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# Neuromuscular efficiency of the quadriceps in women with and without patellofemoral pain

*Eficiência neuromuscular do quadríceps em mulheres com e sem dor patelofemoral*

*Eficiencia neuromuscular del cuádriceps en mujeres con y sin dolor patelofemoral*

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ABSTRACT | Patellofemoral pain (PFP) may contribute to less activation of the quadriceps muscle, favoring joint overload and pain. Neuromuscular efficiency (NME) is a variable that evaluates the relationship between the amount of neural stimuli and the ability to generate force of in a given muscle, with the most efficient being the one that produces greater muscle force, with less activation of muscle fibers. In this sense, this study aimed to evaluate the strength and NME of knee extensors in women with and without patellofemoral pain. A total of 24 adult women, recruited via a questionnaire, aged from 18 to 30 years, with and without patellofemoral pain, participated in this study. Anamnesis, anterior knee pain scale, and numerical visual scale were applied. Subsequently, the knee extensor strength, with a hand-held dynamometer, and the NME of vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF) were assessed. For statistical analysis, appropriate tests were adopted to compare variables between groups and correlate them. In all statistical tests, a $\alpha<0.05$ was adopted. Results showed that women with PFP had 61% lower NME in the VM and 52% in the VL, compared to the group without pain. No significant difference was found for knee extensor strength between groups. We conclude that pain negatively influences VM and VL recruitment but does not change quadriceps ability to generate strength.

Keywords | Muscle Strength; Electromyography; Knee.

RESUMO | A dor patelofemoral (DPF) pode contribuir para menor ativação do músculo quadríceps, favorecendo maior sobrecarga e dor nesta articulação. A eficiência neuromuscular (ENM) é uma variável que avalia a relação entre a quantidade de estímulos neurais e a capacidade de geração de força de um determinado músculo, sendo mais eficiente aquele que produz maior força muscular, com menor ativação das fibras musculares. Nesse sentido, o objetivo do estudo foi avaliar a força e a ENM dos extensores de joelho em mulheres com e sem dor patelofemoral. Participaram deste estudo 24 mulheres, recrutadas por meio de um questionário, com idades entre 18 e 30 anos, com e sem dor patelofemoral. Foram realizadas a anamnese, a escala de dor anterior no joelho e a escala visual numérica e, posteriormente, a avaliação da força extensora de joelho, com dinamômetro manual, e a avaliação da ENM de vasto medial (VM), vasto lateral (VL) e reto femoral (RF). Para análise estatística, foram adotados os testes apropriados para comparação das variáveis entre os grupos e para correlação entre elas. Em todos os testes estatísticos foi adotado o nível de significância de $\alpha<0,05$. Os resultados mostraram que mulheres com DPF apresentaram 61% menor ENM do VM e 52% do VL, em comparação ao grupo sem dor. Não se encontrou diferença significativa para força extensora de joelho

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entre os grupos. Concluímos que a dor influencia negativamente o recrutamento de VM e VL, mas não altera a capacidade do quadríceps de gerar força.
Descritores | Força Muscular; Eletromiografia; Joelho.

**RESUMEN |** El dolor patelofemoral (DPF) puede producir una menor activación del músculo cuádriceps, lo que lleva a una mayor sobrecarga y dolor en esta articulación. La eficiencia neuromuscular (ENM) es una variable que evalúa la relación entre la cantidad de estímulos neurales y la capacidad de determinado músculo de generar fuerza, con más eficiencia para el que produce mayor fuerza muscular, con menor activación de las fibras musculares. Así el objetivo del estudio fue evaluar la fuerza y la ENM de los extensores de rodilla en mujeres con y sin dolor patelofemoral. En este estudio participaron 24 mujeres, con edades entre 18 y 30 años, con y sin dolor patelofemoral, que han sido reclutadas por medio de un cuestionario. Se aplicaron la anamnesis, la escala de dolor anterior de rodilla y la escala visual numérica. Posteriormente, se realizaron evaluaciones de la fuerza extensora de la rodilla con dinamómetro manual y de la ENM del vasto medial (VM), vasto lateral (VL) y recto femoral (RF). Para el análisis estadístico, se adoptaron pruebas apropiadas para comparar variables entre grupos y correlacionarlas. En todas las pruebas estadísticas, el nivel de significación fue de $\alpha<0,05$. Los resultados mostraron que las mujeres con DPF tenían el 61% menor ENM en el VM y el 52% en el VL en comparación con el grupo sin dolor. No hubo diferencias significativas para la fuerza extensora de la rodilla entre los grupos. Se concluye que el dolor influye negativamente en el reclutamiento de VM y VL, pero no cambia la capacidad de generar fuerza del cuádriceps.
Palabras clave | Fuerza Muscular; Electromiografía; Rodilla.

## INTRODUCTION

Patellofemoral pain (PFP) is an extremely common musculoskeletal complaint in active individuals[1]. The onset of symptoms is insidious and usually occurs after an activity that involves joint load, such as walking, stair climbing, squatting, and sitting with knees flexed for a prolonged period[2].

The prevalence of PFP is higher in women, especially physically active ones, and may be related to physiological factors such as ligament laxity, a more pronounced Q angle, dynamic knee valgus, among others[3]. The recurrence of this pain is extremely high, reaching 70% to 90% persistence of symptoms, which result in decreased quality of life, loss of function, sedentary lifestyle, anxiety, and depression. In this sense, some studies indicate that more than 50% of patients with PFP have an unfavorable prognosis within 5 to 8 years[4].

The etiology of the pain is multifactorial and involves joint overload and deficits in quadriceps muscle performance, movement control, and mobility[4].

The quadriceps muscle is formed by four individual muscles, responsible for the extension movement of the knee, via the traction of the patella and the patellar tendon. Therefore, during the movement, all muscles must be efficiently recruited[5], to avoid any alteration in the quadriceps muscle ability to generate force, which could overload some individual muscle or the joint itself.

The combination of different evaluative methods has often been used due to the complexity of human movement[6]. Neuromuscular efficiency (NME) evaluation is obtained by the relationship between the amount of neural stimuli and the muscle force-generating ability. This information is collected via electromyography (EMG)[7] and strength testing, and the muscle that produces greater muscle force with less activation of muscle fibers is considered more efficient[6].

Therefore, NME evaluation is important to analyze the recruitment of motor units and the muscle force-generating capacity, in order to better understand the neuromuscular alterations involved in PFP and, consequently, to prevent the chronicity of symptoms. Therefore, this study aims to compare muscle strength and NME of the quadriceps in women with and without PFP. The hypothesis is that women who suffer from PFP have lower knee extensor strength and, consequently, lower NME compared to asymptomatic women.

## METHODOLOGY

### Subjects

This research included young women, university students aged 18–30 years with a sedentary lifestyle (Table 1). The inclusion criteria for the PFP group required participants to report pain for more than six months while performing activities such as walking, climbing/descending stairs, and squatting, as well as scoring a minimum of five points on the numeric rating scale (NRS). Exclusion criteria included women who had undergone lower limb surgery or suffered knee trauma, and those who did not complete the entire protocol.

Table 1. Sample characterization

| | Control group (n=12) | PFP Group (n=12) | p |
|---|---|---|---|
| Age (years) | 22.45±1.29 | 21.58±1.03 | 0.745 |
| Body mass (kg) | 58.74±8.98 | 57.04±7.37 | 0.628 |
| Height (m) | 1.60±0.04 | 1.63±0.073 | 0.237 |
| BMI (kg/m$^2$) | 22.642±2.96 | 21.193±1.76 | 0.173 |
| AKPS | 95.36±6.72 | 80.41±10.83 | 0.654 |
| NRS | - | 6±1.031553471 | - |

Values expressed as mean±standard deviation. PFP: patellofemoral pain; BMI: body mass index; AKPS: anterior knee pain scale; NRS: numeric rating scale.

## Study design

This is a non-randomized, quantitative, cross-sectional study conducted at the Musculoskeletal Assessment Laboratory of the Universidade Estadual Paulista "Júlio de Mesquita Filho" (Unesp), Marília campus. Data collection was carried out from October to December 2021.

All participants were properly informed of the study objectives and signed an informed consent form (ICF).

## Evaluation procedures

The evaluations began with the collection of personal data and medical history via anamnesis. Then, the anterior knee pain scale (AKPS) was applied, and the participants underwent assessments of knee extensor strength and NME.

## Anterior knee pain scale (AKPS)

The AKPS scale translated into and validated for Brazilian Portuguese[8] was applied, which consists of 13 questions and evaluates lower limb functionality. The scale ranges from 0 to 100 points, in which 100 means no functional limitation; scores below 82 indicate patellofemoral disorders; and 0 means several functional limitations and constant pain[9].

## Numeric rating scale (NRS)

The NRS was used to measure pain intensity, which is a ruler containing numbers from 0 to 10, in which 10 indicates "worst possible pain" and 0, "no pain"[10].

## Knee extensor strength testing

The muscle strength testing of knee extensor was performed bilaterally with a hand-held dynamometer (*Lafayette*®), stabilized with a belt and positioned above the malleolus prominence. Before the start of the protocol, familiarization with the equipment was performed, consisting of two submaximal and two maximal contractions of the muscle group under evaluation[11]. Between familiarization and the start of data collection, there was a two minute interval to avoid fatigue[11].

For the evaluation protocol, three maximal voluntary isometric contractions were performed for knee extension for five seconds, with a 30 second interval between each contraction[12]. The volunteers were seated on the leg extension machine with the knee flexed at 90° (0° of full extension).

## Assessment of muscle activation

For the collection of electromyographic signals, a biological signal acquisition system with eight channels was used. Myosystem-BR1 software program presents the following characteristics: calibrated at a sampling frequency of 2,000Hz, a total gain of 2,000 times (20 times in the sensor and 100 times in the equipment), a 20Hz high-pass filter, and a 500Hz low-pass filter. Active electrodes were used in a bipolar configuration with a capture area of 1cm in diameter and 2cm interelectrode distance (Figure 1). Before placing electrodes, the skin was shaved and cleaned with alcohol. The electrodes were fixed on the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) muscles, according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines. The reference electrode was positioned on the ulnar head, on the contralateral side to the collected limb[13].

Figure 1. Electrode positioning and hand-held dynamometer

## Data analysis

*Dynamometry*

Muscle strength data were processed in routines developed in MATLAB environment (MathWorks®), using a fourth order Butterworth filter with a 3Hz cutoff frequency[14]. Strength data were normalized by the volunteers' body mass. The peak strength was determined by the highest strength value obtained after the onset of muscle contraction.

*Electromyography*

The electromyographic data were processed via routines developed in MATLAB environment (MathWorks)®. For the calculation of the electromyographic signal amplitude, root mean square (RMS) calculation was performed, using a fourth order low-pass filter with a 10Hz cutoff frequency[15]. All electromyographic data were normalized by the peak activation obtained during the maximal muscle strength test.

*Statistical analysis*

Statistical analysis was performed using PASW Statistics 18.0® program (SPSS). After verifying normality and homogeneity of the data, the Student's t-test was applied to compare the variables between the groups, with a $p<0.05$ significance level.

## RESULTS

The Student's t-test showed that there was a significant difference between the groups for the Neuromuscular efficiency (NME). The volunteers with knee pain presented lower efficiency for the VM ($p=0.030$) and VL ($p=0.031$) muscles, being, respectively, 61% and 52% lower compared to the control group, as shown in Table 2. Regarding knee extensor strength, there was no difference between the groups ($p>0.05$).

Table 2. Neuromuscular efficiency of knee extensors

| | Control group (n=12) | PFP Group (n=12) | p |
|---|---|---|---|
| Knee extensors torque (Nm/kg$^{-1}$) | 4.33±1.126 | 3.94±0.814 | 0.408 |
| Rectus femoris (Nm/uv) | 0.63±0.059 | 0.42±0.028 | 0.218 |
| Vastus medialis (Nm/uv) | 0.31±0.010 | 0.12±0.023 | 0.030* |
| Vastus lateralis (Nm/uv) | 0.27±0.016 | 0.13±0.0108 | 0.031* |

Values expressed as mean±standard deviation. * Significant difference; PFP: patellofemoral pain.

## DISCUSSION

This study aimed to evaluate muscle strength and quadriceps NME in women with and without PFP. The initial hypothesis was partially confirmed since a difference was found between the groups for NME of the VM and VL muscles, but not for the ability to generate knee extensor force.

The NME is a variable that provides a good estimate of muscle function since it is directly related to muscle strength and activation capacity[8]. It evaluates an individual's ability to generate force for the same level of muscle activation, with greater efficiency being associated with greater force generation and lower recruitment of muscle fibers[7]. In the context of PFP, this assessment greatly relevant since pain reduces NME, which means that the muscle needs to activate more motor units to generate muscle force. Over the medium and long term, the reduction of NME and capacity for muscle force production may contribute to the chronification of symptoms[16].

This study found a significant reduction in NME for the VM and VL muscles in individuals with PFP in knee extension movement. This reduction in NME may be associated with muscle weakness, which is common in individuals with pain. The AKPS indicated that PFP negatively influenced the performance of daily tasks in symptomatic volunteers.

Studies have shown a relationship between the presence of pain and1 changes in motor control of the quadriceps muscle in individuals with anterior knee pain[17]. Mellor and Hodges[17] found significant differences in motor coordination of the VM and VL between individuals with pain and healthy individuals in their study.

The study by Rathleff et al.[18] evaluated the activation time of the VM and VL during the task of descending stairs, finding no differences when comparing data from subjects with anterior knee pain with healthy subjects. However, when separately analyzing the stance phase, it was possible to identify an increase in electromyographic activation of the VM and VL in subjects with pain compared to the control group. This increase in neuromuscular activity during the stance phase may reflect a need for greater recruitment of motor units to descend stairs, which is one of the movements that causes the most complaints of pain in analyzed individuals.

This hypothesis is supported by the lower capacity for isometric force generation in women with anterior knee pain, which likely determines a higher neuromuscular activation to counteract this muscular weakness in this group compared to the group of healthy individuals.

Regarding the RF muscle, there was no difference in NME. Hamill and Knutzen[19] and Moraes et al.[20] reported that the action of RF is limited as a knee extensor when the hip is flexed. This can be explained by the biarticular anatomy of the muscle, responsible for hip flexion and knee extension movements. In this study, the volunteers were evaluated with hip flexed at 90°, that is, the muscle was not in its favorable position in the length-tension relationship. Although the RF muscle is recruited during knee extension movement in the sitting position, its participation is limited, which may have contributed to the lack of difference between the groups.

Regarding muscular strength, Powers et al.[21] conducted a study comparing muscular strength between women with anterior knee pain and healthy women (without a history of knee joint injury) at a 60° knee flexion angle (0°=maximum extension). The study showed a 23% reduction in maximum voluntary isometric contraction in women with pain compared to healthy women. In addition, the visual analog scale (VAS) was applied, and only women in the group with pain scored during the test execution.

On the other hand, the study by Bolgla et al.[16] evaluated the strength of hip abductors, hip external rotators, and knee extensors in individuals with PFP and found no difference between the groups, which is consistent with our results. Results difference may be explained by the presence or absence of pain during the muscular strength test, as both studies were conducted with a similar number of volunteers: Powers et al.[21]

with 19 women in each group and Bolgla et al.[16] with 18 women in each group. In the study by Bolgla et al.[16], the analyzed subjects did not indicate pain during the test, as in this study, which possibly made the execution similar to that of the control group.

The literature considers a 13% strength difference as clinically important for individuals with PFP compared to those without pain. In this study, although no statistical difference was found for this variable, there was a 9% strength deficit for the PFP group. We believe that in medium and long term, if the pain persists, this difference in strength may increase, which could negatively impact the resolution of the condition. Therefore, and considering other studies, these findings may be clinically relevant, as PFP patients respond positively to quadriceps strengthening programs.

The study showed that the assessment of muscle NME in anterior knee pain is an important variable since it is able to detect a significant difference between the control group and those with PFP. The lower efficiency of the quadriceps may contribute to the persistence of symptoms, which implies a decrease in quality of life, sedentary behavior, anxiety, and depression.

### Study limitations

The study evaluated NME only during isometric knee extension and the findings cannot be generalized to all individuals with PFP. It is suggested that new studies be conducted with a larger sample, including analysis of the NME of the quadriceps muscle during concentric and eccentric contractions, as these better represent muscle recruitment during daily activities. In addition, it is suggested to evaluate NME during the execution of tasks that involve joint load, such as walking, climbing/descending stairs, and squatting.

## CONCLUSION

Women with patellofemoral pain syndrome show lower neuromuscular efficiency of the quadriceps, however, this does not seem to change their ability to generate maximum knee extension force.

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ERRATUM

The version of the article "**Neuromuscular efficiency of the quadriceps in women with and without patellofemoral pain**" published in **volume 30, number 1, 2023**, initially available contained an error concerning the elocation-id.

**Instead of:**
e21002523en

**Should read:**
e22016623en