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ORIGINAL ARTICLE

Temporal Activation of Core Muscles and Vasti in Isolated Patellofemoral Osteoarthritis during Stair-Stepping: A Case Control Study

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ABSTRACT

Background. Patellofemoral osteoarthritis (PF OA) is a leading cause of significant pain and disability of knee joint. Stair climbing dysfunction is commonly reported in this cohort. **Objectives.** To compare the temporal muscle activation between females with PF OA and healthy controls during stair ascent and to decide whether there is a link between altered core activity and Patellofemoral osteoarthritis. **Methods.** An observational comparative study was conducted on 31 females with PF OA and 11 healthy ones. The electromyographic onset times of vasti, gluteus medius (GM), multifidus and transversus abdominus (TrA) muscles were measured during the initiation of stair ascending task. **Results.** A non-significant difference was detected between females with PF OA and controls regarding the onset times of all tested muscles except for the multifidus muscle which showed a significantly delayed activation in the PF OA group. **Conclusion.** Females with patellofemoral osteoarthritis showed a significantly delayed multifidus activation during ascending stairs which indicated the neuromotor dysfunction of core muscles compared to healthy controls. Core stability may be of clinical significance in the management of patients with patellofemoral osteoarthritis. Prospective longitudinal studies are recommended for prioritizing the dysfunction.

KEYWORDS: ***Patellofemoral Osteoarthritis, Stair Ascent, Electromyography, Temporal Activation***

INTRODUCTION

The patellofemoral (PF) joint is commonly involved in the process of knee osteoarthritis. Patellofemoral osteoarthritis (PF OA) is found to be highly prevalent, more than tibiofemoral osteoarthritis (TF OA), especially in the population younger than 50 years old. About 26% of those population are presented with isolated PF OA and viewed similar severity across males and females (1). Most frequently, isolated PF OA is accompanied by remarkable pain and disability, may be more than that reported in TF OA (2, 3). Also, PF OA could be part of a continuum with

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patellofemoral pain (PFP) (4, 5). One half of patients suffering from knee pain have PF involvement (6). Hence, its prevalence is more substantial than ever thought (7). With this in mind, a recent systematic review and meta-analysis report reported higher incidence and prevalence rates of PF OA in individuals with PF pain especially females, or persons who were older or with higher body mass index (BMI) (8, 9).

By modifying joint loads, functional and structural factors can elevate PF joint stress, leading to pain and progressive joint damage (5). The functional and structural factors prompting to Patellofemoral joint stress incorporate mixes of distal (foot and ankle), local (patellofemoral and tibiofemoral), and proximal (core or lumbo-pelvic-hip complex) variables (5).

Since core is the center of most functional kinetic chains, the control of motion, force, and balance in this area will optimize the activity of all kinetic chains (10). The inadequacy of core stability may finish in instability and damage throughout the entire kinetic chain (11).

Stair- ambulation is one of the most painful functions for patients with PF OA (2), as they showed altered kinematics of pelvis and lower limbs during both ascending and descending stairs as well (12). Neuromuscular activation patterns are objective measure that can't be self-reported by subjects with PF dysfunction (13). Put together, identifying the core and vasti temporal activation pattern in stair negotiation should be given high priority, as little is known about those strategies in patients with PF OA.

Most of the previous work evaluated the neuromuscular control of core muscles and vasti in young population with PFP (e.g. Brindle et al. (14); Cowan et al. (15); Aminaka et al. (16); Bolgla et al. (17); Briani et al. (18); Motealleh et al. (19); Dorosti et al. (20). However, there is a lack of information about the dysfunctions of trunk and thigh muscles in older subjects with isolated PF OA. Previous literature suggested that people with PF OA showed some alternation in the activation of vasti muscles (21), reduced volume of the three parts of quadriceps; vastus medialis, vastus lateralis and rectus femoris (22), lower peak force (23), reduced volume (24), and lower strength (25) of the gluteus minimus and medius muscles compared to controls**.** According to the available literature, there is an evident gap of knowledge for the temporal activation of trunk muscles along with vasti in this cohort. Considering these gaps, this study aimed to compare the temporal muscle activation in females with PF OA contrasted with age-matched healthy controls during stair ascent and to decide whether there is a link between altered core activity and Patellofemoral osteoarthritis. We hypothesized that there will not be a significant difference between females with PF OA and their matched healthy group regarding the onset times of vastus medialis obliqus (VMO), vastus lateralis (VL), gluteus medius (GM), multifidus, and transversus abdominus (TrA), during the initiation of stair ascent task.

METHODS

Study Design. An observational case control study was conducted from March, 2019 to October, 2019 with the collaboration of the Faculty of Engineering, Cairo University. The study was approved by the Institutional Review Board of the Faculty of Physical Therapy, Cairo University, Egypt (P.T.Rec/012/001659), registered on the website of clinicaltrial.gov (NCT04589702) and followed the Declaration of Helsinki. Before enrollment, all participants were fully informed about the aim and procedures of the study and signed an informed consent form.

Participants. The study was conducted on female subjects and included two groups; 31 females with PF OA and 11 age-matched healthy controls. Patients were recruited from the Outpatient Clinic of Kasr Al-Ainy Hospital and the Faculty of Physical Therapy, Cairo University as well. However, control subjects were recruited via advertising in the local community. To be included in the study, participants in both groups should be aged between 35 and 45 years, with BMI between 18.5 and 29.9, ambulant alone and can climb stairs without assistance or holding rails (19). In the PF OA group, patients should have an anterior- or retro-patellar pain aggravated by at least two loading functions (eg; squatting, climbing stairs, and/or rising from sitting to standing) (26). Pain should be recurrently presented during these activities on most days during the month immediately prior to enrollment, with an intensity ≥ 4 on the 11 point numerical rating scale (NRS) of pain (15, 19, 27, 28), and a radiological evidence of PF OA with a grade less than two from postero-anterior views (22) according to the adjusted Kellgren - Lawrence (KL) osteoarthritis classification system (29). Patients with any associated pain from TF joint or other knee structures were all excluded from the study.

For healthy group, subjects were included if they had no history of knee dysfunction or pain with any of the aggravating activities which were mentioned above. Subjects from both groups were excluded if they had any of the following; recent or previous pain in the lumbar spine, pelvis, hip, or feet persisted for more than three months and/or necessitated a medical intervention (21); history of fracture or surgeries at lower extremity, pelvis or spine; subluxation/ dislocation of hip or patella; ligamentous or meniscal injury of the knee, postural abnormalities (e.g. scoliosis, genu valgum/varum, pes cavus), leg length discrepancy, neurological disorder, or systemic diseases (e.g. rheumatoid arthritis and diabetes). Athletic people who regularly practice exercises; exceeding two hours per day or every other day, were also excluded (15, 19).

Assessment Procedures and Outcome Measures. Electromyography (EMG)

The neuromotor control of the lower limb and core muscles was evaluated during the initiation of stair ascent using the quantitative EMG. This work was conducted at the Biomedical Engineering Lab, Faculty of Engineering, Cairo University. The onset time of muscle activation was the primary outcome measure in this study. The EMG activities were detected from the most painful limb in the PF OA group, and from the dominant limb in the healthy controls (19, 21, 30). Activity was recorded from the VMO, VL, GM, multifidus and TrA muscles using the eight channels high-resolution wireless bio amplifier (WBA) system (Biomation, Almonte, Canada). Electromyographic data were sampled at 1000 Hz and bandpass filtered at 50-200 Hz. The disposable bipolar Ag-AgCl surface electrodes (Better signal solution medical supply Co., limited, Zhongshan, China) were used and placed according to standardized protocols. On each muscle, three electrodes were used; two electrodes were placed parallel to the muscle fibers and ~ 30 mm apart, and one ground electrode was applied over the closest bony prominence (31). To reduce impedance, skin was cleaned using an alcohol before applying the electrodes. Excess hair was also removed, if needed, to eliminate shifting of the electrodes.

For the VMO, electrodes were located at a point that is 25% of the distance between the patellar superior aspect and the anterior superior iliac spine and around five centimeters medial to the patella. The electrodes for the VL were positioned lateral to the rectus femoris; at the middle of the line between the greater trochanter and lateral femoral epicondyle (32). *For the GM*, the anterior portion of the muscle was investigated (33). The electrodes were located over the muscle belly; one-third of the distance between the greater trochanter and iliac crest (31). The electrodes *for the multifidus muscle* were located at the point that is two centimeters lateral to the spinous process of L5 vertebra (31, 34, 35). *For the TrA*, electrodes were positioned two centimeters inferior and medial to the anterior superior iliac spine. This placement for the TrA also represents the activity of the internal obliques (IOs) muscle, as the two muscles are functionally and anatomically connected and their activity cannot be separated with the surface EMG method (36).

The stair ascent task consisted of ascending two steps; each step was 20 centimeters heigh, 40 centimeters wide, and with no handrails. The first and second step were 30 and 40 centimeters, respectively in depth (19). Before recording, each participant stood barefoot confronting the stairs and 20 centimeters away from the edge of the first step, with his arms at the sides of the body. Subjects instantly climbed the steps in response to a verbal command at their normal pace (18, 20), as controlling the speed of their movement would alter the EMG activity (37). Patients with PF OA started the task with the most painful limb, while healthy subjects started with their dominant limb (19, 21, 30). Before data acquisition, one trial was performed to become familiar with the task. Then the actual test was performed three times for each participant with 30 seconds of rest in between to prevent fatigue. The mean of the three trials was calculated and analyzed for each muscle (15, 19).

Electomyographic Data Analysis. A personal computer was used to store the EMG data which was analyzed to determine the onset of muscle activity using a custom program in Matlab (Math Works, Natick, Massachusetts, USA). The data were full wave rectified and high-pass filtered at 75 KHz (4^{th} order). The baseline activity of the tested muscles was determined in standing position three hundred milliseconds before the commencement of every individual trial. Using Matlab codes, each muscle was considered on when its activity exceeded the threshold of three standard deviations (SDs) above its baseline level and stayed there for a minimum of 25 milliseconds (19, 38).

Statistical Analysis. Management and analysis of the data were conducted using the statistical package for social studies (SPSS) version 22 for windows (IBM SPSS, Chicago, IL, USA). Normality distribution was tested using the Shapiro-Wilk test. The variances homogeneity between groups was examined using Levene's test. Descriptive data are expressed as mean ± standard deviation (mean ± SD). An independent t-test was conducted for comparison of subject's characteristics; age and BMI. A univariate test of one-way multivariate analysis of variance (one-way MANOVA) was performed to compare the EMG onset of each muscle. Post-hoc analysis using the Bonferroni method was carried out for subsequent multiple comparison. The level of significance for all statistical tests was set at $P < 0.05$.

RESULTS

Participants Demographic and Clinical Characteristics. The results revealed a non-significant difference in the general characteristics between the PF OA and control groups ($P<0.05$). Subject characteristics were presented in Table 1.

The Results of EMG Onsets. The mean ± SD values of the EMG onset of the multifidus, TrA, GM, VMO and VL muscles were all presented in table (2). One way between subject MANOVA for outcome measures indicate a statistically no significant effects for group ($F= 1.27$, $p= 0.298$, Partial $\eta2= 0.15$). The univariate tests of one way MANOVA revealed that there were no significant differences ($P>0.05$) in the mean values of EMG onset of TrA, GM, VMO, and VL. While there was a significant difference ($P>0.05$) in the EMG onset of Multifidus between both groups. As well as, the multiple pairwise comparison tests (Post hoc tests) revealed a significant increase of the multifidus onset time in favor to PF OA group when compared to healthy group ($P=0.036$*).

Table 1. Participants Demographic and Clinical Characteristics.

	Healthy (n=11)	PF OA (n=31)	P-Value
Age (years)	41 ± 6.292	44.7 ± 6.24	0.099
BMI (kg/m^2)	29.68 ± 3.6	26.58 ± 5.01	0.075
Illness duration (years)	-	3.83 ± 1.82	
Pain severity (11-NRS)	-	6.9 ± 1.74	

Data were represented as mean ± standard deviation.
PF OA: patellofemoral osteoarthritis; BMI: Body mass index; kg: kilogram. cm: centimeters. 11-NRS:11-point numerical pain scale; P-value: probability value, Level of significance: *Significant value (*P<0.05).

Table 2. The EMG Onsets of all Tested Muscles during Stair Ascent for Both Groups.

Muscle	Healthy (n=11)	PF OA (n=31)	MD	F-value	P-Value
VMO	1.576 ± 0.49	1.74 ± 0.699	-0.166	0.522	0.474
VL	1.28 ± 0.52	1.55 ± 0.909	-0.269	0.851	0.362
GM	1.289 ± 0.45	1.68 ± 0.733	-0.391	2.736	0.106
Multifidus	1.4 ± 0.586	2 ± 0.84	-0.601	4.728	0.036*
TrA	1.348 ± 0.339	1.498 ± 0.898	-0.15	0.287	0.595

Data were represented as mean ± standard deviation of the time onset that measured in milliseconds.
PF OA: patellofemoral osteoarthritis; MD: Mean difference; VMO: Vastus medialis obliques, VL: vastus lateralis, GM: Gluteus medius, TrA: transversus abdominus; P-value: probability value, *Significant level is set at alpha level < 0.05.

DISCUSSION

The current study was planned to compare the temporal activation of core and knee muscles between females with PF OA and their age-matched healthy females during the initiation of stair ascent function. This study demonstrated a non-significant difference between both groups regarding the EMG onset of TrA, GM, VMO, and VL, yet the multifidus was significantly delayed in females with PF OA. Thus, we partially accepted the tested hypothesis. Up to the authors knowledge, there is a lack of studies investigating the EMG onset in people with isolated PF OA during stair ascent task. For that reason, comparing results with previous work is difficult.

Previous studies (e.g. Bolgla et al. (17); Rathleff et al. (39) have suggested that the onset of muscle activation may not change in individuals with PFP. Cowan et al. (38) reported that 30–40% of persons with PFP presented with no difference in the onset time of their vasti. Findings of the VMO in this work were consistent with our hypothesis and agreed with the findings of previous studies investigating the PF pain (e.g. Brindle et al. (14); Aminaka et al. (16); Dorosti et al. (20); McClinton et al. (40); Cavazzuti et al. (41) but contradictory to Cowan et al. (15),

Motealleh et al. (19) and de Almeida Britto et al. (42) who reported a significant delayed activation of VMO in individuals with PFP in comparison to healthy subjects. This contradiction might be due to differences in sample size, age and sex. The study of Cowan et al. (15) was conducted on 10 patients with PFP and 27 healthy controls from both sexes with mean ages of 26± 10.1 and 25± 5.5 years, respectively. The other study of Motealleh et al. (19) included only 30 male subjects;15 with PFP and 15 matched healthy controls, who aged 40 years or less. Also, de Almeida Britto et al. (42) conducted their study on 12 males with PFP and 20 healthy ones, who aged between 23 and 39 years. However, in the current study, we recruited only female subjects because of the reported association between gender and EMG activity (43, 44). Another reason behind the disagreement between our results and others might be methodological differences including the onset determination methods (15), electrodes placements (15, 19), and the speed of stair ascent (15, 19, 20). All these methodological differences can affect EMG findings and are frequently reported as a possible source of inconsistency between studies (45).

The results of VL onset in the current study, supported the tested hypothesis and were consistent with the previous results of Brindle et al. (14), while contradictory to that of Wyndow et al. (21) who reported an earlier onset of VL during stepping up stairs in patients with PF OA compared to controls. This contradiction might be attributed to the different sampling demographic and clinical characteristics; as Wyndow et al. (21) included patients with PF OA from both sexes with a mean age of 59±10 years. Besides, they excluded patients if their radiographic Kellgren-Lawrence grading was ≥ 3, while we excluded patients whose grading was ≥ 2. Thus, patients with concomitant mild tibiofemoral arthritis were allowed to participate in their study unlike us.

Briani et al. (18) reported a significant correlation between the onset of muscle activity and the level of physical activity in females with PFP. Thereby, patient who practices higher levels of physical activity could have more intense pain and may be presented with delayed onset of vasti muscles, while a person whose physical activity is low may not (18, 36). Most of the studies (e.g. Brindle et al. (14); McClinton et al. (40); Cavazzuti et al. (41) that showed non-significant differences in the EMG onset between PF disorder and healthy groups, provided limited data about participants' activity level and did not categorize them according to their physical activity level. Accordingly, participants who had different levels of physical activity and pain could be allocated in the same group, which resulted in heterogeneous data and thus non-significant differences between groups in those studies. In the present study, the athletic persons were excluded, however, participants were not categorized according to their physical activity level. This might provide an explanation for the non-significant difference between PF OA and normal controls concerning the onset of vasti muscles in our work.

The GM onset displayed a non-significant difference between females with PF OA and controls in the present study. Our results supported the tested hypothesis and agreed with Wyndow et al. (21) and Boling et al. (33) and disagreed with Cowan et al. (15), Brindle et al. (14) and de Almeida Britto et al. (42) who reported a significant delay of GM onset between PFP and healthy groups during stair ascent. This disagreement could be related to many reasons. Firstly, there are differences in the selection criteria concerning the age and sex, mentioned before. Secondly, Cowan et al. (15) examined the posterior and anterior parts of the GM and inserted the EMG electrodes into the posterior GM under the ultrasound imaging guidance, however, in our study, we investigated only the anterior part of the GM using surface electrodes which possibly explains the contradiction of the results. Another reason could be the difference in onset determination method; in which Brindle et al. (14) determined the muscle onset by setting the amplitude threshold at 5 SDs of the baseline noise instead of 3 SDs as in our work.

The function of the core muscles is found to influence the body function from the lower back proximally to the ankle and foot distally, possibly, with the greatest impact at the knee joint (46). For that reason, the onset times of multifidus and TrA were evaluated in this work. Prior to extremities movements, multifidus and TrA muscles, as local trunk stabilizers (47), are activated through the feedforward mechanism in the anticipatory postural reactions to provide the required spinal stabilization (48, 49). Normally, the co-contraction between multifidus and TrA muscles controls the pelvis movement and provides the

antero-posterior pelvic stability that allows more precise control distally. Consequently, any disturbed control of the trunk and pelvis can negatively impact movements of the whole lower extremity including the patellofemoral composite. Biomechanically, as the pelvis tilt increases anteriorly, the femur becomes internally rotated and adducted and the tibia moves in a relative external rotation. Consequently, a larger quadriceps angle is created which significantly increases the lateral retropatellar pressure; causing a damage of its articular cartilage with repetitive loading activities (11, 50, 51). Contrary to our hypothesis, the multifidus muscle in this work showed a significantly delayed onset in females with PF OA in comparison to their age-matched control group during ascending stairs. However, the onset of TrA showed a non-significant difference between both groups. Those two results, highlighted the lack of co-contraction between multifidus and TrA muscles in females with PF OA which should be clinically considered. Dorosti et al. (20) stated a non-significant difference of the onset activation of both TrA and multifidus between patients with PFP and controls during stair ascent. Those results agreed with ours concerning the TrA but contradictory to that of multifidus. This may be due to the difference of inclusion criteria as their study was conducted on 17 subjects with PFP and 15 healthy ones from both sexes with mean ages of 26.29± 5.6 and 27.6± 5.46 years, respectively.

Although the knee was the main site of pathology in the study group in this work, there was no significant difference at onset times of knee musculature between this group and healthy controls, noteworthy, a delayed activation was found proximally at the trunk. Delayed activation of multifidus muscles in patients with PF OA might be an adaption or compensation mechanism to lack of distal control or could be a proximal factor for the development of PF OA (11). Due to the cross-sectional design of this study, the exact mechanism of delayed activity of the multifidus muscle whether it's a consequence or a cause of PF OA cannot be established. Thus, prospective longitudinal studies are required.

This study had some limitations that could provide a guide for future studies. Firstly, difficulty in recruiting female patients aged between 35 and 45 years and represented with only isolated PF OA, together with the difficulty of recruiting age-matched healthy females who had no neuromuscular or musculoskeletal pain and /or dysfunction three months prior to the study time were real considerable challenges in this work. These challenges may clarify why this study was conducted on a limited sample (n=31 for PF OA and n=11 for the control), however, this sample size is consistent with that of similar previous work (e.g. Wyndow et al. (21); Briani et al. (18); Santos et al. (52)). It might be more valuable to apply further studies on larger sample size with different clinical characteristics. Secondly, our available EMG system did not allow the synchronized measurement of muscle activity and kinematics of the pelvis and lower limbs; hip, knee and ankle, which could be considered in future studies for precise interpretation of the observed changes in muscle activation.

Future investigations of EMG amplitude and duration of VMO, VL, GM, TrA, multifidus, gluteus maximus and two joint muscles (e.g. hamstrings and triceps surae), not to mention their sequence of activation are recommended for deeper explanation of the neuromuscular control in PF OA in variable functional context.

CONCLUSION

This study revealed a significant delay of the EMG activity of multifidus in females with patellofemoral osteoarthritis during stair ascent compared to controls. This result could highlight the clinical importance of core stability in the management of people with PF OA. However, caution should be taken in interpreting those results, as our study design did not allow prioritization of the dysfunction in the PF OA. Thus, prospective longitudinal studies are needed.

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