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Effects of electrical stimulation of vastus medialis obliquus muscle in patients with patellofemoral pain syndrome: an electromyographic analysis

Efeitos da eletroestimulação do músculo vasto medial oblíquo em portadores de síndrome da dor patelofemoral: uma análise eletromiográfica

Fabiana R. Garcia[1], Fábio M. Azevedo[2], Neri Alves[2], Augusto C. Carvalho[2], Carlos R. Padovani[3], Rúben F. Negrão Filho[2]

Abstract

Background: The use of surface electromyography (SEMG) has been considered a tool for quantitative assessment of patellofemoral pain syndrome (PFPS). Conservative treatments aim to improve patellar alignment, and electrical stimulation of the vastus medialis obliquus (VMO) muscle has been considered effective because it is selective and does not cause joint irritation. Objective: This study aims to investigate the efficiency of a muscle strengthening program with electrical stimulation of the VMO muscle in PFPS by SEMG. Methods: A group of ten young women (age: 23.1±4.9 years; body mass: 66.8±14.0 kg; height: 1.63±6.9 cm; BMI: 25.1±5.6 kg/m^2) with unilateral PFPS participated in the study. They performed the functional test of stair stepping to capture the electromyographic (EMG) activity of the VMO and vastus lateralis (VL) muscles, before and after a program of electrical stimulation of the VMO muscle. The electrical stimulation was performed three times per week for six weeks. For analysis between the VMO and VL muscles, we considered the variables: ratio of time of onset to peak of activation, ratio of the integrals of the signals (t-test for dependent samples), and difference between onsets of activation (Wilcoxon test), with significance level of $p \leq 0.05$. Results: The results only showed change in behavior in the EMG signal for the ratio of the integrals of the signals, indicating that changes occurred in the force-generating capacity of the muscle after the training. Conclusion: The use of electrical stimulation should be considered to complement the conservative therapeutic approach in patients with PFPS, and the analysis of the ratio of the integrals of the SEMG signals should be considered as an instrument of evaluation.

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Key words: electromyography; transcutaneous electrical nerve stimulation; patellofemoral pain syndrome.

Resumo

Contextualização: O uso da eletromiografia de superfície (EMG-S) tem sido considerado como instrumento de avaliação quantitativa na síndrome da dor patelofemoral (SDPF). Tratamentos conservadores objetivam melhorar o alinhamento patelar, e a estimulação elétrica do músculo vasto medial oblíquo (VMO) tem sido considerada por ser seletiva e não causar irritação articular. Objetivo: Verificar o efeito de um programa de fortalecimento muscular com estimulação elétrica do VMO na SDPF por meio da capacidade de avaliação da EMG-S. Métodos: Participaram deste estudo 10 mulheres jovens (idade: 23,1±4,9 anos; massa corporal: 66,8±14,0 kg; estatura: 1,63±6,9 cm; IMC: 25,1±5,6 kg/m^2) com SDPF unilateral, as quais realizaram o teste funcional de subir degrau para captação da atividade eletromiográfica dos músculos VMO e vasto lateral (VL), antes e após um programa de estimulação elétrica do VMO. A eletroestimulação foi realizada três vezes por semana, durante seis semanas. Foram consideradas, para análise entre VMO e VL, as variáveis razão do tempo do início até o pico de ativação, razão da integral do sinal (teste t para amostras dependentes) e diferença de início de ativação (teste de Wilcoxon), com nível de significância de $p \leq 0,05$. Resultados: Os resultados mostraram que ocorreu alteração somente no comportamento eletromiográfico relativo à razão da integral do sinal, mostrando que, após o treinamento muscular, ocorreram mudanças na capacidade de geração da força. Conclusão: O uso da eletroestimulação deve ser considerado no sentido de complementar a abordagem terapêutica conservadora em portadores da SDFP e a análise da razão da integral do sinal de EMG-S, como instrumento de avaliação.

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Palavras-chave: eletromiografia; estimulação elétrica nervosa transcutânea; síndrome da dor patelofemoral.

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[1] Physical therapist

[2] Physical Therapy Department, Faculty of Science and Technology, Universidade Estadual Paulista (UNESP), Presidente Prudente (SP), Brazil

[3] Department of Biostatistics, Institute of Bioscience, UNESP, Botucatu (SP), Brazil

Correspondence to: Rúben de Faria Negrão Filho, Departamento de Fisioterapia, UNESP, Rua Roberto Simonsen, nº 305, CEP 19060-900, Presidente Prudente (SP), Brasil, e-mail: rubnegrao@yahoo.com.br

Introduction

Athletes and other individuals with patellofemoral pain syndrome (PFPS) often seek an effective treatment due to the possibility of feeling pain during simple daily activities or even while practicing sports[1]. PFPS has been described in the literature as anterior knee pain[2] due to patellar malalignment, which predisposes the individual to joint pain and the possibility of cartilage damage[3]. Some theories for the source of the non-traumatic, gradual onset of PFPS leading to patellar malalignment are: increased Q angle; tension on the lateral retinaculum, the hamstrings, the iliotibial band, and the gastrocnemius; excessive pronation of the subtalar joint[4]; increase in lumbar lordosis; history of ankle dislocation; and increase in medial hip rotation, which causes joint torsion[2]. However, the most acceptable hypothesis for this malalignment is the abnormal lateral tracking of the patella[5], which happens due to a neuromuscular imbalance between the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles and leads to a decrease in the activation of the VMO muscle[6].

Conservative treatments for PFPS usually consist of a variety of components developed to improve patellar alignment[5,7,8]. The electrical stimulation of the VMO muscle[9-12] and the quadriceps femoris[13] has been studied as a form of PFPS treatment especially because it is selective and does not stress the patellofemoral joint. This stress often results from physical exercise during the treatment of dysfunctions of the knee extensor mechanism[13].

Surface electromyography (SEMG) as an instrument to assess electrical muscle activity[4,6,11,13-15] has become popular because it can be used in the quantitative assessment of PFPS in physical therapy routines. However, no studies have found evidence of electromyographic (EMG) improvement in the VMO and VL muscles after treatment with electrical stimulation of the VMO in patients with PFPS. The presupposition is that, after the treatment with electrical stimulation, there will be changes in the control of muscle activation and the amount of activation. This is based on the fact that patients with PFPS can exhibit reduction in force and in the activation pattern of the VMO in relation to the VL, with changes in the dynamic behavior of the patellofemoral joint[16]. Thus, the aim of the present study was to use SEMG to assess the effectiveness of a strengthening program with electrical stimulation of the VMO muscle in people with PFPS.

Methods

The study included ten young women (age: 23.1±4.9 years old; body weight: 66.8±14.0 kg; height: 1.63±6.9 cm; body mass index (BMI): 25.1±5.6 kg/m^2) with medical diagnosis of unilateral PFPS. To participate in the experiment, the participants were submitted to an evaluation protocol that included: identification, anamnesis, pain assessment in functional conditions and in functional tests using the visual analog scale (VAS) and clinical examination, including tests to assess the patellofemoral joint, tests to exclude possible ligament or meniscus changes, tests to assess retraction and strength of the lower limb muscles, and also X-ray tests to exclude anatomic changes of the patellofemoral joint.

The inclusion criteria were: 1) report of insidious development of symptoms unrelated to traumatic incident and present for at least a month in three or more functional conditions including squatting for a long period of time, ascending stairs, kneeling, running, sitting for a long period of time, contracting the quadriceps muscles isometrically, and practicing sports with an intensity of 3 or more in the VAS; 2) report of pain while performing the functional tests including descending a 20-cm high step and bilateral squats with knees flexed at 90º; 3) presence of at least three clinical signs and symptoms such as positive patellar compression test; patellar crepitus; increased Q angle; excessive subtalar pronation; high-riding patella (radiographic analysis); contracture of the iliotibial band (positive Ober's or Noble's test); pain on palpation of patellar border; external tibial torsion; patellar malalignment (medialization or lateralization); patellar hypo – or hypermobility and presence of the bayonet sign; 4) acceptance of the use of electric current. The participants not included in the study demonstrated: recent history of knee surgery (in the last three months); subluxation/dislocation; clinical evidence of meniscal injury or ligament instability; cases of patellar tendon pathology; cartilage damage; osteoarthritis; and previous physical therapy for six months or more. After the selection, the participants were informed about the objectives of the study and signed a consent form to participate in this study, which was approved by the Human Research Ethics Committee of the Faculty of Science and Technology – Universidade Estadual Paulista (UNESP), Presidente Prudente (SP), Brazil (Process no. 026/2005).

Procedures

The participants performed the functional test of stair stepping using the limb affected by PFPS, with self-controlled speed, to capture the EMG activity of the VMO and VL muscles, before and after a program of electrical stimulation of the VMO muscle. In order to perform the functional test before the stimulation program, the participants were familiarized with the activity of stair stepping. The skin preparation for electrode placement consisted of shaving, cleansing with hydrated alcohol, and mild abrasion with fine sandpaper[17,18].

To determine the site of electrode placement, the participant was placed in the supine position and a line was drawn from the anterior superior iliac spine to the center of the patella. The line was used as a reference to measure the inclination angle of the muscles. For the VMO, a dot was drawn on the muscle belly, 4 cm above the superomedial patella border, orientated 55° to the vertical[19,20]. For the VL, the dot was drawn 15 cm above the superolateral patella border, orientated 13.6º to the vertical[21]. The electrodes were placed so that the detection surfaces were orientated in the direction of the muscle fibers[22], and the reference electrode was placed on the anterior aspect of the wrist.

After the preparation process, the test of stair stepping was initiated with the participant facing the stairs in the standing position. The participant began the movement by flexing the limb with PFPS, placing it on the first step, and then extending it in unilateral stance. In a continuous movement, the non-affected limb was placed on the second step, completing the stair stepping with full knee extension. During this activity, the participant was instructed to ascend the steps with a ten-second interval between each test, totaling twenty consecutive tests.

After the collection of the electrical activity of the VMO and VL muscles, the electrical stimulation program was initiated. The participants received electrical stimulation to the VMO muscle of the affected limb by two electrodes placed on the muscle, one on the motor point and the other one immediately next to it, in the longitudinal direction of the fiber. The program was performed three times a week, for six weeks (eighteen sessions). The current that was used had the following characteristics: asymmetric bipolar current, with pulse width of 0.5 milliseconds and pulse frequency of 50 Hz. Each stimulation session lasted, initially, 7 minutes (six repetitions, on for six seconds and off for twelve), and progressed to 30 minutes (11 repetitions, on for ten seconds and off for twenty) at the end of the stimulation program. The current intensity was the maximum intensity the participant could bear, without pain during contraction.

During the stimulation, the participants were seated with trunk support, extended legs with slight knee flexion and lower limb muscles completely relaxed to allow electrically-induced, isometric contraction of the VMO, without any voluntary movements. All participants performed the electrical stimulation protocol within the established schedule. Three days after the last session, the second functional test of stair stepping was performed following the same protocol as previously described.

Instrumentation

A signal acquisition system was used (Lynx® Tecnologia Eletrônica Ltda, São Paulo, Brazil), which consisted of two bipolar active surface electrodes, made of two parallel silver bars (10 mm long, 1 mm wide, 10 mm apart) encapsulated in a polyurethane mold. The electrodes were part of a preamplifier circuit with a gain of 20 (±20%), CMRR (common mode rejection ratio) >80 dB, impedance of 10^{12} Ω // %pF, input bias current of 30 x 10^{-12} A, and noise rate of <5 μV pp.

For the stair stepping functional test, the set of stairs consisted of a 60 cm-long platform with two steps 20 cm high on both sides[6]. An electromechanical device (pressure sensor) was placed on the stair steps to inform the moment the foot touched the step during the ascent. The electrodes and the pressure sensor were connected to a 16-channel signal conditioning module (Lynx MCS 1000-V2). In the module, the analogical signals were filtered with cutoff frequency from 20 Hz to 500 Hz[17], by means of an analogical filter (second-order Butterworth), and amplified for a final gain of 1000 times. The system had also a 12-bit analog-to-digital converter (A/D) model CAD 12/36 configured to sampling frequency of 1000 Hz. The signal acquisition program AQDADOS, version 5.0, served as data integration software. In order to perform the electrical stimulation program, the device Nemesys 941 (Quark® Produtos Médicos, Piracicaba, SP, Brazil) was used and its current parameters were tested with an oscilloscope (Degem® model 112, Degem Systems Holdings LTD).

Selection and processing of the electromyographic signal

After the data collection, the ten best EMG tracings out of the 20 obtained from each participant were selected. A window for the analysis of the VMO and VL muscles was determined using the information obtained by the pressure sensor on the step. The selected signals were then submitted to the routine created in Matlab (Mathworks, Natick, MA, USA) to determine three signal variables: 1) onset timing of muscle activation; 2) time between the onset and peak of muscle activation; and 3) integral of the signal.

In the routine, the selected EMG tracings were initially submitted to the total rectification of the signal, linear envelope with low-pass filter of 50 Hz (sixth-order Butterworth). The algorithm identified the onset of muscle activation as the point at which the signal diverged from the baseline (obtained in 200 ms before the activity started) by more than three standard deviations, for 25 ms or more[23]. It also determined the activation peak and calculated the area under the signal curve (integral of the signal). After determining the onset of muscle activation, the activation peak and the integral of the signal for both the VMO and VL muscles, the following values were obtained: 1) difference between the onset of activation of the VMO and the VL muscles (VMO-VL), in milliseconds; 2) ratio of onset to peak of activation of the VMO and the VL muscles (VMO/VL); and 3) ratio of the integrals of the signals of the VMO and the VL muscles (VMO/VL).

All of the performed analyses were comparative, considering the data obtained before and after the electrical stimulation of the VMO muscle for the three SEMG signal variables. The t-test for dependent samples was used to analyze the ratio of onset to peak of activation and the ratio of the integrals of the signals. The Wilcoxon test was used to analyze the difference between the onsets of activation. The significance level was set at $p \leq 0.05$.

Results

According to Table 1, no statistically significant differences were observed for the values of the difference between the onsets of activation and the ratio of onset to peak of muscle activation before and after the electrical stimulation program ($p>0.05$). However, a significant difference ($p<0.05$) was observed in the analysis of the ratio of the integrals of the SEMG signals of the VMO to the VL.

The value of the ratio of the integrals of the signals does not demonstrate in which muscle the change occurred. Therefore, the analysis of the EMG behavior is performed separately for each muscle and is presented in Table 2 (Wilcoxon test).

Table 2 demonstrates that changes occurred in the values of the integral of the SEMG signal for the VMO and VL muscles after the electrical stimulation of the VMO. These differences were significant ($p<0.01$). However, the changes occurred differently in each muscle: the VL showed a decrease in activation and the VMO showed a significant increase in activation after the electrical stimulation.

Discussion

The results demonstrated that, after the stimulation of the VMO muscle, there were no changes in the EMG behavior relative to the difference between the onsets of activation and the ratio of onset to peak of muscle activation of the VMO and VL muscles. In other words, the motor control did not suffer any changes related to the onset of muscle activation when performing the stair stepping test. However, the EMG behavior relative to the integral of the signal demonstrated that the amount of energy consumed by the VMO muscle in order to perform the test increased significantly. This shows that, after the muscle stimulation, there were changes in force-generating capacity during the activity.

The onset of muscle activation appears to play an important role in the balance of the resultant muscle forces when initiating the knee extension movement. The analysis of the difference between the onsets of the VMO and VL muscles has been the most used EMG parameter[6,14,19,20,24-27]. In contrast to our results, evidence of the change of the temporal characteristics (onset of activation) after therapeutic intervention was demonstrated in the studies by Cowan, Bennel and Hodges[6] after the use of patellar taping, and Cowan et al.[14] after treatment program based on McConnell's proposition[7].

The onset to peak of activation timing is an EMG parameter that demonstrates how the signal amplitude increases, and it was included in the present study after analyses performed in a pilot study that demonstrated activation peaks at different times for each muscle. Despite the fact that no study using this parameter was found, it is believed that such analysis

Table 1. Median and mean values of the SEMG signal variables of the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles during the stair stepping test performed by patients with Patellofemoral Pain Syndrome (n=10).

Variable	Moment of assessment		Test results
	Before	After	
Difference between the onset of activation (VMO – VL)*	-1.90±28.90	-0.95±26.30	p=0.770
Ratio of onset to peak of activation (VMO/VL)**	0.94±0.12	1.01±0.18	p=0.278
Ratio of the integral of the signal (VMO/VL)**	0.89±0.30	1.82±0.69	p=0.002

*=median values; **=mean values.

Table 2. Values of the integral of the SEMG signal (μV.s) of the vastus medialis obliquus (VMO) e vastus lateralis (VL) muscles during the stair stepping test performed by patients with Patellofemoral Pain Syndrome (n=10).

Muscles	Moment of assessment		Test result
	Before	After	
VMO	17024	28652	p<0.0001
VL	20201	18072	p=0.0030

would complement the analysis of the onset of muscle activation, given that the moment in which each muscle reaches its maximum activation can influence the resultant forces on the patellar movement. The EMG parameter demonstrated by the integral of the signal indicates the total energy consumed by the muscle during the activity. It has been commonly applied for analysis due to its relation to the force employed by the muscle during the performance of a given task[15,27-30].

Despite the consensus on the use of electrical stimulation to improve resistance and muscle strength, there are few studies on its effect on PFPS[9-13,30]. Regarding electrical stimulation of the VMO muscle in particular, all studies showed improvement, such as: prevention of patellar displacement in patients with chronic patellar instability[9]; improvement in pain relief, muscle strength, and cross-sectional area[10]; rehabilitation of patients post-total knee arthroplasty by analyzing gait speed[30]; increase in VMO activation immediately after the electrical stimulation[11]. Among the studies previously mentioned, only Callaghan and Oldham[13] and Augusto et al.[11] applied SEMG to assess the effects of electrical stimulation on PFPS (analysis of EMG fatigue and ratio of the integral of the signal, respectively).

The results observed in the behavior of the integral of the signal in the present study are consistent with Augusto et al.[11], who attributed the increased activation of the VMO after electrical stimulation to the improvement in force-generating capacity or to the change in motor control relative to the amount of motor unit recruitment. Regarding the improved force-generating capacity, Werner et al.[10] demonstrated that after ten weeks of VMO electrical stimulation training, twice a day, the cross-sectional area and the treated lower-limb torque increased significantly. Although the amount of training in the present study was lower, the possibility of improved energy (integral of the signal) that was observed can be related to better muscle conditioning.

Another aspect to be considered is the improvement in muscle recruitment due to the decrease in pain reported by most of the participants, as it is known that pain leads to reflexive inhibition and a drop in muscle performance[11]. In this case, the point would be to determine why this inhibition occurs only in the VMO muscle of the patients with PFPS. Although the reason is still unclear, the most accepted hypothesis for the neuromuscular imbalance between the VMO and the VL muscles is VMO atrophy[6], which would lead to excessive lateral tracking of the patella and pain due to overload[1], thus creating a vicious cycle of pain – atrophy – pain. Therefore, the positive effect of the program of electrical stimulation of the VMO on the integral of the signal may be related to the decrease in pain in the majority of the participants involved in the present study. Nevertheless, an important limitation of this study was the lack of proper clinical pain assessment after the intervention, given that the information about the participants' pain relief was obtained without a proper protocol.

In conclusion, the positive effect of the electrical stimulation program can be perceived through one of the EMG parameters included in the analysis of the motor control behavior for the patellar stabilizers, and such effect seems to be related to the VMO muscle's force-generating capacity. Therefore, the use of electrical stimulation should be considered to complement the conservative therapeutic approach in patients with PFPS, and the analysis of the integral of the SEMG signal should be used as an assessment instrument.

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