Integrated electromyographic ratio of the vastus medialis oblique and vastus lateralis longus muscles in gait in subjects with and without patellofemoral pain syndrome

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ABSTRACT

The aim of this study was to determine if there is difference between the vastus medialis oblique and vastus lateralis longus (VMO/VLL) muscles activation during treadmill gait level and ascending to 5% degree between healthy subjects and others with patellofemoral pain syndrome. Electromyographic data from the VMO and VLL muscles were obtained in 15 subjects without and 12 with patellofemoral pain syndrome (PFPS) during treadmill gait with and without 5 degrees inclination. The value of the VMO/VLL ratio was determined from the mean of 8 strides, in each condition, during 12 s. The t-Student test did not show significant difference in the VMO/VLL ratio between the two groups, regardless the condition. Although there was not significant difference, the subjects of the control group showed higher values in the VMO/VLL ratio in the two tested conditions than the subject of the PFPS group. The findings suggest that the ratio of the electric activity of the VMO and VLL muscles in individuals with and without SDFP is equal in the gait on flat surface as well as slanted to 5 degrees.

Keywords: Gait. Electromiographic ratio. Patellofemoral pain syndrome.

INTRODUCTION

Patellofemoral pain syndrome (PFPS) is a current problem[1], being one of the most common disorders which affect the knee extensor mechanism[2] occurring more frequently in women[3]. Its incidence varies from 10 to 40%, with the highest rates occurring in athletes[4]. The most widely accepted etiologic factor for PFPS is the abnormal patellar dislocation[5]. In such situation, an imbalance among the patella's primary stabilizer muscles with the force generated by the vastus lateralis muscle (VL) occurs. Moreover, such situation is not suitably balanced by the medium force of the vastus medialis oblique muscle (VMO) resulting hence in lateral dislocation as well as poor patellar aligning[6].

Subjects with PFPS frequently develop excessive lateral dislocation, which could be caused by the weakness of the VMO which is the patella's main medium stabilizer[3,7]. Good balance in the activation of the VMO and VL muscles is necessary in order to keep the aligning normal. Therefore, the abnormal relation in the activation pattern of these muscles could alter the dynamics of the patellofemoral joint[8]. Besides that, it is well-established in the literature that the VMO/VL ratio represents the quantitative measurement of the relative participation of VMO and VL during the muscular contraction. According to McConnell[8] the VMO/VL ratio should be 1:1 in subjects clinically healthy and significantly lower for those with PFPS. Therefore, the training and/or VMO strengthening becomes part of a rehabilitation program in subjects with PFPS[1,8-9].

Some electromyographic studies investigated the VMO and VL muscles ratio in different exercises, such as in closed kinetic chain (ascending and descending stairs; squatting and *leg press*) as well as in open kinetic chain (extension isotonic and isometric contractions and knee flexion)[10-12]. Souza and Gross[11] compared the electromyographic ratio (EMG) of the VMO/VL muscles between healthy and with unilateral PFPS subjects in isotonic contractions of ascending and descending stairs and maximal and submaximal ones of the femoral quadriceps. The healthy subjects showed significantly higher values in the VMO/VL ratio than the ones with PFPS during the isometric contractions. These authors concluded that patients with PFPS have abnormal activation patterns in the VMO/VL ratios. Boucher *et al.*[12] evaluated the VMO/VL ratio in 18 subjects with and without PFPS during maximal isometric contractions in three different knee flexion angles (15°; 30° and 90°). These authors also found a significant decrease in the VMO/VL ratio in the subjects with PFPS, especially in those with higher values of Q angle, suggesting hence, a reduction in the VMO activity. Moreover, it was reported that exercises close to the final extension could increase the muscular imbalance in the VMO/VL ratio.

Conversely, Cerny[10] did not find significant difference between healthy and with PFPS individuals when analyzing the VMO/VL ratio during a series of exercises in open and closed kinetic chain. The author concluded that none of the exercises used selectively recruited the VMO muscle. Sheehy *et al.*[13] did not find difference in the VMO/VL activation peaks ratio between healthy and with PFPS individuals during exercises of ascending and descending a step, suggesting that there is no imbalance between these muscles in both studied groups. Thus, some authors deny the idea of muscular imbalance between VMO and VL, questioning VMO selective strengthening programs as well as the cause of the abnormal patellar dislocation[2,10,14].

The quadriceps eccentric contraction in the touching phase of the gait cycle is considered the primary absorbing mechanism of impact during weight acceptance[15]. However, for patients with PFPS, the knee flexion increase in the response to the load and the quadriceps contraction would increase the reaction forces in the patellofemoral joint, inducing biomechanical alterations in it[16]. Clinically, subjects with patellofemoral pain report limitations in the gait, especially when ascending and descending stairs and walking on slanted surfaces. The discomfort associated with these activities usually results in modifications in the gait patterns in a trial of reducing the muscular demands and consequently pain[17].

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Although there are studies about the gait parameters analysis in subjects with patellofemoral dysfunction[2,16-18], none of them evaluated the VMO/VLL ratio during this functional activity, both in clinically healthy and with PFPS subjects. Moreover, the literature evidenced controversy concerning the electric activity behavior of the vastus muscles in the gait on slanted surface, reporting increase[19] or not[20] in the activity of these muscles. In addition, some authors[21-22] have suggested that exercises in closed kinetic chain (CKC), are safer than exercises in open kinetic chain (OKC) for subjects with PFPS, since exercises in CKC produce minimum stress in the patellofemoral joint during movement's functional breadth causing patients with PFPS to tolerate better exercises in CKC and consequently to exhibit better functional results after a rehabilitation program. Nevertheless, the importance of muscular activity in exercises in OKC and CKC has not been extensively studied, especially during the gait which is considered an exercise in CKC[23].

Therefore, the aim of the present study was to determine whether there is difference in the VMO/VLL ratio during the gait on flat surface as well as slanted to 5° in subjects clinically healthy and others with PFPS.

METHODS

Subjects

Twenty-seven female subjects (18-29 years); 12 with PFPS and 15 clinically healthy (CG) participated in the study. The experimental protocol of this study was approved by the Ethics Committee in Human Research of the Institution and a free and clarified consent form was signed by the participants before it began. The anthropometrical characteristics of the subjects are presented in table 1.

TABLE 1
Mean and standard deviation of the age, height, weight and dominance of the clinically healthy (CG – n = 15) and with patellofemoral dysfunction subjects (PFPS – n = 12)

Characteristics	CG	PFPS	P
Age (years)	21.66 (± 2.82)	20.5 (± 2.34)	0.48
Height (m)	1.64 (± 0.07)	1.63 (± 0.07)	0.81
Weight (kg)	57.76 (± 5.96)	52.81 (± 7.73)	0.77
Right dominance	15 (100%)	7 (58.34%)	
Left dominance	0 (0%)	5 (41.66%)	

The inclusion criteria for the participants in the group with PFPS were anterior or retropatellar pain for at least three of the following activities: to sit for an extended time; to ascend and descend stairs; to squat; to kneel; to run; to practice sports as well as in the quadriceps isometric contraction. Moreover, they should present pain at patellar pressure, pain in the patellofemoral joint of at least 2 in the Visual Analogue Scale (VAS) of 10 cm in the last week; insidious pain beginning non-related to trauma etiology and also pain of any extent in two functional tests: bilateral squatting at 90° and ascending and descending a 25 cm step, both with 30 s duration[24-25]. Subjects who reported history of knee surgery, meniscal and/or ligament lesion and underwent physical therapeutic treatment in the last 6 months were excluded.

The inclusion criteria[16,24-25] considered for clinically healthy subjects were: (a) lack of any pain history; trauma; meniscal or ligament lesion in the knee joint; (b) lack of neurological or osteomioarticular system disease; (c) lack of any problem in the hip or foot joints; (d) no surgery and/or physical therapy treatment in the lower limb; (e) no presence of pain during the functional tests performance of squatting and st*ep*; and (f) presence of at least two of the same clinical signs considered for the PFPS group.

Instruments

The electric activity of the VMO and VLL muscles was captured by differential single active electrodes of bipolar surface (EMG System, Brazil), consisting of two silver-silver chloride bars which were 10 mm long, 1 mm wide and 2 mm high each, parallel placed and 10 mm apart from each other. These electrodes allow a differential amplification of 50 times, with entrance avoidance of 10 GΩ and rejection range of common manner (130 dB to 60 Hz). The electrodes were connected to a signal conditioner mode of 8 channels (EMG System, Brazil) and were amplified and filtered by a Butterworth pass-band filter (20 Hz-500 Hz). The electromyographic data of the VMO and VLL muscles were then digitalized by an AVD converser plaque of 12 bits of dynamic resolution range and the sample frequency was adjusted in 2 KHz, with entrance range of ± 10 V.

Procedures

Prior to the electrodes placement, the skin was trichotomized, cleaned with alcohol and slightly submitted to abrasion to reduce the avoidance and eliminate eventual interference. The electrodes for the VMO were approximately placed 4 cm superior to the patellar superomedial side[8] and oriented 55° in relation to the femoral axis[7]. For the VLL muscle, the electrodes were approximately placed 11 cm superior to the patellar superolateral side with inclination of 15° to the femoral axis[26]. According to the anatomical study by Weinstabl *et al.*[26], the VLL's electrodes position in the present study would be similar to the electrode's positioning for the VL muscle in the other investigations[1,6,8-14,16-17,24,28]. The reference electrode was placed right above the ankle of the studied limb. A *foot-switch* was also placed on the ankle of the studied limb of the subjects and synchronized with the electromyographic signals which generated a different voltage level when in contact with the ground, allowing the identification of different phases of the gait. The ankle touch on the ground until the next ipsilateral touch was defined as a stride, being 100% of the stride time considered[27].

For collection of the electromyographic data the subjects walked on an electrical treadmill (*Pro-action Fitness*), first with no inclination and later with 5° inclination. Such order was chosen to facilitate the experimental procedure and we believe that it would not influence the results, since the time between the two conditions was of approximately 1 minute. The treadmill velocity was pre-set for each individual through the calculation of the mean velocity of a meter-gait on the ground in three trials. The values of the mean velocity of each group were similar (CG – 3.9 ± 0.3 Km/h); PFPS – 3.8 ± 0.4 Km/h), with no statistically significant difference between them.

The electromyographic evaluation was obtained from the musculature of the dominant limb in the CG (the one used for kicking a ball), while the injured or with greater compromising side, in the case of bilateral PFPS, was evaluated in the PFPS group.

Data analysis

The raw electromyographic signals were processed in order to obtain the linear wrapping following the ratification phases in complete wave, straightening by filtering with *Butterworth* of 4th order and slicing frequency of 5 Hz. The breadths of the linear wrappings were normalized by the mean of the value of the ratified and straightened breadth as well as in the activity's time basis[28] by the total duration of the adjusted stride for 100% using a mathematical routine suitably designed in the Matlab 6.08 program (figure 1). The normalization by the mean was chosen since some studies[29-31] verified greater efficiency and applicability of this kind of normalization during dynamic activities, besides demonstrating lower variability[32] when compared with other methods.

The breadth value of the linear wrapping was determined for all muscles concerning the ankle touch on the ground by the trapezoidal integration of the linear envelope[29]. Such integration was calculated from the mean of eight strides, collected in the period of 12 seconds of each subject of both groups. The quotient of the

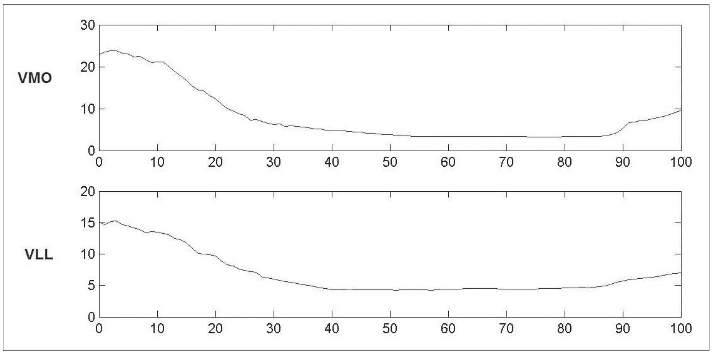

Figure 1 *– Example of the electric signals of the VMO and VLL muscles normalized for the calculation of the mathematical routine of the area below the wrapping one*

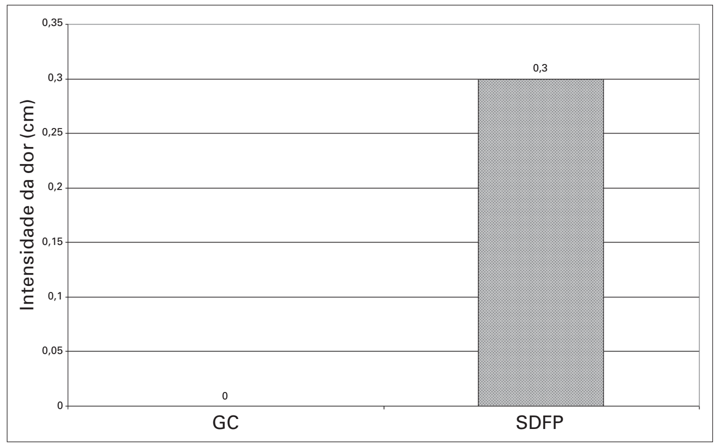

Figure 2 *– Pain intensity perceived by the CG (n = 15) and PFPS subjects (n = 12) after the gait on treadmill*

electromyographic breadth of the VMO by the breadth of the VL or VMO/VLL ratio was later calculated.

Statistical analysis

The Shapiro-Wilks test was used in order to verify the normal data distribution. The characteristics of the subjects (age; height and weight) as well as the Q angle values were compared between the groups using the t-Student test. In order to verify the difference in the pain intensity after the gait on the treadmill, the U test by Mann-Whitney was applied. The difference in the VMO/VLL ratio between the two groups as well as the difference between the conditions (flat surface X slanted surface) was tested by *two way* ANOVA with repeated measurements. All the significance levels were determined as $p \leq 0,05$. The statistical analyses were performed with the *Statistica* 5.0 program.

RESULTS

The results of this study did not evidence statistically significant differences in the VMO/VLL ratio between the CG and PFPS means (table 2). Although no significant difference was found between the two groups, the VMO/VLL ratio was higher in the subjects of the control group, regardless the condition (flat treadmill or slanted at 5º).

TABLE 2
Integrated electromyographic VMO/VL ratio during the gait on treadmill on flat and slanted at 5° surfaces in clinically healthy (GC – n = 15) and with PFPS subjects (n = 12)

Condition	Mean (± SD)		F	P
	CG	PFPS		
Flat surface	1.03 (± 0.25)	1.01 (± 0.17)	0.59	0.45
Slanted surface	1.08 (± 0.30)	0.99 (± 0.24)		

Statistically significant differences were not found either in the Q angle value between the CG and PFPS subjects, although the PFPS subjects have a tendency to show higher values than the clinically healthy ones (table 3).

TABLE 3
Mean, standard deviation and t test for the Q angle values of the CG (n = 15) and PFPS subjects (n = 12)

Variable	CG (n = 15)	PFPS (n = 10)	t	p
Q angle	17.9° (± 3.6)	19.5° (± 3.3)	1.16	0.25

In figure 2 the data on the pain intensity after the gait on treadmill (TRE) of the PFPS and CG subjects are shown. The U test by Mann-Whitney showed that there was no significant difference during the gait on treadmill both on flat and slanted surfaces. The results also showed that the PFPS subjects already presented some pain before the tests performance.

DISCUSSION

The results of this study did not show significant difference concerning the VMO/VLL ratio between the subjects considered clinically healthy and those with PFPS, regardless of the inclination on the gait on treadmill. These results are according to the ones obtained by Cerny[10] who despite not having found significant difference, showed results in which the clinically healthy subjects had greater VMO/VL ratio than the subjects with PFPS in exercises in CKC (*wall slide*; descending stairs; a stride simulation). This result, despite of the different exercise type, was also found in our study both in the gait on flat surface (CG-1.03; PFPS-1.01) and on slanted one (CG-1.08; PFPS-0.99). It is important mentioning that the values above 1 in the VMO/VLL ratio show that the VMO was more activated than its antagonist; while values below 1 show that the VLL was the most recruited during the activity.

A possible explanation for our findings would be the lack of effusion and the presence of minimum pain (0.3 in a 0 to 10 scale), both prior and post the gait on treadmill in the two evaluated conditions in the subjects with PFPS. According to Spencer[31], the decrease in the quadriceps muscle activity has origin in the reflex inhibition, caused by the pain and effusion.

Another possible explanation would be related to the Q angle value (PFPS-19.5°), which is an indicator of poor mechanical aligning of the lower limb, similar to the one in the CG subjects (17.9°). According to Boucher *et al.*[12] when the poor mechanical aligning of the lower limb is mild (Q angle lower than 22°), the VMO/VL ratio in the subjects with PFPS is similar to the one in the clinically healthy ones. Moreover, we believe that being the proposed activity an exercise in CKC and consequently with weight sustaining, it could hamper the patellar lateral dislocation[33].

On the other hand, Souza and Gross[11] showed that the VMO/VL ratio was significantly higher in clinically healthy subjects when compared with subjects with patellofemoral pain. It is possible that the methodological difference is responsible for different results found between our study and the one by Souza and Gross[11]. In our study, electromyographic data normalized by the mean of the linear envelope breadth in 8 strides were used, while Souza and Gross[11] used non-normalized data. Moreover, the functional activities evaluated were different, namely descending stairs versus the gait, as well as the sample, which consisted of men and women in the study by Souza and Gross[11] and only women in the present study. Concerning the sample selection, according to Csintalan *et al.*[34] men and women present differences in the patellofemoral contact pressure and area as well as in the vastus muscles response to load application. According to these authors, such differences could explain the higher incidence of patellofemoral syndrome in women. Besides that, one should be careful when comparing results of healthy subjects and subjects with knee pathology due to the exercise type investigated in the EMG evaluation, such as exercises with maximal and submaximal isometric exertion which would different from isotonic exercises.

Our studies also showed that despite not existing significant difference between the groups, there was a tendency from the clinically healthy subjects to have higher VMO/VLL ratio than the subjects with PFPS, both during the gait on flat and slanted surfaces. Although we do not know whether the differences found in our study 0.02 (gait on flat surface) and 0.09 (gait on slanted surface), in the VMO/VLL ratio would be clinically significant, it is possible to believe that the tendency in the decrease of this ratio could be connected with reduction in the patellar medium stabilization force[10]; however, further studies are still needed in order to confirm such hypothesis.

In the present study, concerning the absolute values of each muscle, the subjects with PFPS showed greater activation on the slanted surface, both in the VMO (flat – 651.82; slanted – 783.64) and VLL (flat – 656.45; slanted – 818.18), especially in the VLL muscle. Although the most current ratio for decrease in the VMO/VLL ratio is the reduction in the VMO muscle activity [1,8,12], our results showed that the reduction in the VMO/VLL ratio value found in the subjects with PFPS is related with a greater recruiting of the VLL muscle, especially during the gait on slanted surface. Additionally, the results showed that there was an increase in the VMO/VLL ratio for the subjects of the control group between the two conditions tested, especially in the VMO muscle activity, showing thus, that in these subjects there is a balance between the patellar primary stabilizers.

Finally, we believe that further studies are still needed for the investigation of the muscular electrical activity behavior during a longer period of time in order to better understand the utilization of the treadmill as an evaluation equipment as well as the treatment and training of subjects with PFPS.

CONCLUSION

In the experimental conditions used, this study verified that clinically healthy subjects and those with patellofemoral pain syndrome presented similar VMO/VLL ratio both on the gait on treadmill on flat and slanted surfaces. The results also showed a tendency of the subjects in the CG to present higher VMO/VLL ratio than the ones with PFPS. Nevertheless, these results still need to be confirmed in further studies.

All the authors declared there is not any potential conflict of interests regarding this article.

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