วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 15 ฉบับที่ 1, กรกฎาคม 2558

Journal of Sports Science and Technology Volume 15, No. 1,July 2015

นิพนธ์ต้นฉบับ (Original article)

เวชศาสตร์การกีฬา (Sports Medicine)

การทำงานของสัญญาณไฟฟ้ากล้ามเนื้อขณะออกกำลังกายในท่าก้าวขึ้นแท่นทางด้านหน้าและยืนย่อขาข้างเดียวพิงผนังในผู้ที่มีอาการเจ็บลูกสะบ้าใต้เข่า

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บทคัดย่อ

วัตถุประสงค์: การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบการทำงานของกล้ามเนื้อกางและหมุนสะโพก กล้ามเนื้อเหยียดเข่าด้านนอก และกล้ามเนื้อเหยียดเข่าด้านใน ขณะก้าวขึ้นแท่นทางด้านหน้าและยืนย่อขาข้างเดียวพิงผนังในผู้ที่มีอาการเจ็บลูกสะบ้าใต้เข่า

วิธีการวิจัย: ผู้เข้าร่วมการวิจัยเป็นผู้ที่มีอาการเจ็บลูกสะบ้าใต้เข่าหญิง จำนวน 10 คน ทำการบันทึกสัญญาณไฟฟ้าของกล้ามเนื้อกางและหมุนสะโพก กล้ามเนื้อเหยียดเข่าด้านนอก และกล้ามเนื้อเหยียดเข่าด้านใน ขณะก้าวขึ้นแท่นทางด้านหน้าและยืนย่อขาข้างเดียวพิงผนัง กระบวนการวิจัยนี้ได้รับการรับรองจากคณะกรรมการจริยธรรมการวิจัยในคนของมหาวิทยาลัยมหิดล ทำการเปรียบเทียบการทำงานระหว่างกล้ามเนื้อต่างๆ ด้วยสถิติการวิเคราะห์ความแปรปรวนทางเดียวร่วมกับเปรียบเทียบพหุคูณด้วยวิธีบอนเฟอโรนีในช่วงขึ้นและลงของการออกกำลังกาย

ผลการวิจัย: ผลการศึกษาแสดงให้เห็นว่ากล้ามเนื้อเหยียดเข่าด้านนอกและด้านในมีการทำงานมากกว่ากล้ามเนื้อกางและหมุนสะโพกในช่วงขึ้นของท่าก้าวขึ้นแท่นทางด้านหน้า และทั้งช่วงขึ้นและลงในท่ายืนย่อขาข้างเดียวพิงผนัง

สรุปผล: การออกกำลังกายในท่าก้าวขึ้นแท่นทางด้านหน้าและท่ายืนย่อขาข้างเดียวหลังพิงผนัง สามารถใช้กระตุ้นการทำงานของกล้ามเนื้อเหยียดเข่าด้านนอก และกล้ามเนื้อเหยียดเข่าด้านในได้มากที่สุด ตามด้วยกล้ามเนื้อกางและหมุนสะโพก ตามลำดับ ในผู้ที่มีอาการเจ็บลูกสะบ้าใต้เข่า

(Journal of Sports Science and Technology 2015;15(1): 179-190)

คำสำคัญ อาการเจ็บลูกสะบ้าใต้เข่า, ก้าวขึ้นแท่นทางด้านหน้า, ยืนย่อขาข้างเดียวพิงผนัง, สัญญาณกล้ามเนื้อไฟฟ้า

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Journal of Sports Science and Technology Volume 15, No. 1,July 2015

นิพนธ์ต้นฉบับ (Original article)
เวชศาสตร์การกีฬา (Sports Medicine)

ELECTROMYOGRAPHY ACTIVITIES DURING FORWARD STEP UP AND WALL SINGLE LEG SQUAT IN INDIVIDUALS WITH PATELLOFEMORAL PAIN SYNDROME

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ABSTRACT

Objective: The aim of the study was to compare electromyography (EMG) activities among gluteus medius (GMed), vastus medialis oblique (VMO), and vastus lateralis (VL) muscles during eccentric and concentric phases of forward step up (FSU), and wall single leg squat (WSS) in individuals with patellofemoral pain syndrome (PFPS).

Materials and methods: Ten females with PFPS were recorded EMG activities of GMed, VMO, and VL muscles during performed the FSU, and WSS exercises. Research procedures were approved by the MU-IRB (Mahidol University Institutional Review Board). EMG activities among muscles were compared by using one way ANOVA with Bonferroni post-hoc test in each of the eccentric and concentric contraction phases.

Results: Findings demonstrated significant greater muscle activities of the VMO and VL than GMed during concentric phase of the FSU and during both concentric and eccentric phases of the WSS.

Conclusion: The FSU and the WSS were able to use for stimulating thigh muscle activations in the VMO, VL, and GMed, respectively in individuals with patellofemoral pain syndrome.

(Journal of Sports Science and Technology 2015;15(1): 179-190)

KEY WORDS: patellofemoral pain syndrome, forward step up, wall single leg squat, electromyography

INTRODUCTION

Patellofemoral pain syndrome (PFPS) is one of the considerable knee joint disorders in young persons [1]. PFPS is characterized by anterior, peripatella and retropatella knee pain that limited functional activities included stair climbing, squatting, kneeling, running, jumping, or sitting with knee flexion for a prolonged duration [2, 3]. Multiple causes of PFPS are related to abnormal alignment of patella or lower extremity, muscle weakness, or muscle tightness [3, 4]. One of the most muscles' weakness is quadriceps, especially in the vastus medialis oblique (VMO) [5, 6]. The VMO muscle plays a crucial role in dynamic and active medial stabilizers of patella from the lateral force, which is controlled by the vastus lateralis (VL) and iliotibial band. The VMO muscle equilibrates patella within intercondylar groove when the knee is flexed and extended [3, 4]. Another important muscle is gluteus medius (GMed). The role of GMed is primary stabilizer of the femur and pelvic when standing on single leg. There are reports about the GMed weakness is related to excessive hip internal rotation, adduction, and knee valgus alignment [3, 7, 8]. Reduction of the VMO and GMed muscle strengths can lead to the increase in patella movement to lateral side. Thus, these proper muscle activations could relieve excessive stress to the patellofemoral joint [3, 8, 9]

Individuals with PFPS have shown the benefits of closed kinetic chain exercise, specifically exercise in GMed and VMO muscles to improve optimal tracking of patella and regular functional activity [3, 10]. Unilateral weight bearing is one of common closed kinetic chain exercises and often been used for treatment knee dysfunctions [11-14]. Several unilateral weight bearing exercises such as the lunge, lateral step up, forward step up (FSU), and wall single leg squat (WSS) are also used for rehabilitation program. For the FSU and WSS exercises, primary movement occurs in the sagittal plane. Both exercises perform like the functional movement and could be used to strengthen the quadriceps and GMed muscles [12, 15-17].

Previous studies demonstrated different degrees of muscle activation during exercises. Simenz et al in 2012 [18] reported the EMG activities during FSU in eccentric and concentric phases of the VMO muscle was greatest followed by the VL and GMed muscles. Hertel et al in 2004 [19] found that the EMG muscle activities during single leg squat performed highly in the VMO, VL, and GMed muscles, respectively. Zeller et al in 2003 [20] reported the single leg squat generated greater EMG activity in the VL than GMed muscles for both male and female. Ayotte et al in 2007 [15] investigated EMG activities in healthy subjects during performed various exercises. The VMO was shown significantly greater EMG activity than GMed during WSS as well as FSU. Santos et al in 2008 [21], studied EMG activities in the VMO, vastus lateralis longus (VLL), and vastus lateralis oblique (VLO) muscles in individuals with PFPS during several step up and single leg squat. The results shown that EMG activity of VLO muscle was greater than VMO.

Although the contribution of VMO and VL muscle activities have been tested in several exercises in healthy subjects. Little is tested in pathologic conditions such as the individuals with PFPS. The present study aimed to compare EMG activities among GMed, VMO, and VL muscles in individuals with PFPS during eccentric and concentric phases of the FSU and WSS exercises. The data would be useful for prescribe appropriate exercise programs in this specific condition.

METHODS

Participants

Ten volunteered females who have PFPS were included in the study. They signed an informed consent approval by Mahidol University Institutional Review Board (MU-IRB 2014/010.1601). Their age, body weight, height, and body mass index were 27.11 ± 5.76 years, 49.70 ± 6.41 kg, 1.59 ± 0.05 m, and 19.59 ± 2.23 kg/m^2, respectively. Inclusion criteria were age ranged between 18 to 40 years, symptomatic was present at the patella region (anterior, retro, or around patella) at least two months prior to the testing day, presented knee pain at the patella region during or after performing activities two or more activities (squatting, stair climbing, kneeling, prolong sitting with knee flexion, running, jumping, or isometric quadriceps muscle contraction), pain scale 1 to 4 on visual analog scales during or after performed activities, positive test of Clarke's sign, and tenderness at peripatella soft tissue or patella facet. Exclusion criteria were who had acute inflammation, trauma of lower extremity, patella dislocation or subluxation, history of back or lower limb surgery/fracture, vestibular disorder, cardiovascular disease, knee deformity (genu recurvatum, severe genu varum, severe genu valgum), leg length discrepancy over 3 cm, osteoarthritis of knee, body mass index over 23.4 kg/m^2, menstruation period or pregnancy on the testing day, and visual impairment which cannot corrected by contact lenses or glasses.

Instrumentation and processing

Silver-Silver Chloride surface EMG electrodes (Ambu Blue Sensor, Ambu A/S Inc., Denmark) were placed on the GMed, VMO, and VL muscles of the tested leg. The sample frequency of EMG data was set at 1500 Hz (TeleMyo DTS Telemetry, NORAXON Inc., USA). EMG data were processed with Noraxon software (MyoResearch XP master). The data were processed using full wave rectification, band pass filtered between 20-500 Hz, root mean square smoothed with window 50 ms, and normalized by individual EMG at the maximum voluntary isometric contraction (MVIC).

Procedure

Before testing, participants performed warm up for 10 minutes on stationary bicycle at self-selected speed and load. The less knee pain was measured for the ones who have bilateral PFPS.

Surface electrodes placement

Skin was prepared with shaved, abraded, and cleaned. Interdistance between electrodes were 20 mm and impedance values less than 10 KΩ. For landmark of GMed muscle, electrodes were placed on proximal one third of distance from iliac crest to greater trochanter. VMO muscle was placed on 4 cm superior and 3 cm medial to the supero-medial patella border, and oriented 55 degrees to the vertical line. VL muscle was placed on 10 cm superior, 6 cm lateral to the superior border of the patella, and oriented 15 degrees to the vertical line [22, 23].

Procedure of MVIC testing

Participants performed MVIC of three muscles. For the GMed muscle testing, participants lying on untested side with strap around the pelvic for stabilization. A strap was placed around 2.5 cm above lateral knee joint line for against hip abduction with extension. They performed isometric contraction in hip abduction with extension direction against the strap wrapping above lateral knee joint line.

For the VMO and VL testing, participants sat on chair with crossed arm over the chest and bent knee at 90 degrees. One strap was fixed at the pelvic stabilization and the other was wrapped over 2.5 cm above medial malleolus for against knee extension. They performed isometric contraction in knee extension direction against to strap wrapping above medial malleolus. Each muscle was tested MVIC for 3 trials and held position for 3 seconds. One minute rest was given between trials and rested for 2 minutes between exercises [15].

Procedure of exercise testing

Prior exercise testing, participant watched the exercise demonstration video and practiced the exercise for 5 repetitions. Exercise was randomly ordered for participants. They performed for 3 repetitions of 3 trials. One minute break was allowed between trials and 2 minutes break was allowed between exercises. During testing, participants controlled their alignments by watched mirror during exercises. Metronome was used for determination of exercise speed and was set at 40 beats/min [15].

Participants performed FSU exercise on 40 x 40 x 15 cm wooden step. They placed untested leg at marker on the non-slip mat which placed on the floor then brought the leg back to the starting position (Fig. 1A). Marker on floor was set at 30 cm from heel of tested leg. Eccentric contraction defined as the range of Gmed, VMO and VL muscles worked eccentrically during the untested leg step down and placed foot on the floor. Concentric contraction referred as the range of GMed, VMO, VL muscles worked concentrically during the untested leg step up and placed foot on the wooden step.

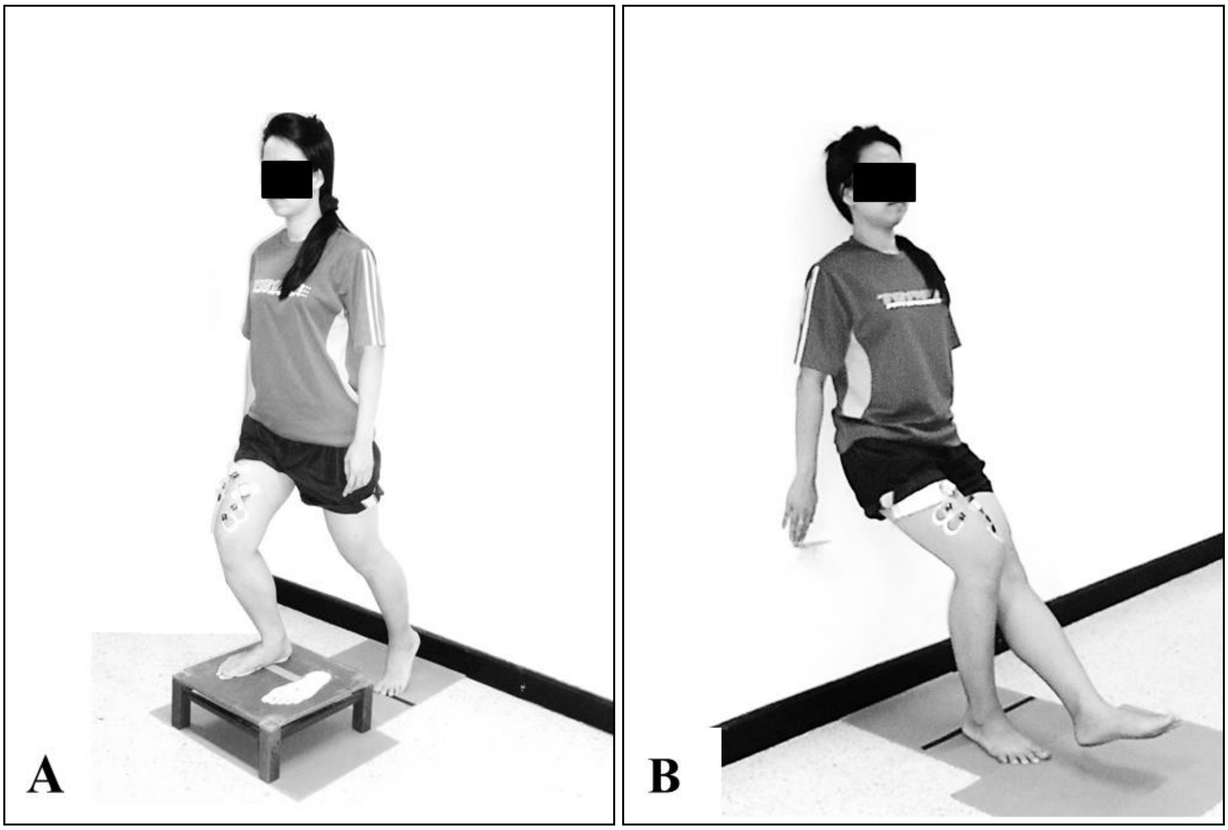

Figure 1. The forward step up (FSU) (A) and the wall single leg squat (WSS) (B).

For the WSS exercise, participants placed their feet at marker on the non-slip mat. Marker was set far from heel of tested leg at 30 cm. Participants touched their back and arm on the wall then raised their untested leg. Untested leg raised throughout 3 repetitions of squat. Marker on the wall was used for control deep of squat descending (15 cm). Participants performed squat down until middle finger lightly touched to marker on wall, after that go back to starting position (Fig. 1B). Eccentric phase represented as the range that GMed, VMO and VL muscles worked eccentrically which occurred during quat down until middle finger touched to the marker placing on the wall. Concentric phase defined as the range that GMed, VMO and VL muscles worked concentrically which occurred during knee was extended to the starting position.

Data collection

EMG activities of GMed, VMO, and VL muscles were collected at the middle part of muscle contraction for each trial. Eccentric and concentric phases of the middle repetition from 3 trials were averaged. To identify the phase of exercises, the rested points of EMG data were marked. Up and down for 1.5 seconds from the rested points were defined as the eccentric and concentric phases, respectively. The averaged MVIC over 1.5 seconds was used to normalize EMG activities during exercise.

Statistical analysis

Data were analyzed by SPSS version 18.0 (S/N 5082368 NY, US). The Kolmogorov-Smirnov goodness of fit test was used for testing normality and demonstrated normal distribution. One way ANOVA with Bonferroni post-hoc test were used to compare EMG activities among GMed, VMO, and VL muscles of eccentric and concentric phases of each exercise. Statistical significance in each of phases among three muscles during FSU and WSS exercises were set at p-value<0.05.

RESULTS

Figure 2 showed means and standard deviations of EMG activities of the GMed, VMO, and VL muscles during the FSU exercise. During eccentric phase, EMG activities of the VMO and VL were greater than the GMed but not showed significant difference ($F_{2,27}$=3.22, p=0.056). EMG activities of the GMed, VMO, and VL muscles were 14.43 ± 5.65, 21.65 ± 9.62, and 22.14 ± 7.02 %MVIC, respectively. During concentric phase, EMG activities of the GMed, VMO, and VL muscles were 20.48 ± 8.45, 42.80 ± 10.52, and 39.60 ± 11.92 %MVIC, respectively. One way ANOVA demonstrated significant difference of EMG activities among GMed, VMO, and VL muscles during concentric phase of FSU exercise ($F_{2,27}$=13.48, p<0.001). Bonferroni post hoc test demonstrated significant difference of EMG activities between the VMO and GMed muscles (p<0.001) and between VL and GMed muscles (p=0.001).

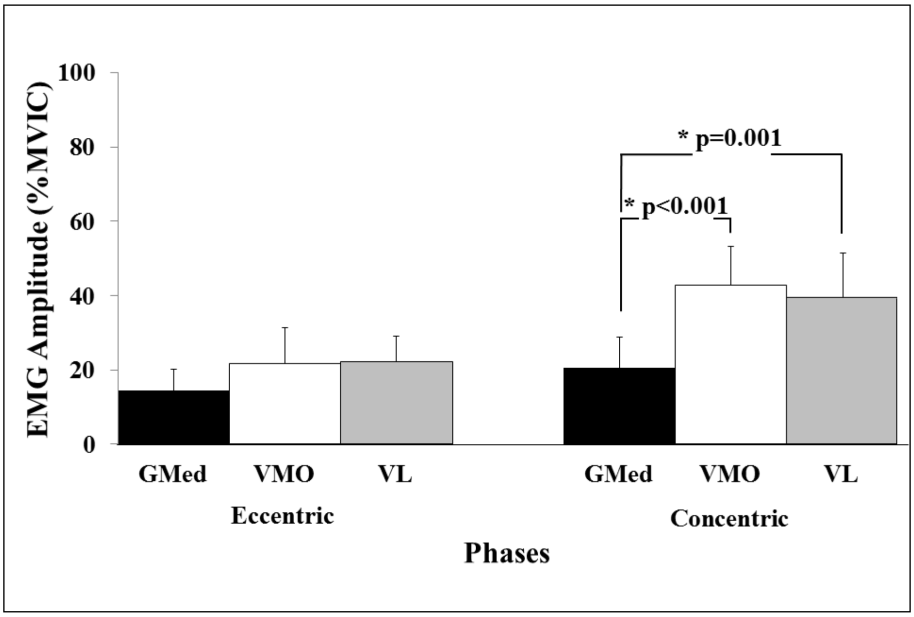

Figure 2. Means and standard deviations of electromyography (EMG) activities (%MVIC) among gluteus medius (GMed), vastus medialis oblique (VMO), and vastus lateralis (VL) muscles during eccentric and concentric phases of forward step up (FSU) exercise.

Figure 3 showed means and standard deviations of EMG activities of the GMed, VMO, and VL muscles during the WSS exercise. During eccentric phase, EMG activities of the GMed, VMO, and VL were 23.60 ± 10.13, 48.85 ± 17.99, and 44.30 ± 12.16 %MVIC, respectively. Significant differences were found in eccentric phase among these three muscles ($F_{2,27}$=9.46, p=0.001). Bonferroni post hoc demonstrated significant difference between VMO and GMed muscles (p=0.001) and between VL and GMed muscles (p=0.007). During concentric phase, EMG activities of the GMed, VMO, and VL were 29.82 ± 13.05, 58.44 ± 22.80, and 55.53 ± 15.04 %MVIC, respectively. Significant differences were found in concentric phase among these three muscles ($F_{2,27}$=8.11, p=0.002). Bonferroni post hoc demonstrated significant difference between VMO and GMed muscles (p=0.003) and between VL and GMed muscles (p=0.008).

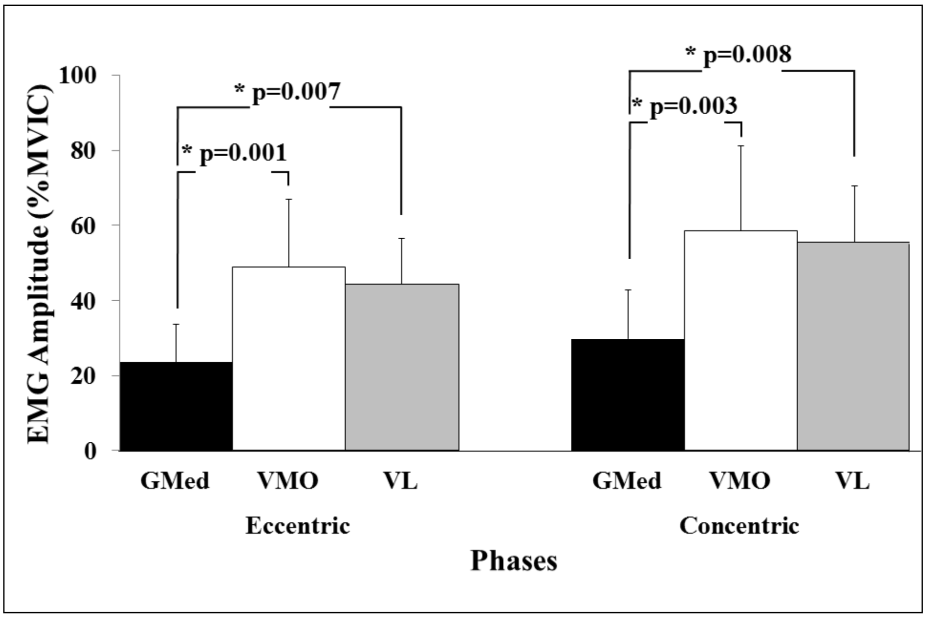

Figure 3. Means and standard deviations of electromyography (EMG) activities (%MVIC) among gluteus medius (GMed), vastus medialis oblique (VMO), and vastus lateralis (VL) muscles during eccentric and concentric phases of wall single leg squat (WSS) exercise.

DISCUSSION

Knowledge from previous studies found that individuals with PFPS showed weakness of the GMed and VMO muscles and tightness of the VL muscle [3, 4]. Muscular dysfunction from weakness and tightness affect to the ability of the muscles to perform functional activities. Several studies used the FSU and WSS exercises in rehabilitation program for improving muscle strength [12, 15, 16]. However, contribution of the muscles during each phase of exercise need to be tested in individuals with PFPS condition.

During descending phase of the FSU and WSS exercises, there were eccentric contractions of the GMed, VMO, and VL muscles. While concentric contraction of these three muscles occurred during ascending phase [24]. Primary movement pattern existed in the sagittal plane when performed FSU and WSS exercises, the present findings demonstrated similar trend of muscle activities [13]. EMG activities of VMO and VL muscles were greater than the GMed muscle during performed both of the FSU and WSS exercises. The VMO and VL muscles were highly activated in the sagittal plane when the GMed was activated more in the frontal plane movement [25]. More explanation of higher muscle activities of VMO and VL may come from the longer lever arm and muscle fibers' length and alignments [26, 27].

Similar to previous studies [15, 18-20], FSU and WSS exercises activated EMG activities of the VMO and VL muscles than the GMed muscle both in the eccentric and concentric phases. Ayotte et al in 2007 [15] evaluated EMG activities during different exercises (FSU, forward step down, lateral step up, mini squat, and WSS). They found that concentric phase of the FSU and WSS exercises showing significant greater EMG activity in VMO muscle when compared to GMed muscle ($p=0.022$). Another research was done during separate phases by Simenz et al in 2012 [18] in healthy persons. During eccentric and concentric phases of the FSU exercise, greatest EMG activity was found in the VMO, followed by the VL, and GMed muscles. During single leg squat, EMG activities were highest to lowest activated in the VMO, VL, and GMed muscles [19, 20]. In individuals with PFPS, one previous study evaluated EMG activities in VMO, VLL, and VLO muscles during FSU and squat maneuvers. The data demonstrated more muscle activated in the VLO and VMO muscles [21].

CONCLUSION

The finding provided information for appropriate selection of exercise prescription toward the targeted muscles (GMed, VMO, and VL muscles) in individuals with PFPS. Greater activation presented in the VMO and VL muscles during concentric phase of FSU and during eccentric and concentric phases of WSS exercises when compared to GMed muscle. Therefore, the concentric phase of FSU exercise can be used to stimulate the VMO and VL muscles highly followed by the GMed muscle. Both eccentric and concentric phases of the WSS exercise can induce muscle activation of VMO and VL muscles more than the GMed muscle.

LIMITATION OF THE STUDY

The study is limited by number of samples and types of exercise. Further study should recruit more number of samples and should investigate in various types of exercise. In addition, more control group or the data of the sound limb might be compared to obtain more information.

ACKNOWLEDGMENTS

This study is partially supported by Thammasat University Hospital. We would like to thank all members of the Faculty of Physical Therapy, Mahidol University for their assistances as well and individuals with PFPS who participated in the study.

REFERENCES

1. Stathopulu E, Baildam E. Anterior knee pain: a long-term follow-up. Rheumatology. 2003 Feb;42(2):380-382.
2. Dixit S, Difiori JP, Burton M, Mines B. Management of patellofemoral pain syndrome. Am Fam Physician. 2007 Jan;75(2):194-202.
3. Halabchi F, Mazaheri R, Seif-Barghi T. Patellofemoral pain syndrome and modifiable intrinsic risk factors; how to assess and address? Asian J Sport Med. 2013 Jun;4(2):85-100.
4. Waryasz GR, McDermott AY. Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. Dny Med. 2008 Jun;7:9.
5. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Hip strength and hip and knee kinematics during stair descent in females with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther. 2008 Jan;38(1):12-18.
6. Lankhorst NE, Bierma-Zeinstra SM, van Middelkoop M. Risk factors for patellofemoral pain syndrome: a systematic review. J Orthop Sports Phys Ther. 2012 Feb;42(2):81-94.
7. Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. J Orthop Sports Phys Ther. 2010 Feb;40(2):42-51.
8. Powers CM. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. J Orthop Sports Phys Ther. 2003 Nov;33(11):639-646.
9. Lee TQ, Morris G, Csintalan RP. The influence of tibial and femoral rotation on patellofemoral contact area and pressure. J Orthop Sports Phys Ther. 2003 Nov;33(11):686-693.
10. Nakagawa TH, Muniz TB, Baldon Rde M, Dias Maciel C, de Menezes Reiff RB, Serrao FV. The effect of additional strengthening of hip abductor and lateral rotator muscles in patellofemoral pain syndrome: a randomized controlled pilot study. Clin Rehabil. 2008 Dec;22(12):1051-1060.
11. 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 Dec;6(4):285-295.
12. Beutler AI, Cooper LW, Kirkendall DT, Garrett WE Jr. Electromyographic analysis of single-leg, closed chain exercises: implications for rehabilitation after anterior cruciate ligament reconstruction. J Athl Train. 2002 Mar;37(1):13-18.

13. Distefano LJ, Blackburn JT, Marshall SW, Padua DA. Gluteal muscle activation during common therapeutic exercises. J Orthop Sports Phys Ther. 2009 Jul;39(7):532-540.
14. Boren K, Conrey C, Le Coguic J, Paprocki L, Voight M, Robinson TK. Electromyographic analysis of gluteus medius and gluteus maximus during rehabilitation exercises. Int J Sports Phys Ther. 2011 Sep;6(3):206-223.
15. Ayotte NW, Stetts DM, Keenan G, Greenway EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. J Orthop Sports Phys Ther. 2007 Feb;37(2):48-55.
16. Boudreau SN, Dwyer MK, Mattacola CG, Lattermann C, Uhl TL, McKeon JM. Hip-muscle activation during the lunge, single-leg squat, and step-up-and-over exercises. J Sport Rehabil. 2009 Feb;18(1):91-103.
17. Reiman MP, Bolgla LA, Loudon JK. A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. Physiother Theory Pract. 2012 May;28(4):257-268.
18. Simenz CJ, Garceau LR, Lutsch BN, Suchomel TJ, Ebben WP. Electromyographical analysis of lower extremity muscle activation during variations of the loaded step-up exercise. J Athl Train. 2012 Dec;26(12):3398-3405.
19. Hertel J, Earl J, Tsang K, Miller S. Combining isometric knee extension exercises with hip adduction or abduction does not increase quadriceps EMG activity. Br J Sports Med. 2004 Apr;38(2):210-213.
20. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. Am J Sports Med. 2003 May-Jun;31(3):449-456.
21. Santos EP, Bessa SNF, Lins CAA, Marinho AMF, Silva KMP, Brasileiro JS. Electromyographic activity of vastus medialis obliquus and vastus lateralis muscles during functional activities in subjects with patellofemoral pain syndrome. Rev Bras Fisioter. 2008 Oct;12(4):304-310.
22. Cram JR, Kasman GS, Holtz J. Introduction to surface electromyography. Gaithersburg: Aspen; 1998.
23. Cowan SM, Bennell KL, Hodges PW. The test–retest reliability of the onset of concentric and eccentric vastus medialis obliquus and vastus lateralis electromyographic activity in a stair stepping task. Phys Ther Sport. 2000 Mar;1(4):129-136.
24. McGinty G, Irrgang JJ, Pezzullo D. Biomechanical considerations for rehabilitation of the knee. Clin Biomech (Bristol, Avon). 2000 Mar;15(3):160-166.

25. Mercer VS, Gross MT, Sharma S, Weeks E. Comparison of gluteus medius muscle electromyographic activity during forward and lateral step-up exercises in older adults. Phys Ther. 2009 Nov;89(11):1205-1214.
26. Neumann DA. Kinesiology of the musculoskeletal system : foundations for rehabilitation. Philadelphia: Mosby/Elsevier; 2010.
27. Zwerver J, Bredeweg SW, Hof AL. Biomechanical analysis of the single-leg decline squat. Br J Sports Med. 2007 Apr;41(4):264-268.