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ORIGINAL ARTICLE

Electromyographic and magnetic resonance imaging evaluations of individuals with patellofemoral pain syndrome

Avaliação eletromiográfica e ressonância magnética do joelho de indivíduos com síndrome da dor femoropatelar

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Abstract

Objectives: To analyze the electrical activity of the vastus medialis obliquus (VMO), vastus lateralis longus (VLL) and vastus lateralis obliquus (VLO) muscles of individuals with patellofemoral pain syndrome (PFPS) during maximum voluntary isometric contraction (MVIC) of lower leg extension with the knee at 30°; to assess pain using a visual analogue scale (VAS); and to assess patellar positioning using magnetic resonance imaging (MRI). **Methods:** Twelve women with PFPS and 12 clinically normal women were evaluated. They performed five MVICs of lower leg extension at 30° for electromyographic (EMG) analysis. Using MRI, the sulcus angle (SA), congruence angle (CA), patellar tilt angle (PTA) and patellar displacement (PD) were obtained. The following statistical tests were used: analysis of variance (ANOVA) for repeated measurements to assess EMGs; Mann-Whitney U test to analyze MRIs; Pearson's (r) correlation test between EMGs and MRIs; and one-way ANOVA to evaluate pain ($p \leq 0.05$). **Results:** In the PFPS group, there was greater electrical activity in the VLL than in the VMO. In both groups, there was greater electrical activity in the VMO and VLL than in the VLO. In the PFPS group, the MRI showed higher SA and lower CA values, and there was a negative correlation between the VMO and the PTA. **Conclusion:** The data suggest that, in individuals with PFPS, greater electrical activity in the VLL combined with an increased SA and a decreased CA may contribute to patellar instability.

Key words: patellofemoral pain syndrome; electromyography.

Resumo

Objetivos: Analisar a atividade elétrica (EMG) dos músculos vasto medial oblíquo (VMO), vasto lateral longo (VLL) e vasto lateral oblíquo (VLO) de indivíduos com síndrome da dor femoropatelar (SDFP) durante contração isométrica voluntária máxima (CIVM) de extensão da perna com o joelho a 30^0, a dor por meio da Escala Visual Analógica (EVA) e o posicionamento da patela por meio da ressonância magnética nuclear por imagem (RMNI). **Métodos:** Avaliaram-se 12 mulheres com SDFP e 12 clinicamente normais, que realizaram cinco CIVM de extensão da perna no ângulo de 30^0 para análise da EMG. Avaliou-se o ângulo do sulco (AS), ângulo de congruência (AC), ângulo de inclinação patelar (AIP) e deslocamento patelar (DP) pela RMNI. Utilizaram-se testes estatísticos: ANOVA, análise de variância de medidas repetidas para EMG; o teste *Mann-Whitney U* para análise da RMNI; o teste de correlação de *Pearson* (r) entre EMG e RMNI e análise de variância *one-way* para avaliação da dor ($p \leq 0,05$). **Resultados:** Verificou-se maior atividade elétrica do músculo VLL em relação ao VMO no grupo com SDFP. Em ambos os grupos, os músculos VMO e VLL apresentaram maior atividade elétrica que o VLO. Para o grupo SDFP, a RMNI revelou maiores valores do AS e menores do AC, e verificou-se uma correlação negativa entre VMO e AIP. **Conclusão:** Os dados sugerem que maior atividade elétrica do VLL, juntamente com o aumento do AS e diminuição do AC, possam ser fatores favorecedores da instabilidade patelar nos indivíduos com SDFP.

Palavras-chave: síndrome da dor patelofemural; eletromiografia.

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Introduction

Patelloferomal pain syndrome (PFPS) is often called patellofemoral stress syndrome or patellofemoral joint dysfunction, and it affects patients of all age groups, especially adolescents and young adults between 10 and 35 years of age, being more common in women than men[1]. It develops gradually with diffuse pain in the peripatellar and retropatellar regions during or after activities such as climbing and descending stairs, kneeling or remaining seated for a long time, followed by crepitation that usually improves with rest[2]. To date, there is no consensus on the definition, etiology, and diagnosis of PFPS[3], but for some authors, the etiology includes factors such as: trauma, overuse, osteochondral changes, irritation of the synovial plica, ligament looseness[4], incongruence between bone components (especially the shape of the trochlear groove, the patella and its position), the alignment between the femur and the tibia, and the Q angle, characterizing patellar malalignment[5,6].

Among the biomechanical factors most related to the development of PFPS, the most prominent is insufficiency or imbalance between the patella's dynamic medial stabilizer (vastus medialis obliquus - VMO) and the dynamic lateral stabilizer (vastus lateralis longus - VLL)[7,8]. Morrish and Woledge[9] and Bevilaqua-Grossi, Monteiro-Pedro e Bérzin[10] reported that the vastus lateralis obliquus (VLO) plays an important role in patellar stabilization, acting in opposition to the VMO. However, there is still some controversy regarding the behavior of these muscles and the patella's position during knee extensions and regarding the association of these physiological factors with anatomical factors in PFPS etiology.

Table 1. Signs and symptoms used as inclusion and exclusion criteria for the PFPS group and the control group.

Inclusion criteria for the PFPS group
• Pain in the patellofemoral joint in the past month and pain in at least three of the following functional activities: crouching down for an extended period of time, ascending or descending stairs, kneeling, running, sitting down for a long time[14,15].
• Presence of at least three of the following clinical signs: patellar crepitation; Q angle greater than 16º; excessive subtalar pronation; high patella; retraction of the iliotibial tract; sensitivity to palpation of the patellar facets; lateral tibial torsion; medial or lateral patellar malalignment; patellar hypo- or hypermobility; and the bayonet sign[16].
Inclusion criteria for the control group
• Absence of pain in the past month verified by the Visual Analogical Scale (VAS)[15].
• Presence of no more than two signs of PFPS[16].
Exclusion criteria for both groups
• History of injury or surgery of the hip, knee and ankle[15].
• Individuals with neurological, cardiovascular and rheumatological diseases[15].
• Use of medication and/or physical therapy prior to the study[17].

According to Bull et al.[11], patellofemoral incongruence is the first pathological condition that affects this joint and is responsible for the luxation, subluxation, chondromalacia, and osteoarthritis. Because patellofemoral incongruence occurs mainly during the first degrees of lower limb flexion, the use of magnetic resonance imaging (MRI) to evaluate patellar alignment and placement is considered an extremely sensitive and efficient method of diagnosis[5]. Several authors have used MRI to study the position of the patella of subjects with PFPS. They analyzed the sulcus angle (SA), congruence angle (CA), patellar tilt angle (PTA), and lateral patellar displacement (PD) in the various degrees of knee flexion and types of contraction[5,12,13]. However, the authors did not investigate the association between these data and electromyographic (EMG) and pain parameters[4,14]. Thus, the purposes of the present study were: (a) to analyze the electrical activity of the VMO, VLL and VLO in subjects performing maximal voluntary isometric contractions (MVICs) at 30° knee flexion during open kinetic chain (OKC) extension; (b) to verify, through MRI, the patellar position based on the SA, CA, PTA and PD at 30° with the quadriceps relaxed; and (c) to assess the intensity and the discomfort caused by pain before and immediately after the performance of these exercises in subjects with and without PFPS.

Methods

Subjects

Twenty-four sedentary women, with a mean age of 22.52 (±3.94) years, were selected. They underwent a functional evaluation and were divided in two groups: PFPS group (n=12) and control group (n=12), according to the inclusion[14-16] and exclusion[15,17] criteria shown in Table 1. The study was conducted in accordance with Resolution 196/96 of the National Health Council and was approved by the Research Ethics Committee of Universidade Federal de São Carlos (UFSCar), São Carlos (SP), Brasil, Protocol no. 039/03. The subjects gave their informed consent.

Equipment

Electromyograph

To capture the electrical activity of the VMO, VLL and VLO, we used simple active differential surface electrodes (Lynx Electronic Technology), consisting of two parallel Ag/AgCl bars, with 100x gain, common-mode rejection ratio (CMRR) of 80 dB and input impedance greater than 100 MΩ. A reference electrode was placed on the tibial tuberosity on the same side as the assessed knee. A 16-channel Signal Conditioning Module (SCM 1000-v2) was also used, with a 10x gain, interfaced with a Pentium III PC with an analog-to-digital converter (ADC 12/36 - 60K) and data acquisition software (Aqdados 5.7 for Windows, Lynx Electronic Technology) with a high-pass filter of 20 Hz and low-pass filter of 500 Hz. Electromyographic signals were sampled synchronously, with a sampling frequency of 2000 Hz per channel and were analyzed using Root Mean Square - RMS (μV).

MRI

The positioning of the patella was evaluated by 0.5 Tesla MRI, developed by the Magnetic Resonance Group of the Institute of Physics of Universidade de São Paulo (resolution = 256x256 matrix; size = 128X128 mm; slice thickness (THK) = 5 mm; slice distance = 6 mm; interslice gap = 1 mm; TR = 500 ms; TE = 25 ms, and means = 4). The images were scanned in T1.

VAS

The Visual Analog Scale, ranging from 0 to 100 mm, evaluated the intensity (sensory dimension) and unpleasantness (affective dimension) of pain[6].

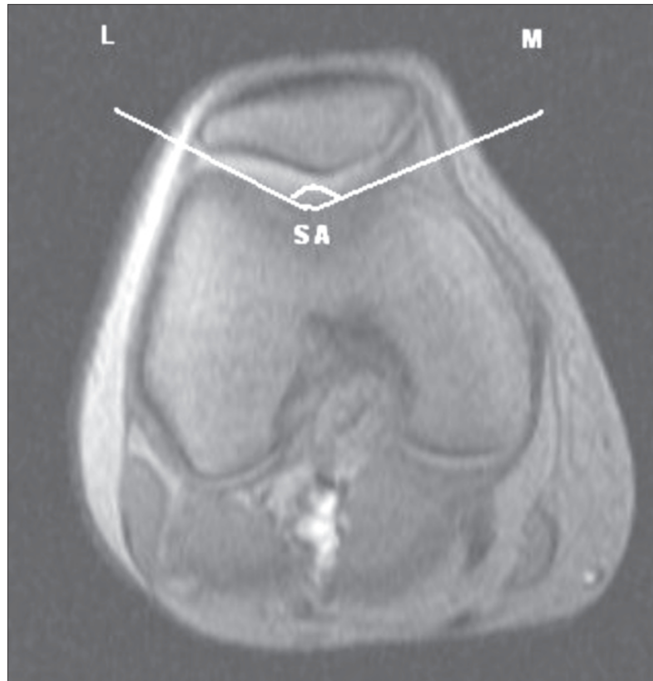
Procedures

The electrodes that capture the electrical potential of the VMO, VLL and VLO were placed parallel to the muscle fibers[18] according to the inclination angles suggested by Lieb and Perry[19] and Bevilaqua-Grossi, Monteiro-Pedro and Bérzin[10]. The subjects performed five MVICs at 30° and 90° flexion (selected at random) during OKC extension, with the 90° angle used for normalization of the EMG signal. Each contraction lasted 6 seconds, with a 30-second rest between contractions and a two-minute rest at each angle to avoid fatigue. Each subject completed the VAS before and immediately after completion of the proposed exercise.

For the MRI analysis, the subjects were positioned supine with the knee flexed to 30° and the quadriceps relaxed[5,12]. A localizer image was obtained in the sagittal plane, positioning the second section over the inferior pole of the patella. After that, nine images were obtained in the axial (transverse) plane. The data analyzed in the MRI images were: SA[20] (Figure 1), CA[20] (Figure 2), PTA[20] (Figure 3), and PD[20] (Figure 4). The image that presented the greatest diameter of the patella was chosen to calculate the mean of three measures. The software NIH Image[21] was used for these evaluations.

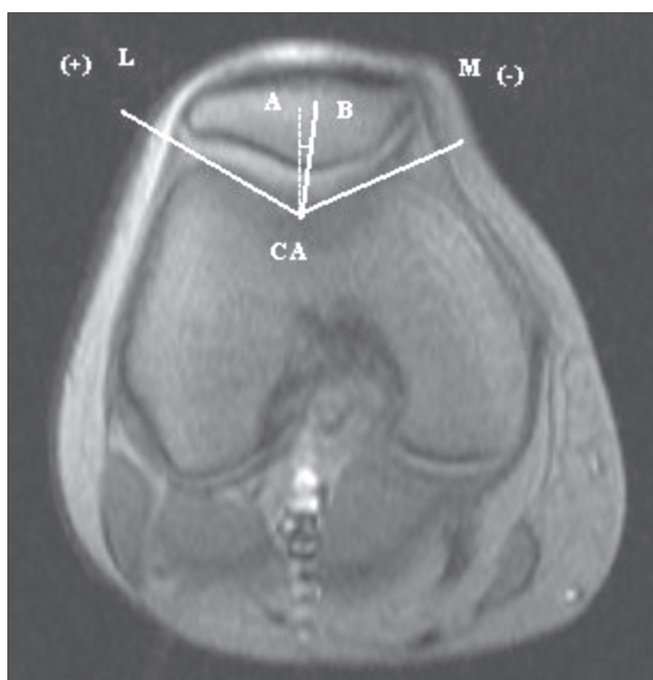
Statistical analysis

The Student t test for independent data was used for the analysis of the anthropometric measurements. To analyze the EMG data, within-group repeated-measures ANOVA was performed for the different muscles at 30°. The Mann-Whitney test was used to assess the positioning of the patella between



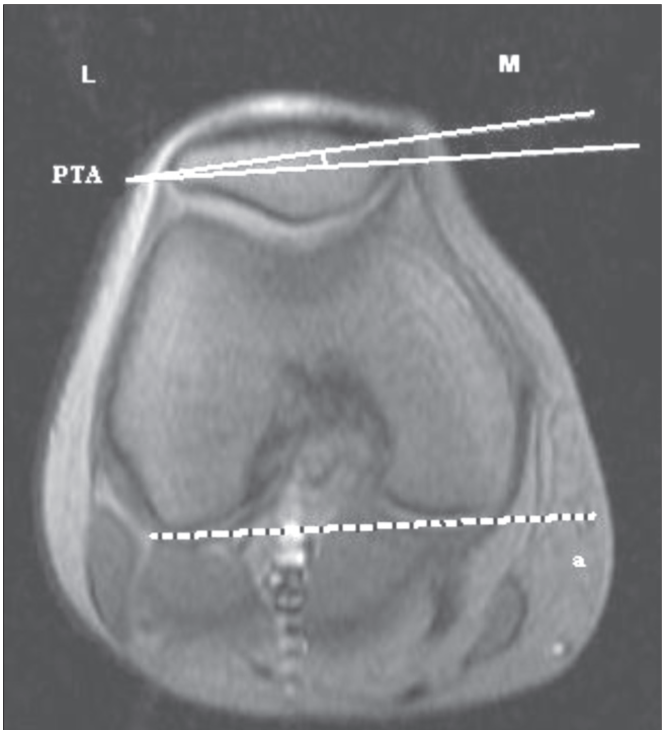
L=lateral; M=medial. The reference value of 138° is closely associated with joint instability[20].

Figure 1. Sulcus angle (SA) between the lateral and medial facets of the femoral trochlea.



L=lateral; M=medial. Lateral deviation (positive values) and medial deviation (negative values). A mean reference value of -6°, was used to assess subluxation[20].

Figure 2. Congruence angle (CA) between the bisecting line of the SA (AC) and the line between the apex of the patella and the medial portion of the trochlear groove (BC).



L=lateral;M=medial [20].

Figure 3. Patellar tilt angle (PTA) formed by the intersection of the line parallel to the posterior femoral condyles and the line between the lateral and medial borders of the patella. Medial opening (positive), lateral opening (negative).

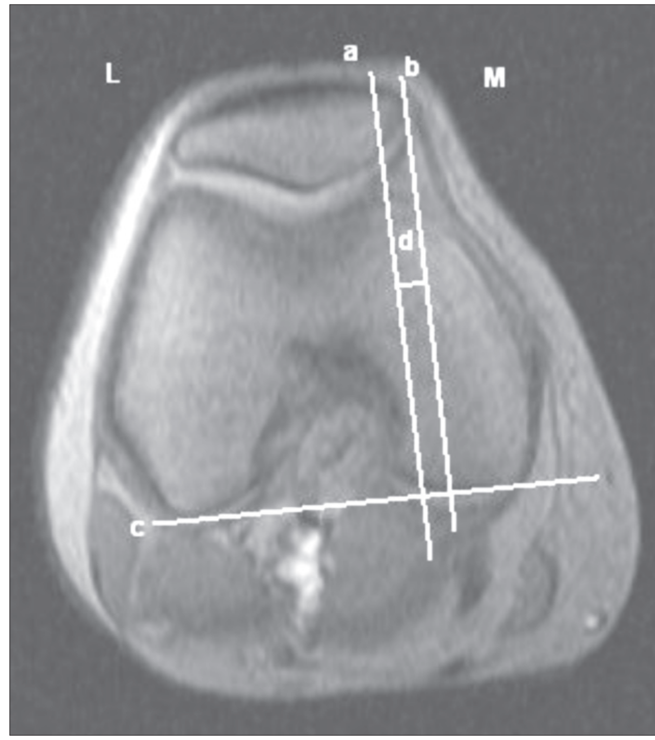


Figure 4. Lateral patellar displacement (PD), distance (d) between the apex of the medial condyle (a) and the medial end of the patella (b) in mm projected perpendicularly in a line parallel to the posterior femoral condyle (c). Negative values (lateral) and positive values (medial)[20].

Table 2. Mean (±SD) of normalized EMG recordings for the VMO, VLL and VLO muscles at 30º of knee flexion in the control group.

	30º			
	VMO	VLL	VLO	p
Control	67.74%±16.34*	-	45.20%ª±15.17	(p=0.0004)
	-	79.82%ᵇ±25.34**	45.20%ª±15.17	(p=0.0016)

*Significant difference between VMO and VLO (p=0.0004) - control group; **Significant difference between VLL and VLO (p=0.0016) - control group; VMO=vastus medialis obliquus; VLL=vastus lateralis longus; VLO=vastus lateralis obliquus.

the groups. Data normality was tested using Shapiro-Wilks' W test. Pearson's correlation (r) test was used between EMG and MRI data. For the analysis of the pain intensity and unpleasantness, one-way ANOVA was performed in which the variable of interest was the difference between before and after, and the factor was the group. Within each group, the paired t test for independent data was performed. The level of significance was set at p<0.05.

Results

The comparison between the age, height, weight, and body mass index (BMI) of each group showed that the PFPS and control groups did not differ significantly (p>0.05).

Electrical activity: In the control group, the VMO and VLL were not significantly different (p=0.1065) and showed higher electrical activity than the VLO (p=0.0004) and (p=0.0016), respectively (Table 2). In the PFPS group, the electrical activity of the VLL was greater than that of the VMO (p=0.0107), and the VMO and VLL showed higher electrical activity than the VLO (p=0.0082 and p=0.0009, respectively; Table 3).

Positioning of the patella: In the PFPS group, the SA was significantly higher than in the control group (p=0.02), however the CA had an opposite behavior, being higher in the control group (p=0.01). No significant difference was found between groups in the PTA (p=0.54) and PD (p=0.15) (Table 4).

Correlation between EMG and MRI: In the control group, there was a weak correlation between all analyzed

Table 3. Mean (±SD) of normalized EMG recordings for the VMO, VLL and VLO muscles at 30° of knee flexion in the PFPS Group.

	30°			
	VMO	VLL	VLO	p
PFPS	62.79%±16.34*	81.92%±25.34	-	(p=0.0107)
	-	81.92%±24.45**	47.60%±15.12	(p=0.0009)
	62.79% ±16.05***	-	47.60%±15.12	(p=0.0082)

*Significant difference between VLL and VMO (p=0.0107) - PFPS group; **Significant difference between VLL and VLO (p=0.0009) - PFPS group; ***Significant difference between VMO and VLO (p=0.0082) - PFPS group; VMO=vastus medialis obliquus; VLL=vastus lateralis longus; VLO=vastus lateralis obliquus.

Table 4. Mean (±SD) of SA, CA, PTA and PD for the control and PFPS groups with the knee flexed to 30° as assessed by MRI.

	SA (°)		CA (°)		PTA (°)		PD (cm)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Control	133.58	5.62	-20.35**	9.26	11.73	4.19	4.38	3.48
PFPS	140.23*	7.74	-8.51	8.30	12.85	3.97	1.93	4.46

*Significant difference (p=0.02); ** Significant difference (p=0.01); SA=sulcus angle; CA =congruence angle; PTA=patellar tilt angle; PD=patellar displacement.

variables. When analyzing the PFPS group, we observed that only the PTA had a moderate to strong negative correlation with the VMO (r=-0.76; Table 5).

Pain: In the PFPS group, both pain intensity (p<0.0001) and unpleasantness (p<0.0001) were significantly greater after the knee extension MVIC exercises when compared to the control group (p=0.0004 and p=0.0006 for intensity and unpleasantness respectively).

Table 5. Pearson's (r) correlation coefficient for the PFPS group comparing EMG and MRI data.

EMG	MRI			
	SA	CA	PTA	PD
VMO	-0.08552	0.165057	-0.76125*	-0.0966
VLL	0.476309	0.091935	-0.62097	0.010465
VLO	-0.27047	0.27674	-0.5869	0.334717

*Pearson's (r) correlation coefficient test.

Discussion

The data revealed that, in the PFPS group, the electrical activity of the VLL was greater than that of the VMO, and that both the VMO and the VLL showed increased electrical activity in relation to the VLO. These results corroborate those of Mariani and Caruso[22] and Boucher et al.[23] who investigated the VMO and VLL in the last 30° of knee extension. Both found a decrease in the VMO activity of the PFPS group in relation to the VLL, noting imbalance between the medial and lateral components.

Despite the methodological differences, Souza & Gross[7] also found lower activity of the VMO in subjects with PFPS in the last degrees of extension and, together with Mariani and Caruso[22], suggested that therapeutic exercises in the final degrees of extension may favor neuromuscular imbalance of the VMO. In the present study, the subjects with PFPS not only showed a preference for activating the VMO, but also favored the action of the VLL. Although there are authors who disagree with these results[24,25], this shows a significant imbalance associated with patients with PFPS. Therefore, caution is recommended during clinical physical therapy practice when performing knee extension MVIC during the last degrees of OKC, when there is greater patellofemoral stress[26].

The VLO muscle requires further studies in people with PFPS given that the present study and other studies[16,27,28], despite methodological differences, found that this portion does not appear to directly interfere in patellar lateralization and in imbalance. According to our results, these changes are attributed, in principle, to the VLL because there were no differences in the activation of this portion in the PFPS subjects. In the control group, there was no difference in electrical activity between the VMO and VLL, but both showed increased electrical activity compared to the VLO. These results are in accordance with Mariani and Caruso[22], Reynolds et al.[29], and Bevilaqua-Grossi, Monteiro-Pedro and Bérzin[10], who analyzed the electrical activity of the VMO and VLL in the last degrees of knee extension and found no significant difference in activation. In contrast, Fonseca et al.[30] found less activation of the VL during OKC extension at 30° and lateral hip rotation.

Although there are few studies on VLO electrical activity in the literature[9-10], the present study disagrees with them. Morrish and Wolege[9] and Bevilaqua-Grossi, Monteiro-Pedro and Bérzin[10] analyzed the EMG activity of the VMO and VLO and found that the activation of these portions was almost synchronous, suggesting that both have reciprocal action in controlling patellar position. However, the results of this study did not agree with this finding because the VLO electrical activity was lower in the PFPS and control groups at 30° flexion. This result may be due to the higher angle of knee flexion compared to previous studies, which resulted in a variation in muscle recruitment.

Some studies[20,31] described in the literature have established that the SA is a good indicator of patellofemoral dysplasia, being intimately related to the instability of the joint, and that the patellofemoral joint is congruent when the CA is zero or when the opening angle faces the medial region of the knee, which is represented by negative values. The results revealed a higher SA and a lower CA in people with PFPS, corroborating Kujala et al.[12] and Guzzanti et al.[32]. For Kujala et al.[12], patients who present, along with a high patella, a narrow and shallow trochlear groove, are more prone to patellar instability. The subjects in the PFPS group showed a lower SA and a lower CA, suggesting a possible cause for the instability of the patellofemoral joint. Regarding the control group, the lower SA and the higher CA provide better patellofemoral congruence. These findings are consistent with the balance achieved between the patellar stabilizers in the control group.

No differences were found for the PD and the PTA in both groups, in agreement with Brossmann et al.[13] who also assessed individuals with the knee flexed to 30°. In the active extension of the knee, however, a difference was observed, suggesting that the type of exercise can influence the positioning of the patella. These results disagree with Kujala et al.[12], possibly due to methodological differences, given that the present study used the posterior femoral condyle as a reference to perform these measures.

There is still no consensus in the literature regarding the evaluation of the positioning of the patella with the quadriceps contracted or relaxed. The present study was performed with the quadriceps relaxed, and this may explain the absence of differences between the groups because, in Taskiran et al.[33], the PTA was lower with the quadriceps contracted in individuals with patellofemoral instability in relation to the control group. In contrast, Kujala et al.[5] evaluated the PD in a control group during knee extension MVICs and compared the images with the quadriceps relaxed, finding no difference between them. For Tennant et al.[34], a moderate lateral tilt and a lateral displacement of the patella are normal factors that occur early in the knee flexion with load and are not necessarily present in symptomatic patients who have malalignment.

According to Brossmann et al.[13], the differences between the PTA of the patients with PFPS can be attributed to the increased Q angle, valgus knee, or the insufficiency of the medial portion of the quadriceps muscle, which cause an increase in patellar tilt. By investigating the association between the position of the patella and the EMG, the data of the present study revealed a negative correlation only between the VMO and the PTA of the PFPS group, suggesting a lower activity of the medial portion of the quadriceps muscle and an increase in the PTA. These results showed, therefore, that the patellar position was not correlated to the electrical activity. Taskiran et al.[33] used computed tomography to analyze the PTA of the knee and EMG to analyze the VMO and VL in nine normal subjects (G1), 10 with knee pain (G2) and 8 with patellar luxation (G3). The results showed a decrease in PTA in G1 and an increase in G2 and G3 during quadriceps contraction at 0°, 15° and 45° of knee flexion. In all the studied angles, the balance between the portions was only verified in G1. In the other groups, there was increased VMO activity relative to the VL, except at 45°. According to the Taskıran et al.[33], the findings do not support the hypothesis of the centralizing effect of the VMO on the patella during knee extension, but that the effect of the VMO may be best seen in the PTA both with the quadriceps contracted and relaxed.

The individuals from the PFPS showed less congruence between the patella and the femur, following the muscle imbalance evidenced by the EMG and a significant increase in pain. Little is known about patients with PFPS and the relationship between pain and muscle weakness[35]. The PFPS is largely characterized by subjective reports of pain and functional disability, and the functional tests seemed to be the most appropriate for its evaluation[36]. Assessing the patient's symptoms is an important part of clinical practice and of the development of research[37]. Thus, with pain being the main symptom of PFPS, one of the most commonly used assessment methods is the VAS. In the present study, the difference in pain levels between both groups was expected; however, it was necessary to evaluate its behavior before and after the completion of the MVIC. The results revealed a significant increase in pain after the exercises.

Pain seems to worsen in activities that involve an increase in patellofemoral compressive force, such as remaining seated for long periods, climbing and descending stairs[38], kneeling or squatting[39]. According to Manske and Davies[40], this pain may be due to stress in the peripatellar tissues and to deficiency in the patellofemoral cartilage when the knee remains flexed for prolonged periods. Another possible cause is the stasis or decline in the movement and consequent reduction in synovial fluid between the posterior surface of the patella and the trochlear groove during the prolonged time in which patients remain seated.

In addition to pain, atrophy and weakness of the quadriceps muscle are found in almost all patients with PFPS[38], and physical therapy approaches often include strengthening of the VMO muscle to promote medial stability of the patella in the trochlear groove and/or produce its realignment[40]. The MRI analysis was performed with the quadriceps relaxed at 30° of knee flexion, however there is a need to develop equipment for analyzing greater angles and a need to examine a larger sample of people with PFPS.

Conclusion

The data suggest that increased electrical activity of the VLL, along with the increase in the SA and the decrease in the CA, may be factors that favor patellar instability in individuals with PFPS. The subjects in the control group showed a better patellofemoral congruence and balance between the VMO and VLL.

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