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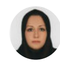
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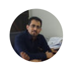
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Experimental Study

Electromyograghic activity of the hip and knee muscles during functional tasks in males with and without patellofemoral pain

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ABSTRACT

Background

Patellofemoral pain (PFP) is a common overuse injury in physically active individuals. It is characterized by anterior knee, retropatellar, or prepatellar pain associated with activities that increase patellofemoral joint stress such as squatting, stair ascending and descending, running, jumping, prolonged sitting, and kneeling. The etiology of PFP is believed to be multifactorial. Recently, proximal factors have been shown to influence the biomechanics of patellofemoral joint.

Objective

The aim of the study was to assess hip and knee muscle activity during single leg stance and single leg squat in males with PFP and a control group without PFP.

Methods

Eighteen males with PFP (age 24.2 ± 4.4 years) and 18 healthy subjects as controls (age 23.5 ± 3.8 years) were included. We evaluated gluteus medius, gluteus maximus, vastus medialis oblique (VMO), and vastus lateralis (VL) electromyograghic (EMG) activity. The muscle activity and reaction time of the proposed muscles were assessed during single leg stance and single leg squat tasks. Independent *t*-test was used to identify significant differences between PFP and control groups.

Results

No difference in activity of the gluteus maximus muscle was found in either task ($p > 0.5$). Significant differences were found in activity of gluteus medius and VMO in both tasks ($p < 0.05$). VL muscle activity had significant difference in single leg stance ($p = 0.01$), however, had no significant difference in single leg squat ($p = 0.1$). No significant differences were found in reaction time of the four studied muscles during both single leg stance and single leg squat ($p > 0.5$).

Conclusion

Males with PFP demonstrated altered gluteus medius, VMO, and VL muscle activity during single leg stance and single leg squat compared to healthy subjects. Gluteus maximus activity did not show any changes between groups. Moreover, muscle recruitment patterns were different between PFP and healthy groups.

1. Background

Patellofemoral pain (PFP) is a common and costly musculoskeletal condition in physically active individuals (Bolling et al., 2009; De Oliveira Silva et al., 2016). Common clinical characteristics of PFP include anterior knee, retropatellar, or prepatellar pain associated with activities that increase patellofemoral joint stress such as squatting, stair ascending and descending, running, jumping, prolonged sitting, and kneeling (Bolgla and Boling, 2011; Peters and Tyson, 2013).

Despite the considerable prevalence of PFP among the general population particularly athletes, the etiology of PFP has remained controversial (Prins and Van Der Wurff, 2009). Most recent investigations have suggested that the source of symptoms in PFP is believed to be multifactorial (Bolgla and Boling, 2011; Peters and Tyson, 2013; Prins and Van Der Wurff, 2009; Khayambashi et al., 2012). Biomechanical and structural factors have been shown to be involved (Saad et al., 2011). These factors could be classified into three mechanistic categories including proximal factors, local factors,

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and distal factors (Davis and Powers, 2010; Powers et al., 2012). A proximal approach has focused on the contribution of the trunk, pelvic, and hip mechanics in PFP. In a local approach, a relationship between PFP and patellar alignment and mechanics is considered. Moreover, a distal approach has concentrated on foot and ankle mechanics and PFP. Therefore, a link between possible trunk and lower extremity biomechanical alterations and development of PFP can be proposed for consideration in diagnosis and treatment (Davis and Powers, 2010; Powers et al., 2012).

Recently, the strength of the hip stabilizer muscles, as a proximal factor, have been shown to influence the biomechanics of the patellofemoral joint (Powers, 2010). Most of the investigations reported hip muscle weakness in females suffering from PFP (Brindle et al., 2003). A systematic review by Prins and Wruff (2009) included 5 cross-sectional observational studies and concluded that females with PFP demonstrated hip abductor, external rotator, and extensor weakness compared to healthy subjects (Prins and Van Der Wurff, 2009). Barton et al., (2013) reviewed the studies that assessed the gluteal muscle activity in patients with PFP. The study findings showed delayed and shorter duration of gluteus medius activity as a cause of impaired hip motion in frontal and transverse planes during step up and down. Contradictory evidence has been found about the gluteus maximus activity during functional tasks. Limited evidence was related to delayed and decreased gluteus maximus activity during running and increased activity during stair ascending (Rathleff et al., 2014). A limited number of prospective studies indicate that hip muscle weakness is not a predictor for the development of PFP (Bolling et al., 2009).

The association between hip muscle weakness and altered lower extremity kinematics during functional activities have been studied in individuals with PFP (Dierks et al., 2008; Mirzaie et al., 2016). Some studies indicated weakness of hip abductor muscles and increased hip adduction during single leg jump and running in females with PFP (Graci et al., 2012; Lee et al., 2012). Power and Souza demonstrated the association between an increased hip internal rotation and decreased hip extensor strength during functional tasks (Souza and Powers, 2009). Conversely, Bolga et al. showed significant hip muscle weakness with no alteration in hip kinematics during stair descent in females with PFP (Bolgla et al., 2008).

Any alterations in patellar alignment and mechanics, as a local factor, such as imbalance between dynamic patellar stabilizers could lead to PFP. Electromyographic (EMG) data has shown delayed muscular activation of vastus medialis oblique (VMO) relative to vastus lateralis (VL) (Cavazzuti et al., 2010). Activation of VL before VMO could create a more lateral patellar tracking and may result in pain in the anterior knee region (Grabiner et al., 1994).

The literature seems to support the role of proximal muscle weakness as a risk factor of developing PFP. Several systematic reviews and original research have assessed the electromyographic activities of gluteus medius and gluteus maximus during weight-bearing activities but the findings are inconsistent (Prins and Van Der Wurff, 2009; Barton et al., 2013; Rathleff et al., 2014; Dierks et al., 2008). It is theorized that the impaired muscle function may lead to PFP.

To the best of our knowledge, no study has assessed both the lower extremity proximal and local muscles as contributing factors in altered patellofemoral biomechanics. Moreover, the anatomical and functional relationship among proposed muscles in functional tasks have been rarely considered in the investigations. No study has tested two or more functional tasks that involve individual activities of daily living simultaneously. None of the studies considered pain as a confounding factor in PFP. Additionally, most of the studies have assessed muscle activity in females with PFP. By considering the high prevalence of PFP in active young males and the importance of the role of lower extremity proximal and local muscles in individuals with PFP, further research seems to be necessary. Therefore, the aim of this study was to evaluate hip and knee muscle activity during single leg stance and single leg squat in males with and without PFP.

2. Methods

2.1. Subjects

Eighteen males with PFP (age 24.2 ± 4.4 years) and 18 healthy matched subjects as controls with no history of previous knee pain (age 23.5 ± 3.8 years) were recruited for this study. All subjects were assessed/diagnosed by an orthopedic surgeon through physical examination and were referred to a physical therapy clinic. Characteristics of the subjects are shown in Table 1. All subjects signed consent forms approved by the Ethical Committee of the Shahid Beheshti University of Medical Sciences before participation. The study began in May 2016 and ended in December 2016.

Patients were eligible for the study if they aged between 18 and 65 years, represented non-traumatic onset of knee pain (VAS≤3), and had retro-patellar pain or anterior knee pain from at least two of the following daily activities: kneeling, squatting, stair climbing, prolonged sitting, walking, and/or hopping/running over the past 3 months. PFP subjects and control groups were excluded from the study if they had: 1) history of knee surgery or patellar tracking/dislocation, 2) history of radicular pain, acute LBP, neurological disorder, 3) patellar, ITB, and pesanserius tendinitis/bursitis and/or sprain, 4) patellar and ligamentous instability, 5) joint effusion, 6) structural abnormalities (genu valgum, genu varum, pelvic abnormalities), 7) VAS >3 during the test, 8) bilateral knee pain, 9) inability to walk without assistive device, 10) increased knee pain with standing, or 11) analgesic and anti-inflammatory drugs at the time of testing (Lee et al., 2012; Nakagawa et al., 2012).

2.2. Procedure

Subjects were prepared for the application of electrode placement by using a light abrasion and cleaning of the skin with medical abrasive paste. Bipolar Ag—AgCl surface electrodes with an interelectrode distance of 10 mm were used to place on the proposed muscles and to record muscle activity. Electrode placements were based on the SENIAM instructions (Nakagawa et al., 2012; Bolgla et al., 2010; Cowan et al., 2002) (URL: http://www.seniam.org) as follows:

Gluteus Maximus: The electrode for the gluteus maximus was placed half the distance between the greater trochanter and the sacrum on an oblique angle.

Gluteus Medius: The electrode for the gluteus medius was placed on one-half of the distance between the greater trochanter and lateral aspect of the iliac crest.

Table 1
Characteristics of the studied sample.

	Healthy	PFP[a]
Age (years)	23.5 (3.8)	24.2 (4.4)
Weight (kg)	74 (19.1)	77 (9.6)
Height (m)	1.76 (0.61)	1.8 (0.51)
Body Mass Index	23.9 (0.98)	23.8 (0.86)
Visual Analog Scale (0–10)	0.00	2.5 (0.51)

[a] PFP: Patellofemoral Pain.

VL: The electrode for the vastus lateralis was applied at 10 cm superior and 6–8 cm lateral to the superior border of patella oriented 15° to the vertical line.

VMO: The electrode of the vastus medialis oblique was applied at 4 cm superior and 3 cm medial to the superior border of patella oriented 55° to the vertical line.

EMG signals were obtained using 8 channel electrode datalog biometrics Ltd., P3X8, UK. EMG signals were strengthened with a band-pass filter 15–500 Hz, an amplifier gain of 100 μv/Div, and a common mode rejection ratio 110 db. The raw EMG was stored on a personal laptop for analysis.

The recorded muscle activity data for each muscle were normalized to a maximum voluntary isometric contraction (MVIC) just prior to the task trials (Bolgla et al., 2010). The gluteus maximus MVIC was recorded with the subject in a prone position at zero hip flexion and 90-degree knee flexion. The gluteus medius MVIC was recorded with the subject in a side-lying position and the hip in zero degrees of flexion, abduction, and external rotation. The vastus lateralis MVIC was recorded with the subject in a sitting position at 90-degree knee flexion. The vastus medialis oblique MVIC was recorded with the subject in a sitting position at 60-degree knee flexion.

Next, a sequence of patellofemoral joint loading tasks was analyzed. The tasks order was single leg stance then single leg squat. During the single leg stance test, the subjects were first instructed to stand on both legs for 15 s and then stand on the involved leg with their hands crossed over the chest for 15 s. The red light was used to indicate the position to be assumed. During the single leg squat test, the subjects were first instructed to stand on the involved leg for 15 s and then the red light signaled the subject to perform the squat task to 60-degree knee flexion and maintain this position for 15 s without any disruption in balance. Three repetitions of each task were achieved. Thirty seconds rest intervals occurred between each task.

2.3. EMG data analysis

Raw EMG data were full rectified and filtered using a cut-off frequency 15 Hz with 4th order butter worth filter (Bolgla et al., 2010). Root mean square (RMS) of each muscle was extracted and mean muscle activity was calculated with this formula:

$$\text{Muscle activity} = \frac{\text{RMS (Task)} - \text{RMS (Rest)}}{\text{MVIC} - \text{RMS (Rest)}}$$

For the reaction time (RT) calculation, the first 10% of EMG amplitude was extracted and the time between the visual feedback and this point was considered for RT of each muscle (Kuriki et al., 2011).

2.4. Statistical analysis

Descriptive data were computed for anthropometric and demographic characteristics. Shapiro-Wilk was used to determine normal distribution. Independent t-tests were used to identify significant differences between PFP and control groups. The alpha level was set at 0.05.

3. Results

Mean gluteus medius, VMO, and VL activation during single leg stance demonstrated a statistically significant difference between PFP and healthy control groups. However, mean gluteus maximus activation did not show a significant difference (Table 2). During the single leg squat, significant differences were identified in mean gluteus medius and VMO and activation levels between PFP and healthy control groups. No differences in mean gluteus maximus and VL activation levels between PFP and healthy control groups were observed during a single leg squat, specifically (Table 2).

Table 2
Mean muscle activity during Single Leg Stance and Single Leg Squat.

Muscle	Group	Single Leg Stance	P Value	Single Leg Squat	P Value
		Mean activation (% MVIC)		Mean activation (% MVIC)	
Gluteus Maximus					
	Healthy	15.94 (5.3)	0.97	24.66 (6.59)	0.87
	PFP[a]	16 (4.97)		25.05 (7.98)	
Gluteus Medius					
	Healthy	22.66 (4)	0.01	22.44 (4.04)	0.04
	PFP	18.11 (6.66)		19.55 (5.47)	
Vastus Lateralis					
	Healthy	37.83 (6.2)	0.01	90.27 (8.92)	0.1
	PFP	49.11 (17.4)		96.33 (12.27)	
Vastus Medialis Oblique					
	Healthy	48.6 (7.2)	0.00	98.27 (7.2)	0.00
	PFP	35.61 (8.8)		87.77 (12.08)	

[a] PFP: Patellofemoral Pain.

When the PFP and control groups completed the single leg stance task, there was no statistically significant difference in the reaction time (Table 3). However, when subjects completed the single leg squat task, there was a significant difference in reaction times of the VL between groups (Table 3).

4. Discussion

The goal of the present study was to assess the electromyographic activity of the hip and knee muscles during functional tasks in males suffering from PFP and healthy subjects. We hypothesized that any deficits in proximal muscles of the lower limb could possibly affect the patellofemoral joint.

Table 3
Reaction time in seconds of muscles during Single Leg Stance and Single Leg Squat.

Muscle	Group	Single Leg Stance	P Value	Single Leg Squat	P Value
		Mean activation (% MVIC)		Mean activation (% MVIC)	
Gluteus Maximus					
	Healthy	0.75 (0.11)	0.27	0.68 (0.09)	0.64
	PFP[a]	0.70 (0.14)		0.70 (0.12)	
Gluteus Medius					
	Healthy	0.70 (0.08)	0.57	0.67 (0.05)	0.16
	PFP	0.68 (0.13)		0.71 (0.11)	
Vastus Lateralis					
	Healthy	0.73 (0.08)	0.69	0.76 (0.06)	0.00
	PFP	0.71 (0.06)		0.68 (0.06)	
Vastus Medialis Oblique					
	Healthy	0.70 (0.08)	0.60	0.70 (0.08)	0.92
	PFP	0.72 (0.14)		0.70 (0.09)	

[a] PFP: Patellofemoral Pain.

4.1. Muscle activity

According to the results, no difference in the activity of the gluteus maximus muscle was found in either task. Regarding the impaired alignment of the lower extremity in subjects with PFP (increased adduction and internal rotation), a noticeable compensatory role of the gluteus maximus muscle can be found in these patients. This muscle appears to have a stabilizing role on the trunk.

Based on our findings, gluteus medius muscular deficits in subjects with PFP in terms of amplitude or level of activity compared to healthy subjects during single leg stance ($p<0.01$) and single leg squat ($p<0.04$) were confirmed. Because gluteus medius is an important stabilizer of the femur movement in both transverse and frontal planes, any deficits in gluteus medius muscle activity or delayed onset may lead to excessive femoral adduction and internal rotation that could be associated with PFPS.

Wilson et al. (Willson et al., 2011) showed a reduced magnitude of the gluteus medius activity and a delayed onset of activity in subjects with PFP. However, no significant difference was found in the gluteus maximus muscle in terms of the magnitude or onset time. In 2003, Brindle et al., (2003) and Cowan et al., (2009) also mentioned an earlier activation of the gluteus medius muscle during stair climbing, which was also confirmed in this study as well as a reduced magnitude of muscles located at the proximal part of the lower limb. However, in contrary, Wilson et al. (Willson et al., 2012) reported an increased gluteus maximus muscle activity in women with PFP, but no changes in the magnitude or onset activation time of the gluteus medius muscle.

Significant differences were found in VMO ($p<0.01$) during a single leg squat and the amplitude of the VMO ($p<0.01$) and VL ($p<0.01$) during standing on the involved leg. Regarding the study findings, VL muscle activity increased during both tasks. This increase in muscle activity could be an attempt to enhance knee joint stiffness. The results are consistent with those of Stensdotter et al. and De Marche Baldon et al. (Stensdotter et al., 2008; De Marche Baldon et al., 2009) who described increased eccentric quadriceps muscle activity as a compensatory strategy to reduce patellofemoral compression. Additionally, Stensdotter et al., (2008) showed increases in the amplitude of the quadriceps muscles during standing.

The magnitude of the VMO muscle activity was reduced in both tasks. The decreased activity could be explained by altered patellar tracking because of impaired alignment of the femur in the transverse and frontal planes.

4.2. Reaction time

No significant differences were found in reaction time of the four studied muscles during both single leg stance and single leg squat in the current study. However, the sequence of muscle recruitment was different between the healthy and PFP subjects during both tasks. In subjects with PFP, the following muscles were activated in turn during single leg stance: gluteus medius, gluteus maximum, VL, and then VMO. However, in healthy subjects, the recruitment pattern was as follows: gluteus medius, VMO, VL, and gluteus maximus. This shows earlier activation of the gluteal muscles to stabilize proximal area in order to maintain proper alignment. During single leg squat, PFPS subjects showed earlier activation of the VL, gluteus maximus, VMO, and gluteus medius. However, healthy subjects showed gluteus medius, gluteus maximum, VMO, and VL muscle recruitment. Regarding the reaction time of the VL and VMO muscles, the current study showed an earlier VL activation in the PFP group when compared to the VMO during either single leg stance or single leg squat. This result is in agreement with cavazzuti et al. (cavazzuti et al., 2010) findings.

This study added more clinical and therapeutic value to the existing literature. Regarding the methods, the lower extremity proximal and local muscles with more anatomical and functional relationship were assessed in two functional tasks that contribute to activities of daily living. This may help clinicians in the diagnosis and treatment of patients with PFP. Pain as a confounding factor in PFP was controlled in this study. Based on the investigations, pain could change the onset time of muscle recruitment and muscle activity. Additionally, despite the high prevalence of PFP in active young males, they were assigned significantly less in previous studies. Therefore, these study findings characterized the role of proximal and local muscles in males with PFP.

4.3. Limitations

The present study could be criticized by several limitations. All subjects were males aged 24–28, therefore our findings may not generalize well to females or even males of different ages. The small sample size was a limitation that should be considered for revision in future studies. In addition, trunk muscles and more muscles of the hip need to be evaluated in future studies. Kinematic analysis is suggested.

5. Conclusions

In conclusion, gluteus medius, VMO, and VL muscle activities were altered in males with PFP during single leg stance and single leg squat compared to healthy subjects. Gluteus maximus activity did not show any changes between groups. Moreover, muscle recruitment patterns were different between PFP and healthy groups. Therefore, our results support the hypothesis that any weakness in proximal muscles of the lower limb could affect the patellofemoral joint.

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