Functional and EMG responses to a physical therapy treatment in patellofemoral syndrome patients

Isabel de C.N. Sacco a,*, Gil Kiyoshi Konno a, Guilherme Benetti Rojas a, Antonio Carlos Arnone b, Anice de Campos Pássaro a, Amélia Pasqual Marques a, Cristina Maria Nunes Cabral a,c

a Physical Therapy, Speech and Occupational Therapy Department, School of Medicine, University of Sao Paulo, Sao Paulo, Brazil
b Orthopedics Clinic, University Hospital, University of Sao Paulo, Sao Paulo, Brazil
c UNIFIEO, Physical Therapy Program, Sao Paulo, Brazil

Received 8 June 2004; received in revised form 10 June 2004; accepted 28 June 2004

Abstract

There are several pathologies related to the patellofemoral joint, in which the patellofemoral syndrome is one of the most common and challenging to treat. The patellofemoral syndrome results from a malalignment of the knee extensor mechanism. The purpose of our study was to describe and compare EMG responses of the vastus medialis and vastus lateralis muscles while walking up and down stairs and other clinical and functional responses in PFS subjects before and after a physical therapy intervention. Eleven subjects were studied and divided in two groups: six subjects with clinically diagnosed patellofemoral syndrome and five healthy control subjects. Subjects were evaluated by a functional and biomechanical evaluation protocol: postural evaluation, pain and knee function evaluation, and electromyographic activity of vastus medialis and lateralis muscles while walking up and down a staircase. Results showed higher efficiency of the vastus medialis muscle in carrying out eccentric exercises and increased muscle activity in both the vastus medialis and vastus lateralis muscles while climbing stairs after physical therapy treatment. We were able to identify an improvement in postural alignment of lower limb muscles and knee functionality among patellofemoral syndrome group subjects after treatment.

Keywords: Patellofemoral syndrome; Electromyography; Biomechanics; Physical therapy; Climbing stairs

1. Introduction

There are several pathologies related to the patellofemoral joint, in which the patellofemoral syndrome (PFS) is one of the most common and challenging to treat. PFS results from an imbalance of the forces placed on the patella during its normal movement [28]. The patient is usually young and active and suffers from retropatellar and peripatellar pain resultant from sitting for prolonged periods, squatting, kneeling, walking up and down stairs. These activities increase patellofemoral compressive forces enhancing pain in these patients [34]. Pain is proportional to the activity being carried out and is particularly evident while walking down stairs and squatting. Crepitation during knee flexion-extension is another common finding in some individuals.

The PFS etiology is still unknown and multifatorial. It includes valgus knee, shortening of the hamstrings,
bigger $Q$ angles and patellar malalignment. In spite of the diverse factors associated with PFS, there is a general consensus that the malalignment of the knee extensor mechanism would be the major cause of patellofemoral pain [20,27].

Considered as a dynamic stabilizer of the patella, the action of the quadriceps femoris muscle influences its position because it is a great muscle with large size which have differences in fiber orientation, as seeing in vastus medialis and vastus lateralis [4,7,21,33], who may lead to pain when muscle forces are related to mal-tracking of the patella.

An abnormal tracking pattern may be suggested by the imbalance of the activity of vastus lateralis (VL) and vastus medialis (VM), especially its obliquus portion (VMO), which is the most important dynamic stabilizers of the patellofemoral joint [17,30,33]. Reduced strength of VMO or abnormal relationship in the timing of activation pattern of the VMO and VL can alter the dynamics of patellofemoral joint and therefore predisposes PFS. It is established that in asymptomatic population the VMO must be activated before the VL, in order to properly pull the patella and avoiding the prevalence of the lateral forces by the action of VL [9]. Hence, the quadriceps muscle is being widely studied in healthy and PFS individuals, particularly portions of the VM and VL in motor tasks that lead this joint to excessive loading, such as walking down and up stairs [25].

Clinical diagnosis must be carefully determined to differentiate from other pathologies with similar symptoms, such as patellalgia, anterior knee pain syndrome and retropatellar arthralgia or knee pain, among others [15,28].

There is a commonly accepted concept that conservative rehabilitation induces relief of symptoms for patients with PFS [34]. Rehabilitation aims to restore the normal coordination of muscle activity, specially during functional movements, using strengthening of the dynamic stabilizers of the patellofemoral joint and stretching of the shorten muscles. These interventions may be associated with a positive clinical outcome including a reduction in pain, improved function and decreased recurrence of pain [10].

Souza et al. [30] carried out a study with female healthy and PFS volunteers and they aimed to determine the electrical activity of the VMO/VL ratio during maximum voluntary isometric contraction with the knee in a flexion of 60° in open kinetic chain. Results did not demonstrate significant differences among the groups for the VMO/VL ratio at knee flexion of 60°. A similar result was obtained in a study using the same methodology for knee flexions of 15°, 30° and 90° angles [2]. However, when subjects were evaluated separately, five with a higher knee $Q$ angle revealed a lower VMO/VL ratio in comparison with other subjects.

Brechter, Powers [3] analyzed patellofemoral joint stress using magnetic resonance imaging, ground reaction forces and joint kinetics in PFS subjects while walking up and down stairs. Results showed that there were no significant differences between PFS and control group regarding joint stress caused by walking up and down stairs. However, they observed in the PFS group, lower knee extensor moment, lower reaction force in the patellofemoral joint and a decrease in cadence while climbing stairs, indicating a protective adaptation because of the pain.

Considering that an imbalance of muscular forces placed on the patella during movement may lead to the onset of PFS, the purpose of our study was to describe and compare EMG responses of the VM and VL muscles while walking up and down stairs and other clinical and functional responses in PFS subjects before and after a physical therapy intervention.

2. Methods

2.1. Subjects and experimental protocol

Eleven active subjects were selected (eight male and three female), between the ages of 18 and 35, divided in two groups: six subjects in the trial group (patellofemoral group – PFG), which had been clinically diagnosed by the University Hospital team with PFS in at least one of the limbs and with positive patellar compression test; and five subjects in the control group (CG), with no prior history of knee pathology.

Subjects in the study were informed of the trial procedures by a research consent agreement and the University Hospital Ethics Committee approved the protocol. Both groups underwent a functional and biomechanical evaluation stage, in which we evaluated posture, knee joint functionality and electromyographic activity of the VL and VM muscles while carrying out locomotor activities. After this first evaluation stage, the PFG group underwent a physical therapy intervention in the University Hospital. The functional and biomechanical evaluation were repeated after the physical therapy intervention in order to identify improvements.

2.2. Functional and biomechanical evaluation

Subjects in both groups (PFG and CG) were evaluated by a functional and biomechanical evaluation protocol consisting of three stages. The first stage consisted of a postural evaluation, observing the proposed postural alignment, given greater attention to the lower limbs [22]. This protocol was developed based on papers by Kendall [22], Lapierre [24] and Daniels and Worthinghan [12], and was always applied by the same
evaluator. Postural evaluation was complemented by the \( Q \) angle measurement [5]. The evaluation of the longitudinal arch of the foot was complemented by a foot print in a static position. From the recorded image we calculated the plantar longitudinal arch rate to categorize the arch type of the subjects: flat, cavus or normal foot [8].

In the protocol's second stage, we sought to evaluate functional injury level of the knee joint complex using a visual analogue scale (VAS) to access pain intensity and two scales widely approved in the scientific literature: (1) knee evaluation scale based on Lysholm [26] and (2) patellofemoral joint evaluation scale based on Karlsson [19].

In the third stage we analyzed electromyographic activity variables of the quadriceps femoris muscle, in its VM and VL portions, synchronized with the angular variation measurement by an electrogoniometer. Such analysis was made while carrying out two locomotor tasks in an auto-selected cadence: walking up and down a staircase. This staircase had four stairs, each measuring 15 cm high. Walking up and down stairs were selected in order to cause excessive loading in the patellofemoral joint and because pain and stress is more evident while performing these tasks. In the PFG group we analyzed the sides having a stronger clinical complaint, while in the CG group the dominant side was analyzed.

We used a surface electromyograph made by EMG Brasil, which enabled the analysis of the selected muscles through active differential electrodes. The EMG surface electrodes are pre-amplified with factor 20 on the electrode itself and factor 50 on the amplifier. We chose to place the electrode at the muscle's motor point, since past studies have demonstrated that this technique provides greater reliability in acquiring the electromyographic signal, decreasing the possibility for cross talk to occur, besides allowing the reproduction of this study before and after the physical therapy intervention [1,11,31].

Angular variation measurement of the knee joint during locomotor tasks was made using a planar electrogoniometer synchronized with the EMG measurement consisting of a fixed rotation potencymeter, aligned with the knee's rotation axis and two wooden paddles that are attached to joint segments by elastic bandages, keeping those paddles parallel to the femur and tibia. Depending on changes in position of the segments in question, the potencymeter alters the electric tensions, which can be calibrated according to previously known positions. In this case, the reference system we adopted took into consideration that at full knee extension the angle measured by the electrogoniometer would be 0\(^\circ\), as suggested by Winter [36], and this value increases according to joint flexion.

Three samples of each task were collected with a sampling frequency of 1000 Hz for periods of 6 s.

### 2.3. Physical therapy treatment

The physical therapy intervention consisted of 25 sessions for 5 weeks, five supervised and controlled by a physical therapist and 20 unsupervised. The purpose of the protocol was to improve the clinical condition and symptoms of patients, as well to restore the normal coordination of muscle activity [5,35]. The protocol consisted of six simple exercises: stretching the hamstrings with patient in sitting and supine position; stretching the quadriceps muscle in lateral position; strengthening the quadriceps femoris muscle while squatting in hip adduction; stretching the iliotibial band in sitting and standing position.

### 2.4. Statistical and mathematical analysis

From the electromyographic data collected, we adjusted the base line or zero reference with the raw signals, when these were offsetting. Afterwards, we proceed a full wave rectification and the phases of each movement were determined from the electrogoniometer data. The root mean square (RMS) values were calculated for these interval phases as a form of representing electromyographic signal intensity.

The electromyographic variables, anthropometric, demographic characterization of the subjects and \( Q \) angle were initially analyzed with respect to their statistical distribution using the Shapiro Wilks \( W \) test. In relation to parametric data, the inferential \( t \) test for independent samples was used to compare the CG and PFG groups, and the \( t \) test for paired samples was used to compare these variables between the PFG before and after intervention groups. In relation to non-parametric data, the Mann–Whitney test was used for the comparisons mentioned above. As to other category variables in our study, these were represented by percentage distribution for the groups and compared using the Chi Square Test or Fischer Exact Test when frequencies in these tables were lower than 5. Differences with a significance level (\( p \)) lower than 0.05 were considered significant.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control group (( n = 5 ))</th>
<th>PFS group (( n = 6 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>27.0 ± 7.0</td>
<td>30.5 ± 8.8</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>71.2 ± 9.8</td>
<td>77.5 ± 24.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170.0 ± 7.0</td>
<td>170.3 ± 10.3</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>24.6 ± 2.8</td>
<td>23.0 ± 3.2</td>
</tr>
</tbody>
</table>
3. Results

Table 1 shows the means and standard deviation for demographic variables and anthropometric characteristics of CG and PFG subjects. The groups studied did not show statistical differences in any of these variables ($p > 0.05$). Therefore, we excluded some factors that could somehow interfere in results obtained in this study. All CG group subjects were physically active, whereas only 50% of PFG subjects were active, however, they had a higher pain level, which restricted their physical activities.

Table 2 shows the means, standard deviation, median and percentage distribution of clinical variables obtained for CG and PFG subjects before (pre-PFG) and after (post-PFG) physical therapy treatment.

The groups were similar in relation to $Q$ angle measured in both knees. There was no significant change in pain level of PFG group subjects when we compared VAS before (4.08 ± 2.82 cm) and after treatment conditions (2.59 ± 1.97 cm).

With respect to median values for functional knee scale scores, the groups had the following results: the CG group obtained a score significantly higher in the Lysholm and Karlsson scales, in comparison with the PFG group, both before ($p = 0.0047$ and $p = 0.0009$, respectively) and after treatment ($p = 0.0189$ and $p = 0.0316$), but without changing the before and after conditions within the PFG group. Therefore, the Lysholm and Karlsson scales showed an improvement tendency of functionality in the PFG.

Before treatment, all PFS subjects had positive results in patellar compression tests, and after treatment, values for this test had a 50% reduction ($p = 0.0455$).

Figs. 1–3 show the percentage distribution of postural alignments for feet, ankles and knees in CG, pre-PFG and post-PFG groups. We did not observe any differences in posture alignment among three groups, however differences were observed between the PFG groups.

![Fig. 1](image1.png)

Fig. 1. Percentage distribution of postural alignments for plantar arches in control group (CG) and patellofemoral groups (pre-PFG and pos-PFG).

![Fig. 2](image2.png)

Fig. 2. Percentage distribution of postural alignments for ankle in control group (CG) and patellofemoral groups (pre-PFG and pos-PFG).

![Fig. 3](image3.png)

Fig. 3. Percentage distribution of postural alignments for knees in frontal, sagittal and transverse planes in control group (CG) and patellofemoral groups (pre-PFG and pos-PFG).
Table 3 shows the means, standard deviation and significance level among groups for EMG RMS values of the VM and VL while walking up and down stairs.

While walking up stairs, the VM muscle of the post-PFG subjects showed a higher RMS in comparison with the pre-PFG (p = 0.0453) and there were no differences comparing to the CG, although this group showed a tendency towards having lower RMS in comparison with post-PFG. The VL muscle had a tendency towards higher RMS in the post-PFG group in comparison with pre-PFG and CG, although it was not significant.

While walking down stairs, the VM muscle in the CG group showed a higher RMS compared to post-PFG (p = 0.0381) and similar muscle activation in comparison with pre-PFG. There was a tendency for the RMS of the VL to be progressively lower in this order: CG lower than the pre-PFG condition lower than post-PFG, although it was not significant. The post-PFG group decreased muscle activation magnitude of the VM muscle in comparison with the pre-PFG (p = 0.0399) and the RMS of the VM for the CG was similar to RMS of the post-PFG.

**4. Discussion**

The patellar compression test is frequently used to evaluate patients complaining of knee pain because it is one of several other frequently positive signs of PFS [2,13]. Since this test consists of exerting traction on the patella in the posterior direction, concurrent with a contraction of the quadriceps muscle [16] and we observed a reduction of positive responses to this test, we can infer that occur an improvement in patellar gliding biomechanics among femoral condyles after treatment while carrying out activities requiring an action from knee extensor muscles (both concentric and eccentric actions).

Although the VAS had no statistical difference among groups, we point out that the PFG in both treatment conditions showed higher values than the CG (mean = 0 cm). Knee pain is a symptomatic characteristic and a diagnostic criteria for PFS [14] and therefore, such result was expected in the PFG group. The mean values of the VAS were similar between pre-PFG and post-PFG but we could not conclude that there was no symptoms improvement with the treatment because, as will be seen, we were able to show a clinical and functional improvement of the patients through knee function scales and clinical testing. Although it is validated and widely published, the VAS is a very subjective evaluation method for pain intensity [18,29].

We did not observe a significant difference in posture between the CG and PFG groups, whether before or after treatment conditions, but we observed some differences (p < 0.05) when we compared the pre-PFG and post-PFG. Initially, patients had lowered longitudinal arches, valgus ankles and knees, and they showed an important improvement in lower limb muscle positioning, decreasing the percentage of patients with these postural alterations, and therefore, having a higher alignment of these lower segments. Another change that we observed, although of small statistical significance, was a decrease in the occurrence of knee rotation. According to the literature, PFS subjects showed some typical postural alignment characteristics, such as lowered feet arches, valgus ankles, rotated and valgus knees [6], just as we observed in this study.

Although some of the data did not have statistically significant differences among groups, we highlight the clinical significance of these postural changes and clinical characterization observed, and that as such, deserve to be pointed out in this discussion.

The first analysis we need to make while observing the RMS values obtained for the VL and VM muscles for the two tasks studied is the fact that there were no significant differences for these values, when comparing the CG and pre-PFG. In other words, corroborating some studies [2,30], our findings did not show differences in activation of the VL and VM muscles in walking up and down stairs activities among healthy and PFS subjects without physical therapy treatment. All statistically significant differences occurred between post-PFG and CG and between pre-PFG and post-PFG.

While walking down stairs, the post-PFG showed a significant decrease in activation of the VM muscle compared to pre-PFG. Studies showed [23] that an eccentric contraction carried out by the quadriceps muscle while walking down stairs needs a smaller number of motor units when compared with other kinds of muscle
contraction, and thus could be considered more efficient. Consequently, the RMS value decrease for the VM muscle after physical therapy treatment might represent lower activation of motor units while walking down stairs leading to a better muscle coordination and consequently, less effort during mechanical overloads [23]. Besides, the RMS value for VM muscle in the post-PFG resembles the CG values demonstrating muscle activation similar to healthy individuals.

The CG showed a significantly higher RMS of the VL muscle while walking down stairs in comparison with the post-PFG. Considering that some studies [14,26,32] recommend physical therapy treatment in order to decrease patella lateral tracking tendencies and consequent patellofemoral joint stress, lower activation of the VL muscle may be considered a positive result of the treatment. Besides, the RMS value also decreased for the post-PFG in comparison with the pre-PFG while walking down stairs.

And finally, post-PFG subjects showed a significant increase in VM muscle activity and higher tendency for activation of the VL muscle while walking up stair in comparison with CG. Higher activation of the VM muscle is one of the aims of intervention in the PFS since there is an improvement in patella alignment. However, it is difficult to obtain strengthening of the VM without increasing activity of the VL muscle, since they are components of the same muscle. We observed that climbing stairs is a good exercise that should be used in clinical practice, since that is the task which we observed higher activation of the VM muscle after treatment.

5. Conclusions

We observed characteristic postural changes among PFS patients, such as lowered longitudinal arches, valgus ankles and knees and also, it was possible to see a tendency towards improvement in lower limb alignment of PFG subjects after physical therapy treatment. We observed an important functional improvement in PFG after treatment identified by Lysholm and Karlsson scales. Both healthy and PFS subjects before physical therapy treatment showed similar muscle activation behavior during walking up and down stairs.

There was a clear improvement among PFG subjects carrying out eccentric exercises (walking down) after physical therapy treatment: decrease in the quadriceps electrical activation, suggesting a higher efficiency of muscle control and coordination, and possibly leading to a smaller energy consume, particularly of the VM muscle. Then, we single out that eccentric knee exercises such as the down phase of squatting, walking down stairs or slopes were efficient to rehabilitate PFS patients in the present study. Furthermore, walking down stairs also showed less activation of the VL muscle, decreasing patella lateral tracking tendencies.

The walking up stairs exercise showed to be effective in increasing muscle activation in both the VM and VL after physical therapy treatment. This finding corroborates some studies stating that there are no widely accepted exercises that favor only activation of the VM muscle in detriment of the VL.

It is important to emphasize that this study was able to demonstrate the need for a physical therapy approach to PFS and that a rehabilitation program can modify the behavior of the knee extensor mechanism in individuals with this pathology. Future studies may seek to reproduce the data obtained in our study using a wider sample. Other contribution to our study is to improve the physical therapy protocol with functional activities.

References


[35] Isabel de Camargo Neves Sacco is a Professor in the Department of Physical Therapy, Speech and Occupational Therapy, School of Medicine, University of São Paulo – Brazil since 1999. She received the PE degree from University of São Paulo, School of Physical Education and Sport, Brazil, in 1995. In 1997 she received a M.Sc. degree from the School of Physical Education and Sport University of São Paulo and in 2001, her Ph.D. degree was received also from the School of Physical Education and Sport University of São Paulo, both in Biomechanics field. She is a member of ISB, Brazilian Society of Biomechanics – SBB and nowadays she is a directory member of the SBB. She is currently on the editorial board of Fisioterapia e Pesquisa, a Brazilian Journal of Physical Therapy and Applied Sciences. She serves as a reviewer of several Journals in her field in Brazil. Her teaching and research interests focus on biomechanics of human locomotion, pathological gait analysis, applied biomechanics in sports.

[36] Gil Kiyoshi Konno is a Physical Therapist who received the degree from Department of Physical Therapy, Speech and Occupational Therapy, School of Medicine, University of São Paulo, Brazil, in 2003. He received the Specialist degree in Sports Physical Therapy from Sports Trauma Center (CETE), Department of Orthopedics, Paulista School of Medicine, São Paulo, Brazil. He is an aspirant member of Sports Physical Therapy National Society (SONAFE). His research interest involves sports and rehabilitation.

[37] Guilherme Benetti Rojas received the Physical Therapy degree from University of São Paulo, School of Medicine – Department of Physical Therapy, Speech and Occupational Therapy, Brazil, in 2003. He is Physiotherapist of the SARAH Network of Hospitals for the Locomotor System since 2004. He supervises and is involved in rehabilitation of adult patients with brain damage and Parkinson’s disease. His research interests include biomechanics of human locomotion and neuroscience.

[38] Dr. Antonio Carlos Arnone is assistant doctor at the Department of Orthotrauma in Universitarist Hospital. University of São Paulo and specialist in knee, shoulder and sport medicine surgery from the Orthopedics and Trauma Institute (School of Medicine, University of São Paulo).
Anice de Campos Pa´ssaro is a physiotherapist in the Department of Physical Therapy, Speech and Occupational Therapy, School of Medicine, University of Sao Paulo and a Professor in the Centro Universitário Capital, Brazil both since 2001. She received the state degree in Physical Therapy in 1997 and M.Sc. degree in 2003 (Biomechanics) from the University of Sao Paulo, Brazil. She is involved and supervises clinical with musculoskeletal rehabilitation. Her research interest is evaluation and rehabilitation of patients with focus in biomechanics.

Amélia Pasqual Marques received her State Degree in Physical Therapy from the School of Medicine, University of Sao Paulo, in 1973, M.Sc. degree in Special Education from the Federal University of Sao Carlos, in 1990, and Ph.D. Degree in Experimental Psychology from the University of Sao Paulo, in 1995. She is currently a free professor at the University of Sao Paulo (since 1984), the editor of Fisioterapia e Pesquisa, a brazilian journal of Physical Therapy, and a directory member of the Regional Council of Physical Therapy and Occupational Therapy. Her research interests include muscle skeletal rehabilitation.

Cristina Maria Nunes Cabral received her State and M.Sc. degrees in Physical Therapy from the Federal University of Sao Carlos in 1997 and 2001, respectively. She is presently doing her Ph.D. in Experimental Physiopathology, University of Sao Paulo. Also, she is currently a professor in the Physiotherapy department of the University Center Fieo and United Metropolitan Faculties. Her research interests include biomechanics and electromyography in studies of patellofemoral dysfunction and muscle skeletal rehabilitation.