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The effects of muscle fatigue on dynamic standing balance in people with and without patellofemoral pain syndrome

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ABSTRACT

The aim was to examine the effects of muscle fatigue of knee extensor and hip abductor muscles on dynamic standing balance of patients with patellofemoral pain syndrome (PFPS) compared to their healthy matched controls. Thirty participants (15 with PFPS, 15 controls) were recruited. Isolated muscle fatigue of two muscles was induced isokinetically in three separate sessions (one practice and two testing sessions) with a rest interval of at least 72 h. In each testing session, fatigue protocol of only one muscle group was performed for the both legs with a rest time of 30 min. After determining peak torque, participants were encouraged to perform continuous maximal concentric–eccentric contraction of the target muscle until the torque output dropped below 50% of peak value for 3 consecutive repetitions. Immediately after the completion of the fatigue protocol, balance testing of participants was undertaken during single leg standing using the Biodex stability system. Balance stability measures included the overall, anteroposterior and mediolateral stability indices (OSI, APSI and MLSI, respectively). Patients exhibited decreased balance stability in the sagittal plane (higher APSI) when compared to controls. Isolated muscle fatigue of the knee extensors and hip abductors reduced balance stability in both study groups. Fatigue of hip abductors was associated with greater balance instability (higher OSI and APSI) than fatigue of knee extensors.

1. Introduction

Patellofemoral pain syndrome (PFPS) is a common musculoskeletal disorder [1,2] which occurs more frequently in athletes and in women compared to non-athletes and men, respectively [3–5]. Nearly 21% of knee complaints [6] and 10–25% of all patients referred to the physiotherapy clinics [7] are diagnosed with PFPS.

Standing balance control is a key component of most daily and sports activities [8]. Balance can be evaluated in both static (force platform) and dynamic (moveable balance platform) conditions and during both double and single leg standing [8,9]. While several studies have extensively examined standing balance control of patients with different knee disorders such as anterior cruciate ligament injury [10–12], little is known on balance ability of patients with PFPS.

Muscle fatigue, which is defined as the decline in force output capacity after repeated muscle contractions [8,13–15], is a common occurrence in most activities of daily living and sporting competitions [14,16,17]. Specifically, most sports injuries occur during the late stage of competitions in which muscles become fatigued [8]. It has been assumed that muscle fatigue is one of the main causes of impaired balance [13,15]. The post-fatigue impairment in balance control is often attributed to deficit in neuromuscular control resulting from altered somatosensory inputs [8,9,13].

Recently, the evaluation of balance control in the presence of isolated muscle fatigue has become a popular research focus [16]. The adverse effects of lower extremity muscle fatigue on balance performance have been reported in the young [8,15,17–19] and elderly [13] healthy populations and also in some pathological conditions such as chronic ankle instability (CAI) [9,16]. This study aimed to examine the effects of muscle fatigue of the knee extensor and hip abductor muscles on dynamic standing balance of patients with PFPS compared to healthy matched controls. From a clinical viewpoint, understanding the effects of muscle fatigue on balance performance may provide important insight into the role of muscle weakness in the development of PFPS. Also, it may help to assess

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the potential contribution of muscle strengthening exercises in the prevention and rehabilitation of patients with PFPS.

Increased fatigability followed by muscle weakness is one of the primary symptoms of patients with different musculoskeletal disorders [19]. Knee extensor (quadriceps) weakness has been considered as a major contributing factor in the development of PFPS [4,5]. Strengthening exercise of this muscle is an important aspect in the management of this condition [20]. Furthermore, several studies have associated the reduction in cross-section area of the hip abductor (gluteus medius) with PFPS [1,4,5]. Improvement of pain and dysfunction in these patients has been attributed to strengthening exercises of this muscle [1]. Theoretically, gluteus medius weakness during single leg standing could result in dropping of the pelvis on the contra-lateral side, increased hip adduction/internal rotation, increased lateral patellar contact pressure, and thereby it may contribute to the development of PFPS [1,3–5].

It was hypothesized that PFPS patients would exhibit poor balance stability during single leg standing on a dynamic moveable platform, compared to controls. Furthermore, dynamic standing balance of patients would be more affected by fatigue of the knee extensor and hip abductor muscles, compared to healthy controls.

2. Materials and methods

2.1. Subjects

Thirty participants (15 with PFPS, 15 controls) between the ages of 19 and 35 years were recruited. All participants provided a written informed consent prior to participation in this investigation.

PFPS patients were recruited from orthopedic and physiotherapy clinics in Tehran, Iran. Inclusion criteria were: (1) non-traumatic anterior or retropatellar pain for more than 6 months [20]; (2) pain on palpation of the patellar facets [1] or facet compression; and (3) pain on at least two of the following activities: prolonged sitting with bent knees, squatting, kneeling, running, hopping/jumping, and ascending or descending stairs [1,2]. Patients were excluded if they had: (1) diagnosis of knee osteoarthritis, patellar tendonitis, or patellar dislocation/subluxation [21]; (2) clinical evidence of knee ligament, meniscus, or tendon injuries [1,21]; (3) involvement of other joints affecting the lower extremities or the back in the past year; (4) history of any neurological deficit [21]; and (5) previous history of surgery including arthroscopy [21]. None of the patients was undergoing physical therapy in the 30 days preceding the study. All participants were asked to refrain from any strenuous exercise for 2 days before testing to prevent muscle fatigue [2].

In order to evaluate pain and disability, all patients completed a 10-cm visual analogue scale (VAS) [20] and the Kujala patellofemoral scale (KPS) [22]. Additionally, in order to match the activity level of patients and healthy subjects, the Tegner activity rating scale [23] was completed by both study groups. The scoring range of the VAS was 0–10, where 0 indicated no pain and 10 the worst pain [20]. The KPS is a 13-item, self completed instrument with different categories consisting of limping, weight bearing, walking, stairs, squatting, running, jumping, prolonged sitting, pain, swelling, painful patellar movements, muscle atrophy, and flexion deficiency [22]. The total score ranges from 0 to 100, with higher scores indicating lower levels of disability [22]. The Tegner activity scale is a one-item instrument that assesses activity levels for sports and occupational activities. It has 11 items with a scoring range of 0–10. Higher scores represent higher levels of physical activity [23]. Iranian-versions of the KPS [22] and the Tegner scale [23] have been validated for use in Iran.

The selection of the control group was based on the same exclusion criteria as for the patient group. Healthy subjects were matched with patients according to gender (12 female, 3 male), age, height, body mass index, and activity level (Table 1).

2.2. Fatigue protocol

This study was approved by the local Institutional Review Board. The fatigue protocol used in this investigation followed previously published protocols for studying balance control in the presence of fatigue of lower limb muscles [9,13,17–19].

Isolated muscle fatigue of knee extensor and hip abductor muscles was induced using a Biodex System IV isokinetic dynamometer (Biodex Inc., Shirley, NY, USA). Three separate sessions (one practice and two testing sessions) with a rest interval of at least 72 h were assigned to each subject in order to minimize possible learning and fatigue effects [8,19]. The practice session was used to allow familiarization with the equipment and procedure. During each testing session, only one muscle group was tested in both legs with a resting time of 30 min. The order of muscle group and side tested were randomly assigned for each participant. The involved leg of each patient was matched with the corresponding leg of a healthy control according to their dominant side. The leg used to kick a ball was defined as dominant [4,8].

At first, 3 practice trials of sub-maximal and 3 of maximal contractions were performed. After a 60 s rest and in order to determine peak torque, 3 repetitions of maximal concentric–eccentric contraction with no rest were performed at the speed of 60°/s [9,18]. The highest torque achieved during the 3 repetitions was considered as peak torque. After 2–3 min, participants were instructed to perform continuous maximal concentric–eccentric contractions of the target muscle at 60°/s until the torque output dropped below 50% of peak torque for 3 consecutive contractions. This definition of fatigued state has been used in previous studies on fatigue-balance [9,13,17–19]. Participants were given verbal encouragement throughout the isokinetic fatigue protocol [17,18].

Patient positioning in the isokinetic dynamometer was based on the guidelines provided by the manufacturer. Concentric–eccentric contraction of the quadriceps was performed through a range of motion from 90° to 30° knee flexion in the sitting position. As maximal knee extension in the open kinetic chain can increase the patellofemoral joint reaction force [20] and in order to reduce the patellofemoral stress to a minimum during the fatigue protocol, the last 30° of knee extension were excluded by the equipment. For the gluteus medius, participants were positioned side-lying in front of the isokinetic dynamometer [4] and concentric–eccentric contraction was performed within the available range of hip abduction.

2.3. Balance testing

According to previous studies, fatigue recovery (i.e. return to above 80% of peak torque after fatigue) occurs within 2–4 min after the completion of the fatigue protocol [17]. Therefore, all balance testing of this investigation was completed immediately after fatigue [4,17].

The Biodex stability system (BSS) SD (Biodex Medical System Inc., Shirley. NY, USA) is used for the quantitative assessment of dynamic standing balance [17]. It consists of a circular moveable platform that provides up to 20° tilt in a range of 360° [15]. The BSS measures stability ranging from 1 to 12 with higher scores corresponding to increased platform stability. All balance testing in this study was conducted on the moderate level of 4. Balance stability measures extracted from the BSS include the overall, anteroposterior and mediolateral stability indices (OSI, APSI and MLSI, respectively). These stability indices represent the mean angular displacement of the platform in degrees from a level, zero-point position [24–26]. Higher and lower stability indices correspond to greater and lesser movement of the

Table 1
Demographic and functional characteristics of PFPS and healthy groups.

	PFPS group ($n = 15$) Mean (SD)	Healthy group ($n = 15$) Mean (SD)	P value (Mean differences)
Demographic data			
Age (year)	25.8 (4.41)	25.2 (5.17)	0.73
Height (m)	1.64 (10.8)	1.64 (10.4)	0.97
Body mass index (kg/m^2)	22.7 (3.78)	22.9 (3.87)	0.88
Duration of symptoms (month)	29.2 (20.7)	N/A	
Tegner activity score [a]	6.46 (1.35)	6.73 (1.16)	0.56
Kujala patellofemoral scale [b]	78.0 (7.74)	N/A	
Visual analogue scale [c] (pain)	5.66 (1.11)	N/A	

PFPS: patellofemoral pain syndrome; SD: standard deviation; N/A: not applicable.
[a] Range of scores is from 0 to 10.
[b] Range of scores is from 0 to 100.
[c] Range of scores is from 0 to 10.