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Original Article

# Comparative Evaluation of Core and Knee Extensor Mechanism Muscle Activation Patterns in a Stair Stepping Task in Healthy Controls and Patellofemoral Pain Patients

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ABSTRACT

**Background:** Patellofemoral pain (PFP) is a common affliction and complex clinical entity. Deficit in neuromotor control of the core may be a remote contributing factor to the development of PFPS. Comparative evaluation of core and extensor mechanism muscle activation patterns between healthy group and patients involved by patellofemoral pain syndrome (PFPS) in a stair stepping task is the aim of this study.

Methods: In this non-randomized interventional study fifteen males with PFPS and fifteen asymptomatic controls participated. Electromyographic (EMG) activity of Vastusmedialisobliquus (VMO), Vastuslateralis (VL), Gluteus medius (GMED), Gluteus Maximus (GMAX), Internal oblique (IO) and Erector spinae (ES) were recorded and EMG onsets were assessed in both stepping up (SU) and down (SD). The time of foot contact determined by a foot switch.

**Results:** During SU: Onset times of all muscles except, VL and ES in the controls were significantly less than PFPS group ($P<0.05$). In PFPS group the temporal sequence of ES, VL and VMO were different from control groups. During SD: Onset times of all muscles except, GMAX and ES in the control group were significantly less than PFP group ($P<0.05$). The sequence of muscle activity in both healthy and PFP groups were the same.

**Conclusion:** Our findings are in line with previous researches about the effects of core on function and control of lower extremity. Activation patterns of core and vasti muscles are different between control and PFPS group during stair stepping task. Designing exercises to correct inappropriate timing of core muscles may have a role in management of PFPS and it needs more future researches.



## Introduction

Patellofemoral pain syndrome (PFPS) is a common affliction affecting both athletes and general populations, especially in activitiesrequired repetitive lower limb loading [1]. 25% of knee athletic injuries that are treated in the sport medicine clinics were related to PFPS [2].

Dye et al. named this syndrome black hole of orthopedics due to its unknown reason [3]. Although the development of PFPS is multi-factorial, abnormal tracking of the patella has been accepted as a most contributing factor. One proposed mechanism for abnormal patellar tracking is reduced control of quadriceps muscle in PFPS [4, 5]. This could be explained either by a delayed activity of Vastusmedialisobliquus (VMO) relative to Vastuslateralis (VL) or reduced force production capabilities of VMO

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relative to VL [4-6].

Patellar tracking is result of an interaction between function of near and remote muscles, passive structures and the neuromotorcontrol systems[7]. Instability and reduced core strength has been implicated as being contributory to increase risk of lower extremity injuries. Exercise targeting the hip, Pelvis and trunk musculatures benefit individual with PFPS by improving strength and motor control of these regions [8, 9]. Since stability of trunk and pelvis is essential for limbs movement [8, 10], pelvic asymmetry in frontal plane and anterior pelvic tilt might result in lower limb injury. Therefore, pelvic asymmetry would be a predictive factor for knee injury or pathology[8-13].

Although, several researchers have suggested that knee joint could be considered as one of the victims of core instabilityand impaired trunk neuromuscular control [13], few studies have evaluated the effect of core and trunk neuromuscular control in individuals with PFPS. Some investigators have studied the activation timing of VM and gluteal muscles during stair climbingusing electromyography (EMG). However,the results of these studies in the field of motor control are inconsistent [7, 14, 15].

Brindle et al. and Cowan et al. demonstrated a delayed EMG activity of gluteus medius (GM) relative to VM muscle in people with PFPS [7, 14]. In contrast, Boling et al. found no significant difference between GM and VM onset times in subjects with PFPS [15]. Furthermore most studies were done on relationship between motor control of GM and VM muscles with PFPS. Buttodate,litt leobjectivedataareavailable that provideadequaterationale for control role of other core muscles that check pelvic in other planes.

Considering that, altered neuromotor control of the core have been proposed as a remote contributing factor to the development of PFPS [16] and in respect to stair negotiation is one of the most common painful activities in patients with PFPS [17, 18], and stepping exercise is suggested for intermediate and final phases of rehabilitation in PFPS [19], the purpose of this study was to identify the core and vasti temporal activation pattern in stair negotiation using EMG.

## Methods

Fifteen males with PFPS and fifteen asymptomatic controls in a convenient sampling took part in thisnon-randomized interventional study. Subjects were matched in variables such as age, height and weight, and body mass index. The subjects in PFPS group with unilateral knee pain wereincluded if they hadanterior or retropatellar knee pain on at least, two of the following activities: prolonged sitting, climbing stairs, squatting, running and jumping. Also they were included if they had pain on patellar palpation, symptoms for at least 1 month, BMI between18.5-24.9, an average pain level of 3 cm or less on a 10-cm visual analog scale (VAS) and insidious onset of symptoms unrelated to a traumatic event. All participants were aged 40 years or less to reduce the possibility of osteoarthritic changes in the patellofemoral joint. Subjects should be score more than 10 on Functional Index Questionnaire (FIQ) provided that subject was able to step up stairs without taking rails.

subjects from either group were excluded from participation if they had: (1) any history of pathology or disorder which might interferewith the kinetics or kinematics of trunk, hip, knee and ankle such as neuromuscular or central nervous system diseases that would impaired gait (for example: vertigo). (2) Orthopedic problems for instance: A history of knee, ankle, hip and spine surgery, previous experience with patellar or hip dislocation/subluxation,history or clinical evidence of lower extremity, pelvis and spine fracture, meniscus or ligament injury, patellar tendon pathology, osteoarthritis, disc herniation or referred pain from the spine, any low back pain or sacroiliac dysfunction in the past 6 months, postural abnormality such as scoliosis, genu varum/ valgum, flat foot or pescavus, leg length asymmetry for more than 1 cm (3) Systemic diseases such as rheumatoid arthritis and diabetes.

Also, the professional athletes (exercise more than 2 hours a day or every other day) were excluded.

The study protocol was approved byEthics Committee of the Tehran University of Medical Sciences and Health Services. Informed consent was obtained from all the participants.

Kinesiological EMG of Vastusmedialisobliquus (VMO), Vastuslateralis (VL), anterior portion of the Gluteus medius (GMED), Gluteus Maximus (GMAX), Internal oblique (IO) and Erector spinae (ES) were recorded using surface electrodes (Silver/silver chloride) with an inter-electrode distance of 20 mm [20].

Electrode locations set as follows:

VMO -approximately 4 cm superior to and 3 cm medial to the superomedial patellar margin and orientated 55 degrees to the vertical [21].

VL-10 cm superior and 6-8 cm lateral to the superior border of the patella and angled 15 degrees to the vertical [22].

GMED - 5 cm posterior to anterior superior iliac spine and 3-4 cm inferior to iliac crest [24].

GMAX - at the midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter [23].

IO - 2 cm inferior and medial to the anterior superior iliac spine [24].

ES - on the erector spinae muscles in the L4 leveland parallel to plumb axis of the spine [25].

Ground electrode was located on the right wrist of the participants over the radial styloid process.

Eight channels EMG system and foot switch (Blue myo, KYA Company, Iran) were used to record electromyographic activity and the time of foot contact with the step respectively. The muscle onset was determined relative to the moment of foot contact [7].

The stair- stepping task consisted of ascending and descending 2 steps (one foot on each step). Each step was 20 cm in height, 80 cm in width, with no handrails. Depth of first and second step was 30 cm and 60 cm respectively. Participants stood on the floor facing the stairs and 20

cm away from edge of the first step. The stair stepping task was performed barefooted while arms hanged at the side of the body. The patients were instructed to start ascending the steps immediately after hearing the audio signal of the X note timer, at their maximum self-selected speed with the involved lower extremity. Subjects in the control group started the stair stepping task with the same leg (right or left) as their counterpart match in the PFPS group [1, 7, 18, 26, 27].

The stair stepping down task was performed in the same way as stepping up but the subjects stood on the second step and 5 cm away from its edge.

Before data collection, subjects performed three practice trials of step up and down to familiarize with the task. Then, the subjects performed 3 test trials with 30 seconds of rest between each trial in order to prevent fatigue [1].

Sequence of ascending and descending the stairs were determined randomly by the examiner and mean of data in 3 test trials was used for analysis.

EMG data were sampled at 1000 Hz and full-wave rectified, then band-pass filtered between 20-500 Hz. Also, Foot switch signal was sampledat 1000 Hz. Using Matlab codes, the onset latency was determined by the temporal distance between the onset of foot switch signal and the point at which the amplitude of EMG activity reached 3 SDs above the baseline level and stayed for more than 30 milliseconds [28]. The determined onset by the computer algorithm was checked visually in the form of rectified, unfiltered EMG signal to detect noise and artifacts on analysis.

*Statistical Analysis*

Since results of Kolmogorov-Smirnov test show normal distribution curve, parametric methods were used. Independent t-test was used to compare muscle onset between control and patients groups on ascending and descending stairs. One-way analysis of variance with repeated measures was used in order to determine the sequence of muscle activation during stair negotiation.

## Results

Onset times of all muscles except VL and ES in the control group were significantly less than PFPS group during ascending stairs (Table 1). In addition, sequence of activity of ES, VL and VMO in PFPS group was different from control groups during stair ascending. (Table 2).

Onset times of all muscles except GMAX and ES in the control group were significantly less than PFPS group during descending stairs (Table 1).There was no significant difference between the two groups with regard to sequence of muscle activation during descending stairs (Table 2 and Figures 1 and 2).

## Discussion

Our results showed that, during ascending stair, VMO, GMED, VL and GMAX muscles in the control group activated significantly before their counterparts in the PFPS group.

Also, during stair descending, VMO, GMED, VL and IO in the control group activated significantly earlier than their counterparts in the PFPS group. Individuals with PFPS also, displayed a delay onset of muscle activation relative to the control groups in both stair stepping up and down.

Based on our results, in thecontrol group, the core muscleswere activated before foot contact with the step in order to provide stability of kinetic chain and resist against its imposed perturbation. Our finding is consistent

**Table 1:** Comparison of muscle onset time between PFPS and control groups during stair stepping task

| | Stepping Up | | | Stepping Down | | |
|---|---|---|---|---|---|---|
| | **CONTROL (Mean±SD)** | **PFPS (Mean±SD)** | **P** | **CONTROL (Mean±SD)** | **PFPS (Mean±SD)** | **P** |
| VMO | -114.69±13.45 | -89.39±38.04 | 0.026* | -211.84±61.17 | -151.20±67.14 | 0.015* |
| VL | -102.16±20.03 | -106.76±38.38 | 0.685 | -182.84±43.10 | -126.17±93.18 | 0.041* |
| GMED | -87.26±85.67 | 15.60±35.89 | 0.001* | -123.20±57.17 | -30.26±58.37 | 0.001* |
| GMAX | -90.60±87.87 | 4.13±32.03 | 0.001* | -152.00±108.29 | -93.26±46.42 | 0.064 |
| IO | -236.20±119.46 | -156.50±89.09 | 0.048* | -371.20±142.11 | -271.06±66.28 | 0.020* |
| ES | -128.53±128.97 | -107.00±92.38 | 0.603 | -317.66±227.91 | -227.33±111.98 | 0.179 |

**Table 2:** comparison of onset time of muscles during stair stepping task in both groups

| | | VM | VL | GMED | GMAX | IO | ES |
|---|---|---|---|---|---|---|---|
| Step Up | Control | *,†,ℓ<br>-114.69±13.45 | *,¥,∏<br>-102.16±20.03 | †,¥,◊<br>-87.26±85.67 | ф<br>-90.60±87.87 | ℓ, ∏, ◊, ф ,ψ<br>-236.20±119.46 | ψ<br>-128.53±128.97 |
| | PFPS | *,†,‡, ℓ<br>-89.39±38.04 | *,¥,Δ<br>-106.76±38.38 | †, ¥, ∞, ◊, λ<br>15.60±35.89 | ‡, Δ, ∞, ф, ж<br>4.13±32.03 | ℓ,◊, ф<br>-156.50±89.09 | λ, ж<br>-107.00±92.38 |
| Step Down | Control | *,†, ℓ<br>-211.84±61.17 | *,¥,∏, ff<br>-182.84±43.10 | †,¥ ,◊, λ<br>-123.20±57.17 | ф, ж<br>-152.00±108.29 | ℓ, ◊,∏, ф<br>-371.20±142.11 | λ, ж,ff<br>-317.66±227.91 |
| | PFPS | †,‡, ℓ,£<br>-151.20±67.14 | ¥,∏,ff<br>-126.17±93.18 | †,¥,∞,◊, λ<br>-30.26±58.37 | ‡,∞, ф , ж<br>-93.26±46.42 | ℓ, ∏,◊, ф<br>-271.06±66.28 | £, □, λ, ж<br>-227.33±111.98 |

*P<0.05 VMO $_{VS}$ VL; † P<0.05 VMO $_{VS}$ GMED; ‡ p< 0.05 VMO $_{VS}$ GMAX; ℓ P< 0.05 VMO $_{VS}$ IO; £ P<0.05VMO $_{VS}$ ES; ¥ P<0.05VL $_{VS}$ GMED; ∏ P<0.05 VL $_{VS}$ IO; ff P<0.05 VL $_{VS}$ ES; Δ P<0.05 VL $_{VS}$ GMAX; ◊ P<0.05 GMED $_{VS}$ IO; λ P<0.05 GMED $_{VS}$ ES; ∞ P<0.05 GMED $_{VS}$ GMA; ф P<0.05 GMAX $_{VS}$ IO; ж P<0.05 GMAX $_{VS}$ ES; ψ P<0.05 IO $_{VS}$ ES

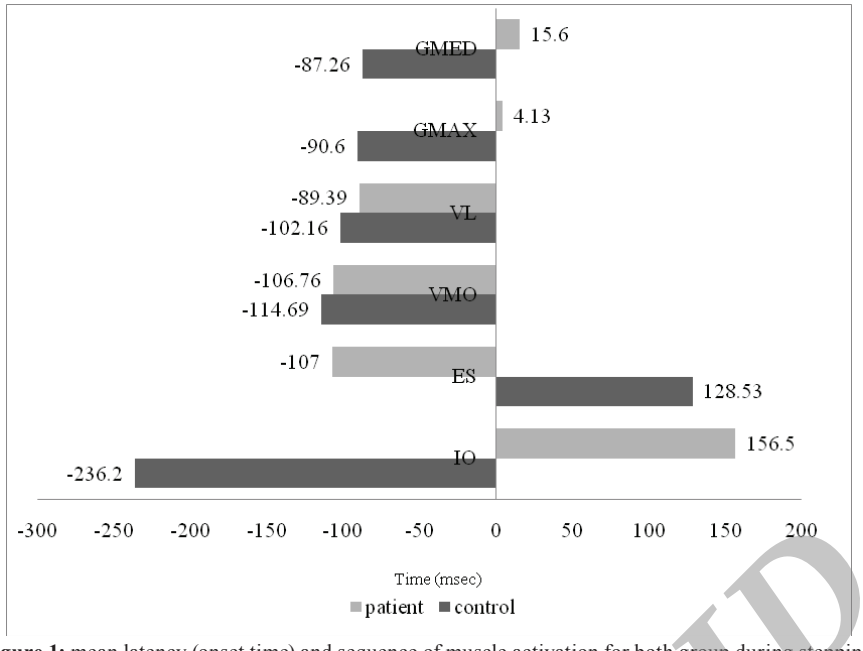


**Figure 1:** mean latency (onset time) and sequence of muscle activation for both group during stepping up.

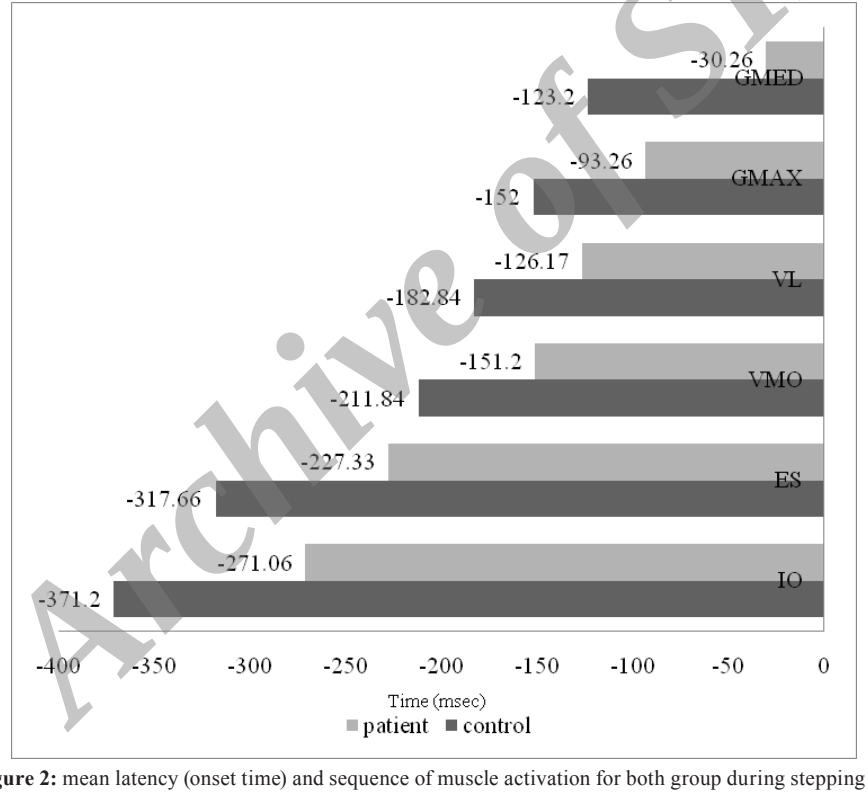


**Figure 2:** mean latency (onset time) and sequence of muscle activation for both group during stepping down.

with those of previous studies [14, 29, 30].

Cresswell et al. demonstrated that, prior to a predictable perturbation, immediate activation of core muscles (transverse abdominis, obliquusabdominisinternus, obliquusabdominisexternus, rectus abdominis and erector spinae) providestrunk stability [31]. This result also confirmed our finding.

In PFPS group GMAX and GMED demonstrated more delayed activity during ascending stair and their onset time occurred after heel strike. This finding concurs with previous research by Cowan et al. and Brindle et al. however differ from the finding of Boling et al. they report no significant difference in GMED onset time between control and PFPS groups [7, 14, 15].

This is the first study which evaluates core muscle EMG activity in conjunction with quadriceps activity during a stair-stepping task, making it hard to compare our result with previous investigations. Alteration in motor control and onset time of core muscles was reported in patients with low back pain [32, 33]. Because, in this study, participants had no low back pain and knee was the site of pathology, difference in the onset of core muscles is a considerable finding.

Delayactivationof core muscles in individuals with PFPSmight be an adaptive or compensatory strategy due to change in knee motor control or may be a proximal

factor for the development of PFPS. As a result of the cross-sectional design of this study the mechanism of delayed core muscle activity cannot be established.

*Sequence of Muscle Activation in Control Group during Stair Negotiation*

In the healthy group sequence of muscle activation were IO, ES, VMO, VL, GMAX and GMED respectively during both phases of stair stepping. Significant difference was found between onset time of IO and other muscles during both phase of stair stepping. However, there was no significant difference between ES and IO onset times. This means thatco-contraction of ES and IO might providecore stability. This finding is consistent with the results of previously mentioned studies indicating contraction of TrA and IO prior to perturbation providing postural stability [10, 35]. Several studies revealed that in healthy subjects IO and TrA contribute tospinal stability by either increasing intra-abdominalpressure (IAP) or by increasing tension in the thoracolumbar fascia (TLF) thus increasing spinal stiffness for inter-segmental control [34].

It has been suggested that the IO pre-activation plays an important role in providing core stability. Hodges et al. reported TrA and IO activation prior to increase in IAP [36]. Increase in IAP lead to increase in tension in the TLF and has been suggested to contribute to increased stability of the spine [32].

According to Belen'Kii, the central nervous system (CNS) can provide postural adjustments in advance of predictable perturbations to the body [37]. It could be suggested that nervous system controls spinal stability anticipating themoment of foot contact to the step through activating abdominal and paravertebral muscles.

On the other hand, ES muscle onset time, had the second rank during stair stepping task. Contraction of this muscle prior to movement of the lower extremity contributes to the stability of proximal part of kinetic chain, in addition their activation prior to internal or external perturbations provide trunk stability [10, 32].

Early "Feed-forward" activation of ES is considered to contribute to either control of center of mass displacement or control of acceleration during stepping down [34].

Feed forward trunk muscle activity has been proposed to control the orientation of the trunk in accordance with control center of mass [37].

In this study, there was no significant difference between onset times of Vasti during stair stepping. This result might indicatesynchronized VMO and VL activity. Our result is consistent with previous studies which have demonstrated concurrentactivity of Vasti muscles during various tasks in healthy group [5, 38, 39]. Moreover Cowan et al. reported that pain free subjects show simultaneous activity of Vasti during stair stepping [38].

VMO was the third muscle which activated during stair descent. The EMG onset of VMO occurred significantly earlier than VL. In the normal population it is proposed that recruitment of VMO should occur prior to the VL to ensure optimal patellar tracking [21].

Grabiner stated that the medial components of thequadriceps have a smaller cross-sectionalarea than their lateral counterparts andit may be necessary for VMO tobe recruited earlier than the VL in order to overcome the larger lateralforces [40]. Our finding about sequence of activation of the medial and lateral components of quadriceps concurs with result of previous researches [5, 7, 14, 15].

Our results showed that onset of activity of the medial and lateral components of the quadriceps group occurred significantly prior to gluteal muscles in both phases of stair stepping task. This result is similar to those reported by Brindle et al. and Boling et al. [15, 16].

Astables 2 and 3 show, in healthy group, GMED and GMAX EMG onsetswere almost simultaneous. Co-contraction of these muscles may provide hip stability during stair stepping.

*Sequence of Muscle Activation in PFPS Group during Stair Negotiation*

In patient group sequence of muscle activation were IO, ES, VL, VMO, GMAX and GMED respectively during ascending phase of stair stepping. However in this group sequence of muscle activation during descent phase were IO, ES, VMO, VL, GMAX and GMED respectively.

Onset of IO EMG occurred significantly before VMO, GMED and GMAX muscles during both phase of stair stepping. The earlier onset of IO can be due to role of this muscle in providing core stability as stated previously. No significant difference in onset time was found between IO and ES muscles. It could be suggested that both muscles activated at the same time in order to establish stability. Previous researches have shown that trunk muscle co-contraction was associated with an increase in trunk stiffness [41, 42].

The EMG onset of ES occurred significantly prior to gluteal muscles during ascending phase. In descending phase onset time of ES was not only before gluteal muscles but also before VMO muscle. In PFPS group simultaneous activation of ES and VMO can be attributed to change in motor control or adaptive strategies.

In ascent phase of stair stepping onset time of VL was significantly earlier than VMO, GMAX and GMED. Result of this experiment indicated anticipatory activity of Vasti before foot contact to the step in PFPS group, but VMO onset of activity occurred after that of VL. This may reflect change in preplanned strategy used by the CNS to control the patella. This finding is consistent with those of several previous studies [15, 21, 43].

In our study no difference was found between EMG onset of VL and VMO during descent phase in subject with PFPS. This results contrast with results of Cowan et al. and Boling et al. [5, 15]. The reasons for thisdiscrepancy may be due to different speed of stair stepping task. In two previous studies subjects ascend and descend the stairs at a rate of 96 steps per minute, while in present study participants performed stair stepping task at self-selected speed.

On the other hand, in both stepping up and down, GMAX onset time was significantly earlier than GMED. In addition, Souza et al.demonstrated altered GMAX motor control in patients with PFPS and reported an

increased GMAX EMG when compared to pain free controls during stepping down [44]. These findings suggest a tendency in subjects with PFPS to use hip strategy more than healthy group.

*Pain and Change in Motor Strategy*

People with PFPS were found to have different motor strategy in stepping up relative to asymptomatic individuals. Change in motor programming as a result of pain may lead to change in motor strategy. This finding of an alteration in motor strategy concurs with previous researches by Matre et al. and Derbyshire et al. [45, 46].

Afferent inputs related to mechanoreceptors, which are present in skin, muscle and jointprovide necessary information related to motor control and stability. Painful stimulus could disrupt the function of sensory receptors and thereby affecting motor strategy [47]. Findings of Gill and Callaghan consistent with hypothesis of this study [48].

Cowan et al. reported an altered motor control of both anterior and posterior portions of GM in individual with PFPS [7]. Findings of Cowan et al. agree with the result from the present study.

*Biomechanical Outcomes of Altered Motor Strategy*

Decreased core stability result from altered activity pattern of the muscles may lead to excessive motion of trunk in various planes and may affect pelvic posture and lower limb mechanics. The trunk and hip stabilizers may pre-activate to compensate trunk motion and control lower limb postures. Reduced pre-activation of the trunk and hip stabilizers may lead to excessive displacement of trunk in frontal plane and increased load to the knee. Decreased core stability and muscular synergism of the trunk and hip stabilizers may increase the injury secondary to lack of control of the center of mass [49].

Result of present study show change in activity pattern of core muscle in patient group, for example individuals in PFPS group demonstrated later onset of GMAX and GMED. Impairment of the neuromotor control of the GMED and GMAX can result in contralateral dropping of the pelvis, adduction and internal rotation of the hip, greater valgus force vector at the knee, altered tracking of patellofemoral joint, thereby contributing to patellofemoral joint pain [8, 14, 50]. Therefore latency in function of these muscles in weight acceptance of stance phase during stair stepping task need to be considered. Studies show that abductor muscles by a concentric contraction raised the pelvis on the contralateral side during stair climbing [51].

In our study, onset latency of GMAX and GMED were transferred from before foot contact with ground to after foot contact with ground, thus can impair posture and motor control.

It could be suggested thatactivity of muscles before foot contact with ground that act as an external perturbation necessary to provide stability of trunk and lower limb in weight acceptance phase. Otherwise excessive displacement of trunk similar to an inverted pendulum may lead to exertion of abnormal forces to the knee and in prolonged time lead to PFPS. A number of studies have reported excessive displacement of trunk in patients with PFPS during stair climbing. Dierks et al.reported that excessive displacement of the trunk in to the affective limb may have been an adaptive strategy used to compensate neuromotor control of muscles related to stabilizing the pelvis such as hip abductors [52]. In this study, kinematic of movement were not evaluated, therefore further study is needed to identify possible changes in trunk movement.

*Altered Motor Strategy in Patients with PFPS*

Few studieshave investigated the comparison of motor strategies between healthy and patients with PFPS. Nadeau et al. demonstrated that patients with anterior knee pain presenting increase in hip extensor moment during gait. Increase in hip extensor moment can be considered as a strategy used by PFPS subjects to compensate decrease in knee extensor moment. These authors stated that PFPS subjects used hip strategy during gait [53].

Souza reported increase GMAX EMG in PFPS subjects when compared to pain-free control during descent phase of stair stepping task [44]. This finding is in agreement with previously results indicating tendency of motor control system of patient individuals to use of hip strategy.

In our study, finding of a delay in GMED relative to GMAX in subjects with PFPS provide support for other studies that suggested use of hip strategy in individual with anterior knee pain [53].

According to present study, it can be mentioned that besides regain of strength of knee extensor moment and appropriate timing of VMO muscles, clinician should incorporate exercises to correct inappropriate timing of GMAX and GMED muscles in to rehabilitation program.

This study demonstrated a link between PFPS and altered core muscle activity which signifies attention to biomechanics and motor control of knee and core muscles as an important target in rehabilitation of patients with PFPS.

## Conclusion

The result of our investigation indicate that activation patterns of core and vasti muscles are different between pain free control and PFPS group during stair stepping task. Exercises to correct inappropriate timing of core muscles may have a role in management of PFPS.

**Conflict of Interest:** None declared.

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