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Core muscle recruitment pattern during voluntary heel raises is different between patients with patellofemoral pain and healthy individuals

Mana Biabanimoghadam [a,*], Alireza Motealleh [a], Sallie Melissa Cowan [b]

[a] Department of Physical Therapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[b] Physiotherapy Department, St Vincents Hospital Melbourne & Physiotherapy School, The University of Melbourne, Melbourne, Australia

A R T I C L E I N F O

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ABSTRACT

Background: Recent studies suggest that the inconsistent outcomes of patellofemoral pain (PFP) treatment may result from the unclear understanding of changes in the structures remote from the knee joint. Due to the crucial influence of core stability on the knee function, this study aimed to evaluate the recruitment pattern of core muscles in individuals with and without PFP.
Methods: Sixty women aged 18 to 40 years, including 30 subjects diagnosed with PFP and 30 healthy controls rose on to their toes as quickly and strongly as possible in response to a sound alarm in standing position. Electromyographic onsets of the transversus abdominis (TrA)/internal oblique (IO), erector spinae (ES), and gluteus medius (GM) muscles were expressed relative to the electromyographic onset of the prime mover (i.e. soleus). Independent t-tests were performed to compare the onsets of each muscle between the groups. The nonparametric Friedman test and the post-hoc of Wilcoxon signed-rank test were used to describe the muscle activation pattern within the groups.
Results: The results revealed different recruitment patterns of the core muscles between the groups. In the healthy group the GM and TrA/IO contracted, almost simultaneously, in anticipation of the prime mover contraction (sol). However, in PFP subjects a significant delay in the contraction of TrA/IO changed the pattern of muscle activation.
Conclusion: The findings demonstrate that muscular stabilization of spine is altered in the presence of PFP and suggest that treatment techniques aimed at improving core stability could be appropriate in the management of PFP.

1. Introduction

Patellofemoral pain (PFP) is a very common problem which often affects young women [1–4]. Patients experience diffuse retropatellar or peripatellar pain aggravated by activities such as stair stepping, running, squatting, and prolonged sitting ultimately limiting sport and activities of daily living [5]. Numerous studies have investigated PFP etiology and pathogenesis, and proposed various treatment approaches. However, despite short-term success [6] the fact that 70 to 90% of the patients with PFP experience chronic or recurring pain [7] implies lack of long-term success in treatment of PFP or perhaps to a lack of understanding of its underlying causes. While it is commonly accepted that multiple biomechanical factors contribute to PFP, recent research has focused on the changes in neuromuscular control of the knee and the proximal structures [8,9]. Traditionally, researchers examined the vasti recruitment pattern in PFP patients. Despite some controversies, the presence of delayed activity of vastus medialis obliquus relative to vastus lateralis in subjects with PFP is generally accepted [10]. However, much is yet to be understood about the changes in motor control of the proximal structures in patients with PFP.

Core stability has become a popular topic in rehabilitation research as well as in clinical practice relating to both function and injury. It refers to the ability of lumbo-pelvic-hip complex to provide a stable foundation for functional movements and is the product of both motor control and muscular capacity [11]. It has been shown that subjects with impaired neuromuscular control of the core are more susceptible to the injuries of lower extremity particularly the knee joint [12]. In addition, biomechanical studies demonstrated the link between altered femoral control and PFJ load [13,14] and there is evidence that greater femoral internal rotation may contribute to the development of PFP [15]. Noehren and colleagues found that runners who develop PFP have greater hip adduction during running compared to healthy runners and suggest that these subjects may use a different proximal neuromuscular control strategy [16].

Research thus far has primarily focused on the changes in neuromuscular control and the strength of the gluteals rather than other

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[*] Corresponding author at: School of Primary Health Care, Faculty of Medicine, Nursing and Health Sciences, Monash University Peninsula Campus, McMahons Road, Frankston, Melbourne, Victoria 3199, Australia. Tel.: +61 99044816 (Business), +61 452412020 (Mobile).
E-mail address: mana.biabanimoghadam@monash.edu (M. Biabanimoghadam).

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proximal muscles in PFP and provided inconsistent results [8]. Some studies indicated delayed onset of gluteus medius (GM) in PFP subjects compared to healthy individuals [8,17,18], and a decrease in strength [19]; whereas, others did not find such differences [8,20]. In addition, Cowan and co-workers found a decrease in strength of the trunk side flexion in PFP, which is a measure of core control [18]. The lack of consistency of findings may relate to differences in tasks examined and the difference in strategies used by the control system to recruit the muscles. The central nervous system (CNS) uses two different muscle activation patterns to preserve the equilibrium in response to a perturbation, anticipatory postural adjustment (APA) and compensatory postural adjustment (CPA) [21]. APA refers to alteration of muscle activation prior to the predicted perturbation while the role of CPA is restoring the balance after the perturbation [21]. A common method to understand the strategy of the CNS to activate muscles is challenging the postural stability through a controlled task and investigating the pattern of muscle response. Hodges and Richardson recorded the activity of deep abdominal muscles in voluntary hip movements and found that the CNS activates these muscles in advance of the lower limb movements to prepare the spine for ongoing perturbations [22]. In a previous study [9], we investigated the compensatory strategy of the CNS in response to an unexpected external perturbation and found that in order to provide stability, the CNS applied different core muscle recruitment patterns in subjects with and without PFP. It is stated that there is an interaction between anticipatory and compensatory postural responses, and the alterations in CPA might be a strategy adopted by the CNS to compensate for suboptimal efficacy of APA [21]. However, the APA of the core muscles has not been investigated during a controlled voluntary task in patients with PFP.

Thus, to improve the understanding of neuromuscular changes in PFP patients the aim of this study was to evaluate the EMG preactivation pattern of core muscles during voluntary ankle movements in individuals with and without PFP.

2. Methods

2.1. Participants

Sixty female subjects between the ages 18 to 40 (30 unilateral PFP and 30 healthy controls) participated in this case control experiment. The PFP patients were selected conveniently from subjects who were referred by orthopedists with diagnosis of PFP to physiotherapy clinic of School of Rehabilitation Sciences, Shiraz University of Medical Sciences. The control subjects were selected randomly from volunteer students and staff of Shiraz University of Medical Sciences who were sex matched with the PFP group. Demographic and functional characteristics of the two study groups are demonstrated in Table 1. The inclusion and exclusion criteria were based on previous studies of PFP [8,9,23] (Table 2) and were examined by the same physiotherapist.

The research was conducted at the Center of Human Motion Science Research (CHMSR), School of Rehabilitation Sciences, Shiraz University of Medical Sciences (SUMS). A detailed explanation of the procedure was provided for all of the participants and they signed the consent form approved by the SUMS ethics committee.

Table 1
Subject demographic and functional characteristics.

Variables	Control group(n = 30)	PFPS group(n = 30)
	Mean(SD)	Mean(SD)
Age (year)	25.17(3.68)	26.20(3.40)
Weight (kg)	62.43(5.48)	64.20(4.93)
Height (cm)	164.83(4.26)	166.13(4.13)
VAS	00.00(00.00)	5.53(1.10)
FIQ	16.00(00.00)	12.30(0.98)

Table 2
Inclusion and exclusion criteria for the PFPS and control subjects.

	Inclusion criteria	Exclusion criteria
PFPS subjects	1. Women aged 18-40 years 2. Unilateral anterior knee pain during at least two of the following activities: running, jumping, hopping, prolonged sitting, kneeling, stair stepping and squatting 3. Positive apprehension test 4. An average pain level of at least 3 cm on the 10-cm VAS in the last month 5. Functional level of 11 or more in Functional Index Questionnaire 6. Symptoms duration of at least three months which was unrelated to traumatic incidence	1. Bilateral PFPS 2. Traumatic knee conditions 3. Other knee joint pathologies such as: osteoarthritis, meniscal and ligamentous injuries 4. Patellar subluxation or dislocation 5. Spinal disorders such as deformities and disk herniations 6. History of trunk or lower extremity surgeries 7. CNS or neuromuscular disorders 8. Metabolic diseases such as rheumatoid arthritis and diabetes 9. Regular participation in a sport activity (at least two hours a day and three times a week)
Control subjects	1. Women aged 18-40 years 2. No history of knee pain 3. Functional level of 16 in Functional Index Questionnaire	As above

2.2. Instrumentation

We used a 16-channel EMG telemetry system (Mega Electronics Ltd., Kuopio, Finland), to measure the EMG activities with common mode rejection ratio of 110 db, sampling rate of 1000 Hz, Band-pass filtered at 8 to 500 Hz through a 14-bit AD converter. Megawin software, version 3.0 was utilized to record and store the data on a personal computer and a custom-made Labview program (National Instruments Corporation, Austin, TX, US), version 11.0, was applied to analyze the EMG data. We also used X-note Stopwatch, a digital countdown timer (version 1.5^c), to command the subjects to start the task.

We recorded the EMG activity of the erector spinae (ES), transversus abdominis/internal obliquus (TrA/IO), GM, and soleus using round, pregelled, self-adhesive, and silver/silver chloride electrodes (Medico Electrodes International, Uttar Pradesh, India).

2.3. Procedures

The electrodes were attached on the affected side of the patients and the matched side of the healthy subjects, parallel to the muscle fibers with a distance of two centimeters between the centers of each pair electrodes while the subjects were at the standing position. We prepared the electrode sites before the attachment by shaving the area, gentle abrading with a fine sandpaper, and wiping with alcohol. For ES the electrodes were placed at the level of L3, five centimeters lateral to the midline [24]. Due to the deep position of the TrA and IO muscles, their EMG activity cannot be distinguished from each other by surface electrodes [25]. Therefore, we positioned the electrodes two centimeters inferior and medial to the Anterior Superior Iliac Spine (ASIS) to obtain the signals from both muscles [25]. For GM electrodes were placed midway between the most lateral border of the iliac crest and the greater trochanter [26]. We attached the electrodes at the midpoint of the posterior of the leg just medial to the tendon of gastronomies for soleus [23]. The ground electrodes were placed over the iliac crest for the core muscles and on the tibial crest for the soleus.

The participants stood with their arms crossed over their chest and their feet shoulder-width apart. They were instructed to rise on to their toes as quickly and strongly as possible in response to the sound alarm of the X-note stopwatch, neither try to balance on their toes nor