP [11, 13]. More specialized, alterations in COP parameters can impact on force transmission through the lower limb kinetic chain and lead to lower extremity overuse injuries, including PFP [13]. In this line, Thijes et al. (2007) reported the COP shifted more slowly from the lateral to the medial side during foot rollover; this could cause less shock absorption in the foot [14]. Consequently, a greater part of the ground reaction forces is transferred to the more proximal joints that could result in an overloading of the PFJ, which would lead to PFP [14]. Mostly, balance restore is neglected in the PFP rehabilitation protocols and conflicting findings to interventions effectiveness in improve postural control have been reported [11, 15]. It is believed that pain, proprioceptive defects, central control, and abnormal muscle activities are the main mechanisms in the poor balance of PFP patients [11]. In painful conditions, sensory impulses may be impairing in the central and peripheral levels of the central nervous system (CNS) and subsequently disruption of movement control and balance [3, 11].

Recently, a systematic review and meta-analysis with quantitative synthesis of 53 studies reported that very low to moderate certainty evidence indicated that patients with PFP have worse anterior- posterior and overall stability indexes during single-leg stance (SMD=0.71, 95% CI: 1.29, 0.14; SMD=0.63, 95%CI: 0.94, 0.32) [15]. Greater COP displacements during dynamic tasks are signs of poor postural control that can higher risk for developing subsequent injuries [15]. Nevertheless, the results of COP analysis show conflicting evidence of COP excursion in PFP patients [16]. For example, Saad et al. (2015) demonstrated females with PFP had higher COP excursion during stair negotiation compared to healthy individuals [17]. In contrast, Silva et al. (2016) reported females with PFP had lower COP excursion during stair climbing [16]. It seems the conflicting evidence was due to the fact that the patients did not have their worst pain when at the time of data collection [16]. Therefore, studies which aimed on pain intensity controlling during data collection is necessary to understand this conflicts. In this regard, previous studies reported the PFJ loading protocol is useful for pain exacerbation in females with PFP and there is a positive correlation between PFJ loading and pain intensity [6, 18]. Furthermore, a meta-analysis indicates that pain intensity in patients with PFP were increased during walking, running, squatting and stair ambulation [19]. Since previous studies showed the PFJ loading exacerbation of the pain and symptoms of females with PFP [18]; It seems different intensity of pain in females with PFP demonstrate different strategies during biomechanical analyzes and clinical evaluations [18]. Thus, the PFJ loading is important factor in physiological or biomechanical strategies when the presence of pain [18, 20].

There is little information about the effect of pain on the balance of patients with PFP has not been investigated. Now the question is whether pain intensity can affect COP excursion. Meanwhile, the studies reported that there is conflicting evidence regarding the relationship between pain and balance [11]. Thus, understanding the effect of pain intensity can provide new insights to management and treatment of PFP [21]. Therefore, the purpose of the current study was 1) the immediate effect of pain exacerbation on COP excursion 2), and the relationship between pain intensity with COP excursion in women with PFP during single leg squat (SLS). We hypothesized that (1) the PFJ loading would significantly increase pain intensity and COP excursion (2) there would be significantly positive correlations between pain intensity with COP excursion.

Method

Participants

The statistical population of the current study were females with PFP (age: 38.90±3.33 years, weight: 59.13±3.9 kg, height: 169.53±4.6 cm). We recruited patients who visited in the orthopedic clinics of Hamedan province from January to April 2023. First, an orthopedic clinician and a physiotherapist (with 15 years of experience) screened the patients through non-invasive tests (stair descent /Clark test). If the PFP symptoms were positive and there were eligibility criteria, the patient was invited to the movement analysis and rehabilitation laboratory.

Inclusion criteria included: pain intensity of 3 out of 10 visual analog scale (VAS), pain exacerbation during weight bearing activities, normal alignment of upper and lower limbs, age range of 18–45 years, unilateral symptoms (PFP in right knee), and suffering from PFP for more than 6 weeks. Exclusion criteria included: history of physical therapy, participation in professional and recreational sports, history of surgery, upper and lower limb malalignment, vestibular and vision disorders, injury and pain in other joints (except PFJ). Ethical approval of the present study was obtained from the Ethics Committee in Biomedical Research of Bu-Ali sina University with the code IR.BASU.REC.1402.012. Before data collection, patients signed an informed consent form. Also, we followed the Helsinki Declaration of 2008.

Sample size

We used the free software G*Power version 3.1.9.2 to sample size planning. Using the reference of a related study that evaluated the effect of PFJ loading on pain intensity, and vertical loading rate, the type I error rate was 0.05, the type II error was 0.20 and the estimated correlation coefficient (r)=0.5 was planned [6]. The output of the software reported at least 26 subjects [6]. However, we enrolled 60 subjects to increase statistical power.

Instrumentation

A plantar pressure platform (ZEBRIS GmbH, Isny, Germany; ICC=0.91) made in Germany was used to record the COP excursion [22]. The Zebris plantar pressure has a platform with dimensions of 54×34 cm and 2560 active sensors with high sensitivity [23]. This platform records the pressure in the range of 1–120 N/cm^2 with a sampling rate of 50 Hz [22]. In addition, Zebris FDM software was used to process and export the data (Fig. 1). The COP parameters including: minor axis (COP displacement in mediolateral direction) and major axis (COP displacement in anteroposterior direction), and sway velocity (Fig. 2).

Experimental protocol

First, we performed randomization through Random Allocation Software. According to the study of Briani et al. (2018), a random order of four block was planned [6]. Thus, block 1 and 2 were considered for the first and second days of pre- pain exacerbation condition. Also, block 3 and 4 were considered for the first and second days of post- pain exacerbation condition. Consequently, conditions or days were randomized. Of note, we assessed pain and COP excursion in pre and post pain exacerbation.

In pre- pain exacerbation condition (without PFJ loading), patients were asked to indicate pain intensity (resting time) as real-time on a 10-cm VAS. Then, patients were asked to perform the SLS three times. In post- pain exacerbation condition (with PFJ loading), the PFJ loading protocol was applied to pain exacerbation. The PFJ loading protocol consisted of a staircase with seven steps (each step being 18 cm high), which participants performed 15 repetitions of stair negotiation with an

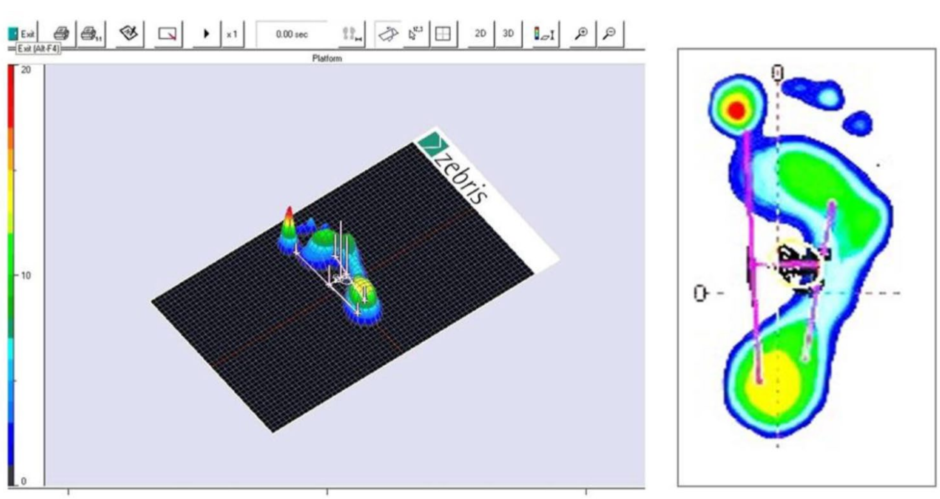

Fig. 1 A sample of the COP excursion during SLS. Abbrevations COP, center of pressure, SLS, single leg squat

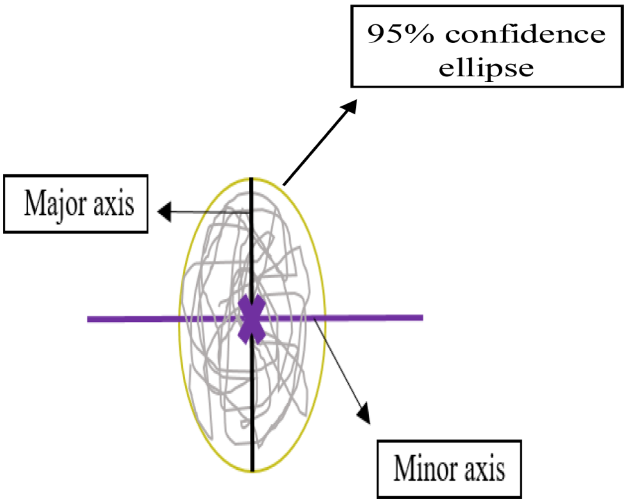

Fig. 2 The horizontal purple line is the connecting line of the three COPs (Center of pressure). The ellipse around includes 95% of the COPs. The middle cross is the center of pressure of the whole body. Minor axis (total traveling distance of COP displacement in mediolateral direction) and major axis (total traveling distance of COP displacement in anteroposterior direction)

external load of 35% of the subject's body mass (carried in a backpack) [6]. Afterward, the pain intensity of the patients was evaluated on a 10-cm VAS and patients were asked immediately to perform the SLS three times. Of note, data collection was done in symptomatic limb (i.e. right limb). Importantly, PFJ loading protocol does not cause neuromuscular fatigue [18]. However, to be sure, we evaluated patients' fatigue after the PFJ loading protocol using the Borg scale.

Task and procedure

The COP displacement in anterior-posterior direction, medial-lateral direction, and sway velocity was recorded during SLS. The SLS is a common clinical assessment that trial balance and musculoskeletal disorders of the lower limbs [24]. Before data recording, information was provided to the patients to familiarize with the test. The patients were taught to stand upright on the platform and place hands on the chest to remove the effect of hands on balance control (they stood on the right foot/limb painful). Of note, in the test limb the hip and knee were in extended position, whilst the contralateral limb from back was flexed to 90° [25]. The head was placed in a neutral position to prevent the vestibular disturbance. The ankles and feet were set in a neutral position.

The SLS were perform up to 60° of knee flexion. We used a flexible electro-goniometer to record the knee joint angle during SLS and made feedback to the patient when the knee reaches the target angle. Before starting the data collection, the patients were familiar with the test and practiced the trial 3 times. A 2-minute rest was considered between each trial to minimize fatigue.

Table 1 Demographic characteristics (mean ± SD)

Variables	Mean ± SD
Age (years)	38.90 ± 3.33
Height (cm)	169.53 ± 4.6
Mass (kg)	59.13 ± 3.9
BMI (kg/m^2)	20.66 ± 1.53
Pain duration (months)	11.52 ± 3.14
Kujala score (points)	49.81 ± 8.70

The International Society for Posture and Gait Research recommends that evaluation of postural control parameters between 25 and 40 s are reliable [26]. Overall, each patient performed SLS test in 3 separate trials and the rest period between each trial was 2 min. The duration of the SLS test in each trial was 30 s, and at this time the COP excursion data was collection. In record of COP excursion, the examiner was blind. Finally, the average of 3 trials was used for COP excursion analysis.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS) (IBM; Armonk, NY, USA) version 21 was used for statistical analysis. Normal distribution of data and homogeneity of variances were checked with Shapirowilk and Levene tests, respectively. A paired t-test (two-tailed) was used to compare pain intensity between pre and post pain exacerbation. In addition, multivariate analysis of variance (MANOVA) to compared the results COP excursion between the two conditions. A Pearson correlation matrix was used to examine the relationship between pain intensity with COP excursion. Of note, the score change from pre- pain exacerbation condition to post- pain exacerbation condition (i.e., pre- pain exacerbation condition – post- pain exacerbation condition=score change) was used to the correlation calculation [6]. Therefore, positive values and negative values are indicating higher values in pre- pain exacerbation condition and post- pain exacerbation condition, respectively [6]. The correlation rates were interpreted in four categories as poor ($r=0.00$ to 0.25), fair ($r=0.25$ to 0.50), moderate to good ($r=0.50$ to 0.75), or excellent ($r=0.75$ to 1) [27]. The effect size was interpreted as small ($d<0.20$), medium ($d=0.21–0.79$), and large ($d>0.80$) [28]. A significance level of $P<0.05$ was considered.

Results

Table 1 shows the demographic data of the patients. No statistically significant difference was observed in demographic characteristics (age: 38.90±3.33 years, height: 169.53±4.6 cm, mass: 59.13±3.9 kg, BMI: 20.66±1.53 kg/m^2, pain duration: 11.52±3.14 months, kujala score: 49.81±8.70 points); So the data distribution is normal ($p>0.05$). Paired t-test show pain intensity is significantly higher in post- pain exacerbation condition

(7.0±1.0 cm) compared to pre- pain exacerbation condition (4.33±1.0 cm) (Fig. 3) with a large effect size ($t_{59}=-16.655$, $P<0.001$, $d=-1.27$). The MANOVA analysis showed a significant difference in the COP parameters between pre and post pain exacerbation (Wilks' Lambda=0.225, $p<0.001$). The compared between pre and post pain exacerbation showed a significant difference with a medium effect size in the COP anterior - posterior displacement ($F_{1, 118}=133.099$, $P<0.001$, $\eta^2=0.530$), medial - lateral displacement ($F_{1, 118}=80.279$, $P<0.001$, $\eta^2=0.405$), and sway velocity ($F_{1, 118}=391.700$, $P<0.001$, $\eta^2=0.768$) (Table 2).

Table 3 shows in the anterior - posterior parameter, an increased COP excursion was shown in post- pain exacerbation condition (36.51±9.99 mm) compared to pre- pain exacerbation condition (19.51±5.50 mm). In the medial - lateral parameter, an increased COP excursion was shown in post- pain exacerbation condition (39.26±9.38 mm) compared to pre- pain exacerbation condition (26.93±5.04 mm). In the sway velocity parameter, an increased sway velocity was shown in post- pain exacerbation condition (28.03±5.57 mm) compared to pre- pain exacerbation condition (12.68±2.24 mm) (Fig. 4).

Pearson correlation matrix showed excellent positive correlation between the increase in pain intensity with COP excursion in anterior-posterior direction ($P<0.001$, $r=0.823$) (Fig. 5), medial - lateral direction ($P<0.001$, $r=0.839$) (Fig. 6), and sway velocity ($P<0.001$, $r=0.810$) (Fig. 7) from pre- pain exacerbation condition to post- pain exacerbation condition.

Discussion

The present study evaluated the immediate effect of PFJ loading on (1) pain intensity and COP excursion (2) the relationship between pain intensity with COP excursion in women with PFP. In the present study, results showed that pain exacerbation negatively influences postural control after PFJ loading. In addition, a positive correlation was observed between increased pain intensity with COP excursion. In general, by reasoning on previous studies, we believe that the increase in pain intensity through neuromuscular system defects increases the COP excursion. As a result, both of our hypotheses are supported. Our results agreement made with previous studies with a similar purpose. For example, Briani et al. (2018) found a positive correlation between pain levels with loading rate during stair negotiation [6].

Postural control during dynamic movements is maintained through muscle strength and proprioception [29]. Previous studies reported poor balance in patients with PFP is associated with weak muscle strength and proprioception deficits [11, 30]. The motor system is responsible for activating muscles to movement. Weak muscle strength, especially when accompanied by pain can lead to make postural instability [31]. In general, balance control and pain-induced muscle inhibition have common pathways in the CNS [32]. Previous study reported

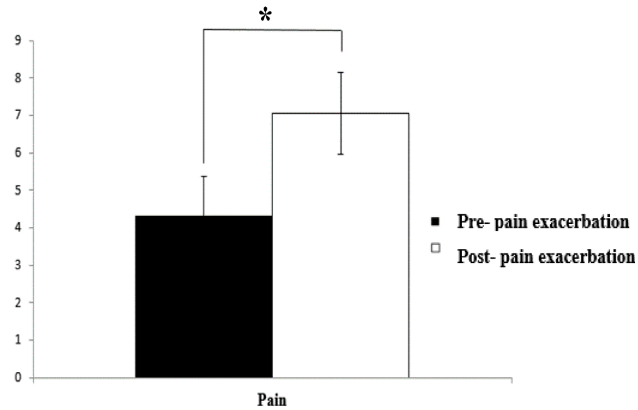

Fig. 3 The pain intensity pre and post pain exacerbation. Abbreviations COP, center of pressure. A.P, anterior - posterior. M.L, medial - lateral. *, statistical significant difference

Table 2 The results of the MANOVA test to compare COP excursion in pre and post pain exacerbation show which there has been a significant difference after pain exacerbation in the A-P excursion, M-L excursion and postural sway velocity. Means and standard deviations data show the amount of COP excursions in the A-P direction, M-L direction, and postural sway velocity

Variables	Mean ± SD	F	DF	Partial Eta Squared	Sig.
A.P excursion (mm)	28.01 ± 11.72	133.099	1	0.530	0.001 *
M.L excursion (mm)	33.09 ± 9.72	80.279	1	0.405	0.001 *
Postural sway velocity (mm/s)	20.36 ± 8.78	391.700	1	0.768	0.001 *

Table 3 Data are means and standard deviations, mean difference, percentage of changes and 95% CI for pre and post pain exacerbation

Variables	Pre- pain exacerbation	Post- pain exacerbation	Mean difference	Δ	95% CI
Pain intensity	4.33 ± 1.03	7.05 ± 1.09	2.72	62.81	5.38,6.00
A.P excursion (mm)	19.51 ± 5.50	36.51 ± 9.99	17	87.13	25.89,30.13
M.L excursion (mm)	26.93 ± 5.04	39.26 ± 9.38	12.33	45.78	31.33,34.85
Sway velocity (mm/s)	12.68 ± 2.24	28.03 ± 5.57	15.35	121.05	18.77,21.95

Abbreviations: A.P, anterior – posterior. M.L, medial – lateral. *, statistically significant ($P<0.05$).

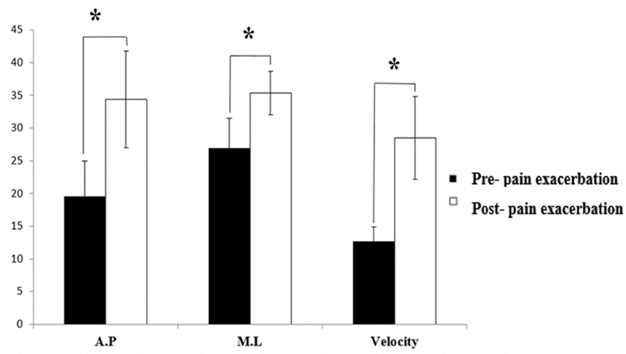

Fig. 4 The COP excursion between pre and post pain exacerbation

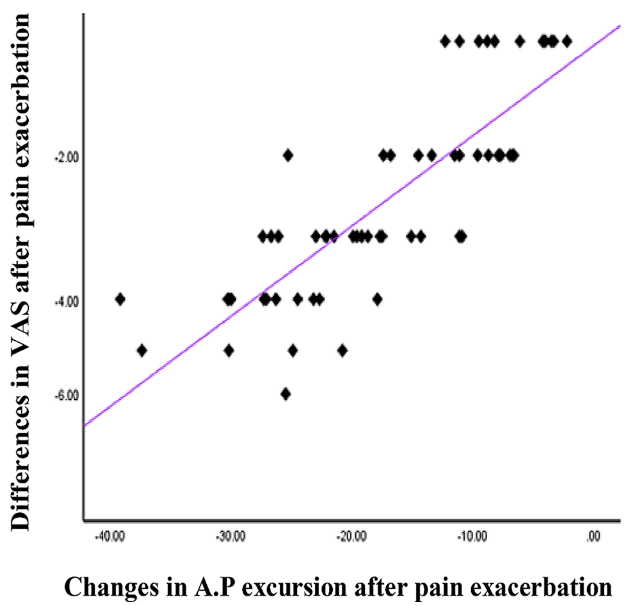

Fig. 5 The correlations between pain intensity with A.P excursion

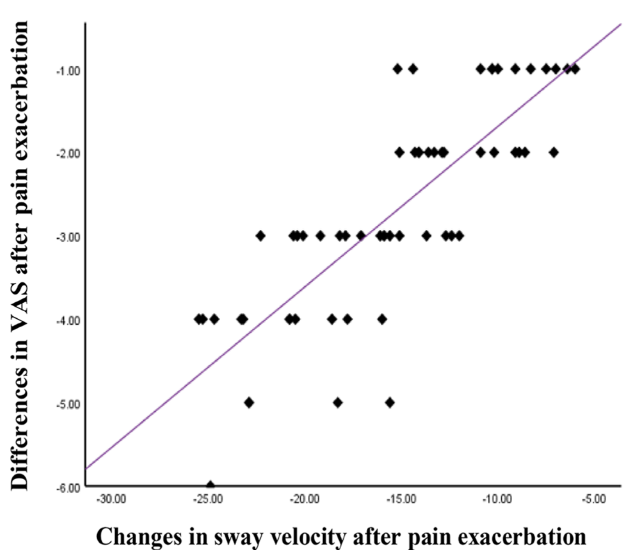

Fig. 7 The correlations between pain intensity with sway velocity

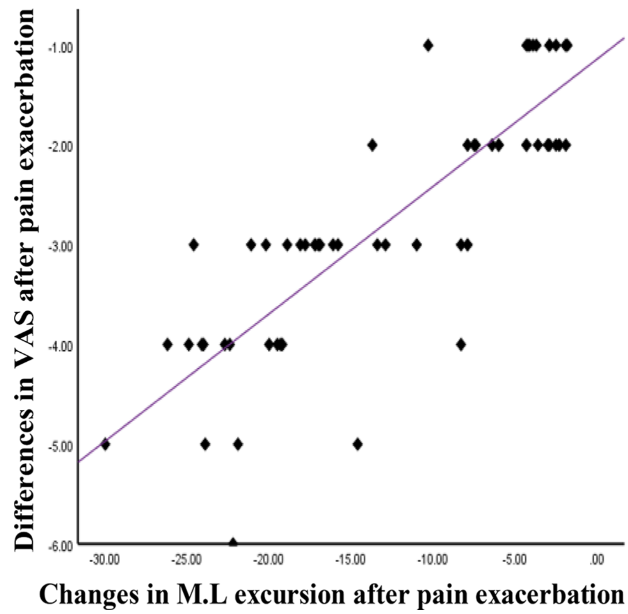

Fig. 6 The correlations between pain intensity with M.L excursion

that pain increases the presynaptic inhibition of muscle afferents and effects the central modulation of the muscle spindles and proprioception; finally, muscle control decreases [32]. Silva et al. (2016) believed that knee extensor muscles control COP excursion in the anterior-posterior direction [31]. Furthermore, Wu et al. (2002) found the eccentric strength of the knee extensors was associated with the COP displacement in anterior – posterior direction [33]. Meanwhile, Gribble (2004) showed that local fatigue of hip and knee extensor muscles leads to postural instability in the anterior-posterior direction [34]. Briani et al. (2020) reported a decrease in peak knee extensor moment following the pain exacerbation [35]. The quadriceps muscle inhibition can be the result of spinal reflex inhibition of the alpha motor neuron. This reflex inhibition is modulated by pre- and post-synaptic mechanisms and it is created by abnormal afferent from a painful joint [21]. Therefore, pain causes a decrease in motor impulses to the muscles; As a result, the potential of the muscle to produce force is limited [21]. Thus, the mechanism of muscle inhibition caused by pain lead to increase COP excursion in the sagittal plane.

On the other hand, increasing COP displacement in the anterior-posterior direction may be a compensatory strategy to reducing PFJ stress or pain resulting from high quadriceps activity [13]. Overall, the PFJ stress is influenced by the quadriceps muscle force and knee flexion angle [36]. Thus, decreased quadriceps activation “quadriceps avoidance” could be a compensatory strategy to reduce PFJ stress [21]. Following this, reduction in the knee extensor moment likely compensate by increasing the ankle plantar flexor moment, leading to a greater displacement of the COP in the anterior direction and increase tibialis anterior activity [13, 35]. As a result, this mechanism can facilitate the plantar flexor muscles recruitment to absorbing the vertical ground reaction force and reducing the load transfer to the knee [13]. In addition, increased activation of the ankle plantar flexors may increase hip extensor demand during SLS; thus decrease quadriceps muscle demand [13]. However, this compensatory mechanism may have negative consequences in this joints [35].

On the other hand, with the anterior displacement of the COP, a larger part of the body's weight is transferred to the forefoot region, which leads to a higher plantar pressure in this area [37]. In this line, Thijs et al. (2015) reported that greater loading on the second and third metatarsals can transmit higher vertical forces to the knee joint, which is an important factor in identifying individuals at risk of PFP [14]. Furthermore, Rathleff et al. (2014) reported that patients with PFP showed higher loading of the forefoot, which has the potential to transfer harmful forces to the external area of the PFJ and develop PFP [38].

Carry et al. (2017) reported that patients with PFP significantly increased COP displacement in the medial - lateral direction compared to the control group during SLS [39]. The moment arm of the gluteus medius muscle is longer than other muscles of the lower limb [40]. The gluteus medius controls frontal and sagittal plane movement by minimizing medial - lateral COP acceleration [31]. The pain onset in patients with PFP can reduce ability of the gluteus medius to control adduction and internal rotation of the hip. The abductor and external rotator muscles of the hip contraction eccentrically to control adduction and internal rotation [41]. As a result, weakness and abnormal activation of the gluteus medius lead to adduction and internal rotation of the hip [42]. In this regard, Lee et al. (2012) reported PFP patients which have hip abductor weakness showed postural instability in the frontal plane. Also, Neghaban et al. (2018) showed hip muscle fatigue leads to increased COP displacement in the medial - lateral direction [43]. In this regard, a decrease in COP displacement in the medial-lateral direction were showed to using a hip stabilizer brace [40]. Therefore, it is argued the pain intensity had correlation to faulty kinematic of the lower limbs, muscle incoordination, and arthrogenic inhibition of the hip and quadriceps muscles [21]. Finally, the pain intensity can effect COP excursion in females with PFP through of the inhibition mechanisms of hip and quadriceps muscles.

Limitations

We had three limitations in this study. First, the current study is cross-sectional, so we cannot determine the cause and effect relationship. Second, our statistical population was only females; Therefore, caution should be generalizing the results to men's population. Third, since only SLS were trialed (because of time constraints), the findings may not reliable to generalize challenging tasks. Therefore, we recommend future studies evaluation the effect of the PFJ loading on kinematic and kinetic variables during challenging tasks in both genders.

Clinical applications

Our findings highlight the potential importance of pain exacerbations during painful daily activities on the imbalance and falls risk in women with PFP. Thus, this study showed that any future study for COP measurements in women with PFP should considered on the effect of pain intensity. Since impaired postural control is a risk factor for PFP and lower extremity injury, clinicians should assess and treat these outcomes in patients with PFP as part of a comprehensive rehabilitation program [15]. In this line, since pain impulses interfere with proprioception, it seems the focus of a rehabilitation program in women with PFP with increased COP excursions can include focusing on pain neuroscience education and proprioception training. Furthermore, clinicians aiming to improve postural control of patients with PFP could use kinesio taping as a short-term intervention and balance training to improvements in postural control at medium- and long-term [15]. Of note, Furthermore, emphasizing psychological factors to reduce kinesiophobia can be useful to restoring proper movement pattern, reducing pain and improve symptoms [9, 10]. A synthesis of treatment effectiveness would benefit clinicians targeting postural control measures [15].

Conclusion

After PFJ loading, women with PFP presented increases in the pain intensity, COP excursions, and sway velocity. In addition, there was an association between the increase in pain intensity and COP excursions. As a result, increasing PFJ loading during challenging activities is an important issue that must be considered in clinical evaluations of females with PFP.

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Author contributions
F.A (Manuscript writing)A.Y (Edit the Manuscript)M.A (Data analysis).

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Data availability
We undertake that the data will be available and sent if needed and requested by the journal and reviewers.

Declarations

Ethics approval and consent to participate
Ethics approval and consent to participate Ethical approval of the present study was obtained from the Ethics Committee in Biomedical Research of Bu-Ali Sina University with the code IR.BASU.REC.1402.012. Before data collection, patients signed an informed consent form.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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