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Comparison of Muscle Activities between Two Unilateral Weight Bearing Exercises in Patellofemoral Pain Syndrome

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Abstract

Patients with patellofemoral pain syndrome (PFPS) usually demonstrate gluteus medius (GMed), vastus medialis oblique (VMO), and vastus lateralis (VL) muscle weakness. An investigation of the different types of exercise needed for this population to stimulate proper muscle is required. This study aimed to compare muscle activities of GMed, VMO, and VL during eccentric and concentric phases between forward step up and wall single leg squat exercises in patients with PFPS. Ten females with PFPS participated in the study. Muscle activities of GMed, VMO, and VL were recorded by electromyography (EMG) during the forward step up, and wall single leg squat exercises. Paired *t*-test was used for analysis of muscle activities between types of exercises. Muscle activities of GMed, VMO, and VL during eccentric and concentric phases were significantly lower in the forward step up than the wall single leg squat. Both forward step up and wall single leg squat exercises were effective in order to activate works of GMed, VMO, and VL muscles in patients with PFPS.

Keywords: Forward step up, wall single leg squat, patellofemoral pain syndrome, electromyography

Introduction

Patellofemoral pain syndrome (PFPS) is a pain syndrome that can occur at either the anterior or retropatella areas. This knee pain usually occurs during performing closed kinetic activities such as descending stairs, squatting, kneeling, jumping, running, and sitting with knee flexion for a long period of time [1,2]. Patients with PFPS frequently display muscle weakness, tightness, and mal-alignments of patella and lower extremities [2,3]. Reduction of the muscle strength often appears in the gluteus medius (GMed) [4] and vastus medialis oblique (VMO) [5]. A weakness of these 2 muscles leads to excessive stress on the patellofemoral joint [2,6,7]. The function of GMed is to control the pelvis and femur during weight bearing on a single leg and to control knee valgus alignment [2,6,8]. For the VMO, it is also a primary dynamic stabilizer of the patella. The VMO pulls the patella medially in order to maintain it within the femoral groove by counter acting the vastus lateralis (VL) and iliotibial band, which pull the patella laterally [2,3]. The most crucial indispensable treatment for patients with PFPS is strengthening exercise particularly for the GMed and VMO muscles [9]. Many studies support the strengthening of these 2 muscles by using closed kinetic chain exercise improved function of patellofemoral joint [2,9]. Various unilateral weight bearing exercises are widely used in rehabilitation such as the forward step up, forward step down, lateral step up, and single leg squat exercises [10,11]. For both forward step up and wall single leg squat exercises, the main lower extremity movement is in the sagittal plane and acts as a regular functional activity used which improves GMed muscle and knee extensor strengthening [12,13].

Ayotte *et al*. [12] studied the activities of 4 muscles in healthy participants during 5 unilateral weight bearing exercises. Higher GMed and VMO muscle activities were shown during the forward step up and wall single leg squat exercises than unilateral mini squat, lateral step up, and retro-step up exercises. Beutler *et al*. [14] found that the forward step up and single leg squat exercises effectively strengthen quadriceps in healthy males and females. Boudreau *et al*. [13] demonstrated that forward step up and single leg squat exercises can generate submaximal strengthening of GMed and rectus femoris muscles in healthy participants. Santos *et al*. [10] studied muscle activations in patients with PFPS during several step and squat exercises but no significant difference of VMO and VL muscle activities between forward step up and single leg squat exercises was found. In normal participants, previous studies found that both forward step up and single leg squat exercises were necessary for strengthening the GMed and quadriceps muscles [12-14].

However, muscle function in patients with PFPS may change and response to exercise is different from normal people. To prescribe proper therapeutic exercise for patients with PFPS, thus, the present study aimed to compare muscle activities in GMed, VMO, and VL between forward step up and wall single leg squat exercises in patients with PFPS. Due to the differences in body posture and center of gravity position during perform the exercises, we hypothesized that the muscle activities were lower in the forward step up exercise than the wall single leg squat exercise.

Materials and methods

The study design was a cross-sectional study. Voluntary participants living in Salaya and nearby areas were included in the study following the inclusion and exclusion criteria; females with an age range between 18 - 40 years, had symptomatic pain in the patella region (anterior, retro, or around patella), had pain scale 1 to 4 from the visual analogue scale during or after performed activities (squatting, descending and ascending stair, kneeling, prolong sitting with knee flexion, running, or jumping), had symptoms for longer than 2 months from the onset, reported knee pain at patella region during or after performing functional activities at least 2 activities associated with PFPS (e.g., squatting, stair climbing, kneeling, prolonged sitting, and isometric quadriceps muscle contraction), a positive sign from the patellofemoral grinding test (Clarke's sign), and peripatella soft tissue or patella facet were palpable pain. They were excluded from the study if they had any recent acute inflammation, trauma of the lower extremity, back and lower limb surgery, fracture, patella dislocation or subluxation, vestibular disorder, cardiovascular disease, leg length discrepancy over 3 cm, genu recurvatum, severe genu varum, severe genu valgum, osteoarthritis of knee, body mass index over 23.4 kg/m^2, menstruation period, pregnancy, and visual disturbances that cannot be adjusted by contact lenses or glasses. The ethical issue was approved by the Mahidol University Review Board, Thailand (MU-IRB 2014/010.1601). Participants signed informed consents before they were included in the study.

Ten females with PFPS participated in the study. The average age, weight, and height were 27.11±5.76 years, 49.70±6.41 kg, and 1.59±0.05 m. One person had a dominant left leg with the remaining nine people a dominant right leg. Data were collected on the symptomatic side which was on the left for eight people and on the right for two people.

Data collection

Before testing, participants were asked to warm up for 10 min on a stationary bicycle. Speed and load of bicycling were defined by the participants individually. After warm up, Silver-Silver Chloride surface EMG electrodes (Ambu Blue Sensor, Ambu A/S Inc., Denmark) were placed on GMed, VMO, and VL muscles [15,16] The skin of each electrode site was shaved, abraded, and cleaned before the electrodes were placed. The inter-distance between the 2 electrodes was 20 mm and skin impedance was lower than 10 kΩ. Muscle activities were collected at a sampling frequency of 1500 Hz, band pass filtering 20 - 500 Hz, gain was 500, and the common-mode rejection ratio was more than 100 dB. (TeleMyo DTS Telemetry, NORAXON Inc., USA) [17,18]. After that, the maximum voluntary isometric contraction (MVIC) of the GMed, VMO, and VL muscles were tested. For GMed muscle testing, the participants lay on their non-evaluated side. Straps were fixed at the pelvis and at 2.5 cm above the knee joint for resisting hip abduction with extension. For the VMO and VL testing, participants sat on an evaluation chair, bent their knees at 90º, and crossed their arms at the chest. Straps were tightly fixed at the pelvis and at 2.5 cm above medial malleolus for resisting knee extension [17]. They were given verbal commands (Ready! Prepare! Go! Go! Go! Relax) during the MVIC test. The MVIC of each muscle was collected in 3 trials. Each trial was held for 3 s with a rest for 1 min between trials. A 2 min break between muscle tests was allowed. Mean value MVIC at the middle part of isometric test for 1.5 s were averaged from the 3 test trials. For the patients who had bilateral PFPS symptoms, they were tested on the knee that had less pain only.

After MVIC testing, the exercise procedures were explained to the participants by watching a demonstration video. They were allowed to practice for 5 repetitions of each exercise and to rest for 2 min after practicing. The types of exercises were randomly assigned to the participants. Both forward step up and wall single leg squat exercises were performed by participants in 3 trials. Each trial of exercise was performed 3 times continuously. Then, rests for 1 min between trials and 2 min between exercises were allowed. For the forward step up exercise, participants stood on a wooden step, size 40×40×15 cm. They were asked to bring the non-evaluated leg backwards with the placed foot on the floor, then, bring the non-evaluated leg back to the wooden step. The distance between forward and backward movements in the forward step up was set at 30 cm [12] (**Figure 1**).

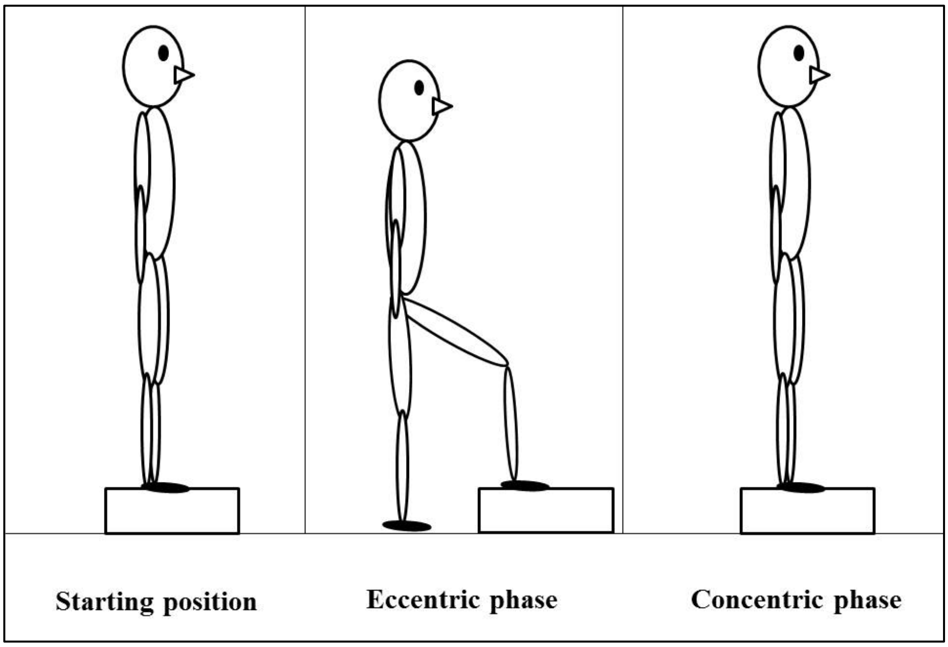


Figure 1 The forward step up exercise.

For the wall single leg squat exercise, participants stood on floor at the designated line, which was 30 cm away from the wall and were asked to place their back and arms on the wall as illustrated in **Figure 2**. They held the non-evaluated leg up during the test and squatted on the evaluated leg until the middle finger touched the marker (marker was set at 15 cm from starting position), and returned to the upward position. The speed of 2 exercises were controlled by a metronome which was set at 40 beats/min (1.5 s for up and 1.5 s for down). During the exercises, participants corrected their body alignments by looking at the mirror which was placed in front of them [12].

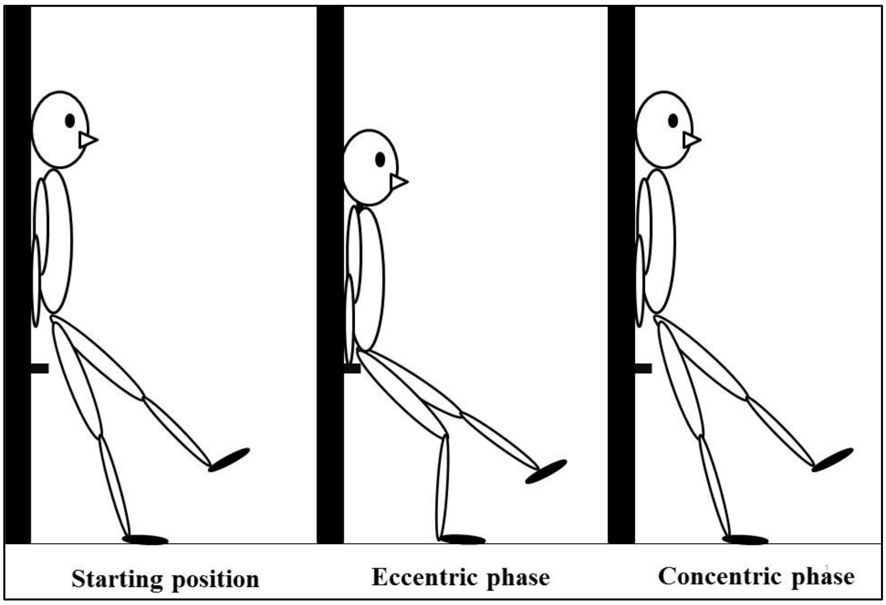


Figure 2 The wall single leg squat exercise.

Data reduction and processing

In order to reduce acceleration and deceleration periods, muscle activities were collected from the 2nd repetition for each trial of the forward step up and wall single leg squat exercises. Eccentric and concentric phases of exercises were analyzed. The phases were marked by video and muscle activities. Muscle activities of concentric and eccentric phases were selected for 1.5 s from the marked point, corresponding to the rhythm setting for the exercise (**Figure 3**). Muscle activities of the 2nd repetition from 3 trials were averaged for each exercise [12]. Muscle activities were full wave rectification, smoothing by root mean square with a window of 50 ms, and normalized to % MVIC by using Noraxon software (MyoResearch XP master).

Statistical analysis

Data were analyzed by SPSS version 18.0 (S/N 5082368 NY, US). The Shapiro-Wilks Test was used for testing normality and demonstrated normal distribution. A pair *t*-test was used for analyzing muscle activities of GMed, VMO, and VL during eccentric and concentric phases between forward step up and wall single leg squat exercises. Statistically significant difference was set at $p < 0.05$.

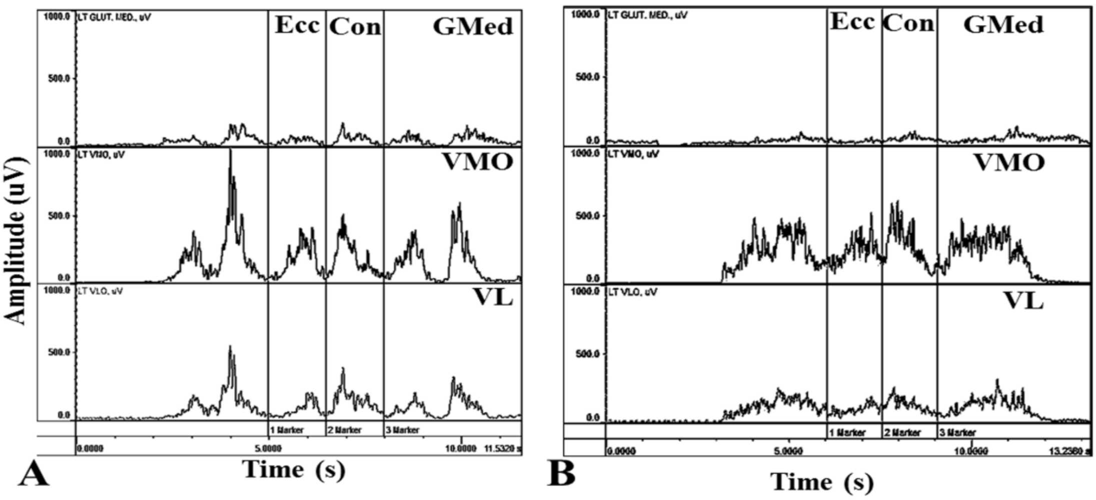


Figure 3 Representative muscle activities in gluteus medius (GMed), vastus medialis oblique (VMO), and vastus lateralis (VL) muscle of 1 trial of a single participant during eccentric (Ecc) and concentric (Con) phases between forward step up (A) and wall single leg squat (B) exercises in patients with PFPS.

Results and discussion

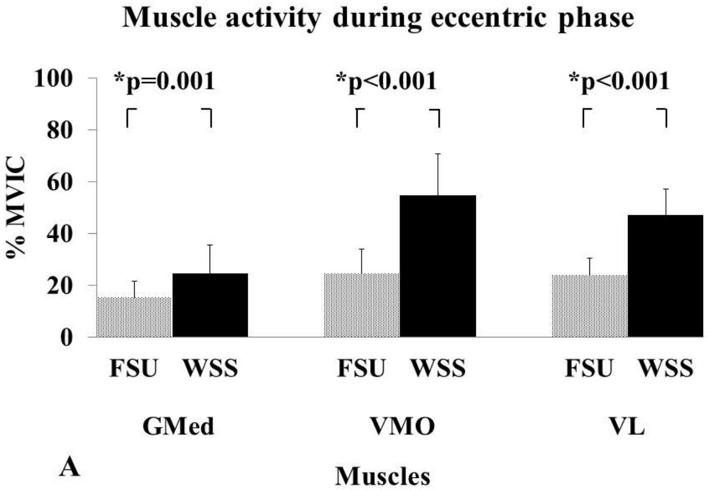
All muscle activities (GMed, VMO, and VL) during the forward step up exercise were significantly lower than during the wall single leg squat exercise in both eccentric (GMed was $p = 0.001$, VMO was $p < 0.001$, and VL was $p < 0.001$) and concentric phases (GMed was $p = 0.008$, VMO was $p = 0.007$, and VL was $p = 0.001$). Muscle activities of GMed, VMO, and VL muscles during the eccentric and concentric phases between the forward step up and wall single leg squat exercises in patients with PFPS are shown in **Figure 4**.

GMed muscle activities at the eccentric phase during the forward step up and wall single leg squat exercises were 15.34±6.36 and 24.62±11.04 % MVIC, respectively. VMO muscle activities at the eccentric phase during the forward step up and wall single leg squat exercises were 24.48±9.55 and 54.62±16.12 % MVIC, respectively. VL muscle activities at the eccentric phase during the forward step up and wall single leg squat exercises were 23.89±6.68 and 46.97±10.10 % MVIC, respectively.

GMed muscle activities at the concentric phase during the forward step up and wall single leg squat exercises were 21.79±9.47 and 31.71±14.86 % MVIC, respectively. VMO muscle activities at the concentric phase during the forward step up and wall single leg squat exercises were 48.35±9.30 and 65.97±22.74 % MVIC, respectively. VL muscle activities at the concentric phase during the forward step up and wall single leg squat exercises were 42.72±10.39 and 60.09±13.42 % MVIC, respectively.

Previous studies reported that patients with PFPS demonstrated weakness of GMed, VMO, and VL [2,4,5,19]. Muscular weakness was the most important factor related to alterations of muscle functions and mal-alignments of lower limbs [6]. Forward step up and wall single leg squat exercises have been proposed for use in exercise protocols for improving the GMed, VMO, and VL muscles in healthy participants [12,14]. Thus, muscle activities of GMed, VMO, and VL between the forward step up and wall single leg squat exercises in patients with PFPS were compared in this study.

Similar to previous studies [10,12,20,21], lower muscle activities of the GMed, VMO, and VL were demonstrated in the forward step up exercise than the wall single leg squat exercise. Ayotte *et al.* [12] studied the muscle activities during the forward step up, wall single leg squat, mini squat, lateral step up, and retro-step up in healthy participants. They found that there were lower muscle activities of the GMed and VMO in the forward step up exercise than the wall single leg squat exercise, but no significant difference was found. Dwyer *et al*. [20], analyzed EMG in each phase of muscle contraction. They found lower muscle activities of GMed in the forward step up than the single leg squat in both eccentric and concentric phases but no significant difference was found. Another study from Lubahn *et al*. [21] which compared GMed and gluteus maximus activities during double leg squat, forward step up, and single leg squat in healthy female participants. Results demonstrated significant differences of muscle activities between the 3 types of exercise ($p < 0.01$). As mentioned above, several works have studied healthy participants. Only one research was performed in patients with PFPS by Santos *et al*. [10]. They compared muscle activity of the VMO, vastus lateralis longus, and vastus lateralis oblique during functional activities. Lower activities of the muscles were found during forward step up than single leg squat, but there was no statistical significance.



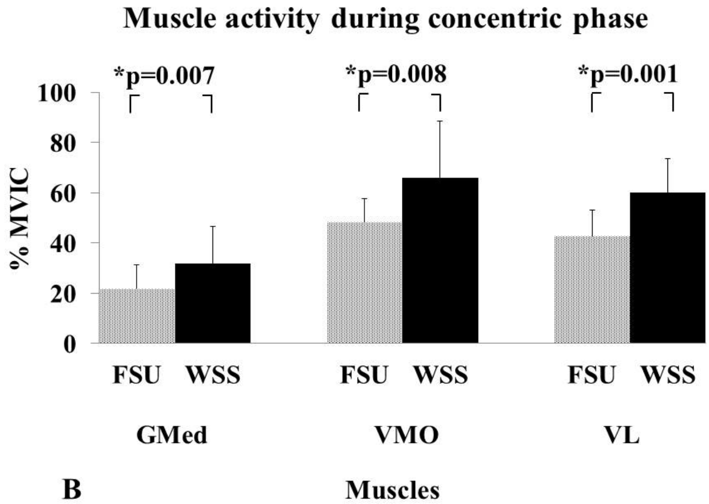


Figure 4 Means ± SD of muscle activities (% MVIC) of gluteus medius (GMed), vastus medialis oblique (VMO), and vastus lateralis (VL) during eccentric (A) and concentric (B) phases between forward step up (FSU) and wall single leg squat (WSS) exercises in patients with PFPS.
*Paired *t*-test, $p < 0.05$

Due to contradictory results from previous studies [4,14], the discussion related to those findings should be done. Quadriceps activity was analyzed during the forward step up and single leg squat at different degrees of knee flexion (30º, 60º, 90º) by Beutler *et al*. 2002 [14]. For the eccentric phase, more quadriceps activity was shown in the forward step up when analyzed at 30º. However, the results found that quadriceps activity at 60º knee flexion was not different. On the other hand, lower quadriceps activity was shown in the forward step up when analyzed at 90º. For the concentric phase, quadriceps activity was not different when compared between the forward step up and single leg squat in all degrees of knee flexion. However, in this previous study, step height for the forward step up was set for the tibial plateau but the descent level for single leg squat was not indicated. These different techniques of analysis, may be the reason for the inconsistent results. The present study used a step height at 15 cm and descent level at 15 cm. Therefore, participants in the study performed both exercises in the functional range (about 45 degrees).

Bolgla *et al*. [4] assessed vastus medialis muscle activity during various exercises. Muscle activity was analyzed during concentric phase for the forward step up and during the isometric phase when the knee was flexed at 30º for the single leg squat. As mentioned above, different findings of muscle activities level during forward step up and wall single leg squat in the present study possibly caused by the different methods, populations, and data analyses.

Conclusions

The forward step up and wall single leg squat exercises were effective to activate the GMed, VMO, and VL muscle activities in patients with PFPS. Lower activities of GMed, VMO, and VL were found during the forward step up exercise when compared to the wall single leg squat exercise.

The findings provide knowledge about the appropriate selection of exercise types in individuals with PFPS. From this finding, females with PFPS having mild knee pain could perform the forward step up exercise in the first step of the rehabilitation program because the forward step up exercise requires less muscle recruitment than the wall single leg squat exercise. For the progression phase, we suggest performing wall single leg squat exercises when patients are familiar with the forward step up exercise or symptoms get better because this exercise challenges the strength of the GMed, VMO, and VL muscles.

The present study may be limited by generalizability to the other types of knee pain and gender because we only studied females who have PFPS. Further study should investigate different types of knee pain, types of exercise, and gender for proper exercise selection in the wider population.

Acknowledgements

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