Patellofemoral pain syndrome: electromyography in a frequency domain analysis

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Abstract. The Patellofemoral Pain Syndrome (PFPS), has a multifactorial etiology and affects approximately 7 to 15% of the population, mostly women, youth, adults and active persons. PFPS causes anterior or retropatellar pain that is exacerbated during functional motor gestures, such as up and down stairs or spending long periods of time sitting, squatting or kneeling. As the diagnostic evaluation of this syndrome is still indirect, different mechanisms and methodologies try to make a classification that distinguishes patients with PFPS in relation to asymptomatic. Thereby, the purpose of this investigation was to determine the characteristics of the electromyographic (EMG) signal in the frequency domain of the vastus medialis oblique (VMO) and vastus lateralis (VL) in patients with PFPS, during the ascent of stairs. 33 young women (22 control group and 11 PFPS group), were evaluated by EMG during ascent of stairs. The VMO mean power frequency (MPF) and the VL frequency 95% (F95) were lower in symptomatic individuals. This may be related to the difference in muscle recruitment strategy exerted by each muscle in the PFPS group compared to the control group.

1. Introduction
The patellofemoral pain syndrome (PFPS) is characterized as an anterior or retropatellar pain in the absence of other disorders and presents clinically as a condition of diffuse pain exacerbated by activities such as climbing stairs, getting a lot of time sitting, squatting and kneeling [1]. The PFPS is a common disease in athletes and affects about 7 to 15% of the population of young active adults, being more common in women, and one of its features is a change in the patellofemoral joint from a patellar instability, generating a slope or lateralization of the patella [2]-[4]. Based on the concept of balance of forces involved in this joint, the quadriceps muscles - vastus medialis obliquus (VMO), vastus lateralis (VL), rectus femoris (RF) and the vastus intermedius - would act together to a uniform extent of the knee, and that lateralization of the patella could be generated by any imbalance in the presence of these forces, many studies have used electromyography (EMG) as a method to describe these muscles in different motor performances [5]-[7]. The EMG is applicable to the surface muscles (VMO, VL and RF) and could be useful clinically to diagnose individuals with the syndrome, or even to characterize and classify individuals likely to develop the disease.

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Trying to make this classification, studies involving analysis of the EMG signal in time domain have been widely used, primarily to diagnose the early activation of the VMO/VL and their relationships. However, there are still many contradictions surrounding this aspect [8]-[11]. The analysis of the EMG signal in the frequency domain have proven effective with respect to criteria for designation of characteristics and types of muscle contraction, as well as determination of muscular fatigue [12]-[14]. For the frequency analysis, the signal should have specific features: stationarity, trend and seasonality. The analysis parameters commonly used are the mean power frequency (MPF), that is the point which divides the area below the frequency spectrum into two equal parts; the 95% frequency (F95), a point that focuses on your left 95% of the total area below the spectrum; and the peak frequency (Fp), which determines the peak frequency in the spectrum.

Thus, the purpose of this study was to determine the frequency characteristics of the EMG signal in patients with PFPS during the weight transfer in ascent of stairs.

2. Materials and methods

2.1. Subjects

33 volunteers were submitted to the EMG analysis. The individuals were divided into two groups: 22 in the control group (mean ± SD: age 23 ± 2 years, body mass 55 ± 6 kg, height 161.2 ± 4.8 cm) and 11 clinically diagnosed with PFPS (age 24 ± 3 years, body mass 57.3 ± 5.3 kg, height 161.9 ± 5.9 cm). The protocol for diagnosis PFPS consisted of tests on the knee joint to exclude signs of the syndrome or other changes in the patellofemoral joint. Prior to participation, all procedures were explained and participants signed an informed consent for the study. The study was approved by the Ethics Committee in research of the FCT / UNESP, n.166/2007 process.

2.2. Exercise protocol

The experimental protocol was the rise of three steps (12 replicates) with 20 cm in height, in a continuous and alternating way. During the course of this experiment were collected signals of vastus medialis oblique (VMO) and vastus lateralis (VL) of the right lower limb, that were the dominant one for the control volunteers and the painful member of the PFPS group volunteers.

2.3. Measurements

For the assessment it was used two pairs of Ag/AgCl surface electrodes, 3M® Meditrace® model, with a 10mm diameter captation surface. The electrodes were placed in parallel, with 20 mm of distance between each other. A pre amplification circuit was used, with a gain of 20 times, CMRR (Common Mode Rejection Ratio) greater than 80 dB and an impedance of 1012 Ω. The signals were captured in a signal conditioner module, LYNX® BIO EMG 1000 model, using three channels for EMG signals. The signals were filtered with a digital band-pass filter of 20 – 500 Hz. All channels had a final gain of 1000 times and 4000 Hz of sampling frequency. The acquisition and storage of the signals were made using the LYNX® Bioinspector 1.8 software.

2.4. Data processing

The signals had to have the prerequisites to the Fourier Transformed calculation (stationarity, seasonality and trend). Therefore, the EMG peak activation was determined (by linear envelopment) and then it was selected 250 points before and after it; determining, in this way, 501 points or 125 ms, that was extracted to analysis. All signals were processed in MatLab®, with an algorithm made to attain MPF and F95 of the signals.

2.5. Statistical analysis

A Shapiro-Wilks normality test was applied. After the normality detection of the data, a t-student statistical test, for independent samples was applied, with a significance level of 5%. The tests were applied comparing both, the groups and the muscles inside the same group.
3. Results
For a better visualization of the means and respective standard deviations, they are disposed in Table I.

|                         | Control (Hz) | PFPS (Hz) | p-value |
|-------------------------|--------------|-----------|---------|
| MPF – VMO               | 61.59±10.7   | 58.15±8.6 | 0.004*  |
| MPF – VL                | 60.24±9.8    | 58.96±9.1 | 0.251   |
| p-value                 | 0.135        | 0.515     |         |

* refers to statistical significant difference.

|                         | Control (Hz) | PFPS (Hz) | p-value |
|-------------------------|--------------|-----------|---------|
| F95 – VMO               | 160.60±34.9  | 162.51±37.7| 0.649   |
| F95 – VL                | 154.04±30.9  | 144.99±26.8| 0.011*  |
| p-value                 | 0.025*       | 0.0002*   |         |

* refers to statistical significant difference.

Looking at the MPF analysis, there was a statistically significant difference (p=0.004) between control and PFPS groups, in the VMO muscle EMG signal. For the F95 analysis, a statistical significant difference (p=0.011) was verified between the groups in the VL muscle. Still in the F95 analysis, it was observed a difference between the VMO and the VL muscles, inside the PFPS (0.0002) and the control (p=0.025) groups. Nevertheless, the lowest power index in the test was found in the last case (power = 0.61), it being known that the closest to 1 shows a more reliability.

The graphics of the Figures 1 and 2 show an illustrative comparison of the frequencies and where were founded the statistical differences.
4. Discussion

As previously related, the aim of this paper was to define the characteristics of the power spectrum of an EMG signal during weight shift phase in stair climbing, in a group of patients with PFPS. Originally, the hypothesis was to find a muscular recruitment strategy difference between VMO and VL muscles, for symptomatic individuals, when compared to individuals of a control group.

The mean power frequency represents a central tendency measure, that divides in half the total area of the spectrum. The F95 is a point where 95% of the total spectrum area is concentrated. Together, both provided important information of the spectrum morphology in relation to data compression in the plot.

Comparing specifically each muscle, it could be observed that in the VMO muscle, the centrality pattern (MPF) is distinct in each group. However, the same was not found when looking to F95, showing, thus, a greater data dispersion in the PFPS group, mainly in the final half of the graphic. In the VL muscle, this relationship was inverted, as it was not possible to find differences in MPF, but in F95, showing a greater dispersion in the control group data. A greater dispersion in the frequency data plot may denote recruitment of muscle fiber with distinct contraction characteristics [13, 15, 16]. It is evident that a slight imbalance of those characteristics between the groups exists, when making a comparison of the relationship of each muscle performance, because the VL muscle data, in the PFPS group, is more concentrated that in the control group, and the VMO muscle data is more disperse.

When comparing the muscles, similar morphologic characteristics on the graphics were found in both groups. It was showed an equalitie of the MPF between VMO and VL muscles, and a more evident dispersion in the VMO plot related to F95 in the VL muscle. However, it has to be emphasized that, in the control group, this difference found in F95 (p=0.025) do not has the same impact that the difference found in the PFPS group (p=0.0002), what indicates a more evident data dispersion in the symptomatic group.
5. Conclusions
The opposite density distribution of the VMO and VL muscles, when the MPF and F95 of the control group is observed, compared to the PFPS group, can represent a distinct relationship in the muscle fibers recruitment tendency. However a normalized analysis of the power spectrum characteristics, as well as the peak frequency, could be helpful to reach an even tighter conclusion about the parameters and characteristics of a frequency domain analysis in patients with patellofemoral pain syndrome. An EMG analysis of others motor gestures could be very useful to complement this study.

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