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Onset of quadriceps activation and torque variation during stair ascent in individuals with patellofemoral pain

Início de ativação do quadríceps e variação do torque durante a subida de escada em indivíduos com dor patelofemoral

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Abstract

Introduction: Studies have used surface electromyography (EMG) to understand motor recruitment in individuals with patellofemoral pain syndrome (PFPS); however, there is no consensus in the literature. **Objective**: To understand if, in addition to neuromuscular disorders, there are changes in rotational patterns in individuals with PFPS. **Methods:** Twenty-two control pain-free subjects and eleven subjects with PFPS were assessed during stair ascent with respect to the onset of muscle activation and percentage of torque variation (PTV). **Result:** The PFPS group showed previous activation of vastus lateralis (VL) (21.1 ± 58.1ms), while simultaneous activation was observed in the control group (2.8 ± 30.7ms, p=0.01). The groups also showed differences in relation to the PTV (p=0.02): the control group showed greater variation in torque (26.7 ± 35.3%) compared to the PFPS group (17.5 ± 35.9%). **Conclusion:** People with PFPS have prior activation of VL and lower tendency towards body rotation, which may suggest patellar lateralization.

Key words: Electromyography; Patellofemoral pain syndrome; Torque.

Resumo

Introdução: Estudos têm utilizado a eletromiografia de superfície (EMG) para entender o recrutamento motor em indivíduos com síndrome dolorosa patelofemoral (SDFP); porém, não há um consenso na literatura. **Objetivo**: Entender se, além de desordens neuromusculares, há mudanças nos padrões de rotação nos indivíduos com SDFP. **Métodos:** Vinte e dois indivíduos controles sem dor e onze com SDFP foram avaliados com relação ao início de ativação muscular e à porcentagem de variação do torque (PVT). **Resultados:** O grupo SDFP apresentou ativação prévia do vasto lateral (VL) (21,1 ± 58,1ms), e o grupo controle, ativação simultânea (2,8 ± 30,7ms, p=0,01). Os grupos também mostraram diferenças em relação à PVT (p=0,02): o grupo controle mostrou uma maior variação do torque (26,7 ± 35,3%) em comparação ao SDFP (17,5 ± 35,9%). **Conclusão:** Pessoas com SDFP possuem ativação prévia do VL e menor tendência de rotação do corpo, o que pode sugerir lateralização patelar.

Descritores: Eletromiografia; Síndrome da dor patelofemoral; Torque.

Introduction

Patellofemoral pain syndrome (PFPS) is described as a diffuse, anterior, or retro-patellar pain which, in the absence of other diseases, is exacerbated by physical or functional activities that overload the patellofemoral joint, such as sitting for a long time and ascending stairs[1]. Both extrinsic and intrinsic factors have been suggested as causes of PFPS. Extrinsic factors are related to excessive physical activity or inactivity. Intrinsic factors, including the imbalance between the vastus lateralis (VL) and vastus medialis (VM) of the quadriceps, increased Q angle, patellar hyper-mobility, patellar misalignment, and excessive rotation of the tibia or femur[2, 3], have been commonly studied and used to characterize PFPS. Due to the large number of people affected by PFPS and its multifactorial etiology, PFPS is still the focus of many studies aiming to discover its cause. Discovering the cause of PFPS would facilitate a clinical approach, reduce pain, improve quality of life, and enable prevention.

Despite the growing number of studies focusing on PFPS, results have not been conclusive, possibly due to differences in experimental protocol, the analyzed activity, and signal processing[4]. Voight and Wieder[5] showed that there is early activation of the VL in relation to the VM in individuals with pain as a reflex response to the percussion of the patellar tendon. Since then, many studies have focused on the early activation of a portion of the quadriceps muscles during different activities requiring knee extension. As discussed in a review article[4], several studies have examined the imbalance of muscle action in the patellar reflex during walking, climbing or descending steps, and squatting. Some authors have determined the onset using automatic detection, with activation defined as the point when the signal increases more than one, three, or five standard deviations above the baseline mean or when the peak signal is reached. Others have defined the onset as the point of attaining 5% of maximal isometric contraction. Some studies have concluded that there is early activation of the VL in subjects with pain, a factor responsible for both the lateralization of the patella and the pain. However, other studies have shown that surface electromyography (EMG) does not identify individuals with this syndrome[4].

To understand PFPS etiology, other studies being developed have attempted to examine anatomical differences and rotational parameters by assessing the patellofemoral joint using functional magnetic resonance imaging or kinetics and kinematics[6-10]. The torque produced by the whole body around the vertical axis is generated from the sum of the horizontal components of the ground reaction force[11], and thus, it can be assumed that the variation of the torque around the vertical axis, produced by the foot on the force plate, reflects a global trend of the rotational movement. The hypothesis is that if there is an anomalous rotation in the lower limbs (exacerbated rotation or a rotation deficit), this rotation can cause gait changes and, therefore, changes in the torque at the support point. Pain can produce changes in the dynamics of certain actions used to avoid or minimize it. It would be interesting to evaluate the parameters related to EMG, as they would provide information about this activation pattern, in addition to its dynamic aspects. Knowledge of its etiology is needed to avoid inadequate treatment.

EMG and the force plate provide information about motor, anatomical, and physiological characteristics after signal processing. These tools were selected to evaluate individuals with and without PFPS during stair ascent because individuals with PFPS commonly report stair climbing as a functional activity that generates significant pain. The aim of this study is to verify the contribution of muscular and mechanical parameters to PFPS: the activation time of the VM in relation to the VL, and the torque produced around the vertical axis of the force plate.

Material and methods

Sample

Thirty-three female individuals were evaluated and separated into two groups: i) control group: 22 pain-free, right-handed individuals, with a mean age of 23 ± 2 years, mean weight of 55.0 ± 6.0 kg, and mean height of 161.2 ± 4.8 cm; ii) PFPS group: 11 right-handed individuals, with a mean age of 24 ± 3 years, mean weight of 57.3 ± 5.3 kg, and mean height of 161.9 ± 5.9 cm, all diagnosed with PFPS and pain in the right knee. The study was approved by the local Human Research Ethics Committee (proc. 166/2007), and all subjects provided written informed consent. The inclusion and exclusion criteria are specified in Table 1[12-14]. In addition to the medical diagnosis, an evaluation protocol was applied by the same physiotherapist for all volunteers to ensure the normal condition of the control group and the pathological condition of the PFPS group. Subjects in the PFPS group were included if they had anterior or retropatellar knee pain while engaged in at least two of the following activities: prolonged sitting, climbing stairs, squatting, running, kneeling, hopping, or jumping. In addition, they were to have had pain on patellar palpation, symptoms lasting at least one month, an average pain level of 3-cm on a 10-cm visual analog scale, and an insidious onset of symptoms unrelated to a traumatic incident[1].

Instrumentation

EMG signals were obtained in a conditioner module (Lynx®, Sao Paulo, SP, BRA; model EMG 1000-8-4I) that presented a band-pass digital Butterworth filter with a cut-off frequency of 20 and 500 Hz and an amplifier with a final gain of 1000 and a sampling rate of 4000 Hz. Two pairs of bipolar electrodes with an Ag/AgCl capture surface and a diameter of 10 mm (Kendall, Mansfield, MA, USA; model Medi-Trace) were positioned at the VM and VL (the electrodes were placed 2 cm under the motor point with 20 mm between them, and the motor point localization was obtained by electro-stimulation). The reference electrode was positioned at the ulnar styloid process. On the electrode cable, there was a pre-amplifier circuit with a gain of 20, CMRR (Common Mode Rejection Ratio) greater than 80 dB, and impedance of 1012 Ω. The data were collected using AqdAnalysis software (Lynx®, Sao Paulo, SP, BRA; model EMG 1000-8-4I).

For the torque evaluation, an AMTI force plate (Advanced Medical Technologies Inc., Watertown, MA, USA; model OR6-6-2000) with a 32-bit (DT3002) data acquisition analog/digital card and a sampling rate of 1000 Hz was used. The staircase consisted of three steps 20 cm in height, and the force plate was coupled to the second step.

Experimental protocol

Data collection was initiated after training the subjects to understand the movement and perform it in a natural manner, cleaning the skin and positioning the electrodes. The movement began with the subject positioned in front of the staircase on the first step, starting from the standing position. The movement occurred continuously, and legs were alternated in a self-controlled rhythm, starting with the right leg to first step on the force plate with it, until the standing position was restored at the third step (Figure 1). Data collection was repeated 12 times, and the speed was not monitored in order to more accurately reproduce the functional activity.

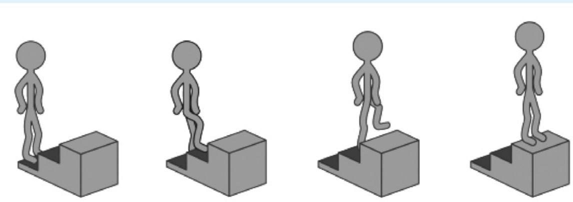

Figure 1: Illustrative schema of stair climbing: starting from the standing position on the first step, the movement occurred continuously with alternating legs, until the standing position was restored on the third step

Analysis

EMG signals were analyzed using an algorithm in Matlab® that consisted of the implementation of a linear envelope (full-wave rectification and application of a low-pass filter of 5 Hz). The beginning of activation was then manually marked for the VM and VL using visual inspection by the same researcher, and the onset time of the VM was subtracted from that of the VL to obtain the delay (Figure 2). Manual detection was used because automatic detection is the technique with the higher standard error of measurement (SEM)[15]. The data were first subjected to the Kolmogorov-Smirnov normality test. All statistical analyses were performed using SPSS version 12.0 (SPSS, Inc., Chicago, IL), and a p-value < 0.05 denoted significance.

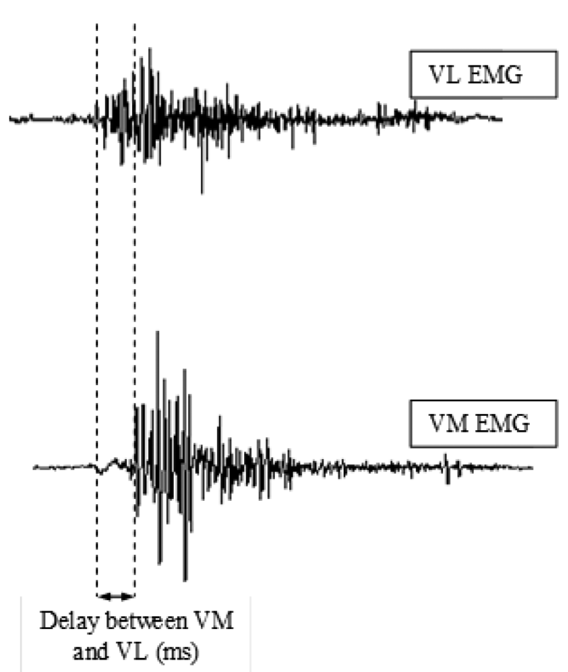

Figure 2: Illustrative schema of the delay calculation between the VM and VL. Time elapsed from the onset of the VL to the onset of the VM. This figure is only illustrative, as the VM EMG was intentionally delayed

For intra-individual analyses, the Student's t-test was applied to the 12 samples from each individual to verify if the samples were equal to 0, less than -10, or greater than 10 ms. Activation was simultaneous when the difference measured between the VM and VL was between -10 and 10 ms. Differences less than -10 ms corresponded to early activation of the VM and differences greater than 10 ms to delayed activation of the VM[16]. Next, the individuals in both groups who showed early, simultaneous, or delayed activation of the VM were quantified. To perform an inter-group comparison, the delay values of all samples of the control group were compared with those of the PFPS group using the Student's t-test and considering significance at a p-value < 0.05.

Data related to the torque were obtained from the force plate and were submitted to a fourth-order digital Butterworth filter and a 5-Hz frequency in Matlab®. Because the purpose was to analyze the trend toward rotation, the torque that was analyzed was the vertical component corresponding to variations in Fx and Fy. A negative variation indicated a trend to medial rotation of the body, and positive variation a tendency to lateral rotation. Because this study proposes to evaluate the global tendency of the body, subtracting the negative from the positive torque results in the final rotational tendency of the body. In this way, the difference between the maximum positive and negative values of the torque was calculated. This value was normalized by the peak torque and multiplied by 100 to compare individuals, providing the percentage torque variation (PTV): $PTV = \{[(\tau_{max} - \tau_{min})/ \tau_{max}]. 100\}$ (%), where τ corresponds to the torque (Figure 3). Data from the control group were compared with the PFPS using the Student's t-test and considering significance at a p-value < 0.05.

Results

The EMG data showed that in the PFPS group, 64% of patients had simultaneous activation of the VM and VL and 36% had early activation of the VL. In the control group, 59% of subjects showed simultaneous activation of the VM and VL, 27% exhibited early activation of

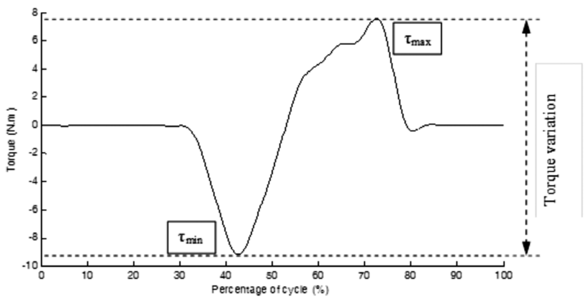

Figure 3: Typical curve of torque around the vertical axis, showing how torque variation (the smallest to largest values of torque) was determined for posterior calculus of the percentage torque variation (PTV). Percentage of cycle refers to the total movement, from the first to the third step of the stair

the VL, and 14% exhibited early activation of the VM, which was calculated using an intra-individual Student's t-test (table 1).

Based on the inter-group statistic, the PFPS group on average tended to exhibit early activation of the VL (21.1 ± 58.1 ms), and the control group tended to be synchronous (2.8 ± 30.7ms), p = 0.001. The same trend occurred for the PTV. In the control group, there was a major change in the PTV (26.7 ± 35.3%) compared with the PFPS group (17.5 ± 35.9%), p = 0.02. Table 2 shows these comparisons.

Discussion

The results showed that during stair ascent, in both groups, more individuals exhibited early or simultaneous activation of the VL relative to VM; thus, this parameter did not sufficiently distinguish the two groups. However, the difference in activation times was significant, which may suggest that although it is not possible to intra-individually distinguish the presence or absence of the syndrome, on average, individuals with pain tended to exhibit early activation of the VL. Some studies, in determining the onset of EMG, have failed to distinguish individuals with PFPS from clinically healthy individuals during different activities

Table 1: Inclusion and exclusion criteria[20-22]

Inclusion criteria of PFPS subjects	Medical diagnoses; Anterior or retropatellar knee pain while engaged in at least two of the following activities: prolonged sitting, climbing stairs, squatting, running, kneeling, hopping, or jumping; Pain on patellar palpation; Symptoms for at least 1 month and with insidious onset unrelated to a traumatic accident; Pain level in the last week of at least 3 cm on a 10-cm visual analog scale; Presence of at least 3 of the following clinical signals: positive Clarke's sign, positive McConnell test, positive Waldron test, positive Zohler's sign, Q-angle superior to 18°, positive Noble compression test, or patella in medial or lateral position; Female in the age range of 18-30 years; Ability to execute normal daily life activities; Written, informed consent.
Exclusion criteria of PFPS subjects	Other specific diseases of the knee, such as gonarthrosis, ligament injury, meniscus injury or bilateral knee pain, patellar tendon pathology, chondral damage, osteoarthritis, or spinal referred pain; Knee surgery; History of patellar dislocation or subluxation; Knee treatments, such as arthroscopy, steroid injection, oral steroid, opiate treatment, acupuncture, or physiotherapy during the last 6 months; Presence of neurological diseases and inflammatory process.
Inclusion criteria of healthy controls	No pain in the knees during the last year; No local or systemic health problems, including chronic pain; No previous surgery to the knees; No regular analgesic use; Age between 18 and 30 years; Written, informed consent.

and have concluded that muscle imbalance may not be a predisposing factor for pain[17, 18]. For stair climbing, studies have also demonstrated that the relationship between muscle imbalance

Table 2: Values for electromyography onset and percentage of torque variation (PTV) comparing the patellofemoral pain syndrome (PFPS) and control groups

	PFPS group	Control group	P-value
Onset mean (ms)	21.1 ± 58.1	2.8 ± 30.7	0.001*
PTV mean (%)	17.50 ± 35.90	27.70 ± 35.30	0.02*

* Refers to a significant difference by Student's t-test ($p<0.05$)

and PFPS is controversial: there are studies indicating that individuals with PFPS present an imbalance of the muscles as well as those that do not indicate this finding[4]. Although the results presented in the literature are not conclusive, the effect on pain of muscular parameters, such as muscle imbalance or weakness, should be considered because studies have found that after undergoing strength training, individuals exhibit clinical improvement of their pain[19]. In this study, the difference between the groups was statistically confirmed; in the PFPS group, early activation occurred in the VL, and in the control group, the activation was simultaneous, confirming that a delay in the VM in the individuals with PFPS can lead the patella into a lateral position, causing pain. More studies should further explore the differences in EMG parameters related to PFPS and the associations with other measurements, such as rotation or torque. In these results, we observed individuals from the control group with previous activation of the VL; this may indicate that there is a failure in the evaluation protocol, or that some individuals in the control group do not present a diagnosis of PFPS, but are predisposed to having the syndrome.

The torque data indicated a lower tendency to rotate the body in horizontal directions for the individuals with PFPS. Studies using force plates were designed to calculate joint movements using inverse dynamics[18, 20-22]. In this study, specific joints were not investigated because the torque produced on the force plate around the vertical axis showed a trend toward global movement of the whole body above the support point at the platform, the foot. Thus, a lack of neuromotor control may generate a rotation or rotation deficit; as observed in this study, another body part may be directly reflected in the point of support and consequently exacerbate the symptoms of pain. Conversely, pain can generate a different movement strategy that leads to abnormal rotation of the body. When studying the kinetic and kinematic parameters and EMG data during the unilateral move of one leg in the standing position (one-leg stance) in both trained and untrained individuals, it was noted that the change in the center of gravity that occurred in the swinging leg was achieved by rotating the supporting leg externally on the ankle. To keep the axis of the head and trunk vertical, untrained individuals inclined laterally and counter-rotated the head at the neck to keep the inter-orbital line in the horizontal plane, while trained individuals (dancers) performed an anticipatory counter-rotation at the trunk on the hip joint, maintaining the vertical axis of the head and trunk [23].

When stepping on the platform, torque variation occurs in the medial direction. As the body projects forward to reach the third step, and weight bearing shifts to the forefoot, the body tends to move laterally. During this time, the weight of the body is supported on the right leg, and the left leg is in balance, leaving the first step to reach the third, which occurs with the right foot, fixed on the platform. This is possible because the movement dissociation afforded by the joints reaches the center of gravity and stays in balance, due to which a lateral rotation of the body above the point of support is expected.

The PTV showed that the control group presented more variation, indicating that the individuals with PFPS exhibited a lower tendency to rotate the body in horizontal directions, suggesting smaller movement dissociation that would be associated with muscle or joint stiffness. Other studies showed that the hip muscles in individuals with PFPS exhibit weakness and lower performance, which suggests a deficit in the movements and control of the joint[17, 24]. As it was shown that there is an abnormal pattern of rotation in subjects with PFPS and that this change must be associated with muscle or joint stiffness, future studies should use kinematic tools that allow for calculation of joint torques, especially of the knee and the hip, to ensure where this rotation is abnormal and to guide treatment correctly. Moreover, as this change may be related to stiffness, it should be included in physical assessment tests for range of motion.

Although the specific moments for each joint were not calculated, muscular parameters measured by EMG and mechanical parameters measured by PTV distinguished the groups with regard to pain. Individuals with PFPS had a tendency toward early activation of the VL, which was associated with a decrease in body rotation. Thus, it can be suggested that research on PFPS and its treatment should be based not only on muscle periarticular structures (VM and VL) but also on a global analysis, incorporating more complex treatments that involve coordination training, balance, proprioception, stretching, and strengthening. The correlation between EMG and specific moments needs to be investigated in future studies.

EMG and PTV results showed a high standard deviation, which may be explained by the fact that stair climbing is more complex than walking with respect to motor control. A study conducted to test reproducibility in kinetic and kinematic parameters during normal stair climbing showed an elevated intra-subject variance in the data due to the variation in motor performance during movement adaptation. There was an increasing trend toward the reproducibility of data in the upper steps (in this case, when going from the first to the third step), but this reproducibility was not as high as walking on the plane, suggesting that more steps need to be placed after the third one[25]. The limiting factors of our study were the size of the staircase and the experimental environment: wires and electrodes that made the test condition evident to the participants and led them to possibly change their pattern of movement in order to improve it. Few studies have evaluated stair climbing, and most of them have used stairs with two-to-five steps[24, 26-28]. Using an ergometer, such as a moving stairway, or a bigger staircase would lead to a more homogeneous sample and thus a better understanding of this movement pattern. Furthermore, studies need to be conducted to evaluate the reproducibility and reliability of data and to obtain the best method of signal processing, which would improve our understanding of PFPS.

Conclusions

Using EMG and torque, the results showed that although there was no intra-individual difference between the groups, there were differences in EMG and the tendency to rotate, suggesting a change in the neuromotor control of individuals with PFPS when compared with the control group. The analyzed parameters showed that people with pain experience early activation of the VL, which can lead to patellar lateralization, less dissociation of body movements, different strategies to maintain the center of gravity in balance, and possibly abnormal rotation in the body that generates pain. Pain causes changes throughout the body, and therefore, treatment should be global and include coordination, balance, proprioception techniques, and muscle stretching and strengthening. More studies involving the mechanical parameters associated with EMG may be useful for understanding PFPS; in addition, exploration of the EMG signal beyond its onset may also contribute to future research.

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