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Electromyographic Onset and Activity Level of Medial and Lateral Hamstrings, Vastus Medialis Obliquus, and Vastus Lateralis in Women with Patellofemoral Pain During Stair Descent

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ABSTRACT

Background: Delayed activation of medial hamstrings (MH) relative to lateral hamstrings (LH) could lead to external tibial rotation. It is a long-held belief that altered force sharing between the vastus medialis obliquus (VMO) and the vastus lateralis (VL) plays a main role in the pathophysiology of PFP. It was presumed that patients with patellofemoral pain (PFP) exhibit altered muscular activation pattern of MH and LH during functional tasks. The aim of this study was to compare the electromyography (EMG) activity of hamstrings and quadriceps in patients with PFP and healthy subjects during stair descent.

Methods: Twenty-four women with PFP and 24 non-symptomatic individuals, aged 18-40 years, were recruited through convenience sampling and participated in this observational cross-sectional study. The EMG activity of MH and LH, VMO and VL was recorded during stair descent. The main outcome measures were onset latency and amplitude of muscle activity relative to the moment of foot contact measured by foot switch. Groups were compared by Mann-Whitney test. Repeatability of task was evaluated using intra-class correlation coefficient (ICC).

Results: A statistically significant difference was seen in the onset of hamstring heads between groups (P=0.014). The LH activated before the MH in the PFP group. Normalized muscular activity was significantly reduced for VMO (P=0.002), VL (P=0.045), and LH (P=0.019) in patients with PFP compared to the control group.

Conclusions: Differences in temporal activation patterns of LH and MH may result in a lack of rotational knee stabilization and lead to increased patellofemoral joint pressure. Earlier activation of LH rotates the tibia externally and likely produces lateral patellar tracking.

Introduction

Patellofemoral pain (PFP) is a common complaint of active adults and adolescents, accounts for up to 40% of knee problems, and afflicts 26% of young athletes [1, 2]. Incidence of PFP is about 22 per 1000 persons per year with 2-10 times higher incidence in women [3]. The prevalence of PFP was reported as 16.74% among Iranian female athletes [4]. PFP is a multifactorial condition resulting in anterior or peripatellar pain. The pain is exacerbated by repetitive loading activities such as stair descent, prolonged sitting, kneeling, squatting, running, hopping, and jumping [5]. Understanding the pathophysiology of PFP seems necessary for early diagnosis of the disease and to design proper preventive or curative programs.

The quadriceps muscle is the primary active stabilizer of patellar tracking, responsible for normal function of

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patellofemoral joint [6]. Abnormal lateral tracking of the patella is a common admissible etiology for PFP. This could be due to an altered temporal control of the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles and reduced activity of the VMO [7]. Abnormal patellar tracking can result in abnormal shearing and compressive forces on the patellofemoral joint during routine daily activities. Increased local stresses can contribute to articular damage leading to early osteoarthritis [8]. Several studies have evaluated electromyographic (EMG) activity of VMO and VL to assess timing patterns and muscle activity levels during functional activities such as stair ascent or descent [9, 10]. Prior studies have reported a delay in VM onset time relative to that of VL in patients with PFP compared to a healthy control group during stair stepping [7, 11], while others found no difference in VMO or VL onset timing during similar tasks [12, 13]. Overall, there is no consensus regarding the imbalance between vasti muscles in patients with PFP [14].

Hamstrings impact the patellofemoral joint by changing the kinematics of the tibiofemoral joint. Several in-vitro studies have shown that altered kinematics of the tibiofemoral joint could lead to mal-tracking of the patella and resultant cartilage degradation [15, 16]. Abnormal transverse displacement of the tibia has a significant effect on the pressure distribution pattern of the patellofemoral joint [17, 18]. Increased posterior translation and external rotation of the tibia can affect lateral tracking of the patella and lead to increased patellofemoral contact pressure [16]. Because PFP is theorized to be associated with increased external tibial torsion, it could be speculated that an imbalance between MH and LH might result in patellar mal-tracking [19, 20]. Dieter et al. reported delayed activity of semitendinosus (ST), the medial rotator of the tibia, relative to the biceps femoris (BF), the lateral rotator of the tibia, in patients with PFP. They also reported greater activity levels of the BF and lower activity levels of the ST in patients with PFP [19]. Patil et al. assessed EMG timing patterns of quadriceps and hamstrings in patients with anterior knee pain during maximal isometric contraction. They showed that LH activated earlier in patients with PFP in comparison to non-symptomatic individuals, which may lead to increased abduction and external rotation moments [20].

It is worth noting that earlier onset activity of LH relative to MH in patients with PFP was approved during non-functional tasks such as isometric contraction [20] and cycling [19].

We hypothesized that individuals with PFP have an earlier onset time and greater EMG activity of LH relative to MH during stair descent, as a demanding and functional task, when compared to healthy individuals.

Therefore, the purpose of this study was to compare the vasti and hamstrings muscle activity levels and the temporal activation patterns of these muscles in individuals with and without PFP during stair descent.

Methods and Materials

Participants

Twenty-four women with PFP and 24 non-symptomatic women aged 18-40 years participated in this observational cross-sectional study which was performed at the motion lab of Rehabilitation Sciences Research Center, Shiraz University of Medical Sciences, Shiraz, Iran, between January 2018 and October 2018. The sample size was calculated based on a previous study, considering LH onset latency as the primary outcome measure [19], an alpha level of 0.05, and a power of 80%. The inclusion criteria of the PFP group were : 1) a history of unilateral retro- or peripatellar pain for at least one year provoked by at least two of the following activities: prolonged sitting, stair navigation, squatting, running, kneeling, hopping, or jumping [21]; 2) positive patellar grinding test; 3) pain level of at least 30 mm on a 100 mm visual analog scale (VAS) in the preceding 3 months; 4) functional level of at least 11 on the Functional Index Questionnaire (FIQ); and 5) BMI between 18.5 and 23.9.

Exclusion criteria were having a history of low back pain (LBP) and sacroiliac joint dysfunction for at least the previous 6 months, a history of knee surgery during the preceding six months, leg length discrepancy and physiotherapy, acupuncture or steroid injection during the last 6 months. Metabolic or rheumatologic diseases influencing the musculoskeletal system such as diabetes and rheumatoid arthritis were also considered as exclusion criteria. Patients with PFP were recruited through advertisements placed in the physiotherapy and orthopedic clinics affiliated with Shiraz University of Medical Sciences.

The control group included healthy female volunteers aged 18-40 years recruited through friends or acquaintances of researchers. They were matched to the PFP group in age and BMI, and the assessed leg was assigned according to the symptomatic side of their matched counterparts. The study was approved by the local Medical Ethics Committee in accordance with the standards of the Helsinki Declaration (Ethics code: IR.SUMS.REC.1395.S318), and a written informed consent form was signed by participating individuals prior to beginning the study.

Instrumentation

EMG Recording

Surface EMG recordings were made using a 16-channel portable EMG telemetry system (ME6000 Biomonitor, © Mega Electronics Ltd., Microkatu, Finland), with built in 305×amplification, band pass filter of 8-500 Hz, 1.6 μV noise referred to input, input impedance of 1012 Ω, common mode rejection ratio of 110 dB, and a sampling rate of 1000 Hz. Data was transmitted through a 14-bit analogue-to-digital convertor and stored for later processing.

The skin was cleaned and abraded with alcohol prep pads before electrode attachment. Pairs of pre-gelled Ag-AgCl disposable self-adhesive electrodes (Medico Electrodes International, Uttar Pradesh, India) with a center-to-center distance of 20 mm were placed over the bellies of VMO, VL, LH and MH, parallel to muscle fibers in accordance with SENIAM guidelines. VMO electrodes were placed at 80% distal from the anterior superior iliac spine (ASIS) to the joint space in front of the medial

ligament with the ground electrode placed over the tibial tuberosity. VL electrodes were placed at a distance of 2/3 distal from the ASIS to the lateral side of the patella with the ground electrode placed over the fibular head. The LH electrodes were applied at approximately the middle line, connecting ischial tuberosity to the lateral epicondyle of the tibia with the ground electrode applied over the greater trochanter. The MH electrodes were placed at the midpoint of the line, connecting the ischial tuberosity to the medial epicondyle of the tibia with the ground electrode applied over the medial tibial condyle. An adhesive anti-allergic tape was used to fix the wires to prevent cable motion artifact during the trials. (Figure 1).

To determine the exact time of foot contact, a pair of flexible, very thin (thickness: 1 mm), mechanical on-off foot switch sensors with a durable 25-mm diameter membrane switch with a 15-mm sensor area on a 100-mm flexible tail (MA-153, Motion Lab Systems, Inc., Baton Rouge, LA, USA) were placed over the third step. To avoid disturbing the normal pattern of descending the stairs, the stair set was covered with carpeting; hence, the participants were not aware of the foot switch sensors. The foot switch sensor signals were synchronized with EMG recorders connected to a data logger interface with a computer. EMG onsets were determined relative to the exact time of foot contact.

Stair Apparatus

The staircase consisted of five steps with step height=11 cm, width=40 cm, length=72 cm. For familiarization, each participant had three trials of stair navigation.

Procedure

The participants stood over the staircase, barefoot, arms by sides, and the feet approximately shoulder-width apart with an even distribution of weight over the lower limbs. Following the alarm of a stopwatch (Xn timer), the PFP group descended the steps at a self-selected pace with the uninvolved leg. The control group descended the steps with the matched limb. As control of descending time influences EMG signals by disturbing a normal gait cycle [22], the speed of stair descent was not controlled. Before the beginning of the trial, EMG was recorded for 3 seconds during quiet standing to monitor EMG baseline noise. Five trials were performed with a 30-second rest interval to prevent fatigue. To evaluate between-session repeatability, the protocol was re-measured at subsequent sessions a week apart on eight participants of each group.

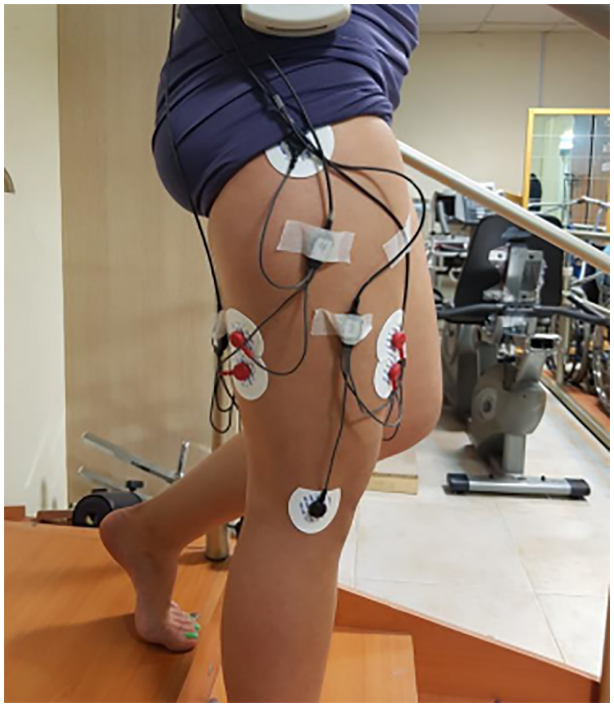

Figure 1: Surface EMG electrode placement in participants

EMG Analysis

To normalize the EMG signal, maximum voluntary isometric contraction (MVIC) was recorded for each muscle group. Participants were asked to have a maximal muscle contraction against a static resistance for 5 seconds. MVIC of VL and VMO was obtained through two different positions, one when the individual was sitting with hip and knee flexed 90 degrees, and another while the individual was sitting with knees flexed 60 degrees. Two positions were also used for LH and MH: 1) sitting with hip and knee 90 degrees flexed, and 2) prone with knees flexed 60 degrees. Three attempts at each test were performed separated by 2 minutes to reduce fatigue. The order of performing the tests was randomized. The highest value recorded for each muscle from the attempts was used as the normalization value.

All analyses were performed using MATLAB software (MathWorks, Inc., Natick, MA, USA). The raw EMG signals for the stair descent trials were sampled at a frequency of 1000 Hz, band-pass filtered at 20-500 Hz, fully rectified and processed using the root mean square (RMS) algorithm with a 55-ms moving window [12]. Raw EMG data was visually checked to verify the identified onsets. The onset time of the EMG signal during stair navigation was determined if the amplitude exceeded 3 standard deviations of baseline for a minimum of 25 ms prior to or after foot contact [23]. EMG was recorded 3 seconds before the initiation of the trial. The average of five trials was used for statistical analysis. EMG amplitude of each muscle was normalized to MVIC. A computer algorithm determined the maximum RMS amplitude during stair descent. The VMO onset was subtracted from the VL onset to quantify the quadriceps timing difference. A positive value was interpreted as the earlier activation of VMO, while a negative value represented a VMO delay. Considering MH and LH, the onset time difference was calculated by subtracting the onset time of MH from that of LH. The onset time difference among five trials was averaged for each participant. A positive value showed that MH activated earlier than LH, whereas a negative value indicated that LH activated prior to MH.

The functional activity level of the participants was controlled using the FIQ which, first developed by Stratford, is one of the most widely used outcome measures for measuring functional limitations in patients with PFP [24]. The FIQ consists of eight items, each having three response choices with a total scoring range of 0-16. Higher scores indicate less difficulty in performing functional activities.

Statistical Analysis

Data was analyzed using SPSS software version 21.0 (SPSS Inc., Chicago, IL). The Shapiro-Wilk test confirmed the non-normal distribution of data. Differences between groups were tested using the Mann-Whitney test. Between-session repeatability was evaluated using the intra-class correlation coefficient (ICC).

Results

Baseline characteristics of the participants are summarized in Table 1. The patients in PFP group had No significant difference between the groups was found in the baseline data. In addition, there was no significant difference in stair descent time between the two groups (PFP group: median: 3390 ms (25% IQR: 2988, 75% IQR: 4129), control group: median: 3514 ms (25% IQR: 3046,75% IQR: 4018), P=0.75; Table 1).

To evaluate between-session repeatability, onset-time latency and amplitude of muscle activity were assessed during two separate sessions, and ICC was calculated. Table 2 demonstrates ICC for all the measures. The results showed a moderate to high reliability for onset latency and moderate reliability for normalized amplitude.

A statistically significant difference was seen in the onset time of medial and lateral heads of hamstrings (LH-MH) between the groups (P=0.014), while no significant difference was found for onset time of the heads of quadriceps (VL-VMO) (P=0.24). It was shown that LH activated before MH in patients with PFP, while MH activity preceded that of LH in the control group (Table 3).

Normalized EMG amplitude of both groups are shown in Table 3. The PFP group showed significantly lower activation of VMO (P=0.002), VL (P=0.045), and LH (P=0.019) compared to the control group.

Regarding the range of FIQ score in this study (range: 11-13) and the smallest detectable change of the Persian version of FIQ (2.7) [25], it could be concluded that we had a homogenous group of patients with PFP considering functional activity level.

Discussion

The results showed that LH activated before MH in patients with PFP. Moreover, the PFP group showed significantly lower activation of VMO, VL, and LH in comparison to the control group.

Quadriceps Activation Pattern

Previous studies have reported delayed onset of VMO relative to VL during stair navigation, which could be a contributing factor to PFP [7, 9]. Others, however, have demonstrated no significant difference between VMO and VL onset latencies [10, 26]. Kuriki et al. demonstrated that people with PFP have prior activation of VL during

Table 1: Comparison of baseline characteristics of participants

Groups	Control (n=24)	PFP (n=24)	P value
Age (year)	23.25 (2.55)	24.95 (2.38)	0.37
Weight (kg)	59.16 (7.20)	59.45 (5.91)	0.87
Height (m)	1.65 (0.04)	1.65 (0.04)	0.76
Body Mass Index (kg/m2)	21.39 (1.95)	21.53 (1.62)	0.78
Visual Analog Scale (0-100)	00.00 (0.00)	50.62 (10.05)	-
Functional Index Questionnaire (0-16)	16.00 (0.00)	11.58 (0.77)	-

Data is presented as mean (standard deviation).

Table 2: Interclass correlation coefficients for onset latency and normalized EMG amplitude of muscles

Variable		Session 1 Median (25,75 IQR)	Session 2 Median (25,75 IQR)	ICC (2, 1)
Onset time (ms)	VMO	- 123.37 (-189.50, 7.12)	-97.67 (-17, 237.25)	0.64
	VL	-137.00 (-208.37, -78.60)	-118 (-161.92, -84.75)	0.90
	MH	-190.08 (-240.44, -121.00)	-125.00 (-190.92, -40.68)	0.79
	LH	-197.00 (-242.71, -55.22)	-179.32 (-242.13,45.32)	0.88
Normalized amplitude	VMO	0.38 (0.28, 0.46)	0.37 (0.28, 0.47)	0.55
	VL	0.42 (0.37, 0.49)	0.41 (0.32, 0.46)	0.64
	MH	0.30 (0.24, 0.41)	0.28 (0.22, 0.39)	0.78
	LH	0.39 (0.33, 0.47)	0.32 (0.29, 0.38)	0.63

IRQ: Interquartile range, VMO: Vastus Medialis Obliquus, VL: Vastus Lateralis, MH: Medial Hamstrings, LH: Lateral Hamstrings

Table 3: Onset time difference during stair descent

		Control group	PFP group	P value
		Median (25%, 75% IQR)	Median (25%, 75% IQR)	
Onset time difference (ms)	VL-VMO	-42.33 (-212.90, 12.93)	-7.83 (-77.00, 36.93)	0.24
	LH-MH	46.00 (-10.31, 145.92)	-55.83 (-234.80, 142.75)	*0.01
Normalized EMG activity	VMO	0.41 (0.35, 0.45)	0.33 (0.28, 0.39)	*0.002
	VL	0.42 (0.34, 0.49)	0.38 (0.29, 0.43)	*0.04
	MH	0.37 (0.27, 0.44)	0.36 (0.28, 0.41)	0.42
	LH	0.40 (0.35, 0.47)	0.35 (0.26, 0.42)	*0.02

VMO, vastus medialis obliquus; VL, vastus lateralis; MH, medial hamstring; LH, lateral hamstring, EMG, electromyography, *: statistically significant difference

stair ascent, which may suggest patellar lateralization [27]. The observed difference could be attributed to the task involved. The activation pattern of different heads of quadriceps might differ during stair descent vs. stair ascent. In line with our findings, Aminaka et al. found no difference in onset latency of VMO between patients with PFP and healthy individuals [23].

Our findings were consistent with those reporting no significant difference between VMO and VL onset. Weight bearing tasks such as stair navigation challenges neuromuscular control by altering the muscle activation pattern to provide stabilization of the joint [28]. Stair stepping rate might be a source of the divergent results of the current study from those of Cowan et al. [7] and Boling et al. [29]. In previous studies, stepping rate was controlled with a metronome, whereas participants in the current study had a self-selected pace when descending the stairs. Different physical activity levels of patients could also lead to controversial results. Briani et al. showed that delayed onset of VMO relative to VL was only observable in women with PFP and a high level of physical activity [30]. They evaluated physical activity using the international physical activity questionnaire long form, while we evaluated the physical activity with FIQ, which does not categorize the level of physical activity in patients with PFP.

Patients with PFP demonstrated a significantly lower amplitude of VMO and VL in comparison to non-symptomatic matched participants. Modification of muscular activity is a compensatory mechanism to reduce patellofemoral compressive force during pain provoking activities. These results agree with those of Santos et al., who assessed the influence of open and close kinetic chain activities on EMG amplitude of VMO, VL longus, and VL obliquus. They reported significantly less values for VMO/VLL ratios in patients with PFP [31].

Hamstrings Activation Pattern

Patients with PFP descend stairs by activating LH prior to MH. Lateral-medial imbalance in the hamstrings could be a contributory factor in the causation of anterior knee pain. LH rotates the tibia laterally as opposed to MH. Earlier activation of LH in comparison to MH would rotate the leg externally during stair descent in patients with PFP. The current findings are in line with those of Patil et al. [20], who reported the earlier onset time of VL relative to VMO as a contributing factor to abnormal knee external rotation moments in patients with PFP. Sheehan et al. [16] demonstrated that external rotation of the tibia would increase the patellofemoral contact pressure in response to lateral translation of patellar tendon. Moreover, in vitro studies demonstrated that hamstring loading induced tibial external rotation and posterior translation, which might lead to an increased pressure on the lateral patellar cartilage [15]. According to Shultz et al. [32], synchronous activity of the MH and LH during external perturbation stabilize the knee joint against the rotatory function of these muscles in contrast to the unilateral activation of the muscles.

A lower activation level of LH was found in patients with PFP compared to the control group. This result was similar to that of Liebensteiner et al. [33], who concluded that the reduced activation of hamstrings during eccentric contraction might be a compensatory strategy to limit harmful loading of the patellofemoral joint. It was suggested that reduced activity of the hamstrings may be associated with a pain inhibitory response that influence not only the agonist muscles, but also the antagonist group. Dieter et al. reported greater LH and lower MH activation levels in patients with PFP compared to the control group [19]. Observed differences might be attributed to different recruited populations, physical activity levels, and evaluated tasks. They evaluated EMG activity of the muscles in a group of cyclists with PFP during cycling.

Based on the current findings, neuromuscular and motor control training exercises to facilitate or accelerate the onset activity of MH should be considered in the rehabilitation program of patients with PFP. Special attention should also be paid to strengthen VMO, VL, and LH when prescribing exercise for patients with PFP.

To the best of our knowledge, this study was the first to evaluate the EMG amplitude and onset activity of hamstrings in patients with PFP during a functional task. However, this study had some limitations. Neuromuscular control could be affected by sex hormones. The current study investigated a female population. Therefore, generalizing the results to the entire population of PFP patients must be done with caution. The kinetic and kinematic data of the participants in this study were not evaluated. Future studies are warranted to concurrently evaluate EMG, kinematic, and kinetic data in patients with PFP during stair navigation. Furthermore, data indicating how long the patients in the current study had been experiencing PFP was not available. As chronicity might impose greater alterations in neural activity, it should be regarded as an outcome measure for future studies.

Conclusion

In conclusion, different activation levels and onset latency of LH and MH might interfere with knee rotational stability and lead to external rotation of the leg, which might result in a greater patellofemoral joint contact pressure force in patients with PFP and lead to pain and disability when doing weight bearing activities such as stair descent.

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Conflict of Interest: None declared.

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