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Effectiveness of the open and closed kinetic chain exercises in the treatment of the patellofemoral pain syndrome

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ABSTRACT

The aim of this study was to analyze the therapeutic effects of the open kinetic chain (OKC) and closed kinetic chain (CKC) exercises to treat the patellofemoral syndrome (PFSD). For this, 24 volunteers, bearers of the PFSD were randomly divided in two groups: group I ($n = 12$) performed the OKC exercises; group II ($n = 12$) performed the CKC exercises. Both groups were submitted to eight consecutive weeks of treatment consisting of three weekly sessions performed in alternate days. To analyze the activation pattern of the vastus medialis oblique (VMO) and the vastus lateralis (VL) muscles, the electromyographic signals (EMG) were collected using bipolar surface electrodes quantified by the root mean square (RMS) normalized by the maximal voluntary isometric contraction of the quadriceps. The pain intensity and the functionality of the volunteers were assessed using scales. The analysis of the amounts of the VMO/VL ratio in both groups I and II showed no significant differences as to the pre- and post-treatment times in the concentric ($p > 0.05$) and eccentric ($p > 0.05$) phases of the OKC and CKC exercises. Despite of this, the VMO muscle presented a lower activation rate compared to the VL in the eccentric phase of the CKC exercise. It was found significant increases in the functionality ($p < 0.05$), and a reduction in the pain intensity ($p < 0.05$) between the pre- and post-treatment times in both groups, but group II showed higher amounts compared to group I in both variables. The results found in this study suggest that according to the conditions of the trial, the OKC and CKC exercises provoke no changes in the patterns of the EMG activation in the VMO and VL muscles. However, they promoted an improvement in the functionality and a reduction in the pain intensity after the eight week intervention, and the CKC exercises presented better performances than OKC exercises.

Keywords: Knees. Electromyography. Exercise. Functional recovery.

INTRODUCTION

The patellofemoral pain syndrome (PFSD) is a quite often affection seen in the orthopedic practice attacking mainly athletes and young adults. Although its etiology remains unknown, the force unbalance between the vastus medialis oblique (VMO) and the vastus lateralis (VL) muscles, which are the main dynamic stabilizers of the patella is considered the main factor that causes the symptoms' onset. Such unbalance causes changing in the patellar kinematics, contributing to increase the strength of the patellofemoral's reaction and compression(1).

The electromyographic (EMG) activation patterns of these muscles have been widely investigated(2,3). Some authors point out the decrease in the EMG activity of the VMO compared to the VL in individuals bearers of the PFSD, and they are searching for exercises to promote its selective activation(1,4).

Aiming the balance and function recovery of the extensor muscles of the knees and to re-establish the joint stability, the OKC and CKC exercises have been employed in rehabilitation programs to treat patellofemoral disturbances.

During the accomplishment of the OKC exercises, the femoral quadriceps muscle actuates isolately, thus favoring the increase in the forces of the patellofemoral compression(5). The CKC exercises generate muscular co-contraction, propitiating higher stability of the joint, besides of reproducing commonly performed functional movements in the day-to-day activities(6).

Despite of the increasing preference by CKC exercises and the discontinuance of OKC exercises to treat individuals with PFSD, there is scarcity of scientific reports showing which method is most effective when employed in the form of muscular training.

The aim of this study was to analyze the therapeutic effect of the OKC and CKC exercises on the pain intensity and the patellofemoral pain in individual bearers of the PFSD. For this, the EMG activation patterns of the VMO and VL muscles, the pain intensity, and the functionality of the participants were assessed.

METHODS

Casuistic

This study was composed by 24 volunteers (17 women and 7 men) bearers of PFSD. The inclusion criteria adopted were: pain in the knees for more than two months, pain intensity higher than three and lower than eight in the visual analog scale (VAS), and pain or discomfort reported at least when performing two of the following situations: ascending and descending steps, kneeling, running, squatting, and remaining seated for prolonged times. It was excluded from the study those individuals who presented signals of any other condition in the knees joint.

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The study was conducted according to the Resolution 196/96 of the National Health and Medical Sciences Council of the Campinas State University (Unicamp). All volunteers signed a free and clarified consent term approved by the committee.

The volunteers were randomly distributed in two groups: group I (n = 12), and group II (n = 12), as shown on table 1.

TABLE 1
Anthropometric data of groups I and II

	Group I (N = 12)		Group II (N = 12)		
	Mean	**S.D.**	**Mean**	**S.D.**	**P**
Age	22.5	± 2.94	23.83	± 2.62	0.23
Weight	67.0	± 5.51	68.4	± 4.46	0.77
Height	167.0	± 3.81	168.2	± 3.56	0.39
BMI	24.01	± 1.71	24.23	± 1.94	0.54

Captions: Group I: treatment with OKC exercises; group II: treatment with CKC exercises.

Intervention programs

The treatment protocol consisted of three weekly physiotherapy sessions performed along eight weeks in alternate days. Table 2 presents the exercises that were part of the program for both groups I and II. To perform the isometric OKC and CKC exercises, it was performed four series of 10 repetitions, and each repetition was sustained for eight seconds followed by one minute resting period. As to the isotonic CKC exercises (45º leg press) and the OKC exercises (flexor-extensor bench), it was initially analyzed the maximal repetition (MR) of the femoral quadriceps (FQ) for each participant, and next, three series of ten repetitions were performed: the first at 20%, the second at 40%, and the third at 60% of the MR.

TABLE 2
Intervention protocols for groups I and II

Group I (N = 12)	Group II (N = 12)
Isometric of the quadriceps with the knees at a 90° angle*	Isometric of the quadriceps with the knees at a 20° angle**
Isometric of the quadriceps with the knees at a 70° angle*	Isometric of the quadriceps with the knees at a 40° angle**
Isometric of the quadriceps with the knees at a 50° angle*	Semi-squatting (0º to 50º)
Flexor-extensor bench (90º to 50º)	Leg press (0º to 50º)

Captions: Group I: treatment with OKC exercise; group II: treatment with CKC exercises.
* Exercises performed on the flexor-extensor bench; ** Exercises performed on the leg press device at 45 cranes.

The OKC exercises were performed with a knees' ROM comprised between a 90 and 50º flexion (0º considered as the whole extension of the knees). To the CKC exercises, the ROM of the knees was from 0 to 50 grades flexion (0º considered as the whole extension of the knees). These criteria were adopted following the works performed by Steimkamp *et al.*(7) and Escamilla *et al.*(8), who suggested these angles as the most safe to perform the OKC and CKC exercises.

Aiming the isolate assessment of the muscular training effects, all volunteers were instructed to perform no activity involving flexibility exercises along the training period(9).

Pain and functionality

Aiming to measure the pain intensity upon the rest and while performing functional activities, the VAS and the Kujala scale were respectively applied(10,11).

Electromyographic assessment

The electrical activity of the VMO and VL muscles was attained by means of an eight-channel Myosystem electromyography (Noraxon, Scottsdale, Arizona) that presents a 114 dB rejection ratio in the common mode, an entry impedance between 20 MΩ and 1 GΩ, and bandwidth between 16 and 500 Hz. The electromyographic signals were collected at a 1,000 Hz frequency using the MyoResearch version 2.10 data acquisition software (Noraxon, Scottsdale, Arizona). These signals were stored on a PC for later visualization and analysis. To collect the electrical activity of the muscles, bipolar surface electrodes constituted by Ag/AgCl (Duo-Trode, Myotronics, Inc.) were used with two centimeters distance between the detection sites. The electrodes of the VMO and VL muscles were fixed over the muscular abdomen, and they were oriented at 55 and 15º related to the longitudinal axle of the femur, respectively(12,13). A reference electrode (ground) was fixed on the tibia's tuberosity. In order to reproduce the same position of the electrodes in the electromyographic assessment performed after the training program, it was measured the distance and the angles between them and the center of the patella. Thus, the amounts initially attained for each volunteer were reported and repeated in the final assessment.

To control the angle variation of the knee while performing the exercises, it was used a NorAngle double-axle electrogoniometer (Noraxon, Scottsdale, Arizona) connected to the conditioner module of the electromyographic signals. To fasten it, it was used two plastic poles which were positioned on the lateral spots of the thigh (upper pole), and on the lateral portion of the leg (lower pole) of each volunteer(14). The joint positioning and the EMG activity were simultaneously recorded with the same sampling frequency (1,000 Hz).

The velocity to perform the exercises was controlled by means of a metronome adjusted to accomplish thirty touches per minute. Before starting the data collection, all volunteers were familiarized with the trial as to the correct performance of the exercises.

To the group submitted to the CKC protocol, the collections were performed during the semi-squatting exercise in its eccentric phase (down) and in the concentric phase (up). From the stand up position, the volunteers performed five repetitions of the squatting and rising movements, and it was granted one minute rest between each repetition. Each repetition lasted four seconds.

To the group submitted to the OKC protocol, the data collections were performed on a flexor-extensor bench. The volunteers remained seated having their lumbar and thoracic spine supported, hips and knees at a 90º flexion. Next, they performed five repetitions of the extension movement (concentric phase), and flexion of the knees (eccentric phase), and it was granted also one minute rest between each of them. The load used during the exercise was of 40% of the MR, and each repetition lasted four seconds.

Normalization of the EMG signals

Several studies suggest the normalization of the EMG signal by the maximal voluntary isometric contraction (MVIC)(15). For this, it is demanded an exercise that promotes the MVIC of the assessed muscles, and then, the mean value is attained by the root mean-square (RMS) of that exercise, which will represent the maximal electrical activity these muscles are able to generate(16). Thus, the means of the amounts in RMS of the other exercises are quantified as a percentage of that amount.

In this study, the MVIC of the knee extensor positioned at a 90º flexion was used to normalize the data, and having the tibia at a neutral positioning. The MVIC collections were performed on a flexor-extensor bench, and each contraction lasted four seconds.

Statistical analysis

To perform intergroup comparisons as to the amounts attained in the Kujala and VAS scales in the pre- and post-treatment times, as well as to verify the homogeneity of the groups, the Mann-Whitney test was used. As to the intergroup analysis of the VMO/VL ratio, the Kujala scale and the VAS between the pre-and post-treatment, the Wilcoxon test was used for related sampling. The significance level adopted for the statistical tests was 5%.

RESULTS

It is verified on table 3 the values of the means and the standard deviations of the normalized EMG activity of the VMO and VL muscles related to the group I during the concentric and eccentric phases of the flexor-extensor exercise of the knees (OKC).

TABLE 3
Normalized EMG activity of the VMO and VL muscles in concentric contraction (CC) and eccentric contraction (EC) in the pre- and post-treatment times related to the group I

	Group I (N = 12)				
	Mean		S.D.		P
	Pre	Post	Pre	Post	
VMO CC	51.57	53.31	± 8.47	± 8.83	–
VL CC	55.18	56.67	± 8.26	± 8.24	–
VMO/VL CC	0.93	0.94	± 0.06	± 0.07	0.79
VMO CE	33.33	35.32	± 8.25	± 9.26	–
VL CE	35.65	38.04	± 8.55	± 8.71	–
VMO/VL CE	0.93	0.92	± 0.03	± 0.07	0.85

Means and Standard deviations (SD) of the EMG activity in RMS (expressed as a percentage of the MVIC) and the ratio related to the VMO and VL muscles in Concentric Contraction (CC) and Eccentric Contraction (CE) in the flexor-extensor OKC exercise of the knees (n = 12).

There was no statistically significant differences in the VMO/VL ratio between the pre- and post-treatment times in the concentric (p = 0.79) and eccentric (p = 0.85) phases of the exercise.

As to the group II, table 4 shows the means and the standard deviations of the normalized EMG activity of the VMO and VL muscles, as well as the VMO/VL ratio in the concentric and eccentric phases of the semi-squatting exercise (CKC). These data show that there were no significant differences in the amounts of the VMO/VL ratio in the concentric (p = 0.56) and eccentric (p = 0.26) phases of the exercise after the treatment.

TABLE 4
Normalized EMG activity of the VMO and VL muscles in concentric contraction (CC) and eccentric contraction (EC) in the pre- and post-treatment times related to the group II

	Group II (N = 12)				
	Mean		S.D.		P
	Pre	Post	Pre	Post	
VMO CC	22.57	23.51	± 7.99	± 7.50	–
VL CC	25.31	26.79	± 8.00	± 7.87	–
VMO/VL CC	0.89	0.88	± 0.10	± 0.10	0.56
VMO CE	15.38	16.37	± 5.87	± 5.33	–
VL CE	22.09	22.01	± 8.04	± 6.37	–
VMO/VL CE	0.72	0.77	± 0.17	± 0.23	0.26

Means and Standard Deviations (SD) of the EMG activity in RMS (expressed as a percentage of the MVIC) and the ratio related to the VMO and VL muscles in Concentric Contraction (CC) and Eccentric Contraction (EC) in the CKC semi-squatting exercise (n = 12).

Tables 3 and 4 show that the amounts of the VMO/VL ratio were lower than 1, indicating a decrease in the VMO activation compared to the VL. Such decrease was observed both in the concentric and in the eccentric phases in both assessed exercises, and it was detected a higher discrepancy between the amounts of the activation percentage of those muscles in the eccentric phase of the CKC exercise.

Figures 1 and 2 are box-plots representing graphic depictures of the VAS amounts and the Kujala scale found in both groups I and II in the pre- and post-treatment times.

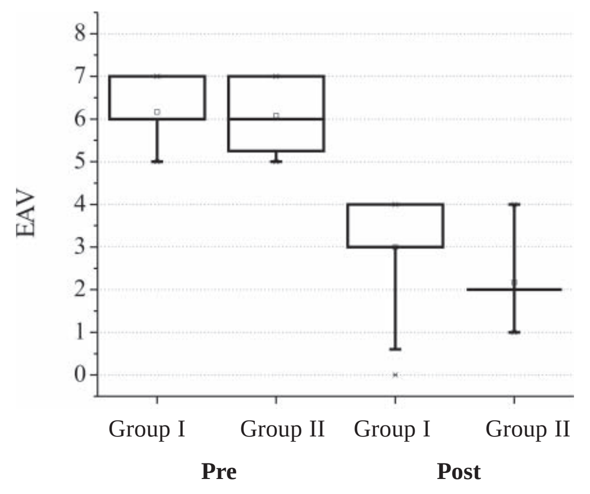

Figure 1 *– Comparison of the pain intensity between group I (n = 12) and II (n = 12), measured by the analog-visual 10 cm scale, in the pre- and post-treatment times*

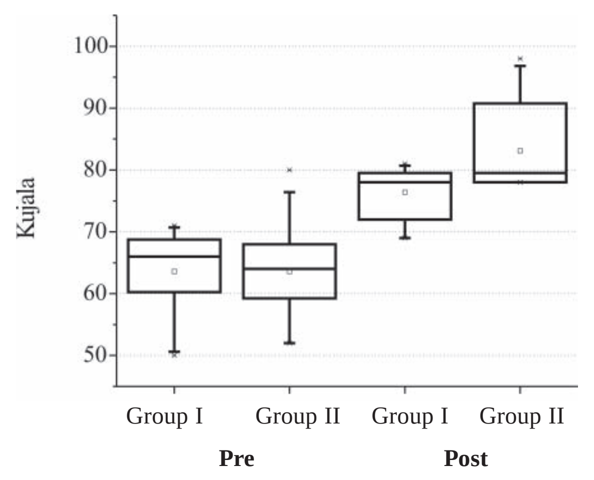

Figure 2 *– Comparison of the functionality between group I (n = 12) and II (n = 12), measured by the Kujala scale in the pre- and post-treatment*

In figure 1 it is verified the results related to the pain intensity measured by the VAS before and after the treatment.

The intergroup analysis has shown that before the beginning of the program, there was no statistically significant difference between the means of groups I and II as to the pain's VAS (p = 0.82). However, upon the completion of the program, group II attained an accentuated improvement compared to the group I (p = 0.02). The intergroup comparison disclosed that both groups presented a statistically significant improvement after the eight week treatment (p = 0.0005 for group I; p = 0.0005 for group II).

Figure 2 illustrates the results attained through the functional Kujala scale. As to the intergroup comparison, it was observed no statistically significant different in the beginning of the treatment between them (p = 0.68). But when performing the same comparison at the end of the treatment, it was evidenced better results for the group II (p = 0.03). As to the intergroup analysis, both presented significant gains in the functionality after the treatment (p = 0.0005 for group I; p = 0.0005 for group II).

DISCUSSION

The results found in this study disclosed that after an eight week treatment, the groups attained a significant reduction in the pain intensity and an improvement to perform functional activities. The group II has shown higher results than group I in both assessed variables. These findings are in accordance to the ones found by Witvirouw *et al.*(17), who, after submitting 60 individuals to a five week treatment using OKC and CKC exercises, observed an increase in the torque peak of the FQ and ischiotibialis muscles, pain reduction and functional gain in both assessed groups.

In another study, Witvirouw *et al.*(18) reported excellent results related to the pain and functionality after treating individuals reporting patellofemoral pain, but they did not evidence any effect of such treatment on the reflexive response time of the VMO and VL muscles. Likewise, Stiene *et al.*(19) concluded that after an eight week treatment, the CKC exercises were more effective than the OKC exercises in the functional recovery of individual bearers of patellofemoral disorder.

Bennett & Stauber(20) initially assessed 41 individuals with PFSD, and they identified a reduction in the extensor torque of the knees during the eccentric phase of the OKC exercise. Thus, they applied a treatment program using only OKC exercises performed on the isokinetic dynamometer, and they evidenced that in about four weeks, the individuals had a reduction in the pain, re-establishing the extensor torque of the knees, and they returned to the sportive activities.

The above exposed statement suggests that both the OKC and the CKC exercises can be employed to treat the PFSD. Nevertheless, before prescribing the activities to strengthen the FQ, it is necessary to understand the biomechanical principles of the patellofemoral joint in order to make an exercise scheduling that combines effectiveness and safety. In the present study, the knee's ROM was limited during the accomplishment of the exercises that integrated the treatment program, opposed to the previously mentioned studies. According to Steimkamp *et al.*(7), while performing OKC exercises it must be avoided the last extension grades of the knees, since such angles have a lower joint contact, but the compressive strengths are distributed over a small area, thus increasing the patellofemoral stress.

As to the CKC exercises, the authors suggest to avoid higher than 45º angles of the knee flexion, since despite the higher joint stability with the increment of the flexion, there is also an increase in the compressive strengths and a higher patellofemoral stress. Similar results were described by Doucette & Child(21), who suggest performing OKC exercises with higher than 30º angles for the knee flexion, while CKC exercises must be performed in angles closed to its whole extension.

The results related to the EMG activity has shown that after the treatment, there was no significant differences in the VMO/VL ratio in the eccentric and concentric phases of the OKC and CKC exercises. However, the comparison of these findings with prior studies was difficult, as it was not found any work in the literature assessing the isolate effects of the muscular training in OKC and CKC on the EMG activation patterns of the stabilizer muscles of the patella in PFSD bearers. Nonetheless, even being not influenced by the treatment, the EMG activation patterns of the VMO and VL muscles has shown to be distinct in the concentric and eccentric phases in the assessed exercises. The RMS amounts related to the VMO/VL ratio in the pre- and post-treatment times disclosed an accentuated reduction in the VMO activation in the eccentric phase of the CKC exercise. These findings confirm what was found by Shenny *et al.*(22), who reported a decrease in the VMO activation related to the VL in individuals with patellofemoral pain while descending steps (eccentric contraction). Souza & Gross(23) reported similar findings after assessing the VMO/VL ratio during isometric, concentric isotonic, and eccentric isotonic contraction of the FQ, showing a reduction in the EMG activity of the VMO compared to the VL in symptomatic individuals.

Owings & Grabiner(1) identified a higher EMG activity of the VL compared to the VMO in the eccentric phase of the leg extension OKC exercise, suggesting a deficit in the motor controlling of the patellar stabilizers in PFSD bearers.

On the other hand, Powers *et al.*(24) identified activation patterns similar to the VMO and VL muscles in individuals with patellofemoral pain, and they did not observe any commitment of the VMO activation while performing CKC activities. Similar results were described by Cerny(25), who did not observe significant differences in the VMO/VL ratio in individuals PFSD bearers performing CKC exercises. One possible explanation for the differences in the results of these studies is related to the diversity of methods used to the acquisition and processing the electromyographic signals(26). Furthermore, the inherent variability of the individuals with PFSD remains as a challenge to determine the specific activation patters of the stabilizer patella muscles among such population.

Even when it does not cause any alteration in the muscular activation patterns, the interventional schedule adopted in this study has shown to be effective to treat the PFSD. Such fact can be attributed to the strengthening of the FQ as a whole, once the extensor muscles of the knees absorb part of the strength imposed to the joint while performing activities that cause an overload to it. Thus, it is believed that the recovery of the quadricipital function is able to re-establish the biomechanical properties of the patellofemoral and femorotibial functions, to increase the extensor torque of the knees and to improve the clinical and functional pictures in individual bearers of PFSD(17,20).

Powers *et al.*(27) identified that together with a reduction in the torque generated by the FQ, there was a commitment of the locomotive function in symptomatic individuals, pointing out the importance of the quadricipital strengthening in the PFSD treatment. In recent reviews, Wilk & Reinold(28) and Crossley *et al.*(29) showed evidences pointing that the FQ strengthening exercises are an indispensable part of rehabilitation programs involving patellofemoral disorders. But despite these reports, the mechanism by which the FQ strengthening promotes an increase in the functionality and reduction of the symptoms in individuals bearers of patellofemoral pain is not quite clarified.

Before the scarcity of studies assessing the effects of the muscular training to treat the PFSD, it is necessary to conduct further studies involving a higher amount of individuals in the sampling, longer intervention periods and using different exercises to help in the collection of information that propitiate to perform and apply a more effective rehabilitation program that favor the improvement of the quality of life in individuals bearers of such affection.

CONCLUSION

In the experimental conditions used in this study, the OKC and CKC exercises promoted a reduction in the pain intensity and improvement of the functionality in PFSD bearers. The CKC exercises have shown to be more effective compared to the CKC exercises.

As to the EMG activation patterns, the exercises were not able to change the amounts of the VMO/VL ratio. Nevertheless, the VMO muscle presented an accentuated reduction in the activation related to the VL in the eccentric phase of the CKC exercise.

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

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