



Electromyographic activity of the quadriceps and gluteus medius muscles during/different straight leg raise and squat exercises in women with patellofemoral pain syndrome

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ABSTRACT

Patellofemoral pain syndrome (PPS) is characterized by anterior knee pain and affects young female adults. Physiotherapy is the most indicated treatment. The objective of the study was to analyze electromyographic activity of the quadriceps and gluteus medius muscles during different open and closed kinetic chain exercises in women with PPS. Twenty-two clinically healthy women and 24 women with symptomatic PPS were assessed through surface electromyography of the quadriceps and gluteus medius during the following exercises: straight leg raise with and without lateral hip rotation; squats; squats with adduction and hip abduction; and squats combined with lateral hip rotation. When comparing the groups, only the quadriceps muscle showed higher activity in the PPS group. In the comparisons between the exercises, in relation to gluteus medius and quadriceps muscle activity, the straight leg raise and straight leg raise with lateral hip rotation exercises showed more activity than squats in both groups. Among the squats, squats with adduction generated more gluteus medius activity in both groups, and no difference was noted among the squats for the quadriceps muscle. Therefore, rehabilitation programs that include exercises such as straight leg raises, straight leg raises with lateral hip rotation, and squats with adduction may be used for PPS patients.

1. Introduction

Patellofemoral pain syndrome (PPS) is one of the most common knee joint disorders and accounts for 11–17% of clinical complaints in relation to this joint (Crossley et al., 2016). It affects 20% of the general population, primarily in the age range of 18–35 years (Selfe et al., 2016). Individuals with PPS may manifest strong signs and symptoms of anxiety, depression, catastrophization and kinesiophobia, which may be correlated to increased pain and reduced physical function (Maclachlan et al., 2017).

It is known that 90% of PPS patients also have symptoms four years after diagnosis and only 6% do not have symptoms in 16 years (Selfe et al., 2016). Despite the relevance of studies involving PPS, the etiological factors have not been properly established. However, some authors describe it as multifactorial in nature, including biomechanical changes, not only in the patellofemoral joint, but also in the proximal and distal joints of the knee (Boling et al., 2009; Davis and Powers,

2010; Halabchi et al., 2013). Among the biomechanical changes, weakness of the abductor muscles, lateral rotators of the hip (Davis and Powers, 2010) and quadriceps (Giles et al., 2013) are mentioned the most as PPS risk factors (Barton et al., 2013; Felício et al., 2011a, 2011b; Fukuda et al., 2010).

Conservative treatment is always the first approach for these individuals. Open and closed kinetic chain exercises that emphasize the quadriceps, abductors and lateral rotators of the hip are the most indicated in rehabilitation programs for these patients (Bolglia et al., 2011; Nakagawa et al., 2012; Selfe et al., 2016; Thomson et al., 2016; Nascimento et al., 2017).

Among the exercises used, squats (SQ) and straight leg raises (SLR) seek to strengthen the quadriceps and hip stabilizer muscles and are frequently prescribed in the rehabilitation of individuals with knee joint dysfunctions (Bevilaqua-Grossi et al., 2009; Distefano et al., 2009; Fukuda et al., 2010; Nakagawa et al., 2012).

According to Nascimento et al. (2017), PPS patients who underwent

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conservative treatment using exercises to strengthen the associated hip and knee muscles experienced better results, such as decreased pain and improved functional activities, compared to exercises that sought only to strengthen the local stabilizers of the knee. This is because, in addition to stabilizing the pelvis during movement, the gluteus medius (GMed) muscles also promote hip abduction and control the internal rotation of the femur.

In summary, there are no studies in the current literature that compare the electromyographic activity of the hip and knee stabilizer muscles during the proposed exercises in women with and without PPS. Knowing which exercises simultaneously promote greater electromyographic activity of the hip and knee joint stabilizer muscles would represent an important contribution to rehabilitation programs for patients with PPS.

The hypothesis of this study was that individuals with PPS present reduced electrical activity in the vastus medialis oblique (VMO) and GMed muscles, and increased vastus lateralis obliquus (VLO) muscle activity when compared to control individuals (without PPS). In addition, individuals with PPS present better balance in electrical activity of the knee joint stabilizer muscles and an increase in GMed muscle activation during exercises associated with lateral rotation and hip abduction, regardless of the type of exercise performed. However, there were no studies in the analyzed literature evaluating exercises that are capable of simultaneously producing balance in the activity of the knee joint stabilizer muscles and an increase in the activity of the GMed muscles.

Therefore, the objective of the present study was to analyze the electromyographic activity of the quadriceps and GMed muscles during different open and closed kinetic chain exercises in individuals with and without PPS.

2. Materials and methods

Sedentary women with a mean age of 23.6 (SD = 5.2) years in the control group and 24 (SD = 3.9) years in the PPS group participated in the study. All the study participants were informed about the procedures that would be performed during the study and signed free and informed consent forms in accordance with the standards of the institution's Ethics Committee for Research involving human subjects (CAAE: 03782512.9.0000.5235).

The study participants underwent a physiotherapeutic assessment and were divided into two groups according to the inclusion criteria (Table 1) (Davis and Powers, 2010; Felicio et al., 2011a, 2011b): (1) Control group – clinically healthy women (control) (n = 22); and (2) PPS group (symptomatic) – women with patellofemoral pain syndrome (n = 24).

The groups are characterized in Table 2.

All the participants underwent an assessment of electrical activity of the quadriceps muscle, using the VMO, vastus lateralis longus (VLL) and VLO muscles, and of the GMed muscle during different SLR and

Table 1

Inclusion and exclusion criteria for the control and PPS groups.

Inclusion Criteria (Cowan et al., 2002; Davis and Powers, 2010)	
Control Group	PPS Group
<ul style="list-style-type: none"> – Maximum of two signs indicating lower limb misalignment (e.g., increased Q angle, excessive subtalar pronation, lateral pelvic tilt, increased dynamic valgus) – Absence of anterior knee pain 	<ul style="list-style-type: none"> – Minimum of 3 cm in the VAS for anterior knee pain – Pain reported in at least two of the following activities: squatting, running, jumping, going up/down the stairs and remaining seated for long periods of time – Minimum of three signs indicating lower limb misalignment
Exclusion Criteria (Felicio et al., 2011a, 2011b)	
<ul style="list-style-type: none"> – History of traumatic injuries or surgery in the following locations: spine, sacroiliac and lower limbs – Neurological, cardiovascular and rheumatic diseases – Underwent previous physiotherapy for changes in the musculoskeletal system in the spine and lower limbs – Changes that prevented performing the exercises 	

Table 2

Mean (standard deviation) for the anthropometric and muscular strength data of the participants from the control (n = 22) and PPS (n = 24) groups.

	Control (n = 22)	PPS (n = 24)
Age (years)	23.6 (5.2)	24.0 (19)
Body mass (kg)	60 (17.3)	58.2 (13.4)
Height (cm)	161.2 (5.2)	159.8 (4.9)
Muscular Strength (kgf/kg)		
Hip abductors	14.1 (4.7)	14.4 (5.1)
Quadriceps	46.1 (11.1)	42.6 (14.5)*

The Student's *t*-test for independent samples, program STATA 9.1*, *p* < 0.05 was used.

squatting exercises.

3. Instruments

3.1. Surface electromyography

An EMG System 810C electromyograph with eight channels was used. Electromyographic signals were conditioned through software-programmable amplifiers and 20–1000 Hz analog bandpass filters. The signals were digitized with a sampling frequency of 4 kHz, with 14-bit resolution and simultaneous sampling of the signals, and the gain in the equipment was adjusted to 100 times. To view and process the electromyographic signals, the program SuiteMYO Version 1.0.0.3 was used (Ferreira, 2014).

Seven active single differential surface electrodes (10 × 1 × 1 mm) from the EMG System were used, made up of two rectangular bars of silver (Ag/AgCl), and encapsulated in acrylic resin (23 × 21 × 5 mm) with a 20-time gain in the electrodes. The common mode rejection ratio was 130 dB.

4. Procedures

4.1. Assessment of electrical activity of the quadriceps and GMed muscles

Electrical activity was captured through a maximum voluntary isometric contraction (MVIC) in different SLR and squatting exercises (Fig. 1A–F).

During the squatting exercise, the knee flexion angle was 60° (Felicio et al., 2011b); the hip remained in a neutral position for rotation during the conventional squat (SQ) (Fig. 1A). In the squats combined with adduction (SQ-ADD) (Fig. 1B) and hip abduction (SQ-ABD) (Fig. 1C) (Felicio et al., 2011b), the volunteer kept the hip in a neutral position for rotation and a device was attached to the distal femur for the participant to perform isometric contractions (adduction and abduction) during the test (Fig. 1B and C). And during squat-lateral rotation, the volunteers were positioned with lateral rotation of 30°

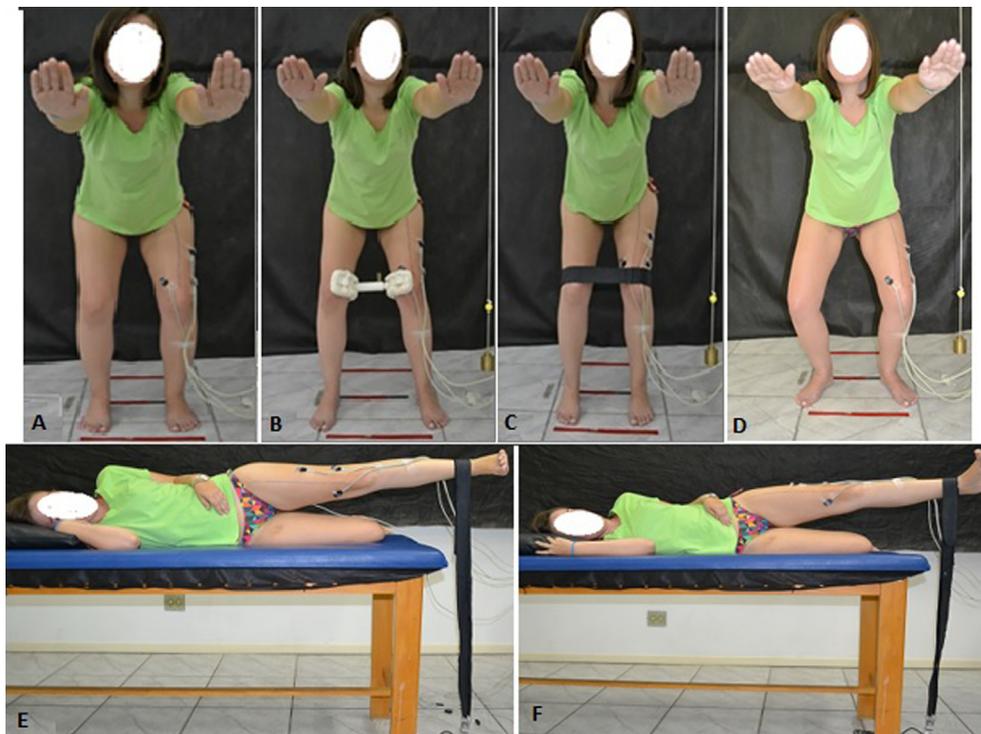


Fig. 1. (A) Squat (SQ) exercise, (B) Squat combined with adduction (SQ-ADD); (C) Squat combined with abduction (SQ-ABD); (D) Squat combined with lateral hip rotation (SQ-LR), (E) Straight leg raise (SLR) exercise and (F) Straight leg raise exercise combined with a 30° lateral hip rotation (SLR-LR).

during the squat – lateral rotation exercise (SQ-LR) (Fig. 1D).

During the SLR activities, MVIC in hip abduction combined with knee extension was requested. The participants were positioned with the lumbar spine and the hip in a neutral position for flexion and abduction. In the conventional SLR exercise (Fig. 1E), the hip remained in a neutral position for rotation, and during the straight leg raise with lateral hip rotation (SLR-LR) exercise (Fig. 1F), (Say et al., 2006) lateral rotation of the hip was 30°.

The limb assessed for the control group was the dominant limb, and for the PPS group, the one with anterior knee pain.

With respect to the placement of the electrodes, the skin was previously shaved and sanitized with 70° GL alcohol, in order to reduce myoelectric impedance (Hermes et al., 2000). The electrodes were fastened to the skin with Micropore® adhesive tape, in the quadriceps regions, where the portions of the VMO, VLO and VLL muscles and GMed muscle were examined.

In the VMO muscle, the electrode was positioned 4 cm above the superomedial border of the patella, at a slope of 55° in relation to the center of the patella and anterior superior iliac spine (Felicio et al., 2011a, 2011b). In relation to the VLL, the electrode was positioned 15 cm from the superomedial border of the patella, at a slope of 13.6° (Bevilaqua-Grossi et al., 2009; Felicio et al., 2011a, 2011b). To position the electrode in the VLO, it was necessary to locate the lateral epicondyle of the femur and the muscle belly; the electrode was positioned at a slope of 50.4° in relation to the center of the patella and anterior superior iliac spine (Bevilaqua-Grossi et al., 2009; Felicio et al., 2011a, 2011b).

The electrode for capturing the electrical signal of the GMed muscle was positioned in the proximal region across the line between the iliac crest and greater trochanter of the femur (Felicio et al., 2011b; Barton et al., 2013). The reference electrode was positioned in the central region of the sacral bone.

The participants were instructed to wear the shorts of their choice or clothing that would allow access to the target region.

The patients randomly performed three repetitions of each activity - SLR, SLR-LR, SQ, SQ-LR, SQ-ADD, and SQ-ABD. The signal of each

activity was captured during MVIC and maintained for 6 s, with a 2-minute interval between each activity.

Electromyographic activity of the patellar stabilizers (VMO, VLO and VLL) was normalized by the amplitude of knee extension MIVC activities; the knee flexion angle was 90° and the extension was performed on a leg extension machine for the quadriceps (Fig. 2A) (Felicio et al., 2011a, 2011b). GMed muscle activity was normalized by MVIC in the GMed muscle function test position (Oliveira et al., 2014) with the knee flexed at 90° (Fig. 2B). Therefore, the amplitude values of the myoelectric activities were presented as a percentage of the maximum values of each muscle assessed.

To assess the quadriceps muscle, the mean among the VMO, VLO, and VLL muscle portions was used, since studies have indicated similar activities among the portions in both healthy individuals and those with PPS (Giles et al., 2015; Felicio et al., 2011a, 2011b).

The amplitude values of the activities were shown as percentages of the maximum values for each muscle evaluated. The dominant limb was evaluated for the control group; for the PPS group, the limb evaluated was the one that presented the highest pain in a Visual Analogic Scale (VAS) in the previous month.

4.2. Statistical analysis

The data normality of the electrical activity of the muscles during different exercises was tested with the Kolmogorov-Smirnov normality test, i.e., parametric tests were used.

The Student's *t*-test for independent samples was used for comparison between the control and PPS groups in relation to electrical activity of the GMed and quadriceps muscles during the different exercises. The ANOVA test for repeated measurements was used for comparison between the exercises for each group; the differences were performed two-by-two by pairing the Student's *t*-test with the Bonferroni correction.

A significance level of 5% was considered for all the tests, and the program SPSS Version 17.0 was used.

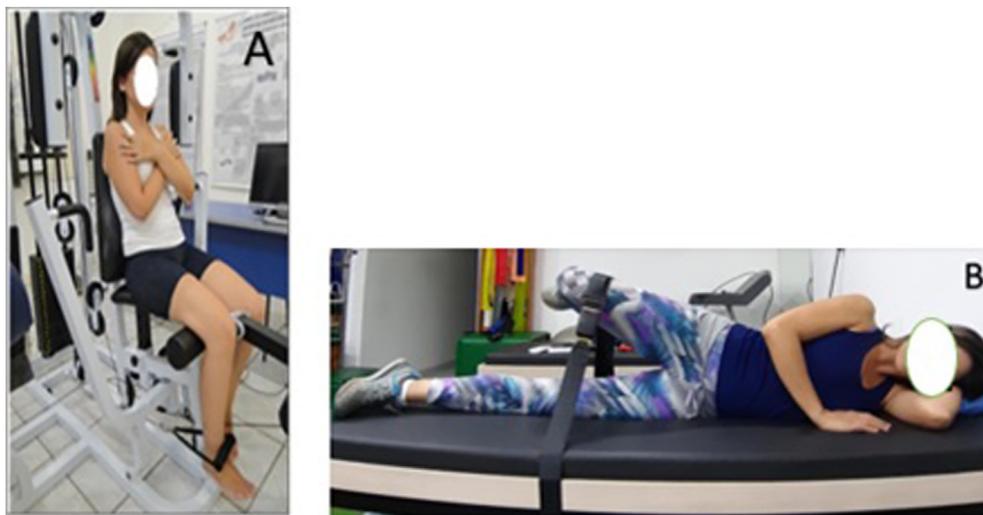


Fig. 2. (A) Isometric strength test of the knee extensor muscles; (B) Isometric strength test of the hip abduction muscles.

5. Results

5.1. Electromyographic activity of the GMed and quadriceps muscles

5.1.1. Comparison between groups

Regarding the electromyographic activity of the quadriceps muscle, the PPS group did not present a statistically significant difference in relation to the control group during all squat exercises and the SLR-LR exercise. However, during the SLR exercise for the quadriceps muscle, the PPS group presented an increase in electrical activity in relation to the control group (Table 3).

5.2. Comparison between exercises

5.2.1. Control group

Electromyographic activity of the GMed muscle for the control group was higher during the SLR and SLR-LR exercises, compared to the SQ, SQ-ABD, SQ-ADD, and SQ-LR exercises. During the squats, the SQ-ADD generated the highest activity of the GMed, followed by the SQ-ABD.

Table 3

Mean (standard deviation) and [minimum and maximum values] (% of MVIC) of the GMed and quadriceps muscles among the groups.

	Control (n = 22)	PPS (n = 24)
Squat		
GMed	11.67(± 6.24) [4.14; 24.46]	10.54(± 4.73) [2.54; 20.88]
QUAD	45.10(± 18.65) [13.48; 104.75]	42.23(± 16.05) [9.94; 85.84]
Squat-Abduction		
GMed	33.4(± 15.35) [11.83; 65.24]	33.37(± 18.19) [10.95; 99.84]
QUAD	42.18(± 20.45) [8.17; 11.49]	42.86(± 18.73) [9.4; 101.78]
Squat-Adduction		
GMed	72.25(± 44.5) [29.94; 197.15]	51.75(± 28.82) [11.51; 139.36]
QUAD	51.54(± 24.45) [11.93; 152.53]	49.91(± 22.33) [18.16; 135.28]
Squat-Lateral Rotation		
GMed	11.33(± 6.12) [4.48; 27.44]	13.17(± 4.15) [6.77; 23.32]
QUAD	44.27(± 18.54) [22.38; 99.93]	42.55(± 19.99) [12.36; 112.59]
Straight Leg Raise		
GMed	108.52(± 43.16) [52.22; 170.24]	89.61(± 25.07) [50.05; 133.99]
QUAD	72.05(± 34.47) [13.67; 148.08]	91.5(± 38.19) [25; 181.77]*
Straight Leg-Lateral Rotation		
GMed	73.08(± 32.99) [25.4; 157.12]	66.38(± 31.68) [36.39; 177.26]
QUAD	77.62(± 30.63) [19.31; 137.06]	93.4(± 39.67) [27.08; 168.99]

Independent Student's *t*-test for independent samples.

* *p* < 0.05.

Regarding the quadriceps, the SLR and SLR-LR exercises caused higher activity of this muscle, compared to squats, where there was no difference between the different squats (see Graph 1).

5.2.2. Patellofemoral pain syndrome group

Electromyographic activity of the GMed muscle for the PPS group was higher during the SLR and SLR-LR exercises, when compared to the SQ, SQ-ABD and SQ-LR exercises, similar to the results for the control group. Only SLR generated higher activity of the GMed compared to SQ-ADD. As for the comparison between the SLR and SLR-LR, the SLR exercise was more efficient in GMed activation. During the squatting exercises, SQ-ADD showed a higher activity of the GMed, compared to the SQ and SQ-LR exercises. During the SQ-ABD, electromyographic activity of the GMed muscle was higher, in relation to the SQ-LR and SQ exercises.

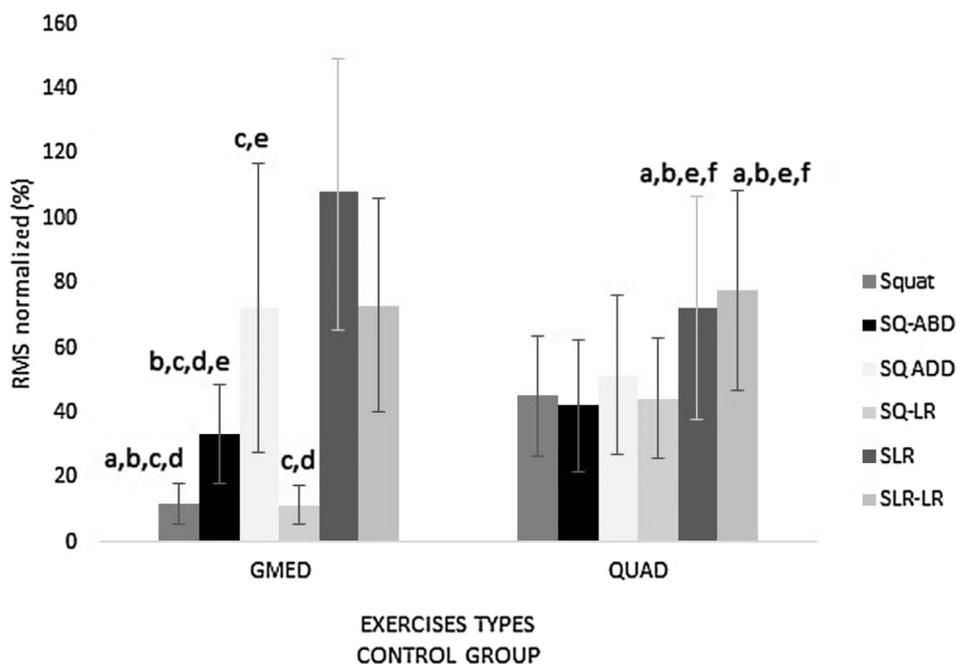
When comparing the electromyographic activity of the quadriceps, the SLR and SLR-LR exercises generated higher activity of this muscle than all the squatting exercises. No difference was noted in the activity of this muscle between the different squats or between the SLRs (Graph 2).

6. Discussion

The objective of the present study was to analyze electrical activity of the quadriceps and GMed muscles during different open and closed kinetic chain exercises in women with PPS. It was observed that the PPS group showed higher activity than the control group only during SLR. Considering the comparison between the different exercises performed by the PPS group, the SLR and SLR-LR exercises caused greater simultaneous electromyographic activity of the quadriceps. Based on this, the SLR and SLR-LR exercises are the ones most indicated for individuals with PPS, since they provide greater simultaneous activity between the quadriceps and GMed muscles. However, clinical trials should be performed to verify the contribution to rehabilitation programs for this population.

The consensus on PPS treatment (Crossley et al., 2016) recommends prescribing exercises aimed at strengthening the hip and knee muscles, since they have proven to be effective in easing short-, mid- and long-term pain.

The literature recommends the use of open and closed kinetic chain exercises to treat individuals with PPS, emphasizing the hip and knee stabilizer muscles (Van Der Heijden et al., 2016; Fukuda et al., 2012; Nakagawa et al., 2012). However, few studies have assessed simultaneous activity between the quadriceps muscles and the GMed muscle,



Graph 1. Comparison of muscular activity of GMed and quadriceps among the exercises for the control group. (a) Statistically significant difference between SQ-ABD; (b) statistically significant difference between SQ-ADD; (c) statistically significant difference between SLR; (d) statistically significant difference between SLR-LR; (e) statistically significant difference between SQ-LR; (f) statistically significant difference between SQ.

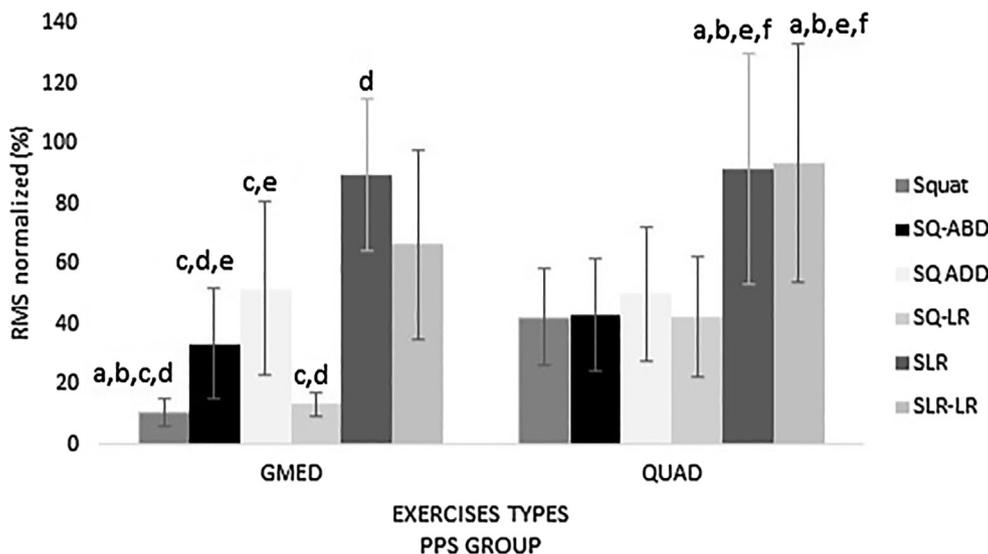
which is the main hip stabilizer. This makes these results important for the scientific community and physiotherapists working in clinical practice.

The objective of a study by Bolgla et al. (2011) was to compare the strength of the hip and knee stabilizer muscles and electromyographic activity in individuals with and without PPS. The authors concluded that women with PPS had less hip muscle strength and also generated higher electromyographic activity of the GMed and quadriceps during closed kinetic chain exercises. However, the authors did not assess SLR exercises. The present study verified greater activation in the PPS group during the SLR in relation to the control group only for the quadriceps muscle. This could be related to a difference in the pattern of activation because of knee pain (Gawda et al., 2019). In addition, agonist muscles are emphasized during open kinetic chain exercises, whereas closed kinetic chain exercises emphasize the muscle chain of the lower limbs (Nascimento et al., 2017).

In relation to open kinetic chain exercises, such as SLR and SLR-LR, the authors of the present study found increased electromyographic activity of the hip and knee stabilizer muscles, compared to other

exercises; these findings suggest that these exercises can be included in rehabilitation programs for individuals with PPS. Although there are few studies that correlate the proposed exercises, Fukuda et al. (2012) and Baldon et al. (2014) conducted a strengthening program that included SLRs during the treatment of women with PPS, even though the objective of their studies was not related to the assessment of SLR exercises. The program proved to be effective in easing pain and improving function in these individuals. Therefore, taking into consideration the findings of the present study, the inclusion of SLR and SLR-LR exercises improves activity of the quadriceps and GMed muscles.

In the closed kinetic chain exercises, during squats, SQ-ADD generated increased activity of the GMed compared to SQ and SQ-LR exercises. It is known that the GMed muscle is an important pelvic stabilizer during closed kinetic chain functional exercises, since its reduced function can lead to biomechanical changes of the trunk, pelvis, knees, and ankle/foot (Nakagawa et al., 2012). The increase in GMed activity during the proposed functional exercise (SQ-ADD) could be related to its internal rotation function, mainly in hip flexion, since



Graph 2. Comparison of muscular activity of GMed and quadriceps among the exercises for the PPS group. (a) Statistically significant difference between SQ-ABD; (b) statistically significant difference between SQ-ADD; (c) statistically significant difference between SLR; (d) statistically significant difference between SLR-LR; (e) statistically significant difference between SQ-LR; (f) statistically significant difference between SQ.

this function may occur during closed kinetic chain exercise associated with isometric adduction of the hip, related to hip internal rotation, which increases the electromyographic activity of the GMed (Neumann, 2010). However, during the SQ-ADD, the GMed must remain active in order to perform this function, while avoiding consequent abnormal movements of the lower limbs.

During SQ-ADD, the electromyographic activity of the GMed muscle was higher, compared to SQ-LR and SQ. Exercise programs that include exercises such as SQ-ADD have been prescribed for patients with PPS (Thomson et al., 2016; Van Der Heijden et al., 2016), and have been included in different clinical trials (Rabelo et al., 2017). The outcomes have included improvements in pain, function, muscle strength, and the kinematics of these individuals. Therefore, among the squatting exercises, SQ-ADD and SQ-ABD can be included during rehabilitation programs for women with PPS.

The present study had some limitations. The PPS group was not stratified into patients with weak quadriceps muscles and/or lateral rotators; therefore, anterior knee pain symptoms were considered. However, stratification into subgroups is also found in other studies (Selfe et al., 2016). Other aspects to be considered relate to using only the lateral hip rotation position and not isometric contraction of these muscles, which could have minimized the action of the lateral rotator muscles as well as the GMed. Another limitation is lack of measurement of pain levels in individuals in the PPS group during the various activities performed. However, the results of the present study can contribute to improving rehabilitation programs for individuals with changes in the patellofemoral joint.

7. Conclusion

The findings of the present study showed that SLR and SLR-LR exercises generated the highest simultaneous activity of the GMed and quadriceps muscles in both groups. During the closed chain kinetic exercises, SQ-ADD and SQ-ABD resulted in greater simultaneous contraction of the GMed and quadriceps muscles. Therefore, rehabilitation programs that include exercises such as SLR, SLR-LR, SQ-ADD, and SQ-ABD may be used for PPS patients.

Declaration of Competing Interest

We declare that there is no conflict of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jelekin.2019.05.017>.

References

- Barton, C., Lack, S., Malliaras, P., Morrissey, D., 2013. Gluteal muscle activity and patellofemoral pain syndrome: a systematic review. *Br. J. Sports Med.* 47, 207–214.
- Baldon, R.M., Serrão, F.V., Scattone Silva, R., Piva, S.R., 2014. Effects of functional stabilization training on pain, function, and lower extremity biomechanics in women with patellofemoral pain: a randomized clinical trial. *J. Orthop. Sports Phys. Ther.* 44 (4), 240–248.
- Bevilaqua-Grossi, D., Felício, L.R., Silvério, G.W.P., 2009. Início da atividade elétrica dos músculos estabilizadores da patela em indivíduos com SDPF. *Acta Ortop. Bras* 17 (5), 297–299.
- Bolglia, L.A., Malone, T.R., Umberger, B.R., Uhi, T.L., 2011. Comparison of hip and knee strength and neuromuscular activity in subject with and without patellofemoral pain syndrome. *J. Sports Phys. Ther.* 6, 285–296.
- Boling, M.C., Padua, D.A., Marshall, S.W., Guskiewicz, K., Pyne, S., Beutler, A., 2009. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome. *Am. J. Sports Med.* 37 (11), 2108–2116.
- Cowan, S.M., Bennell, K.L., Crossley, K.M., Hogdes, P.W., Macconnell, J., 2002. Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. *Med. Sci. Sports Exerc.* 34, 1879–1885.
- Crossley, K.M., van Middelkoop, M., Callaghan, M.J., Collins, N.J., Rathleff, M.S., Barton, C.J., 2016. Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). *Br. J. Sports Med.* 50 (14), 844–852.
- Davis, L.S., Powers, C., 2010. Patellofemoral pain syndrome: proximal, distal and local factors – an international research retreat. *J. Orthop. Sports Phys. Ther.* 40 (3), A1–A48.
- Distefano, L.J., Blackburn, J.Y., Marshall, S.W., Padua, A., 2009. Gluteal muscle activation during common therapeutic exercises. *J. Orthop Sports Phys. Ther.* 39 (7), 532–540.
- Felício, L.R., Baffa, A.D.P., Liporaci, R.F., Saad, M.C., Oliveira, A.S., Bevilaqua-Grossi, D., 2011a. Analysis of patellar stabilizers muscles and patellar kinematics in anterior knee pain subjects. *J. Electromyogr. Kinesiol* 21 (1), 148–153.
- Felício, L.R., Dias, L.A., Silva, P.M.C., Oliveira, A.S., 2011b. Bevilaqua-Grossi. Ativação muscular estabilizadora da patela e do quadril durante exercícios de agachamento em indivíduos saudáveis. *Rev. Bras Fisioter* 15, 206–211.
- Ferreira, A.S., Guimarães, F.S., Silva, R.C.S., Magalhães, M.A.R., 2014. Effects of supervised practice on the accuracy of observers for manual segmentation of simulated electromyograms. *Kinesiology* 2, 171–178.
- Fukuda, T.Y., Rossetto, F.M., Magalhães, E., Bryk, F.F., Lucareli, P.R.G., Carvalho, N.A.A., 2010. Short-Term effects of hip abductors and lateral rotators strengthening in females with patellofemoral pain syndrome: a randomized controlled clinical trial. *J. Orthop. Sports Phys. Ther.* 40 (11), 736–742.
- Fukuda, T.Y., Melo, W.P., Zaffalon, B.M., Rossetto, F.M., Magalhães, E., Bryk, F.F., Martin, R.L., 2012. Hip posterolateral musculature strengthening in sedentary women with patellofemoral pain syndrome: a randomized controlled clinical trial with 1-year follow-up. *J. Orthop. Sports Phys. Ther.* 42 (10), 823–830.
- Gawda, P., Ginszt, M., Zawadka, M., Skublewka-Paszowska, M., Smolka, J., Lukaszik, E., Majcher, P., 2019. Bioelectrical activity of vastus medialis and rectus femoris muscles in recreational runners with anterior knee pain. *J. Hum. Kinet.* 27 (66), 81–88.
- Giles, L.S., Webster, K.E., McClelland, J.A., Cook, J., 2013. Does quadriceps atrophy exist in individuals with patellofemoral pain? A systematic literature review with meta-analysis. *J. Orthop. Sports Phys. Ther.* 43 (11), 766–776.
- Giles, L.S., Webster, K.E., McClelland, J.A., Cook, J., 2015. Atrophy of the quadriceps is not isolated to the vastus medialis oblique in individuals with patellofemoral pain. *J. Orthop. Sports Phys. Ther.* 45 (8), 613–619.
- Halabchi, F., Mazaheri, R., Seif-barghi, T., 2013. Patellofemoral pain syndrome and modifiable intrinsic risk factors: how to assess and address? *Asian J. Sports Med.* 4 (2), 85–100.
- Hermens, H.J., Freiks, B., Disselhorst-Klug, C., Rau, G., 2000. Development of recommendations for SEMG sensors and sensors placement procedures. *J. Electromyogr. Kinesiol* 10, 361–374.
- MacLachlan, L.R., Collins, N.J., Matthews, M.L.G., Hodges, P.W., Vicenzino, B., 2017. The psychological features of patellofemoral pain: a systematic review. *Br. J. Sports Med.* 51 (9), 732–742.
- Nascimento, L.R., Teixeira-Salmela, L.F., Souza, R.B., Resende, R.A., 2017. Hip and knee strengthening is more effective than knee strengthening alone for reducing pain and improving activity in individuals with patellofemoral pain: a systematic review with meta-analysis. *J. Orthop. Sports Phys. Ther.* 15, 1–35.
- Nakagawa, T.H., Moruya, E.T., Maciel, C.D., Serrão, F.V., 2012. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *J. Orthop. Sports Phys. Ther.* 42 (6), 491–501.
- Neumann, D.A., 2010 Feb. Kinesiology of the hip: a focus on muscular actions. *J. Orthop Sports Phys. Ther.* 40 (2), 82–94.
- Oliveira, L.V., Saad, M.C., Felício, L.R., Grossi, D.B., 2014. Análise da força muscular dos estabilizadores do quadril e joelho em indivíduos com Síndrome da Dor Femoropatelar. *Fisioter Pesq* 21 (4), 327–332.
- Rabelo, N.D.D.A., Costa, L.O.P., Lima, B.M., Dos Reis, A.C., Bley, A.S., Fukuda, T.Y., Lucareli, P.R.G., 2017. Adding motor control training to muscle strengthening did not substantially improve the effects on clinical or kinematic outcomes in women with patellofemoral pain: a randomised controlled trial. *Gait Posture* 58, 280–286.
- Say, K.G., Pulzatto, F., Santos, G.M., Vassimon, B.V.L., Oliveira, A.S., Bevilaqua-Grossi, D., Pedro, M., 2006. Efeito da rotação do quadril na síndrome da dor femoropatelar. *Rev. Bras Fisioter* 10 (1), 75–81.
- Selfe, J., Janssen, J., Callaghan, M., Witvrow, E., Sutton, C., Richards, J., Stokes, M., et al., 2016. Are there three main subgroups within the patellofemoral pain population? A detailed characterization study of 127 patients to help develop targeted intervention (TIPPS). *Br. J. Sports Med.* 50 (14), 873–880.
- Thomson, C., Krouwel, O., Kuisma, R., Hebron, C., 2016. The outcome of hip exercise in patellofemoral pain: a systematic review. *Man Ther.* 26, 1–30.
- Van Der Heijden, R.A., Lankhorst, N.E., Van Linschoten, R., Bierma-Zeinstra, S.M., Van Middelkoop, M., 2016. Exercise for treating patellofemoral pain syndrome: an abridged version of Cochrane systematic review. *Eur. J. Phys. Rehabil. Med.* 52 (1), 110–133.



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