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DE SAÚDE DO ALCOITÃO
SANTA CASA da Misericórdia de Lisboa

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The influence of electromyographic biofeedback in a physiotherapy program following meniscectomy: A randomized double-blinded controlled trial

Projeto elaborado com vista à obtenção
do grau de Mestre em Fisioterapia,
na Especialidade de Músculo-Esquelética

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ABSTRACT

Objective: The objective of this study was to investigate if, in patients who underwent arthroscopic partial meniscectomy, the physiotherapy program with electromyographic biofeedback (EMG BFB) was more effective than a physiotherapy program alone for increasing knee extension range of motion, quadriceps strength, motor control, and knee functionality, and for reducing pain.

Methods: Thirty-three subjects between 18 and 55 years old, submitted to arthroscopic partial meniscectomy less than two weeks before starting physiotherapy were included in the study. Patients were randomly allocated in experimental (n=16) and control groups (n=17) performing a four-week physiotherapy program with and without EMG BFB, respectively. The primary outcome measures were passive and active knee extension range of motion (Goniometry with Clinometer®), quadriceps strength (Maximum Voluntary Isometric Contraction (MVIC) at 90º and 45º using MicroFET®3), motor control (Onset of vastus medialis obliquus and vastus lateralis with surface electromyography using PhysioPlux®), functionality (Nijmegen Gait Analysis Scale (NGAS) and, Knee and Osteoarthritis Outcome Score) and pain (Visual Analogue Scale). They were measured at baseline (pre-intervention) with follow-ups after two and four weeks.

Results: After two weeks, active range of motion ($p = .031$), MVIC 90º ($p = .013$), MVIC 45º ($p = .003$), and NGAS ($p = .012$) were significantly better in EMG BFB group, compared to control group. These improvements continued after four weeks in active range of motion ($p = .015$), MVIC 90º ($p = .003$), MVIC 45º ($p = .001$) and NGAS ($p = .013$) in the EMG BFB group. Differences found between groups after two and four weeks on passive range of motion, motor control, activity limitations and pain were non-significant.

Conclusion: The inclusion of EMG BFB on a standard physiotherapy program after arthroscopic partial meniscectomy is effective in improving active knee range of motion, quadriceps strength, and gait performance.

Keywords: Physiotherapy, Electromyographic Biofeedback, Exercise, Meniscectomy

RESUMO

Objetivo: O objetivo deste estudo foi investigar se, em indivíduos submetidos a meniscectomia parcial por artroscopia, o programa de fisioterapia com biofeedback eletromiográfico (BFB EMG) é mais eficaz que um programa de fisioterapia isolado no aumento da amplitude de extensão do joelho, força do quadricípite, controlo motor e funcionalidade do joelho, e na diminuição da dor.

Metodologia: Trinta e três sujeitos entre os 18 e os 55 anos, submetidos a meniscectomia parcial por artroscopia menos de duas semanas antes de iniciarem fisioterapia foram incluídos no estudo. Os pacientes foram alocados aleatoriamente no grupo experimental (n=16) e no grupo de controlo (n=17), realizando um programa de fisioterapia de quatro semanas com e sem BFB EMG, respetivamente. As principais medidas de resultados foram a amplitude de extensão passiva e ativa do joelho (Goniometria com Clinometer®), a força do quadricípite (Contração Isométrica Voluntária Máxima (CIVM) a 90º e 45º usando o MicroFET®3), controlo motor (tempo de ativação do vasto medial oblíquo e vasto lateral com eletromiografia de superfície usando o PhysioPlux®), funcionalidade (Nijmegen Gait Analysis Scale (NGAS) e, Knee and Osteoarthritis Outcome Score) e dor (Escala Visual Análoga), e foram medidas no momento inicial (antes da intervenção) e após duas e quatro semanas de intervenção.

Resultados: Após duas semanas, a amplitude de extensão ativa do joelho ($p = .031$), CIVM 90º ($p = .013$), CIVM 45º ($p = .003$) e NGAS ($p = .012$) estavam significativamente melhor no grupo do BFB EMG comparativamente ao grupo de controlo. Estas melhorias mantiveram-se após quatro semanas na amplitude de extensão ativa do joelho ($p = .015$), CIVM 90º ($p = .003$), CIVM 45º ($p = .001$) e NGAS ($p = .013$) no grupo do BFB EMG. As diferenças entre grupos após duas e quatro semanas na amplitude de extensão passiva do joelho, controlo motor, limitações da atividade e dor não eram significativas.

Conclusão: A inclusão do BFB EMG num programa de fisioterapia convencional após meniscectomia parcial por artroscopia é eficaz no aumento da amplitude de extensão ativa do joelho, força do quadricípite e performance na marcha.

Palavras-chave: Fisioterapia, Biofeedback Eletromiográfico, Exercício, Meniscectomia

INTRODUCTION

Musculoskeletal conditions affect people in all regions of the world. They were the leading cause of disability in four of the six WHO regions in 2017 and is expected its social impact and burden to increase in the upcoming years (World Health Organization, 2019). The International Association for the Study of Pain (IASP) highlighted these conditions relevance, stating that virtually all adult population have experienced one or more brief episodes of musculoskeletal pain associated with injury or overuse. IASP additionally described that the knee pain prevalence in that population ranges from 10 to 15% (International Association to the Study of Pain, 2010).

The knee is a complex joint and is vulnerable to several types of injuries. The most common are the ligament, meniscal, and cartilage injuries of different etiologies. The meniscal tear can be either traumatic or degenerative, and is the second most common injury in the knee, with a prevalence ranging from 12 to 14% (Englund, Guermazi and Lohmander, 2009; Logerstedt *et al.*, 2018). Younger active patients are more likely to sustain traumatic meniscus injuries, while older individuals are more likely to have degenerative tears (Logerstedt *et al.*, 2018).

Arthroscopic partial meniscectomy (APM) is the primary surgical procedure used to treat meniscus tears. The incidence rate of meniscus procedures has substantially increased over the past decade (Logerstedt *et al.*, 2018). More than 4 million arthroscopic meniscectomies are performed each year worldwide, making it one of the most commonly performed procedures in orthopedic surgery (Khan, Evaniew, Bedi, Ayeni and Bhandari, 2014). The mean annual prevalence of meniscal lesion is 66 per 100,000 inhabitants, 61 of which result in meniscectomy (Logerstedt *et al.*, 2018; Ridley, McCarthy, Bollier, Wolf and Amendola, 2017). There is a surgical intervention recommendation for symptomatic meniscal tears since untreated tears can increase in size and may affect the articular cartilage, resulting in osteoarthritis. Partial or total meniscectomy are usual surgical options in these cases. In APM, resection must be restricted to the dysfunctional portions, preserving as much as possible the injured meniscus. (Oravitan & Avram, 2013).

After knee surgery, as a result of reflex inhibition of motor neurons and immobilization, rapid atrophy and weakness develop in the quadriceps muscle, which is responsible for the extensor mechanism of the knee (Akkaya *et al.*, 2012). Impairments in proprioception, muscle strength and knee extension, and poor patient-reported outcomes are present early after meniscal injury and until six months after APM (Christanell, Hoser, Huber, Fink and Luomajoki, 2012; Logerstedt *et al.*, 2018).

During the initial postoperative weeks, some exercises are challenging to perform because of pain, joint effusion, and possibly a disruption in regular joint receptor activity. The distortion of joint receptors' feedback compromises the facilitatory and inhibitory influences on joint musculature,

making muscle contraction patterns irregular and less effective. These changes could be a handicap for executing rehabilitative exercises and, consequently, for the recovery of muscle control and strength (Oravitan & Avram, 2013). Unfortunately, there is still a lack of investigation of the mechanisms underlying quadriceps weakness after APM. Such knowledge would help to identify neural and muscle impairments in patients undergoing APM, with the ultimate goal to optimize their postoperative rehabilitation strategies (Glatthorn, Berendts, Bizzini, Munzinger and Maffiuletti, 2010).

Several studies show that vastus medialis part of quadriceps, especially the vastus medialis oblique muscle (VMO), was more affected than vastus lateralis muscle (VL) after arthroscopic partial meniscectomy. A VMO and VL imbalance and improper timing of activation between the two muscles are perceived to result in abnormal patellar tracking and a decreased extensor capacity of the knee. This muscle weakness is a result of reflex inhibition of motor neurons. It is defined as pathogenic muscle weakness and is an important problem during the postoperative rehabilitation program. The electromyographic biofeedback (EMG BFB) could be used in these conditions to restore the VMO/VL ratio while promoting their simultaneous contraction (Akkaya *et al.*, 2012; Cowan, Bennell, Hodges, Crossley and McConnell, 2003; Kirnap, Calis, Turgut, Halici and Tuncel, 2005; Kushion *et al.*, 2012; Oravitan & Avram, 2013).

Electromyographic biofeedback uses surface electrodes to measure underlying muscular activity. The electromyographic activity is converted to an auditory or visual signal, revealing to the individual, a representation of muscular contraction. This feedback permits individuals to quantify a physiological event since they allow alterations in neuromuscular control, granting the patient the ability to reach a desired muscular contraction (Giggins, Persson and Caulfield, 2013; Kim, 2017; Lepley, Gribble and Pietrosimone, 2012). The use of EMG BFB should follow the cognitive, associative, and autonomous motor relearning stages proposed by Fitts and Posner but with a progressive smaller influence over the time in the exercise program. In the cognitive phase, the target is improving motor control and approach regular contraction pattern, mainly through isometric exercises. After that, in the associative stage, movement and progressive resistance should be added to the exercise program. Finally, in the autonomous stage, the capacity to execute tasks with stabilizers control in different positions and velocities should be assessed by introducing functional exercises in the rehabilitation program (Akkaya *et al.*, 2012; Cowan *et al.*, 2003; Kirnap *et al.*, 2005; Kushion *et al.*, 2012; Oravitan & Avram, 2013; Wulf, 2007).

The latest evidence suggests that the inclusion of EMG BFB in a physiotherapy program has the potential to promote clinically significant biomechanical changes. Its importance in a rehabilitation program has increased over the last years, and the 2018 physiotherapy guidelines on

meniscal lesions recommend that the electromyographic biofeedback should be part of the physiotherapy program (Giggins *et al.*, 2013; Logerstedt *et al.*, 2018).

It has been hypothesized that EMG BFB can potentially affect strength by improving motor unit recruitment as well as optimizing firing rates through cortically generated mechanisms. However, there is confounding evidence on whether EMG BFB training can increase quadriceps strength better than exercise alone can (Lepley *et al.*, 2012).

A systematic review of the effects of EMG BFB on quadriceps strength proposes that future investigations should explore its impact on other measures of physical function, such as joint kinematics, muscle activation, dynamic stability, and self-reported outcomes of function (Lepley *et al.*, 2012).

This study objective is to investigate if, in patients that underwent arthroscopic partial meniscectomy, a physiotherapy program with electromyographic biofeedback is more effective than a physiotherapy program alone for increasing knee extension range of motion, quadriceps strength, motor control, and knee functionality, and for reducing pain.

METHODS

This study design was a parallel, double-blind, randomized controlled trial, with allocation ratio 1:1, and it was approved by the Alcoitão School of Health Sciences ethics committee. The methods used in this trial were determined after a previous pilot study with a volunteer who did not participate in the main study. This trial report followed the Consolidated Standards of Reporting Trials (CONSORT) guideline recommendations.

Participants

The study was developed between December 2018 and September 2019. A total of 33 participants, 21 males and 12 females, aged between 18 and 55, were recruited from a Health and Rehabilitation Clinic in Oeiras, Portugal, where they started a physiotherapy program. Patients of both genders aged between 18 and 55 who underwent arthroscopic partial meniscectomy less than two weeks before beginning physiotherapy were included in the study.

The exclusion criteria were: concomitant anterior cruciate ligament injury; osteoarthritis > grade II; previous surgeries in the ipsilateral knee; unconsolidated fractures; partial or total amputation in upper or lower limbs; permanent or temporary dysfunctions of the central or peripheral nerve system. Subjects were randomly allocated in experimental and control groups, and the flow chart in figure 1 represent their progress through the trial. Patients' demographic data is detailed in table 2.

Randomization

We used the block randomization to ensure balance in sample size across groups over time (Kang, Ragan and Park, 2008). We created blocks of four participants with the six possible combinations between control and experimental groups. A co-worker not involved in the study randomly allocated the blocks in the website randomization.com (Dallal, 2018). Then, another colleague uninvolved in the study concealed the allocation order in numbered opaque envelopes. Whenever a subject fulfills every criterion to participate in the study, the leading investigator opened the respective envelope. The subjects and the assessors were blind regarding the group allocation.

Procedure

The patients that were submitted to meniscectomy by arthroscopy were identified during the check-in at the clinic and invited to meet the leading investigator. After reading the study objectives and procedures and clarifying any doubts, they signed the informed consent form if they agree to integrate the trial (Appendix 1). All patient's data was encrypted and stored with password protection according to the European Union general data protection regulation, and its elimination is scheduled for October 2024.

In the first session, before starting any procedure, the subjects answered the socio-demographic questionnaire (Appendix 2) and the International Physical Activity Questionnaire (IPAQ) (Appendix 3). They were then assessed for knee extension range of motion, quadriceps strength, motor control, knee functionality, and pain, repeating this evaluation two and four weeks after the beginning of the physiotherapy intervention.

Intervention

The sample was randomly allocated into two groups. The control group with 17 patients, completed a standard physiotherapy program based on the updated Journal of Orthopaedic and Sports Physical Therapy (JOSPT) clinical practice guidelines for meniscal and cartilage lesions (Logerstedt *et al.*, 2018), which included lower limb massage, mobilization, strengthening and neuromuscular re-education exercises, neuromuscular electrical stimulation of quadriceps and cryotherapy. The experimental group with 16 patients completed the same physiotherapy program, but it was added the electromyographic biofeedback during the exercises three times a week. Both groups followed this program within four weeks with a treatment frequency of 5 sessions per week, performed and supervised by the same physiotherapist in every session.

Every subject followed the same treatment and exercise order, starting with the massage and the knee mobilization, followed by the correspondent exercise program, and finishing with the Neuromuscular Electrical Stimulation (NMES) and the cryotherapy.

Subjects from the experimental group did the exercise protocol with the EMG BFB device, using Ag/AgCl Covidien Kendall® disposable surface EMG electrodes with a 24 millimeters diameter. Skin preparation included shaving and cleansing with 70% alcohol to ensure electromyographic signal quality. The electrodes were placed in the center of the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles, aligned with the muscle fibers, and the reference electrode at the anterior tibial tuberosity, following the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations (SENIAM, 2018).

The physiotherapy program was completed, as described in table 1.

Table 1: Four-week Physiotherapy Program.

Physiotherapy Interventions	**Treatment Weeks**			
	1	**2**	**3**	**4**
Massage	x	x	x	x
Passive Mobilization	x	x		
Active Mobilization	x	x	x	x
Neuromuscular Electrical Stimulation (NMES)	x	x	x	x
Proprioceptive Training		x	x	x
Cryotherapy	x	x		
1. Isometric Quadriceps Exercises*	x	x		
2. Isometric VMO Exercises *	x	x		
3. Isometric Hip Adduction Exercises	x	x		
4. Isotonic Gastrocnemius Exercises	x	x		
5. Straight Leg Raise *	x	x	x	x
6. Isotonic Quadriceps Exercises *	x	x	x	x
7. Isotonic Hip Extension Exercises	x	x	x	x
8. Isotonic Hip Adduction Exercises	x	x	x	x
9. Isotonic Hip Abduction Exercises	x	x	x	x
10. Isotonic Hamstrings Exercises	x	x	x	x
11. Standing Isotonic Gastrocnemius Exercises		x	x	x
12. Wall Slide 0º to 30º *		x		
13. Static Ergometer		x	x	x
14. Closed Kinetic Chain Exercises *		x	x	x
15. Lunge *			x	x
16. Wall Slide 0º to 45º *			x	
17. Wall Slide 0º to 90º *				x
18. Treadmill Progression: gait > run				x
19. Single leg vertical jump				x
20. Running with direction changes				x
Specific Sport Exercises				x
Lower Limbs Stretching	x	x	x	x

Note. * The Experimental Group performed the exercises with Electromyographic Biofeedback

Instruments and outcome measures

The data collection took place following the same order with every subject, starting with the self-reported scales and proceeding to the rest of the evaluation. Range of motion and strength were measured three times. VMO and VL onset timing was measured five times to assess motor control, and the best three were selected to minimize measurement errors.

Range of motion

The evaluation of the active knee extension range of motion (ROM) was done with the patients on supine position on the physiotherapist table with both legs hanging below the knees using the smartphone app Clinometer® (Plaincode, Stephanskirchen, Germany) with the upper end of the device placed close to the anterior tibial tuberosity and aligned with the tibial crest, the patient performed an active knee extension till reaching the maximum ROM available (Ockendon & Gilbert, 2012). The passive knee extension ROM assessment followed the same procedure, but with a physical therapist performing passive knee extension until reach maximum ROM available.

Smartphone-based apps are valid and reliable tools for quantifying the range of motion in the knee. A smartphone placed on the anterior medial surface of the tibia offers accurate measurements of knee extension range of motion in line with more expensive technologies with excellent inter-tester reliability (ICC = .99 ; 95%CI = .99 to 1.00) and intra-rater reliability analysis showing similar results with Intraclass Correlation Coefficients (ICC) of .99 (Hancock, Hepworth and Wembridge, 2018; Støve, Palsson and Hirata, 2018).

Strength

The quadriceps strength was measured using the MicroFET®3 (Hoggan Scientific, Salt Lake City, Utah, USA) dynamometer. This handheld dynamometer has a good to excellent intra-test reliability ICC values for the knee testing protocol (ICC = .88 ; 95%CI = .78 to .94). The inter-test reliability was moderate (ICC = .60 ; 95%CI = .42 to .76) and (ICC = .66 ; 95%CI = .48 to .80) (Clarke, DA Mhuircheartaigh, Walsh, Walsh and Meldrum, 2011). One accessor performed every strength test during the study to prevent bias.

The patients sat in the leg extension chair with both legs in front of the equipment lever, which was locked at 90º or 45º of knee flexion range of motion to perform the intended test. Three maximum voluntary isometric contractions against the resistance with the dynamometer were required at 90º and 45º knee flexion.

Motor control

To assess motor control, we measured the VMO and VL onset timing, using electromyographic biofeedback PhysioPlux® (PLUX, Lisbon, Portugal). This BFB EMG system has a Samsung tablet connected by Bluetooth® to an Analog to Digital (AD) converter that has 12 bits resolution with a sampling frequency of 1000Hz with five cable exits. One cable connected to the reference electrode and two cables with an integrated differential amplifier connected to muscle electrodes as described before. The surface electromyography has an adequate intratester reliability when measuring the VMO-VL onset timing (ICC = .70 ; 95% CI = .96 to .98) and with an excellent measurement precision (Bolgla, Malone, Umberger and Uhl, 2010).

Functionality

The Nijmegen gait analysis scale (NGAS) and Knee Injury and Osteoarthritis Outcome Score (KOOS) were the two variables measured to assess knee functionality.

Gait analysis

The NGAS (Appendix 4) was used to evaluate the subjects' gait pattern. We recorded the gait during the assessment, and the scale was filled in after it. We filmed patients from an anterior and posterior view while they walked 10 meters away and toward the camera at a comfortable speed. After that, we recorded the lateral view while walking a 5 meters distance.

The visual observation of a patient's gait using NGAS was considered moderately reliable as inter-rater reliability among experienced raters (physiotherapists with ten years or more of experience) was (ICC = .42 ; 95%CI = .38 to .46) and the average intra-rater reliability was .63 (ICCs 95%CI ranging from .57 to .70) (Brunnekreef, van Uden, van Moorsel and Kooloos, 2005).

Activity limitation

We used the Portuguese version of the self-reported measure KOOS (Appendix 5) to assess the activity limitation of patients. It consists of five subscales scored separately: pain, other symptoms, function in daily living, function in sport and recreation, and knee-related quality of life. The scores are transformed to a 0–100 scale, where 100 represents no knee-related problems. The KOOS is a valid self-reported outcome measure in patients with different knee injuries undergoing different procedures, including meniscectomy. The KOOS has a test-retest reliability from good to excellent with ICC ranging from .82 to .94 for the KOOS subscales (Goncalves, Cabri, Pinheiro and Ferreira, 2009).

Pain

To measure pain was used the Visual Analogue Scale (VAS) (Appendix 6), which test-retest reliability is excellent (ICC = .97 ; 95%CI = .96 to .98) and has been described as a valid instrument to assess acute pain (Bijur, Silver and Gallagher, 2001).

Statistical methods

We used the Statistical Package for Social Sciences (SPSS®) 24 software (IBM Corp, Armonk, New York, USA) for the statistical analysis of this study.

Differences between groups were calculated using non-parametric tests Chi-square for gender and Mann-Whitney U for physical activity variable.

To determine the normal distribution of the remaining variables, we used the Shapiro-Wilk test. If normality was rejected, we checked the Skewness (SK < 3) and Kurtosis (Ku < 7) to assess if the deviations from normality were small (Kline, 2015). Since the normality or minor deviations from

it allow the use of parametric tests, we applied the Student's t-test for independent measures to compare groups in age, height, weight, body mass index, education level, and time since surgery.

To compare effects between groups in the dependent variables, one-way analysis of variance (ANOVA) with Bonferroni adjustment was used. The required equality of variances to perform this test could be assumed because when the group size is homogeneous, only slight deviations from homogeneity exist (Marôco, 2018). Since p-values from the results of the statistical tests do not indicate the magnitude or importance of a difference, we reported the effect sizes to give meaning and emphasize the power of statistical tests (Espírito Santo & Daniel, 2015).

We calculated the within-group differences and the between and within effects interaction using a repeated-measures ANOVA. A Greenhouse-Geisser correction was used if the sphericity assumption was not verified.

To conclude the statistical analysis, we performed a linear regression with every characterization variable and the intervention to analyze their effect over the outcomes.

RESULTS

The progress of all participants through the trial is displayed in the flow chart (Figure 1).

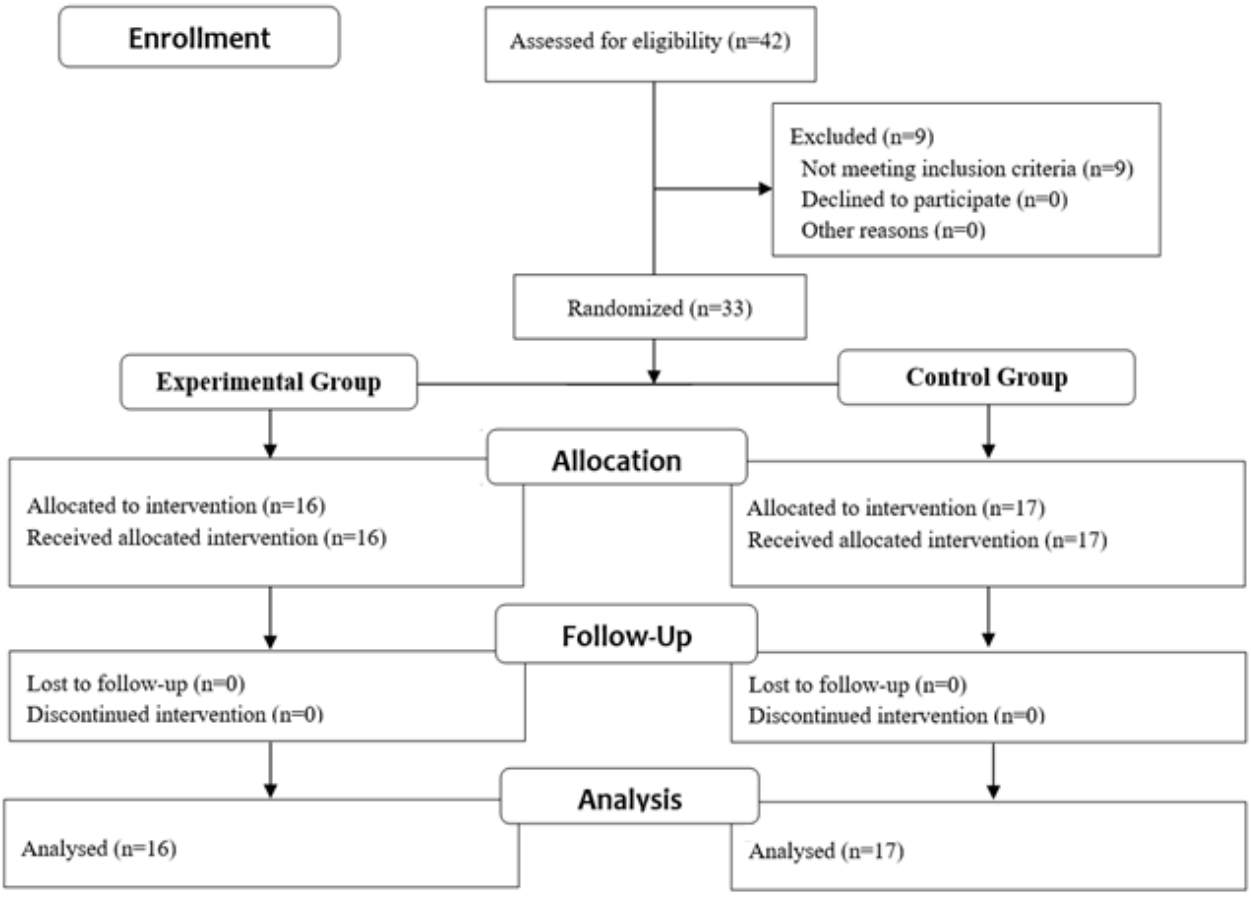

Figure 1: Trial flow chart.

Forty-two patients who have been submitted to meniscectomy by arthroscopy were screened for eligibility. Thirty-three satisfied the eligibility criteria, agreed to participate, and were randomized into the experimental group (n=16, mean ± SD age 40.00 ± 12.25 years; 75% male; 25% female) or the control group (n=17, mean ± SD age 47.12 ± 11.23 years; 52.9% male; 47.1% female). Baseline features between both groups were similar for all outcomes, as shown in table 2. All subjects completed the physiotherapy program. There were no dropouts or complications.

Table 2: Baseline demographics in both groups.

	Experimental Group (*n*=16)		**Control Group (*n*=17)**		***p***
	Mean (± *SD*)	Range	Mean (±*SD*)	Range	
Age (years)	40.00 (±11.80)	18-55	47.12 (±11.23)	18-55	.086 [a]
Height (*cm*)	176.00 (±7.65)	158-192	173.12 (±8.13)	160-187	.303[a]
Weight (*kg*)	82.06 (±15.55)	63-120	74.35 (±11.76)	53-100	.117[a]
BMI (kg/m^2)	26.53 (±5.11)	20.98-40.60	24.75 (±3.30)	20.30-34.60	.241[a]
Education (years)	12.25 (±1.65)	9-16	12.65 (±2.85)	4-16	.631[a]
TSS (days)	11.81 (±2.69)	5-14	13.18 (±1.47)	9-14	.078[a]
	Frequency (*n*)		Frequency (*n*)		
Gender					
Male	75% (12)		52.90% (9)		.188[b]
Female	25% (4)		47.10% (8)		
Physical Activity					
Low	25% (4)		17.65% (3)		
Moderate	12.50% (2)		23.53% (4)		1.000[c]
High	62.50% (10)		58.82% (10)		

Note. Physical Activity = International Physical Activity Questionnaire Score; SD = Standard Deviation; BMI = Body Mass Index; TSS = Time Since Surgery; Education = Education Level; [a]Student's t test; [b]Chi-square test; [c]Mann-Whitney U test; *p* = p-value; **p* < .05

Participants completed a four-week physiotherapy program, and the experimental group used electromyographic biofeedback while performing the exercise program. Their knee extension ROM, quadriceps strength, motor control, functionality, and pain were measured before the physiotherapy intervention (O_1), after two weeks (O_2) and after four weeks (O_3). Normality tests were carried out on every dependent variable, which were approximately normally distributed. For these variables, the differences between groups in each assessment moment were determined with a one-way ANOVA, while a repeated measures ANOVA determined the within-group differences over the study length.

Range of motion

We assessed active and passive knee extension ROM. Both tests revealed that these two variables had no differences between groups at baseline. Passive knee extension ROM differences

after two weeks and four weeks were not significant (Table 3). Despite the results between groups, a within-subjects ANOVA with a Greenhouse-Geisser correction showed that mean passive knee extension ROM differed significantly between time points [$F(1.51, 46.78) = 22.32$, $p < .001$]. These results reveal that the passive knee extension ROM increased in both groups during the study with slight positive results on experimental group, which is confirmed by the interaction effect regarding within and between factors [$F(1.51, 46.78) = 5.26$, $p < .015$].

Table 3. Passive knee extension range of motion outcomes – comparison between groups.

	Experimental Group (n=16)	**Control Group (n=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
PKEROM O_1 (º)	-6.98 (±4.61)	-5.43 (±3.44)	1	1.21	.281	.04	-1.55 [-4.42, 1.33]
PKEROM O_2 (º)	-3.04 (±2.69)	-4.55 (±3.62)	1	1.82	.187	.06	1.51 [-0.77, 3.79]
PKEROM O_3 (º)	-2.33 (±2.62)	-3.45 (±3.24)	1	1.18	.286	.04	1.12 [-0.98, 3.22]

Note. PKEROM = Passive Knee Extension Range of Motion; (º) = degrees; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; **p* < .05

A significant increase in the active knee extension ROM disclosed at the $p < .05$ level after two weeks [$F(1, 31) = 5.09$, $p = .031$, $\eta^2p = .14$] and after four weeks [$F(1, 31) = 6.62$, $p = .015$, $\eta^2p = .18$] with a medium effect size ($\eta^2p =]0.05; 0.25]$) (Marôco, 2018) on both measurements, is detailed in table 4. A repeated measures ANOVA with a Greenhouse-Geisser correction showed that the active knee extension ROM increased within groups over time [$F(1.33, 41.20) = 71.16$, $p < .001$]. The interaction effect confirmed that despite both groups had positive effects between measurements, the EMG BFB group had accentuated differences during the study [$F(1.33, 41.20) = 8.83$, $p = .002$].

Table 4. Active knee extension range of motion outcomes – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
AKEROM O_1 (º)	-16.88 (±7.40)	-14.70 (±7.17)	1	0.74	.397	.02	-2.18 [-7.35, 2.99]
AKEROM O_2 (º)	-6.67 (±3.92)	-10.63 (±5.91)	1	5.09	.031*	.14	3.96 [0.38, 7.54]
AKEROM O_3 (º)	-4.23 (±2.81)	-8.10 (±5.36)	1	6.62	.015*	.18	3.87 [0.80, 6.94]

Note. AKEROM = Active Knee Extension Range of Motion; (º) = degrees; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; **p* < .05

Strength

Strength was assessed in two different knee positions. Maximum voluntary isometric contraction (MVIC) was measured at 90º and 45º of knee flexion. There were no differences between groups at baseline in these two variables. After two weeks, the strength assessed with MVIC at 90º was significantly higher on the EMG BFB group [$F(1, 31) = 6.91$, $p = .013$, $\eta^2p = .18$] with a medium effect size, and a significant difference was also detected after four weeks [$F(1, 31) = 10.43$, $p = .003$, $\eta^2p = .25$] with a high effect size ($\eta^2p =]0.25; 0.50]$) (Marôco, 2018) as described in table 5. A within-groups comparison show that strength increased on both groups over time [$F(2, 62) = 89.24$, $p < .001$] but the interaction effect denotes that experimental group had a marked evolution [$F(2, 62) = 24.15$, $p < .001$].

Table 5. Strength outcomes with MVIC at 90º – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
MVIC 90º O_1 (*N*)	194.24 (±83.70)	213.60 (±99.63)	1	0.36	.551	.01	-19.36 [-84.91, 46.18]
MVIC 90º O_2 (*N*)	342.05 (±115.51)	242.65 (±101.66)	1	6.91	.013*	.18	99.40 [22.26, 176.54]
MVIC 90º O_3 (*N*)	399.78 (±99.74)	285.82 (±102.73)	1	10.43	.003*	.25	113.97 [42.01, 185.92]

Note. MVIC = Maximum Voluntary Isometric Contraction; *N* = Newton; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; *$p < .05$

Following the same path, the strength assessment with MVIC at 45º also revealed no differences at baseline and a positive influence of the EMG BFB on increasing strength after two weeks [$F(1, 31) = 10.05$, $p = .003$, $\eta^2p = .25$] and four weeks [$F(1, 31) = 12.52$, $p = .001$, $\eta^2p = .29$] with high effect sizes in both measurements, which is detailed in table 6. A repeated measures ANOVA with a Greenhouse-Geisser correction disclosed strength improvements within both groups between time points [$F(1.61, 49.89) = 99.18$, $p < .001$], and the interaction effect revealed an accentuated increase in EMG BFB group [$F(1.61, 49.89) = 26.14$, $p < .001$].

Table 6. Strength outcomes with MVIC at 45º – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
MVIC 45º O_1 (*N*)	192.39 (±74.96)	198.95 (±85.58)	1	0.06	.817	.00	-6.56 [-63.83, 50.71]
MVIC 45º O_2 (*N*)	339.65 (±107.04)	229.56 (±92.24)	1	10.05	.003*	.25	110.08 [39.27, 180.89]
MVIC 45º O_3 (*N*)	400.04 (±103.63)	272.31 (±103.65)	1	12.52	.001*	.29	127.73 [54.10, 201.35]

Note. MVIC = Maximum Voluntary Isometric Contraction; *N* = Newton; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; *$p < .05$

Motor control

We assessed motor control, measuring onset timings of vastus medialis oblique and vastus lateralis. Onset timings were measured using surface electromyography, and the formula (VMO Δt – VL Δt) was applied afterward to analyze data. Statistical analysis reported in table 7 determined that differences between groups from baseline throughout O_2 and O_3 were not significant. A repeated-measures ANOVA with Greenhouse-Geisser correction showed that the groups did not improved their onset timings during the study [$F(1.04, 32.10) = 0.03$, $p = .879$], and had no interaction effect [$F(1.04, 32.10) = 3.11$, $p = .086$].

Table 7. Vastus medialis obliquus and vastus lateralis onset timing outcomes – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
Onset O_1 (*ms*)	-22.00 (±68.10)	11.08 (±44.83)	1	2.75	.107	.08	-33.08 [-73.77, 7.61]
Onset O_2 (*ms*)	-5.29 (±2.88)	-9.53 (±21.11)	1	0.63	.432	.02	4.24 [-6.63, 15.10]
Onset O_3 (*ms*)	-5.13 (±3.42)	-7.73 (±18.84)	1	0.30	.591	.01	2.60 [-7.16, 12.36]

Note. Onset = Onset timing difference; *ms* = milliseconds; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; *$p < .05$

Gait analysis

We used the Nijmegen gait analysis scale (NGAS) to analyze subjects' gait. A one-way ANOVA was used to find differences between groups scale scores. The groups were similar at baseline but after two weeks there was a significant effect of EMG BFB on NGAS scores [$F(1, 31) = 7.18$, $p = .012$, η^2p = .19] and the statistically significant differences continued after four weeks

[$F(1, 31) = 6.88$, $p = .013$, $\eta^2p = .18$] with a medium effect size in both measurements as presented in table 8. The intra-group analysis revealed that both groups had a positive effect over time [$F(1.51, 46.74) = 151.62$, $p < .001$], and the interaction effect confirmed that the evolution was accentuated on the EMG BFB group [$F(1.51, 46.74) = 23.65$, $p < .001$].

Table 8. Nijmegen Gait Analysis Scale outcomes – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
NGAS O_1	8.25 (±2.62)	6.24 (±3.35)	1	3.68	.064	.11	2.02 [-0.13, 4.16]
NGAS O_2	1.63 (±1.75)	4.06 (±3.21)	1	7.18	.012*	.19	-2.43 [-4.29, -0.58]
NGAS O_3	0.50 (±1.10)	2.29 (±2.52)	1	6.88	.013*	.18	-1.79 [-3.19, -0.40]

Note. NGAS = Nijmegen Gait Analysis Scale; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; *$p < .05$

Activity limitation

To assess activity limitations related to knee injury, we used knee and osteoarthritis outcome score (KOOS), and its scores from 0 to 100 were statistically analyzed. The one-way ANOVA confirmed that there were not any significant inter-group differences at baseline and during the study (table 9). Despite these results, intra-group analysis indicated that there was a positive evolution of KOOS scores on both groups over time [$F(1.59, 49.38) = 68.74$, $p < .001$] without interaction effect [$F(1.59, 49.38) = 3.38$, $p = .052$].

Table 9. Knee and Osteoarthritis Outcome Score outcomes – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
KOOS O_1	47.21 (±18.24)	52.07 (±14.59)	1	0.72	.403	.02	-4.86 [-16.55, 6.83]
KOOS O_2	60.67 (±14.84)	60.97 (±13.57)	1	0.00	.952	.00	-0.30 [-10.39, 9.79]
KOOS O_3	71.53 (±14.49)	67.54 (±15.63)	1	0.58	.453	.02	3.99 [-6.73, 14.71]

Note. KOOS = Knee and Osteoarthritis Outcome Score; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; *$p < .05$

Pain

To identify differences between groups regarding pain, we used the visual analog scale (VAS) and, an inter-group analysis, described in table 10, confirmed that the control and experimental groups did not have significant differences from baseline throughout O_2 and O_3. Despite these results, intra-group analysis indicated that there was a positive evolution of VAS scores on both groups during the study [$F(1.17, 36.39) = 24.42$, $p < .001$] without interaction effect [$F(1.17, 36.39) = 0.27$, $p = .647$].

Table 10. Visual Analog Scale outcomes – comparison between groups.

	Experimental Group (*n*=16)	**Control Group (*n*=17)**	***df***	***F***	***p***	**η^2p**	***CI* 95%**
	Mean (±*SD*)	Mean (±*SD*)					*MD* [Range]
VAS O_1	2.79 (±2.53)	2.79 (±2.43)	1	0.00	.999	.00	0.00 [-1.76, 1.76]
VAS O_2	1.39 (±1.32)	1.74 (±1.59)	1	0.45	.508	.01	-0.34 [-1.38, 0.70]
VAS O_3	0.91 (±1.21)	1.21 (±1.40)	1	0.43	.518	.01	-0.30 [-1.23, 0.63]

Note. VAS = Visual Analogue Scale; *SD* = Standard Deviation; *df* = degrees of freedom; *F* = F-value; *p* = p-value with one-way ANOVA; η^2p = eta partial square (effect size); *CI* = Confidence Interval; *MD* = Mean Difference; **p* < .05

Linear regression

We performed a linear regression to analyze the effect of the independent variables on the outcomes. Its results are reported in table 11, where the group variable stood out as the only outcome predictor.

Table 11. Linear regression results.

	AKEROM		**MVIC 90º**		**MVIC 45º**		**NGAS**	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*
Group	-1.95	.062	-5.10	.000*	-4.42	.000*	3.57	.001*
Age	-0.78	.444	-1.24	.226	-1.51	.144	-0.08	.938
BMI	0.93	.363	0.08	.939	-0.66	.515	0.78	.442
Gender	0.66	.517	1.06	.298	0.47	.641	0.53	.599
Education	-1.32	.198	-0.98	.336	0.34	.740	-0.29	.776
IPAQ	-0.91	.374	1.82	.081	1.02	.320	1.07	.295
TSS	1.10	.281	-0.04	.970	-1.00	.329	0.54	.597

Note. AKEROM = Active Knee Extension Range of Motion; BMI = Body Mass Index; MVIC = Maximum Voluntary Isometric Contraction; NGAS = Nijmegen Gait Analysis Scale; IPAQ = International Physical Activity Questionnaire; TSS = Time Since Surgery; Education = Education Level; *p* = p-value with Linear Regression; *t* = t-test; **p* < .05

DISCUSSION

The objective of this study was to investigate the effects of the addition of electromyographic biofeedback in a physiotherapy program on knee extension range of motion, quadriceps strength, motor control, knee functionality, and pain in patients that underwent arthroscopic partial meniscectomy.

During the four-week rehabilitation program, there were significant improvements in passive and active knee extension ROM, quadriceps strength, gait performance, activity limitations, and pain within groups as a result of the physiotherapy program applied. However, the comparison between groups, demonstrated that the inclusion of the EMG BFB in a rehabilitation program is effective in improving active knee extension ROM, isometric quadriceps strength, and gait performance. Despite this positive influence, EMG BFB had no significant effects in passive knee extension range of motion, VMO and VL coordination, activity limitations, and pain between groups.

Effects on knee extension range of motion

Results revealed that both groups increased passive and active knee extension ROM during the study. However, the inter-group comparison demonstrated that, despite this progression, the exercise program using EMG BFB was more effective than the physiotherapy exercise program alone in increasing the active knee extension range of motion after two and four weeks with medium effect sizes. Existing evidence conclude that EMG BFB therapy, in the early phase of rehabilitation, is useful in enhancing knee extension (Christanell *et al.*, 2012), and our results are consistent with that. An improved VMO activation and muscle function promoted by the addition of EMG BFB, allow a wider active ROM and is a probable explanation for the significant differences found in active ROM, as were previously reported by other authors (Christanell *et al.*, 2012). A possible passive ROM limitation did not influence the active ROM results since both groups improved their passive ROM over time, without significant differences between groups.

Effects on strength

We observed a parallel evolution between the MVIC at 90º and 45º measurements throughout the study. The strength assessed with MVIC at 90º and 45º increased within both groups during the study, but the between-group comparisons with both measurements revealed a significant impact of EMG BFB in increasing strength during the entire rehabilitation process after APM, which is accordance with previous studies (Ekblom & Eriksson, 2012; Kirnap *et al.*, 2005; Pietrosimone *et al.*, 2015). Nonetheless, there is conflicting evidence on the effect of EMG BFB on strength, with authors stating that EMG BFB was not effective (Oravitan & Avram, 2013), and two systematic reviews

describing that the EMG BFB had positive effects on strength, but its efficacy was not unequivocal (Lepley *et al.*, 2012; Wasielewski, Parker and Kotsko, 2011), This unclear and conflicting evidence lead these systematic reviews authors into suggesting that further examination of EMG BFB should be conducted to determine its actual effect on strength (Lepley *et al.*, 2012; Wasielewski *et al.*, 2011). Our investigation, following this recommendation, determined its efficacy by finding significant differences between experimental and control groups after two and four weeks, with effect sizes ranging from medium to high, both in MVIC at 90º and 45º.

The strength development was one of the main objectives after this surgical procedure since available evidence suggests that quadriceps weakness after APM is mainly attributable to activation failure and is not related to nerve or muscle injury but is caused by reflex inhibition of motor neurons (Akkaya *et al.*, 2012; Glatthorn *et al.*, 2010). Knowing that muscular strength development is underpinned by a combination of morphological and neural factors including muscle cross-sectional area and architecture, motor unit recruitment, rate coding, motor unit synchronization, and neuromuscular inhibition (Folland & Williams, 2007; Suchomel, Nimphius, Bellon and Stone, 2018), the exercise program should target the neural adaptations to revert quadriceps weakness after APM. This objective and the path to achieve it is supported by several authors, who describe that rapid rise in strength within the first two weeks of a training program, is primarily due to neurological adaptations (Folland & Williams, 2007; Vila-Chã & Falla, 2016), and, although both groups improved strength after two weeks as a consequence of the exercise program, the inclusion of EMG BFB seem to lead patients to increase muscle activation, enhancing the neural adaptations provided by training, resulting in a development in muscular function as previously described by Wasielewski *et al.* (2011) in a systematic review. This relation between improved neuromuscular activation patterns and subsequent force production should be taken into consideration (Suchomel *et al.*, 2018), as the enhanced neural adaptations provided by the utilization of EMG BFB were the probable cause of the significant strength gains from experimental group in comparison to the control group. This increased strength in the early stages of an exercise program due to the referred neural adaptations significantly increases the loading and training stimulus to which the muscle could be exposed, maximizing further strength gains as training continues. (Folland & Williams, 2007). The results after four weeks confirmed this, as the first two weeks' results allowed a more effective strength training on third and fourth weeks, revealing even greater strength differences between groups, by the end of the four-week program.

Effects on motor control

We assessed motor control measuring onset timings of vastus medialis obliquus (VMO) and vastus lateralis (VL). Onset timings were measured using surface electromyography, and the formula (VMO Δt – VL Δt) was applied afterward to analyze data. The theorized influence of EMG BFB over these muscles onset timings was supported by the consistent evidence that motor learning and retention improved as the focus of attention transitioned from an internal emphasis (e.g., instructing a patient to contract muscles with maximal effort) to an external emphasis (e.g., telling a patient to manipulate a bar graph that represents underlying muscle activation) (Pietrosimone *et al.*, 2015). However, although both groups went towards a zero value that represented a simultaneous activation of VMO and VL with a slight advantage to the experimental group, they did not have significant differences. Our findings are not in accordance with Oravitan and Avram (2013), who concluded that the decrease of the onset time and offset time were influenced by using EMG BFB in the rehabilitation protocol. The method used for the assessment of the onset timing and the aim of each evaluation are the key factors to understand these conflicting results. We used the time difference between VMO and VL onset to study the inter-muscle coordination while Oravitan and Avram (2013) used the time difference between an acoustic signal and the VMO and VL onset, which focused on the intra-muscular coordination. Intra and inter-muscular coordination are both part of exercise-related neural adaptations (Suchomel *et al.*, 2018), and our study results suggest that EMG BFB could have different effects over them.

Several elements of this multifaceted treatment program promote inter-muscular coordination making it hard to determine with precision which component or combination of elements was responsible for the change in electromyographic onset timing difference. Current literature confirms that VMO muscle is more affected than VL muscle postoperatively, as several factors, like pain and joint effusion, could cause a decrease in proprioceptive feedback, affecting the execution of the exercises (Kirnap *et al.*, 2005). Therefore, the motor control improvement evidenced on both groups could not be attributed exclusively to the using of EMG BFB during exercises but to multiple influencing factors. The reduction of pain and joint effusion during the treatments allowed the execution of the exercise program, which has shown to affect the electromyographic onset of VMO relative to VL more than a placebo treatment (Cowan *et al.*, 2003), and the neuromuscular electrical stimulation, which positive influence over muscle activation and function has been previously described (Glaviano & Saliba, 2016). The exercise and NMES seem to influence the inter-muscular coordination more than the EMG BFB since its addition in the rehabilitation program did not produce significant differences between groups. It would be interesting to study the influence of EMG BFB in a physiotherapy program without the NMES, although it is recommended by the clinical practice

guidelines, to investigate the evolution of motor control without the influence of other modalities over the activation timing.

Additionally, several factors influence the onset of EMG activity, including the amount of EMG background activity and the presence of artifacts like cross-talk (Cowan *et al.*, 2003). Although this study methods comprised and prevented these potential interferences, their possible influence over the onset results cannot be completely discarded.

Effects on functionality

The functionality study included two variables, the gait analysis, assessed with NGAS, and the activity limitation measured with KOOS.

Effects on gait

Results revealed that preforming the exercise program with EMG BFB is effective in improving the gait pattern throughout the rehabilitation program. Although both groups had an enhanced gait performance over time, after two and four weeks, the NGAS scores significantly differ between groups, with medium effect sizes. There is a strong relationship between these results and the previous findings described in this study since knee range of motion limitations and strength impairments have an essential influence over gait pattern. Current literature indicate that quadriceps muscle weakness is associated with reduced knee excursion and that limited knee extension ROM could lead to higher knee flexion angles during lower extremity weight-bearing and consequently to smaller excursion of knee joint contact surfaces during gait, allowing increased focal areas of knee joint contact loading (Mündermann, Dyrby and Andriacchi, 2005; O'Connell, Farrokhi and Fitzgerald, 2016). This weakness and its influence over functional ROM and gait, confirm that postoperative rehabilitation protocols of the knee should include quadriceps muscle strengthening exercises to revert the adverse effects on gait pattern, as recommended by Kirnap *et al.* (2005).

The differences found on NGAS scores throughout the investigation confirm that the positive influence of EMG BFB on quadriceps strength and active knee extension ROM functionally manifests as improved gait performance.

Effects on activity limitation

On activity limitation, both groups increased their KOOS scores during the rehabilitation program but without significant differences between groups after two and four weeks. These results contradict the existing evidence on the effect of EMG BFB over functionality measured by self-reported scales. Previous studies confirm EMG BFB efficacy in improving functional outcomes (Akkaya *et al.*, 2012; Giggins *et al.*, 2013; Oravitan & Avram, 2013; Wasielewski *et al.*, 2011),

although only Oravitan and Avram (2013) used the KOOS to assess it, while the rest of the studies used the Lysholm Knee Scoring Scale. This fact could be of particular importance since between these two scales, the clinical practice guidelines only recommended KOOS to assess activity limitations (Logerstedt *et al.*, 2018). This recommendation could indicate that the KOOS is preferable to withdraw conclusions on the effect of EMG BFB over self-reported activity limitations.

We theorized that a positive influence of EMG BFB on quadriceps strength, active knee extension ROM and NGAS, could be seen on the scores of the self-reported scale KOOS. Still, the results showed non-significant differences between groups over time. A possible explanation for these findings could be that KOOS subscales have different content validity depending on the subjects evaluated. The activities of daily living subscale has better content validity for older patients and sport and recreation for younger patients with knee injuries, while the pain subscale is more relevant for painful knee conditions (Collins *et al.*, 2016). The differences in KOOS subscales could be essential to follow a subject self-reported evolution regarding activity limitations over time as confirmed by its excellent test-retest reliability (Collins *et al.*, 2016). Nonetheless, it could also influence the outcomes of groups, since subjects had different ages, activity levels, injury origin, and baseline pain levels, despite the inclusion and exclusion criterion applied.

Effects on pain

The results confirmed that the inclusion of EMG BFB in a rehabilitation program after arthroscopic partial meniscectomy is not effective in reducing pain. Conflicting evidence on this matter is available. A systematic review recommended caution to the postoperative use of EMG BFB to alleviate pain because the existing evidence is not conclusive (Wasielewski *et al.*, 2011). Despite this conclusion, our findings were clear, and are consistent with authors who stated that the rehabilitation program with EMG BFB does not influence pain (Christanell *et al.*, 2012; Oravitan & Avram, 2013). In our study, the pain decreased between baseline and the fourth week in both groups without significant differences between them, which confirms that this evolution is not related to the using of EMG BFB. Pain control interventions used in the standard physiotherapy program that were common to both control and experimental groups seem to contribute to a positive effect over pain. The EMG BFB did not have a positive nor negative impact on pain. Despite the conflicting evidence on its benefit, a systematic review confirmed our findings that EMG BFB has no harmful effects (Lepley *et al.*, 2012), and could be used to other objectives without risk.

Linear regression

To analyze the effect of the independent variables on the outcomes, we made a linear regression. It confirmed that the intervention was the only outcome predictor. The linear regression results mean that the effects of EMG BFB on active knee extension ROM, quadriceps strength, and gait performance are independent of the characterization variables of the subjects. This fact is of particular relevance to this investigation external validity as its results could be reproduced in patients submitted to arthroscopic partial meniscectomy regardless of their demographic characteristics.

Study limitations

This study design considered limitations and recommendations from previous investigations. Nonetheless, several limitations were found and should be considered in future investigations, such as the inexistence of a pre-operative baseline measure and a follow-up at six months. The utilization of a handheld dynamometer to assess strength and the possible influence of the assessor's technic over the outcomes. The physiotherapist that performed the rehabilitation program was not blind.

Clinical applications

The electromyographic biofeedback is effective in enhancing quadriceps strength, active knee extension ROM, and gait pattern when used in a physiotherapy program after arthroscopic partial meniscectomy. EMG BFB seems to promote patients' compliance and integration in the rehabilitation process. Knowledge of muscular activity can provide a crucial insight to neuromuscular control, which can lead to strength and active ROM gains, helping the patients return to normal function patterns sooner, and consequently, promoting a faster recovery and return to daily activities.

CONCLUSION

The adding of electromyographic biofeedback to a standard physiotherapy program following arthroscopic partial meniscectomy contributes to improve quadriceps strength, active knee extension range of motion, and gait performance. The EMG BFB seems to promote patient’s integration in the physiotherapy program and its effects allow speeding up and consolidating the rehabilitation process, helping patients accomplish physical activities that require better strength and range of motion, as were previously recommended by clinical practice guidelines.

Further studies should address different populations or try to reduce this investigation limitations. We suggest the inclusion of a pre-operative baseline measurement and longer follow-up times, the utilization of isokinetic dynamometer to assess strength (gold standard), the consideration

of different approaches to motor control study, including intra-muscular and inter-muscular coordination, and muscular electric potential balance, the inclusion of physical performance measures regarding functionality assessment, the compliance level measurement and finally, blinded physiotherapists to ensure greater internal validity and an increased methodological quality.

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APPENDICES

APPENDIX 1

Informed Consent Form

DECLARAÇÃO DE CONSENTIMENTO INFORMADO

Considerando a "Declaração de Helsínquia" da Associação Médica Mundial, a International Ethical Guidelines for Biomedical Research Involving Human Subjects e os Padrões de Prática da Fisioterapia da Associação Portuguesa de Fisioterapeutas (2005)

Randomized Controlled Trial

Reabilitação do joelho pós-meniscectomia: A influência do biofeedback eletromiográfico num programa de fisioterapia

Eu, abaixo-assinado, _____
_____:

Fui informado de que o Estudo de Investigação acima mencionado se destina a determinar se o biofeedback eletromiográfico é uma mais valia, quando integrado num programa de fisioterapia convencional.

Sei que neste estudo está prevista a realização de uma entrevista inicial com um questionário preenchido pelo investigador, de uma avaliação inicial realizada pelo investigador e colaboradores, de um programa de fisioterapia convencional para reabilitação após meniscectomia, de uma avaliação intermédia e final realizadas pelo investigador e colaboradores, tendo-me sido explicado em que consistem e quais os seus possíveis efeitos.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais à luz do Regulamento Geral de Proteção de Dados e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado bem como a realização de filmagens necessárias à elaboração do estudo, autorizo a utilização dos meus dados e recebo uma cópia deste consentimento informado.

Também autorizo a divulgação dos resultados obtidos no meio pedagógico ou científico, garantindo o anonimato.

___/___/_____ _____

(assinatura do participante)

___/___/_____ _____

(assinatura do Fisioterapeuta)

APPENDIX 2

Socio-demographic Questionnaire

Questionário de dados sociodemográficos			
I.D.:			
Data:			
Nome:			
Data Nasc.:	/ /	**Idade:**	
Sexo:	□ Masculino □ Feminino		
Habilitações Literárias	□Sem escolaridade □1º ciclo □2º ciclo □3º ciclo □Ensino Secundário □Licenciatura □Mestrado Integrado □Mestrado □Doutoramento □Outra? Qual_____		
Nível de Atividade Física (IPAQ)	□ Baixo □ Moderado □ Alto		

Critérios de Inclusão	**Sim**	**Não**
Idade compreendida entre 18 e 55 anos?		
Submetido a meniscectomia por artroscopia?		
Decorreram menos de 2 semanas desde o dia da cirurgia?		
Critérios de Exclusão	**Sim**	**Não**
Lesão do ligamento cruzado anterior no joelho operado?		
Osteoartrose > Grau II no joelho operado?		
Cirurgias prévias no joelho operado?		
Fraturas não consolidadas nos membros inferiores?		
Fraturas não consolidadas nos membros superiores?		
Amputação parcial de qualquer membro inferior ou superior?		
Amputação total de qualquer membro inferior ou superior?		
Disfunções permanentes do sistema nervoso central?		
Disfunções não permanentes do sistema nervoso central?		
Disfunções permanentes do sistema nervoso periférico?		
Disfunções não permanentes do sistema nervoso periférico?		

APPENDIX 3

International Physical Activity Questionnaire

(IPAQ)

Questionário Internacional de Atividade Física (IPAQ)

Estamos interessados em conhecer os diferentes tipos de atividade física, que as pessoas fazem no seu quotidiano. Este questionário faz parte de um estudo alargado realizado em vários países. As suas respostas vão-nos ajudar a conhecer o nosso nível de atividade física, quando comparado com o de pessoas de outros países.

As questões que lhe vou colocar, referem-se à semana imediatamente anterior, considerando o tempo em que esteve fisicamente ativo/a. Por favor, responda a todas as questões, mesmo que não se considere uma pessoa fisicamente ativa. Vou colocar-lhe questões sobre as atividades desenvolvidas na sua atividade profissional e nas suas deslocações, sobre as atividades referentes aos trabalhos domésticos e às atividades que efetuou no seu tempo livre para recreação ou prática de exercício físico / desporto.

Ao responder às seguintes questões considere o seguinte:

Atividades físicas vigorosas *referem-se a atividades que requerem um esforço físico intenso que fazem ficar com a respiração ofegante.*

Atividades físicas moderadas *referem-se a atividades que requerem esforço físico moderado e tornam a respiração um pouco mais forte que o normal.*

*Ao responder às questões considere apenas as atividades físicas que realize durante pelo menos **10 minutos seguidos***.

Q.1 Diga-me por favor, nos últimos 7 dias, em quantos dias fez atividades físicas **vigorosas**, como por exemplo, levantar objetos pesados, cavar, ginástica aeróbica, nadar, jogar futebol, andar de bicicleta a um ritmo rápido?

		Dias

Q.2 Nos dias em que pratica actividades físicas **vigorosas**, quanto tempo em média dedica normalmente a essas actividades?

		Horas			**Minutos**

Q.3 Diga-me por favor, nos últimos 7 dias, em quantos dias fez actividades físicas **moderadas** como por exemplo, carregar objectos leves, caçar, trabalhos de carpintaria, andar de bicicleta a um ritmo normal ou ténis de pares? Por favor não inclua o "andar ".

		Dias

Q.4 Nos dias em que faz actividades físicas **moderadas**, quanto tempo em média dedica normalmente a essas actividades?

		Horas			**Minutos**

Q.5 Diga-me por favor, nos últimos 7 dias, em quantos dias andou pelo menos 10 minutos seguidos?

		Dias

Q.6 Quanto tempo no total, despendeu num desses dias, a andar/caminhar?

		Horas			**Minutos**

Q.7 Diga-me por favor, num dia normal quanto tempo passa sentado? Isto pode incluir o tempo que passa a uma secretária, a visitar amigos, a ler, a estudar ou a ver televisão.

		Horas			**Minutos**

MUITO OBRIGADO PELA SUA COLABORAÇÃO

APPENDIX 4

Nijmegen Gait Analysis Scale

(NGAS)

Nijmegen gait analysis scale

Orthopedic gait analysis form

				STANCE PHASE			SWING PHASE	
	Item	**Question**		**Early**	**Mid**	**Late**	**Early**	**Late**
General	**1**	Is a shortened stance phase present?	Left		Yes / No		NA	
			Right		Yes / No		NA	
Trunk	**2**	Is the trunk anterior to the hips?				Yes / No		
	3	Is the trunk posterior to the hips?				Yes / No		
	4	Is lateral flexion present?	Left		Yes / No		NA	
			Right		Yes / No		NA	
	5	Is arm-swing reduced?	Left			Yes / No		
			Right			Yes / No		
Pelvis	**6**	Is the posterior rotation excessive?	Left	NA		Yes / No	NA	
			Right	NA		Yes / No	NA	
Hip	**7**	Is the extension reduced?	Left	NA		Yes / No	NA	
			Right	NA		Yes / No	NA	
Knee	**8**	Is the extension reduced?	Left	NA			NA	Yes / No
			Right	NA			NA	Yes / No
	9	Is the flexion movement absent ?	Left	Yes / No	NA		NA	
			Right	Yes / No	NA		NA	
	10	Is the flexion reduced?	Left	Yes / No	NA		NA	
			Right	Yes / No	NA		NA	
	11	Is the extension absent?	Left	NA	Yes / No	NA	NA	
			Right	NA		Yes / No	NA	
Ankle	**12**	Is the plantar flexion reduced?	Left	NA		Yes / No	NA	
			Right	NA		Yes / No	NA	

NA = not applicable

APPENDIX 5

Knee and Osteoarthritis Outcome Score Scale

(KOOS)

Knee injury and Osteoarthritis Outcome Score (KOOS), Portuguese version LK1.0

QUESTIONÁRIO KOOS SOBRE O JOELHO

Data:__/__/____ Data de nascimento:__/__/____

Nome: _____

INSTRUÇÕES: Este questionário pretende saber como vê o seu joelho. Esta informação dar-nos-á dados sobre como se sente em relação ao joelho e até que ponto é que é capaz de desempenhar as suas actividades normais.
Responda a cada uma das perguntas marcando o quadrado adequado, apenas um quadrado para cada pergunta. Se não tiver a certeza sobre a resposta a escolher, por favor escolha a que achar melhor.

Sintomas

Estas perguntas devem ser respondidas tendo em conta os sintomas no seu joelho durante a **última semana**.

S1. Tem tido o joelho inchado?

Nunca	Raramente	Às vezes	Frequentemente	Sempre
☐	☐	☐	☐	☐

S2. Tem sentido ranger, ouvido um estalo ou qualquer outro som quando mexe o joelho?

Nunca	Raramente	Às vezes	Frequentemente	Sempre
☐	☐	☐	☐	☐

S3. Tem sentido o joelho preso ou bloqueado quando se mexe?

Nunca	Raramente	Às vezes	Frequentemente	Sempre
☐	☐	☐	☐	☐

S4. Tem conseguido esticar o joelho completamente?

Sempre	Frequentemente	Às vezes	Raramente	Nunca
☐	☐	☐	☐	☐

S5. Tem conseguido dobrar o joelho completamente?

Sempre	Frequentemente	Às vezes	Raramente	Nunca
☐	☐	☐	☐	☐

Rigidez

As perguntas que se seguem dizem respeito ao grau de rigidez no joelho que teve na **última semana**. Rigidez é uma sensação de dificuldade ou lentidão a mexer o seu joelho.

S6. Até que ponto sente rigidez no joelho logo após acordar de manhã?

Nada	Pouco	Moderadamente	Muito	Muitíssimo
☐	☐	☐	☐	☐

S7. Até que ponto sente rigidez no joelho depois de se sentar, deitar ou descansar **ao fim do dia**?

Nada	Pouco	Moderadamente	Muito	Muitíssimo
☐	☐	☐	☐	☐

Dor

P1. Com que frequência tem dores no joelho?

Nunca	Uma vez por mês	Uma vez por semana	Todos os dias	Sempre
☐	☐	☐	☐	☐

Que intensidade de dor no joelho é que teve durante a **última semana** nas seguintes actividades?

P2. Rodar/virar-se/torcer sobre o joelho

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P3. Esticar o joelho completamente

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P4. Dobrar o joelho completamente

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P5. Andar sobre uma superfície plana

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P6. Subir ou descer escadas

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P7. À noite, na cama

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P8. Estar sentado/a ou deitado/a

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

P9. Estar de pé

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

Actividades da vida diária

As perguntas que se seguem dizem respeito à sua função física. Por função física referimo-nos à sua capacidade de se deslocar e de cuidar de si. Para cada uma das actividades seguintes, indique o grau de dificuldade que sentiu na **última semana** por causa do seu joelho.

A1. Descer escadas

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A2. Subir escadas

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

Para cada uma das seguintes actividades indique, por favor, o grau de dificuldade que teve na **última semana** devido ao seu joelho.

A3. Levantar-se a partir da posição de sentado/a

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A4. Manter-se de pé

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A5. Dobrar-se para baixo/apanhar um objecto

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A6. Andar numa superfície plana

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A7. Entrar ou sair do carro

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A8. Ir às compras

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A9. Calçar meias/collants

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A10. Levantar-se da cama

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A11. Descalçar meias/collants

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A12. Estar deitado/a na cama (virar-se, manter a posição do joelho)

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A13. Entrar/sair da banheira

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A14. Estar sentado/a

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A15. Sentar-se ou levantar-se da sanita

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

Para cada uma das actividades seguintes, indique o grau de dificuldade que sentiu na **última semana** por causa do seu joelho.

A16. Tarefas domésticas pesadas (ex.: pegar em caixas pesadas, esfregar o chão, etc.)

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

A17. Tarefas domésticas leves (ex.: cozinhar, limpar o pó, etc.)

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

Actividades desportivas e de lazer

As perguntas que se seguem dizem respeito à sua função física, estando activo/a a um nível mais elevado. As perguntas devem ser respondidas tendo em conta o grau de dificuldade que teve durante a **última semana** por causa do seu joelho.

SP1. Pôr-se de cócoras

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

SP2. Correr

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

SP3. Saltar

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

SP4. Rodar/virar-se/torcer sobre o joelho afectado

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

SP5. Ajoelhar

Nenhuma	Pouca	Moderada	Muita	Muitíssima
☐	☐	☐	☐	☐

Qualidade de Vida

Q1. Com que frequência é que tem consciência do problema que tem no joelho?

Nunca	Uma vez por mês	Uma vez por semana	Todos os dias	Constantemente
☐	☐	☐	☐	☐

Q2. Modificou o seu estilo de vida para evitar actividades que poderiam afectar o joelho?

De modo algum	Um pouco	Moderadamente	Muito	Completamente
☐	☐	☐	☐	☐

Q3. Até que ponto é que a falta de confiança no joelho o/a incomoda?

Nada	Um pouco	Moderadamente	Muito	Muitíssimo
☐	☐	☐	☐	☐

Q4. Em geral, o joelho causa-lhe muitos problemas?

Nenhuns	Poucos	Alguns	Muitos	Muitíssimos
☐	☐	☐	☐	☐

APPENDIX 6

Visual Analogue Scale

(VAS)

Escala Visual Análoga

Sem Dor _____ **Dor Máxima**