Journal of Surgery and Trauma. 2026; 14(1):19-28. https://jsurgery.bums.ac.ir

Original Article

Open Access Publish Free

The Effect of Targeted Hip, Knee, and Combined Exercise Protocols on Muscle Activation Patterns in Individuals with Lateral Patellar Compression Syndrome

Mohadeseh Jafari Rajeouni[1], Mahdi Majlesi[2], Ali Fatahi[1]

[1] Department of Physical Education and Sport Sciences, CT.C., Islamic Azad University, Tehran, Iran

[2] Department of Sport Biomechanics, Ha.C., Islamic Azad University, Hamedan, Iran

Corresponding Author: Tel: +989184077540; Email: m.majlesi@iau.ac.ir

Received: August 28, 2025

Revised: October 04, 2025

Accepted: October 21, 2025

Citation: Jafari Rajeouni M, Majlesi M, Fatahi A. The Effect of Targeted Hip, Knee, and Combined Exercise Protocols on Muscle Activation Patterns in Individuals with Lateral Patellar Compression Syndrome. J Surg Trauma. 2026;14(1):19-28. DOI:10.61882/jsurgtrauma.14.1.19

Abstract

Introduction: Lateral Patellar Compression Syndrome (LPCS), one of the most common patellofemoral disorders among athletes, is associated with both proximal biomechanical impairments (e.g., hip muscle weakness) and local dysfunctions (e.g., imbalance between vastus medialis and vastus lateralis activity). Despite conflicting evidence about the effectiveness of isolated exercise protocols, this study aimed to compare the effects of targeted hip, knee, and combined exercise protocols on key muscle activation patterns in LPCS.

Methods: In a quasi-experimental pretest-posttest study with a control group, 57 athletes with LPCS were assigned to three intervention groups (Hip: n = 13; Knee: n = 15; Combined: n = 14) and a healthy control group (n = 15). Electromyographic activity of the vastus medialis obliquus (VMO), vastus lateralis (VL), and gluteus medius (GM) was recorded during a single-leg stance task using surface EMG, following SENIAM guidelines. Intervention groups completed their respective 8-week training protocols (3 sessions/week). Root mean square values were analyzed using paired t-tests, repeated-measures ANOVA, and one-way ANOVA in IBM SPSS Statistics software (Version 26).

Results: Compared to controls, LPCS participants exhibited significantly lower activation of VMO and GM, and higher activation of VL (all $P < 0.01$). The combined protocol resulted in the most remarkable simultaneous improvements in VMO and GM ($P < 0.01$), while isolated knee and hip protocols specifically enhanced VMO and GM, respectively ($P < 0.01$). VL activity remained unchanged ($P > 0.01$).

Conclusions: The combined exercise protocol, due to its synergistic effect on the simultaneous activation of the VMO and GM, seems to be the most effective approach for neuromuscular rehabilitation in athletes with LPCS. These findings highlight the importance of incorporating both hip- and knee-focused exercises into rehabilitation programs.

Key words: Electromyography, Exercise Therapy, Patella, Patellofemoral Pain Syndrome

Introduction

Lateral Patellar Compression Syndrome (LPCS) is a common patellofemoral disorder in athletes, characterized by increased abnormal pressure on the lateral facet of the patella during knee flexion (1). Epidemiological studies show that this syndrome affects up to 25% of athletes involved in high-knee-stress sports, such as futsal, volleyball, and mountaineering, with a significantly higher prevalence in female athletes, compared to males (2). The severe effects of this condition include chronic anterolateral knee pain, decreased athletic performance, limitations in daily activities (such as stair climbing), and a higher risk of early-onset osteoarthritis, all of which significantly impair athletes' quality of life.

Recent biomechanical studies suggest that LPCS results from a complex interaction of proximal and local factors. Proximally, deficits such as weakness of the gluteus medius (GM) and external hip

[DOI: 10.61882/jsurgtrauma.14.1.19]

rotators lead to excessive internal rotation of the femur and adduction. This condition contributes to dynamic knee valgus, changes the direction of forces on the patellofemoral joint, and increases lateral patellar contact pressure (3). Locally, neuromuscular impairments include reduced electromyographic activity of the vastus medialis obliquus (VMO), compared to the vastus lateralis (VL), leading to dominance of lateralizing forces on the patella. This imbalance, along with increased patellar tilt (>11°) and congruence angle (>7°), accelerates lateral patellar instability (4).

Conventional exercise-based interventions usually focus on three main strategies. The first is hip-focused protocols, which are designed to strengthen the hip abductors and external rotators—particularly the GM—in order to control pelvic dynamics and reduce knee valgus. These usually consist of exercises like side-lying hip abduction, clamshells, and single-leg bridging (5, 6). The second strategy involves knee-focused protocols that emphasize strengthening the VMO and restoring its balance with the VL. By targeting VMO hypertrophy, these protocols are designed to enhance the medial stabilizing forces acting on the patella. They commonly include isometric, isokinetic, and functional exercises such as knee extensions performed in 0–30° of flexion with tibial external rotation (7, 8). The third approach involves combined protocols that incorporate both hip and knee exercises to comprehensively target the underlying pathomechanical factors. Clinical studies have demonstrated that combined protocols are more effective than isolated approaches for improving pain and function (9, 10).

Despite increasing evidence of their effectiveness, few studies have investigated their impact on the simultaneous electromyographic activity of both the knee extensors (VMO/VL) and the hip abductors (GM). This limitation limits our comprehension of the neuromuscular mechanisms underlying clinical improvements and prompts several key questions. For instance, it is still unclear whether hip-focused exercises not only strengthen the GM but also improve VMO activation, or if knee-focused protocols affect proximal hip muscles. Moreover, the potential synergistic effects of combined interventions and the time needed for neuromuscular adaptations require further study. Given this knowledge gap, the present study had two main objectives: (1) to compare neuromuscular activity between athletes with and without LPCS, and (2) to evaluate the effects of three exercise protocols—hip-focused, knee-focused, and combined—on the electromyographic activity of the VMO, VL, and GM in athletes with LPCS.

The findings of this research could serve as a foundation for developing personalized, mechanism-based rehabilitation protocols.

Methods

Study Design

This study employed a quasi-experimental pretest–posttest design with a control group. All procedures were approved by the Ethics Committee of Islamic Azad University, Central Tehran Branch (Code: IR.IAU.CTB.REC.1404.079) and were conducted in accordance with the principles of the Declaration of Helsinki.

Participants

The study population included male and female athletes with LPCS attending physiotherapy clinics in Rasht, Iran. Participants were recruited through convenience sampling, based on their willingness to participate and meeting the inclusion criteria. Using G*Power software (version 3.1.9.7) and considering potential attrition, the required sample size was estimated at 60 participants (four groups of 15 each). From this population, 45 athletes with LPCS who participated in futsal, athletics, handball, basketball, volleyball, or mountaineering and met the criteria were allocated to three intervention groups: knee exercise protocol (KEG), hip exercise protocol (HEG), and combined exercise protocol (CEG). In addition, 15 healthy, physically active athletes (matched with the main groups for age, height, weight, and gender, and meeting the control group inclusion criteria) were selected as the control group (CG). A one-way ANOVA showed no significant differences in age, height, weight, or BMI among the four groups ($p > 0.05$). Of the 60 initially recruited participants, one from the combined group (due to three absences from the training program) and two from the hip group (due to inability to complete tests or training sessions) withdrew. Consequently, a total of 57 participants completed the study: knee group (n = 15), hip group (n = 13), combined group (n = 14), and healthy control group (n = 15). The inclusion criteria for participants with LPCS included a clinical diagnosis from an orthopedic specialist (chronic anterior/lateral knee pain lasting more than 6 months with an intensity ≥3 on the VAS,

[DOI: 10.61882/jsurgtrauma.14.1.19]

exacerbated by at least two specific activities, and confirmed by positive knee functional tests, Clarke's test, patellar compression test, and patellar apprehension test). Additional criteria were absence of meniscal or ligament injuries, no osteoarthritis, dislocations, or knee locking, no history of knee surgery, no neurological disorders or pregnancy, normal body mass index (BMI), at least three years of sports experience with a minimum of 180 minutes of weekly activity, and age between 18 and 30 years (7). The inclusion criteria for the healthy control group were: age between 18 and 30 years, at least three years of sports experience with a minimum of 180 minutes of weekly activity, and no history of surgery, injury, pain, or physiotherapy involving the spine, hip, knee, or ankle joints. Exclusion criteria for all participants included lack of cooperation during assessments, occurrence of new disabling injuries, absence from more than two consecutive or three non-consecutive training sessions, or withdrawal from the study. All participants provided informed consent.

Data Collection Tools

The electrical activity of the vastus medialis obliquus (VMO), vastus lateralis (VL), and gluteus medius (GM) muscles was recorded using an eight-channel electromyography (EMG) system (ME6000, MegaWin, Finland). After shaving the area, lightly abrading the skin with an abrasive pad, and disinfecting with 70% alcohol, disposable surface electrodes (Skintact F-55) with an inter-electrode distance of 2 cm were placed on the muscles according to the SENIAM protocol (11). The electrode placement was as follows: VMO, 4 cm medial and superior to the superomedial border of the patella, with an orientation of 55°; VL, 10 cm superior and 5 cm lateral to the superolateral border of the patella; and GM, located at the midpoint between the anterior superior iliac spine and the greater trochanter.

Maximal voluntary isometric contractions (MVIC) were used for normalization: VMO and VL during knee flexion at 90°, and GM during hip abduction, each performed as three 5-second contractions with a 1-minute rest period interval. Subsequently, EMG signals were recorded during a single-leg stance task (15 seconds, three trials with 60 seconds rest between each) at a sampling frequency of 1000 Hz. The single-leg stance was chosen because it is a functional weight-bearing task, which challenges dynamic stability and reliably elicits muscle activation patterns relevant to LPCS, including those of the GM and VMO, in a controlled manner (Earl-Boehm et al., 2018). Raw signals were band-pass filtered from 10–450 Hz to remove low-frequency noise and power-line interference, fully rectified, and low-pass filtered at 6 Hz using a fourth-order Butterworth filter. In the final processing step, the root mean square (RMS) of the signals was determined over 1-second windows using the standard formula: RMS = √(1/N ∑_(i=1)^N x_i^2), where N is the number of data points in each window and x_i represents the EMG voltage value at the i-th sample (Konrad, 2005), normalized to the MVIC values.

Intervention

All three intervention groups completed their respective exercise protocols for 8 weeks (24 sessions total), with three sessions per week. The detailed exercises, including their detailed specific sets, repetitions, and progression rules, are thoroughly outlined in Table 1. All groups maintained the same total training volume (1320 minutes) with a matching session structure (15-minute warm-up, 30-minute main exercise, 10-minute cool-down). In brief, the KEG performed knee-focused strengthening and stretching exercises, while HEG engaged in hip-focused strengthening and stretching exercises (9). The CEG implemented an integrated protocol that combined all exercises from both KEG and HEG groups. Exercise intensity was individually calibrated based on each participant's initial strength assessment to ensure equivalent relative effort. The principle of progressive overload was implemented bi-weekly for all groups. All sessions were conducted under the direct supervision of a single trained researcher to ensure consistency. Participants and the EMG assessor were blinded to group assignment.

Outcomes

The primary outcomes were the normalized RMS electromyographic activity of the VMO, VL, and GM muscles recorded during a 15-second single-leg stance task. These variables were analyzed to determine pre- to post-intervention changes across the knee, hip, and combined exercise groups, providing an index of neuromuscular adaptation in athletes with LPCS.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics software (Version 26). The normality of the

[DOI: 10.61882/jsurgtrauma.14.1.19]

quantitative data distribution was assessed using the Shapiro-Wilk test, and the homogeneity of variances was verified with Levene's test. To compare the interventions, a 2 × 4 mixed-model analysis of variance (mixed-model ANOVA) was employed. The main effects of Time and Group, as well as the Time × Group interaction effect, were assessed. In the case of significant main or interaction effects, Bonferroni-adjusted pairwise comparisons were used for post-hoc analysis to examine within-group changes (comparing time points for each group) and between-group differences (comparing the four groups at each time point). Furthermore, to control for baseline differences in the post-test comparison, Analysis of Covariance (ANCOVA) was used with pre-test scores as the covariate. Additionally, Tukey's HSD post hoc test was used for overall comparisons between groups. The statistical significance level was set at $p \leq 0.05$ for all analyses. The exact statistical test used for each comparison is reported alongside the results.

Table 1. Detailed exercise parameters for the Knee (KEG), Hip (HEG), and Combined (CEG) exercise groups

Group	Exercises	Total Exercises per Session	Sets × Reps/Duration	Progression
KEG	Knee-focused: 1. Quadriceps sets, 2. Isometric knee extensions, 3. Hamstring curls, 4. Terminal knee extensions, 5. Posterolateral corner stretches	10 (5 exercises × 2)	3 × 10-12 reps (strength) 3 × 30s holds (stretch)	Bi-weekly; increase resistance (5-10%) or reps (2-3) based on tolerance.
HEG	Hip-focused: 1. Clamshells, 2. Side-lying hip abduction, 3. Glute bridges, 4. Lateral band walks, 5. IT band and hamstring stretches	10 (5 exercises × 2)	3 × 10-12 reps (strength) 3 × 30s hold (stretch)	Bi-weekly; increase resistance (5-10%) or reps (2-3) based on tolerance.
CEG	Combined: All exercises from KEG and HEG	10 (5 knee + 5 hip)	3 × 10-12 reps (strength) 3 × 30s holds (stretch)	Bi-weekly; increase resistance (5-10%) or reps (2-3) based on tolerance.

Note: All groups trained 3 sessions/week for 8 weeks (total 24 sessions). Each session lasted 55 minutes (15 min warm-up, 30 min main exercise, 10 min cool-down). The principle of progressive overload was applied bi-weekly to all groups.

Results

Anthropometric Characteristics

Baseline anthropometric characteristics of all participants are summarized in Table 2. Multivariate analysis of variance (MANOVA) revealed no significant differences among the four study groups in age, height, weight, or body mass index (BMI) ($p > 0.05$ for all variables), indicating that the groups were homogeneous at the start of the study.

Muscle Activity

The initial comparison between CG and participants with LPCS revealed apparent differences in muscle activation among the affected individuals (Figure 1). Specifically, a one-way ANOVA showed that the LPCS group had significantly lower activation of the VMO (32.6% lower, $p < 0.01$) and GM (22% lower, $p < 0.01$) compared to the control group. In contrast, VL activation was 23.2% higher in the LPCS group than in controls ($p < 0.01$).

Before intervention, a one-way ANOVA showed no significant differences in muscle activity levels among the three exercise intervention groups (KEG, HEG, and CEG) for any of the three muscles examined ($p > 0.05$, Table 3). This confirmed their homogeneity at the start of the study and ensured that any post-intervention differences would likely result from the exercise protocols.

Effects of Exercise Interventions

Following the 8-week intervention period, a one-way ANCOVA (using pre-test values as covariates) revealed significant differences in muscle activity patterns among the three exercise groups ($p < 0.01$, Table 4). Post-hoc analyses with Bonferroni-adjusted comparisons showed that both the CEG and KEG had significantly higher VMO activity than the HEG ($p < 0.01$), with no significant difference between CEG and KEG ($p > 0.05$). For GM activity, both CEG and HEG exhibited significantly higher activation than KEG ($p < 0.01$), and there was no significant difference between CEG and HEG ($p > 0.05$). There were no significant differences in VL activity among the three groups following the intervention ($p > 0.05$).

Table 2. Multivariate analysis of variance (MANOVA) comparing of demographic characteristics study groups

Variable	Groups	Mean ± SD	df	F	P value
Age (years)	CG	27.1 ± 3.2	3	0.776	0.388
	KEG	26.2 ± 2.7			
	HEG	24.5 ± 2.5			
	CEG	25.8 ± 2.8			
Height (cm)	CG	165.2 ± 1.5	3	1.345	0.619
	KEG	166.7 ± 1.4			
	HEG	165.9 ± 1.3			
	CEG	164.6 ± 1.6			
Weight (kg)	CG	66.5 ± 8.4	3	0.497	0.506
	KEG	64.7 ± 6.6			
	HEG	65.8 ± 6.8			
	CEG	66.1 ± 7.1			
BMI (kg/m²)	CG	22.8 ± 3.4	3	1.431	0.297
	KEG	24.1 ± 3.3			
	HEG	23.7 ± 2.9			
	CEG	23.9 ± 2.9			

Note: CG = Control Group; KEG = Knee Exercise Group; HEG = Hip Exercise Group; CEG = Combined Exercise Group.

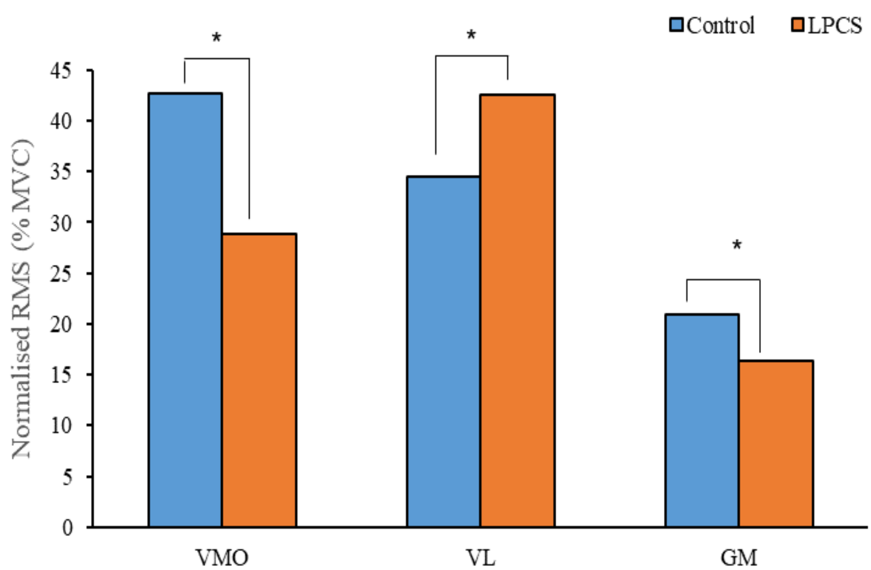

Figure 1. Comparison of normalized muscle activity (%MVC) between the Control group and those with Lateral Patellar Compression Syndrome (LPCS). * Significant difference between groups at $P < 0.01$

Analysis of percentage changes in muscle activity from pre- to post-intervention revealed clear patterns (Figure 2). A one-way ANOVA showed that the most significant improvements in VMO activation occurred in CEG (38.7% increase) and KEG (36.1% increase), both of which significantly exceeded the improvement seen in HEG (3.7% increase) ($p < 0.01$).

For GM activation, the most substantial improvements occurred in CEG (33.3% increase)

[DOI: 10.61882/jsurgtrauma.14.1.19]

and HEG (28.6% increase), both of which significantly surpassed the improvement in KEG (5.5% increase) ($p < 0.01$). Tukey's HSD post-hoc tests confirmed these group differences. No significant differences were observed among groups in VL activation changes ($p > 0.05$).

Table 3. Comparison of muscle activity levels before intervention among the training groups

Variable	Group	Mean ± SD	df	F	P value
VMO Activity (%MVC)	KEG	28.8 ± 3.5	2	0.795	0.253
	HEG	29.6 ± 3.8			
	CEG	29.2 ± 3.2			
VL Activity (%MVC)	KEG	42.5 ± 5.3	2	0.413	0.198
	HEG	41.7 ± 5.9			
	CEG	40.6 ± 6.5			
GM Activity (%MVC)	KEG	16.3 ± 2.1	2	0.725	0.405
	HEG	16.8 ± 2.1			
	CEG	15.9 ± 1.8			

Note: VMO Activity (%MVC) = Vastus Medialis Obliquus muscle activity (as a percentage of maximal voluntary contraction); VL Activity (%MVC) = Vastus Lateralis muscle activity (as a percentage of maximal voluntary contraction); GM Activity (%MVC) = Gluteus Medius muscle activity (as a percentage of maximal voluntary contraction).

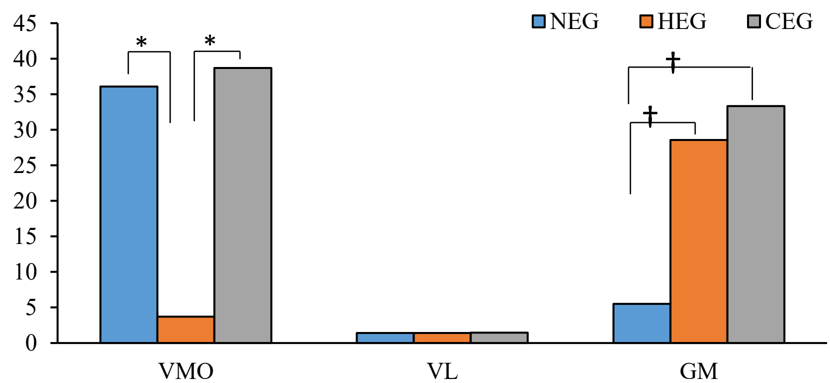

Figure 2. Comparison of percentage changes in muscle activity (pre- to post-intervention) across different interventions. Percentage change = [(Post–Pre)/Pre×100]. *Significant difference compared with the HEG; †Significant difference compared with the KEG.

Table 4. Comparison of muscle activity levels after intervention among the training groups

Variable	KEG	HEG	CEG
VMO Activity (%MVC)	39.4 ± 2.7 (+36.8%) *	30.4 ± 7.5 (+3.7%)	40.5 ± 5.8 (+38.7%) *
VL Activity (%MVC)	43.5 ± 1.2 (+1.4%)	42.6 ± 3.2 (+1.4%)	41.4 ± 2.8 (+1.8%)
GM Activity (%MVC)	17.2 ± 2.4 (+5.5%)	21.3 ± 6.4 (+28.6%) †	21.3 ± 2.1 (+33.3%) †

Note: KEG = Knee Exercise Group; HEG = Hip Exercise Group; CEG = Combined Exercise Group. VMO = Vastus Medialis Obliquus; VL = Vastus Lateralis; GM = Gluteus Medius. Values are presented as mean ± standard deviation, with percentage change in muscle activity from baseline (pre-intervention) to post-intervention shown in parentheses. *: Significant difference compared with the hip exercise group ($p < 0.01$); †: Significant difference compared with the knee exercise group ($p < 0.01$).

Discussion

The present study aimed to compare neuromuscular activity between athletes with and without LPCS and to investigate the effects of three exercise protocols on the activation of key stabilizers at the knee and hip in affected athletes.

A key finding of this study was the significant reduction in the VMO activation in athletes with LPCS. This deficit is a key factor in the pathomechanics of the syndrome, as this muscle is the primary medial stabilizer of the patella (12, 13). The observed impairment confirms previous research documenting altered VMO/VL activation ratios and delayed VMO onset during functional tasks (4, 14, 15), indicating a fundamental disruption in neuromuscular control. While some studies under different testing conditions have not reported this deficit (16, 17), the consensus and our findings strongly suggest that interventions for LPCS should prioritize selective VMO recruitment strategies. In contrast, VL activity was higher in the LPCS group.

[DOI: 10.61882/jsurgtrauma.14.1.19]

This excessive activity indicates a dominance of the lateral force vector on the patella, which can lead to its lateral displacement and compression. This may represent a compensatory mechanism by the central nervous system to maintain knee extension torque when pain or instability occurs (18, 19). Our results support morphological studies showing VL hypertrophy in LPCS patients (7) and biomechanical models linking VL hyperactivity to abnormal patellofemoral kinematics (2). The discrepancy with studies showing no difference in VL activity (20) likely results from variations in motor tasks, highlighting that movement specificity significantly influences muscular recruitment patterns.

Proximally, athletes with LPCS demonstrated apparent weakness in GM activation. This deficit is a critical biomechanical factor that can lead to excessive femoral internal rotation and dynamic knee valgus, increasing patellofemoral stress (21, 22). Our results are consistent with a significant body of evidence identifying GM weakness and delayed activation as hallmark impairments in patellofemoral pain (6, 23, 24). This proximal dysfunction is now widely more recognized within a kinetic chain framework, where alterations in foot biomechanics (25) and central neuromuscular control (37) can affect proximal muscle function. Therefore, a comprehensive rehabilitation approach must consider these potential upstream and downstream contributors to GM dysfunction.

The analysis of intervention effects revealed that protocols with knee-focused exercises (KEG and CEG) were significantly more effective at enhancing VMO activation than the hip-focused protocol (HEG) alone. This emphasizes the importance of specificity and the need to target the VMO to address its deficit directly. The underlying mechanism for this improvement likely involves enhanced neuromuscular efficiency and improved recruitment patterns of the VMO's motor units (27, 28). Although the improvement we observed was significant, it is important to note that training intensity and exercise selection (e.g., terminal knee extension) are likely key factors influencing this effect (29, 30). A notable finding was that none of the three exercise protocols caused significant changes in VL activation. This suggests that the VL's recruitment pattern is deeply ingrained and less susceptible to isolated interventions, or that it is already recruited optimally during functional period activities. This finding aligns with previous reports showing the VL's limited response to targeted training (16, 19). It indicates that restoring the VMO/VL balance might be more effectively achieved by focused enhancement of VMO activity rather than by attempting to suppress VL. However, techniques like biofeedback have shown promise in altering VL activity (30).

For proximal control, the hip-focused (HEG) and combined (CEG) protocols were significantly more effective than the knee-focused protocol (KEG) in improving GM activation. This strongly demonstrates the importance of adaptation and confirms that exercises must directly target the hip abductors to address GM weakness. The improvements probably result from both morphological changes and enhanced neural drive to the muscle (31, 32). Functional, weight-bearing exercises appear to be particularly effective at prompting these neuromuscular adaptations (33, 36). Furthermore, our results, along with other evidence (34, 35, 37), suggest that the improvements may also stem from positive adaptations within the central nervous system, resulting in more efficient movement patterns and muscle coordination.

This study has several limitations that need to be acknowledged. First, the relatively small sample size and inclusion of both male and female athletes may limit the applicability of the findings to specific athletic populations. Second, electromyographic activity was evaluated only during a static single-leg stance task, which may not fully reflect dynamic functional movements such as jumping or running. Third, although the eight-week intervention period was sufficient to induce neuromuscular adaptations, longer follow-up measurements could clarify the persistence of these effects over time. Fourth, factors like pain intensity, movement kinematics, and psychological variables (e.g., fear of movement) were not quantitatively assessed, which may have affected muscle activation. Finally, the study focused only on surface EMG recordings, so deeper or synergistic muscle activity could not be evaluated. Future research involving larger samples, dynamic task analyses, and longitudinal follow-ups is recommended to improve the external validity and mechanistic understanding of exercise interventions in athletes with LPCS.

Conclusions

In conclusion, the combined exercise protocol, including both hip- and knee-focused exercises, clearly outperforms isolated approaches in

[DOI: 10.61882/jsurgtrauma.14.1.19]

simultaneously enhancing VMO and GM activation in athletes with LPCS. The persistence of VL hyperactivity across all protocols indicates its resistance to change and highlights the need for more targeted interventions. Despite limitations such as attrition in the sample and unmeasured confounders, this study emphasizes the practical importance of adopting a comprehensive rehabilitation strategy. Future research should investigate long-term outcomes and central nervous system mechanisms to enhance treatment effectiveness further.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of the Islamic Azad University, Central Tehran Branch (Ethics Code: IR.IAU.CTB.REC.1404.079). All research procedures were performed in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their enrollment in the study.

Consent for Publication

Not applicable.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Funding Statement

The authors did not receive any specific grant from the government, commercial, or not-for-profit sectors.

Acknowledgements

The authors express their gratitude to all participants for their involvement in this study.

Authors' Contribution

MJR conducted participant recruitment, implemented the training interventions, collected and organized the electromyographic data, and drafted the initial manuscript. MM conceived and designed the study, supervised the entire research process, interpreted the results, and was the primary contributor to the writing and revision of the final manuscript. AF contributed to study design, supervised data acquisition procedures, performed the statistical analyses, and provided methodological and editorial revisions. All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of Interest

All authors declared that there are no conflicts of interest to report.

Declaration of Generative Artificial Intelligence (AI) in Scientific Writing

During the preparation of this work, the authors used ChatGPT, an AI-assisted tool, to enhance the readability and language of the manuscript. After using this tool, the authors carefully reviewed and edited the content as needed and took full responsibility for the published article.

References

1. Saper MG, Shneider DA. Diagnosis and treatment of lateral patellar compression syndrome. Arthrosc Tech. 2014;3(5):e633–e638. [DOI: 10.1016/j.eats.2014.07.004]
2. Hosseini SH, Nezhad SG. Morphological differences of knee extensor muscles between women with and without lateral patellar compression syndrome. Sci J Rehabil Med. 2022;11(5):754–769. [DOI: 10.32598/SJRM.11.5.7]
3. Xie P, István B, Liang M, editors. The relationship between patellofemoral pain syndrome and hip biomechanics: A systematic review with meta-analysis. Healthcare. 2022. [DOI: 10.3390/healthcare11010099]
4. Kordi Yoosefinejad A, Mazaheri M, Sobhani S, Motealleh A. Electromyographic onset and activity level of medial and lateral hamstrings, vastus medialis obliquus, and vastus lateralis in women with patellofemoral pain during stair descent. J Rehabil Sci Res. 2022;9(3):128–133. [URL: https://jrsr.sums.ac.ir/article_48328.html]
5. Foroughi F, Sobhani S, Yoosefinejad AK, Motealleh A. Added value of isolated core postural control training on knee pain and function in women with patellofemoral pain syndrome: A randomized controlled trial. Arch Phys Med Rehabil. 2019;100(2):220–229. [DOI: 10.1016/j.apmr.2018.08.180]
6. Saad MC, de Vasconcelos RA, de Oliveira Mancinelli LV, de Barros Munno MS, Liporaci RF, Grossi DB. Is hip strengthening the best treatment option for females with patellofemoral pain? A randomized controlled trial of three different types of exercises. Braz J Phys Ther. 2018;22(5):408–416. [DOI: 10.1016/j.bjpt.2018.03.009]
7. Hosseini SH, Farahmand F. Effect of two quadriceps strengthening protocols on morphological characteristics of knee vastus muscles in patients with lateral patellar compression syndrome. J Bodyw

Mov Ther. 2024;40:726–732.
[DOI: 10.1016/j.jbmt.2024.05.017]
8. Keyhanfar A, Hosseini S, Nemati N. Comparison of the effect of two methods of muscular exercise therapy on pain relief, functional abilities and static balance in patients with chronic patellofemoral pain. J Health Care. 2017;19(2):117–128.
[URL:https://hcjournal.arums.ac.ir/browse.php?a_id=785&sid=1&slc_lang=en]
9. Asadi S, Hosseini SH, Daneshmandi H. Comparison of the effects of knee local, proximal, and distal training on knee pain, function, and dynamic balance in athletes with patellofemoral pain syndrome. Sci J Rehabil Med. 2020;9(2):219–227.
[DOI: 10.22037/jrm.2019.112347.2179]
10. Manojlović D, Kozinc Ž, Šarabon N. Trunk, hip and knee exercise programs for pain relief, functional performance and muscle strength in patellofemoral pain: systematic review and meta-analysis. J Pain Res. 2021;14:1431–1449.
[DOI: 10.2147/JPR.S301448]
11. Hashim H, Mohammed SA, Mohammed Ali B, Ismaeel SA, Nasir M. Biceps and triceps muscle activation under progressive loads: a study on functional symmetry of the upper limbs. J Sport Biomech. 2025;11(1):64–78.
[DOI: 10.61186/JSportBiomech.11.1.64]
12. Pal S, Draper CE, Fredericson M, Gold GE, Delp SL, Beaupre GS, et al. Patellar maltracking correlates with vastus medialis activation delay in patellofemoral pain patients. Am J Sports Med. 2011;39(3):590–598.
[DOI: 10.1177/0363546510384233]
13. Yang J-S, Fredericson M, Choi J-H. The effect of patellofemoral pain syndrome on patellofemoral joint kinematics under upright weight-bearing conditions. PLoS One. 2020;15(9):e0239907.
[DOI: 10.1371/journal.pone.0239907]
14. Lotfi H, Nodehi Moghadam A, Shati M. Comparing electromyographic activity of quadriceps muscle during straight leg raise in individuals with and without patellofemoral pain syndrome. Phys Treat Spec Phys Ther J. 2018;7(4):197–204.
[DOI: 10.32598/ptj.7.4.197]
15. Bennell K, Duncan M, Cowan S, McConnell J, Hodges P, Crossley K. Effects of vastus medialis oblique retraining versus general quadriceps strengthening on vasti onset. Med Sci Sports Exerc. 2010;42(5):856–864.
[DOI: 10.1249/MSS.0b013e3181c12771]
16. Balogun J, Broderick K, Dolan-Aiello M. Comparison of the EMG activities in the vastus medialis oblique and vastus lateralis muscles during hip adduction and terminal knee extension exercise protocols. Afr J Physiother Rehabil Sci. 2010;2(1):1–5.
[DOI: 10.4314/ajprs.v2i1.62597]
17. Cavazzuti L, Merlo A, Orlandi F, Campanini I. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Gait Posture. 2010;32(3):290–295.
[DOI: 10.1016/j.gaitpost.2010.06.025]
18. Shi H, Huang H, Ren S, Yu Y, Liang Z, Wang Q, et al. The relationship between quadriceps strength asymmetry and knee biomechanics asymmetry during walking in individuals with anterior cruciate ligament reconstruction. Gait Posture. 2019;73:74–79.
[DOI: 10.1016/j.gaitpost.2019.07.151]
19. Glaviano NR, Marshall AN, Mangum LC, Hart JM, Hertel J, Russell S, et al. Improvements in lower-extremity function following a rehabilitation program with patterned electrical neuromuscular stimulation in females with patellofemoral pain: a randomized controlled trial. J Sport Rehabil. 2019;29(8):1075–1085.
[DOI: 10.1123/jsr.2019-0278]
20. Mirzaie GH, Rahimi A, Kajbafvala M, Manshadi FD, Kalantari KK, Saidee A. Electromyographic activity of the hip and knee muscles during functional tasks in males with and without patellofemoral pain. J Bodyw Mov Ther. 2019;23(1):54–58.
[DOI: 10.1016/j.jbmt.2018.11.001]
21. dos Anjos Rabelo ND, Lucareli PRG. Do hip muscle weakness and dynamic knee valgus matter for the clinical evaluation and decision-making process in patients with patellofemoral pain? Braz J Phys Ther. 2018;22(2):105–109.
[URL: 10.1016/j.bjpt.2017.10.002]
22. Rinaldi VG, Prill R, Jahnke S, Zaffagnini S, Becker R. The influence of gluteal muscle strength deficits on dynamic knee valgus: a scoping review. J Exp Orthop. 2022;9(1):81.
[DOI: 10.1186/s40634-022-00513-8]
23. Alsaleh S, Murphy N, Miller S, Morrissey D, Lack S. Local neuromuscular characteristics associated with patellofemoral pain: a systematic review and meta-analysis. Clin Biomech. 2021;90:105509.
[DOI: 10.1016/j.clinbiomech.2021.105509]
24. Barton CJ, Lack S, Malliaras P, Morrissey D. Gluteal muscle activity and patellofemoral pain syndrome: a systematic review. Br J Sports Med. 2013;47(4):207–214.
[DOI: 10.1136/bjsports-2012-090953]
25. Farahpour N, Jafarnezhadgero A, Allard P, Majlesi M. Muscle activity and kinetics of lower limbs during walking in pronated feet individuals with and without low back pain. J Electromyogr Kinesiol. 2018;39:35–41.
[DOI: 10.1016/j.jelekin.2018.01.006]
26. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Comparison of hip and knee strength and neuromuscular activity in subjects with and without patellofemoral pain syndrome. Int J Sports Phys Ther. 2011;6(4):285–293.

[URL: https://pubmed.ncbi.nlm.nih.gov/22163090]
27. Honarpishe R, Bakhtiary AH, Olyaei G. Effect of quadriceps exercise training on muscle fiber angle in patients with patellofemoral pain syndrome. Middle East J Rehabil Health Stud. 2015;2(4):e32216. [DOI: 10.17795/mejrh-32216]
28. Crouzier M, Hug F, Sheehan FT, Collins NJ, Crossley K, Tucker K. Neuromechanical properties of the vastus medialis and vastus lateralis in adolescents with patellofemoral pain. Orthop J Sports Med. 2023;11(6):23259671231155894. [DOI: 10.1177/23259671231155894]
29. Ng G, Zhang A, Li C. Biofeedback exercise improved the EMG activity ratio of the medial and lateral vasti muscles in subjects with patellofemoral pain syndrome. J Electromyogr Kinesiol. 2008;18(1):128–133. [DOI: 10.1016/j.jelekin.2006.08.010]
30. Qi Z, GYF N. EMG analysis of vastus medialis obliquus/vastus lateralis activities in subjects with patellofemoral pain syndrome before and after a home exercise program. J Phys Ther Sci. 2007;19(2):131–137. [DOI: 10.1589/jpts.19.131]
31. Goller M, Quittmann OJ, Alt T. How to activate the glutes best? Peak muscle activity of acceleration-specific pre-activation and traditional strength training exercises. Eur J Appl Physiol. 2024;124(6):1757–1769. [DOI: 10.1007/s00421-023-05400-3]
32. Neto WK, Soares EG, Vieira TL, Aguiar R, Chola TA, de Lima Sampaio V, et al. Gluteus maximus activation during common strength and hypertrophy exercises: a systematic review. J Sports Sci Med. 2020;19(1):195–203. [URL: https://pubmed.ncbi.nlm.nih.gov/32132843]
33. Glaviano NR, Saliba S. Differences in gluteal and quadriceps muscle activation during weight-bearing exercises between female subjects with and without patellofemoral pain. J Strength Cond Res. 2022;36(1):55–62. [DOI: 10.1519/JSC.0000000000003392]
34. Banan Khojasteh M, Khalkhali Zavieh M, Kalantari KK, Akbarzadeh Baghban A, Daryabor A, Mikaili S. Effect of biofeedback training of hip muscles on pain, muscle strength and their electromyography in patellofemoral pain syndrome. Arch Rehabil. 2024;25(3):520–539. [DOI: 10.32598/RJ.25.3.3826.1]
35. Kölle T, Alt W, Wagner D. Effects of a 12-week home exercise therapy program on pain and neuromuscular activity in patients with patellofemoral pain syndrome. Arch Orthop Trauma Surg. 2020;140(12):1985–1992. [DOI: 10.1007/s00402-020-03543-y]
36. Felicio LR, de Carvalho CAM, Dias CLCA, dos Santos Vigário P. Electromyographic activity of the quadriceps and gluteus medius muscles during different straight leg raise and squat exercises in women with patellofemoral pain syndrome. J Electromyogr Kinesiol. 2019;48:17–23. [DOI: 10.1016/j.jelekin.2019.05.017]
37. Moktasab M, Majlesi M, Farahpour N, Azadian E. Electromyographic patterns of lower limb muscles during gait in congenital blindness and sighted people. J Adv Sport Technol. 2019;3(2):1–8. [URL: https://jast.uma.ac.ir/article_853.html]
38. Earl-Boehm JE, Bolgla LA, Emory C, Hamstra-Wright KL, Tarima S, Ferber R. Treatment success of hip and core or knee strengthening for patellofemoral pain: development of clinical prediction rules. J Athl Train. 2018;53(6):545–552. [DOI: 10.4085/1062-6050-510-16]