EMG Activity of Gluteal, Abdominal, Back and Hamstring Muscles during Lunge in Three Direction and Wall Squat Position in Asymptomatic Individuals

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Abstract

Objective: To compare muscle activity of gluteal, abdominal, back and hamstring muscles during forward lunge, transverse lunge, sideway lunge and wall squat positions in asymptomatic individuals. Material and Method: Eight asymptomatic participants (aged 20.75±1.03 years) were recruited. Surface electromyography (EMG) was used to measure muscle activity of gluteus maximus (GMax), gluteus medius (GMed), transversus abdominis/internal abdominal oblique (TrA/IO), lumbar erector spinae (LES), lumbar multifidus (LM), semitendinosus (ST) and biceps femoris (BF) muscles on dominant side during forward lunge, transverse lunge, sideway lunge and wall squat positions. Participants were asked to hold at end position for 5 seconds 3 repetitions. EMG data in the last 3 seconds were normalized using percentage of maximum voluntary isometric contraction (MVIC) averaged across 3 repetitions. Friedman's analysis of variance was used to compare EMG amplitude among 7 muscles in 4 positions and Wilcoxon signed rank test was used to compare between positions. The p-value less than 0.05 was considered as statistical significance. Results: The highest muscle activation of GMax, GMed and hamstring muscles were found in sideway lunge position. However, sideway lunge position was not significantly different when compared with forward lunge and transverse lunge positions. The lowest muscle activation of LES muscle was found in forward lunge position. For LM muscle, wall squat was greater than forward lunge and transverse lunge, while sideway lunge was greater than transverse lunge. Conclusion: It was suggested that sideway lunge might be the most appropriate position for enhancing gluteal, hamstring and back muscles.

Keywords: EMG, gluteus, back, hamstring, positions

Introduction

The two large gluteal muscles consist of gluteus maximus (GMax) and gluteus medius (GMed). GMax is the largest muscle which attaches perpendicularly to the sacroiliac (SI) joint [1]. Following its attachment, this muscle is the most important hip muscle that contributes to the SI joint stability as a force closure in many daily activities, such as lifting, walking and running [1-3]. While, GMed is the one of important hip abductor muscle which origin on the external iliac surface and inserts on lateral surface of greater trochanter. This muscle plays a role to control pelvic level during leg stance and hip alignment during landing phase [4].

However, gluteal muscles are usually elongated and weak due to seating during the day [3]. Currently, many studies found the weakness of proximal muscles had more impact on daily function compared with distal segments. They suggested the strengthening of gluteal muscles to maintain pelvic level, pelvic tilt, hip abduction and hip external rotation during single leg support. Due to the inability to maintain proper alignment of the pelvis and the femur or the weakness of gluteal muscles about 10 percent can lead to tibial stress fracture, low back pain, iliotibial band friction syndrome, anterior cruciate ligament injury, and patellofemoral pathology. Therefore, the strengthening exercise of gluteal muscles becomes necessary in these patients [5].

GMax muscles and hamstrings muscles (HAM) are the synergists of a muscular force-couple to tilting pelvic posteriorly during hip extension and work eccentrically to decelerate hip flexion at terminal swing phase during loading response [6]. The literature has reported that HAM strains are 12-16% of all injuries in sport. It is possible that weakness of the GMax leading to overuse of HAM. To decreasing the rate of injury, the improving in strength and endurance become necessary [3,7,8].

Lumbar paraspinal muscles are important to make stability during dynamic movements. Lumbar erector spinae muscle (LES) is a global stabilizer muscle. It will increase activity when the local stabilizer, such as lumbar multifidus muscle (LM), is weak or having spinal instability [9]. The excessive LES could cause pain in themselves as pain-spasm-pain and may lead to impinging force on the spine [10-12]. Takaki et al. indicated that during the hip extension position, the contraction of the GMax and transversus abdominis/Internal abdominal oblique (TrA/IO) muscle generates pelvic posterior tilt while the contraction of LES generates pelvic anterior tilt torque [13]. This counteraction can stabilize pelvis during leg lifted. But the dominant muscle activity of LES or the less activation of GMax causes the excessive anterior pelvic tilt during hip extension. While, the LM is not related the pelvic tilt but the improving of LM muscle provides the stability of the pelvis for the GMax and HAM working. In a recent study, the selective activation of the LM and TrA/IO, independent of the other trunk muscles, has been emphasized as the target of exercise interventions at the same time while decrease the activation of LES [14,15].

To strengthen some muscles, Anderson et al. suggested that strengthening adaptation of muscle will be changed when work at least 40 - 60% of participant's maximum voluntary isometric contraction (MVIC) [16]. Following this suggestion, the prone hip extension exercise, which is a common exercise, recruits gluteal muscles about 20% of MVIC that may not enough to strengthen gluteal muscles [17]. Boren et al. studied the exercises for gluteal muscles in many positions. The lunge exercise, weight on one leg, and wall squat, weight on two legs, are the exercises that can activate gluteal muscles more than 40%. In addition, lunge exercises have been divided into three directions, lunge, transverse lunge and sideway lunge. The directional movement of lunge exercise effects on the difference working between GMax and GMed [3].

Several studies found the opened-chain kinetic position has less effective of muscle activity, strength and functional performance than closed-kinetic position [3]. There are the different in muscle recruitment and joint motion between two types. The closed-kinetic chain position of lower extremity has been more similarly in functional daily activities. Second, the proprioceptive feedback was stimulated by compression from body mass in closed-kinetic chain position. Finally, the close kinetic chain position induces more complex intra-muscular and extra-muscular coordination of agonist and antagonist muscles. So, the closed-kinetic chain positions are usually used to strengthening and functional rehabilitation in lower limb. There was no study investigated the activity of gluteal, hamstring, back and abdominal muscles, during performing closed-kinetic chain positions such as forward, transverse, sideway lunges and wall squat.

This study therefore aimed to investigate the muscle activity of these muscles during performing lunge in three directions and wall squat. The purpose of this study was to compare the %MVIC of LES, LM, GMax, GMed, biceps femoris (BF), semitendinosus (ST) and TrA/IO muscles among four positions; lunge, transverse lunge, sideways lunge and wall squat in asymptomatic participants.

Materials and Methods

Eight asymptomatic participants (4 males, 4 females) were recruited. The inclusion criteria were age between 20-30 years, normal lumbar lordosis angle (the normal lumbar angle is 30.75 to 45.57 in females and 18.53 to 34.63 males [18]) and normal Asian body mass index (18.5 - 22.9 kg/m^2) following Table 1. The exclusion criteria were presence of neurological, musculoskeletal, cardiopulmonary or systemic diseases, hip flexion contracture (positive in modified Thomas test), leg length discrepancy (more than 20 mm), regular exerciser (more than active lifestyle I) and history of surgery or serious injury. Prior to the study, the researcher explained all the procedures to the participants. All subjects signed an informed consent form approved by the Mahidol University Central Institutional Review Board (COA No. MU-CIRB 2017/156.2010). Electromyography (EMG) data were collected using a Telemyo 2400 G2 (Noraxon systems, Inc., USA). The electrode sites were shaved and cleansed with rubbing by sand paper and alcohol to prepare the skin (The interelectrode impedance was less than 5 kiloohm [19]). Ag/AgCl surface electrode (Blue sensor, diameter 34 mm and sensor area 13.2 mm^2) were placed parallel to the muscle fibers and interelectrode distance of 2 cm. EMG data were collected for the following muscles of the dominant hip, abdominal and lumbar region side [20]: GMax, GMed, BF, ST, TrA/IO, LM and LES muscles. The sampling frequency was 1000 Hz. CMMR value was >95 dB. The manual muscle testing positions for the MVIC were those recommended by Kendall et al. The participants were performing maximal voluntary contraction following the beep sound for 5 seconds 3 repetitions. The average value of maximum contraction in last 3 of 5 seconds were collected. The proper electrode placements were confirmed during performing maximal voluntary contraction. The participants were randomized in the sequence of four closed-kinetic chain positions: forward lunge, transverse lunge, sideway lunge and wall squat positions by sealed envelope. Participants were asked to hold at end position in each position for 5 seconds 3 repetitions following beep sound and two-minute rest period. The raw data were filtered by Butterworth filter, bandpass 30 to 350 Hz were used. For normalization, the average root mean square (RMS) of 3 trials of last 3 of 5 seconds were calculated into %MVIC for each muscle following this equation [20].

$$\%MVIC = \frac{EMG_{position} - EMG_{rest}}{EMG_{max} - EMG_{rest}} \times 100$$

Table 1 Descriptive characteristics of the participants (n = 8).

Variable	mean±SD
Age (years)	20.75±1.03
Body mass index (kg/m^2)	20.64±1.85
Lumbar lordosis angle ($^\circ$)	32.96±4.71

Results and Discussion

Friedman and Wilcoxon signed rank test were applied to analyze EMG data for comparing the values of dependent variables and pairwise comparisons, respectively.

Figure 1 presents box plots of GMax, GMed, BF, ST, LES, LM and TrA/IO muscle activation among forward lunge, transverse lunge, sideway lunge and wall squat positions. There was a statistically significant difference of GMax, GMed, BF, ST, LES and LM activation among four closed-kinetic chain positions ($\chi^2(3)$ = 14.55 p = 0.02, $\chi^2(3)$ = 16.35 p = 0.01,

$\chi^2(3) = 19.05$ $p < 0.01$, $\chi^2(3) = 16.443$ $p = 0.01$, $\chi^2(3) = 15.45$ $p = 0.01$ and $\chi^2(3) = 14.85$ $p = 0.02$ respectively), while there was no significant difference of TrA/IO activation among lunge in three directions or wall squat ($\chi^2(3) = 7.35$, $p = 0.062$). Post hoc analysis with Wilcoxon signed-rank tests was applied for GMax, GMed, BF, ST, LES and LM activation.

Median (IQR) of GMax activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 13.23 (11.55 to 26.79), 12.81 (9.33 to 16.85), 11.47 (9.78 to 23.28) and 5.08 (4.45 to 12.67) respectively. There were significant differences between transverse lunge and wall squat (p = 0.012), between sideway lunge and wall squat (p = 0.012), and between forward lunge and wall squat (p = 0.012). But there was no statistical significance between forward lunge and sideway lunge (p = 0.327), between forward lunge and transverse lunge (p = 0.401) or between transverse lunge and sideway lunge (p= 0.674).

Median (IQR) of GMed activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 8.02 (5.64 to 13.16), 8.35 (3.90 to 10.64), 7.24 (3.54 to 12.34) and 2.63 (1.24 to 4.25) respectively. There were significant differences between forward lunge and wall squat (p = 0.012), between transverse lunge and wall squat (p = 0.012), and between sideway lunge and wall squat (p = 0.012). But there was no statistical significance between forward lunge and transverse lunge (p = 0.161), between forward lunge and sideway lunge (p = 0.208) or between transverse lunge and sideway lunge (p= 1.000).

Median (IQR) of ST activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 15.04 (8.25 to 18.83), 14.10 (7.63 to 20.00), 12.87 (9.19 to 25.22) and 6.79 (4.08 to 9.32) respectively. There were significant differences between forward lunge and wall squat (p = 0.012), between transverse lunge and wall squat (p = 0.012), and between sideway lunge and wall squat (p = 0.012). But there was no statistical significance between transverse lunge and sideway lunge (p= 0.123), between forward lunge and sideway lunge (p = 0.401) or between forward lunge and transverse lunge (p = 0.866).

Median (IQR) of BF activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 12.26 (10.48 to 41.51), 12.26 (10.36 to 44.73), 16.35 (12.73 to 52.94) and 8.31 (6.72 to 27.30) respectively. There were significant differences between forward lunge and wall squat (p = 0.012), between transverse lunge and wall squat (p = 0.012), and between sideway lunge and wall squat (p = 0.012). But there was no statistical significance between forward lunge and sideway lunge (p = 0.069), between transverse lunge and sideway lunge (p= 0.093) or between forward lunge and transverse lunge (p = 0.123). Median (IQR) of LES activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 9.26 (5.24 to 15.18), 18.40 (7.58 to 24.05), 31.64 (24.14 to 35.75) and 26.62 (23.20 to 27.98) respectively. There were significant differences between forward lunge and sideway lunge (p= 0.012), between forward lunge and transverse lunge (p = 0.017), between forward lunge and wall squat (p = 0.017), between transverse lunge and sideway lunge (p = 0.017) and between transverse lunge and wall squat (p = 0.025). But there was no statistical significance between sideway lunge and wall squat (p = 0.05).

Median (IQR) of LM activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 22.83 (13.38 to 27.29), 21.16 (11.82 to 27.90), 29.33 (17.86 to 31.55) and 29.32 (25.36 to 40.44) respectively. There were significant differences between forward lunge and wall squat (p= 0.012), between transverse lunge and wall squat (p = 0.012), between transverse lunge and sideway lunge (p = 0.036). But was no statistical significance between forward lunge and sideway lunge (p = 0.069) between forward lunge and transverse lunge (p = 0.208) or between sideway lunge and wall squat (p = 0.263).

Median (IQR) of TrA/IO activation in forward lunge, transverse lunge, sideway lunge and wall squat positions were 12.83 (8.73 to 16.41), 13.26 (5.95 to 17.59), 18.99 (6.74 to 23.71) and 8.66 (5.62 to 14.17), respectively.

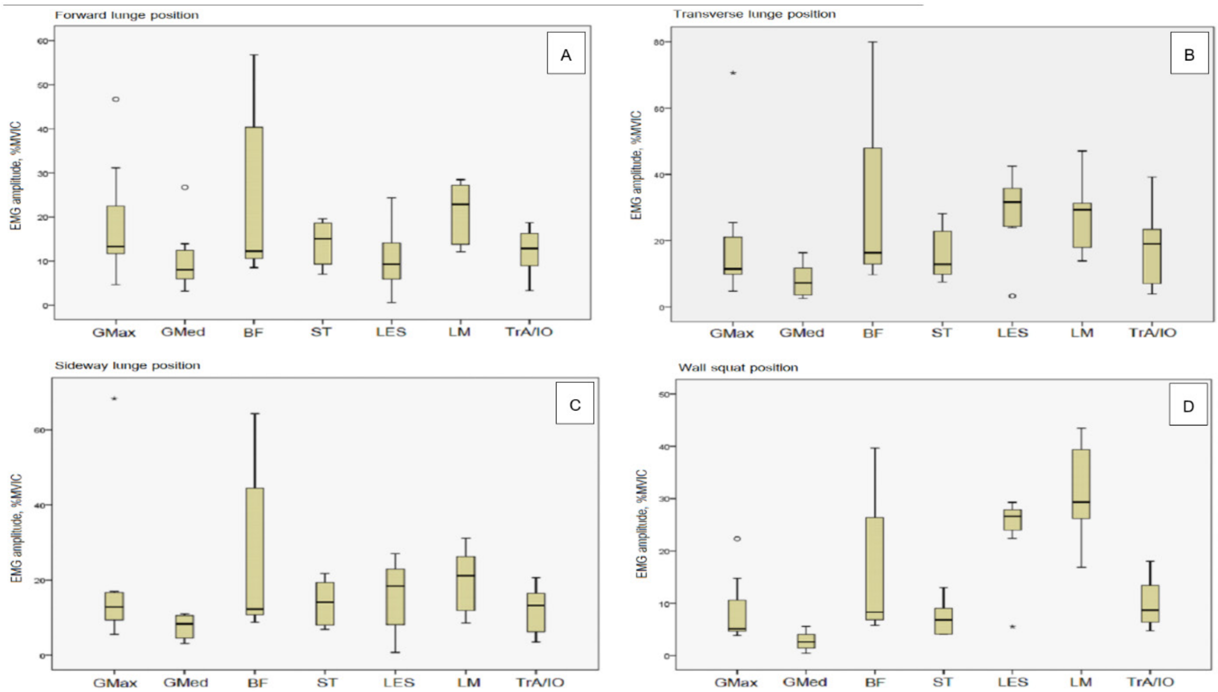

Figure 1 Box plots of GMax, GMed, BF, ST, LES, LM and TrA/IO muscle activation among (A) forward lunge, (B) transverse lunge, (C) sideway lunge and (D) wall squat positions. The dots and star represent outliers. Abbreviations: EMG, electromyography; MVIC, maximum voluntary isometric contraction; GMax, gluteus maximus; GMed, gluteus medius; BF, biceps femoris; ST, semitendinosus; LES, lumbar erector spinae; LM, lumbar multifidus; TrA/IO, transversus abdominis/internal abdominal oblique.

Hip extension and knee flexion exercises are often used in rehabilitation for individuals with hip, knee and lumbar spine pathologies. However, these two exercises are related with lumbar hyperextension, lumbar rotation and anterior tilting of the pelvis during hip extension exercises performed in prone position. Moreover, the deficit of abdominal control and dominant muscle activity of the LES may contribute to excessive anterior pelvic tilt during hip extension in prone position. While, knee flexion or hamstring curl can produce shear force. The stress to knee joint and the anterior cruciate ligament is more likely to be resulted in injury. Therefore, this study was chosen only closed-kinetic chain exercise. However, no study has investigated the muscle activation of GMax, GMed, LES, LM TrA/IO, ST and BF during performing forward lunge, transverse lunge, sideway lunge and wall squat positions.

From previous study, they reported that hyperlordosis of lumbar was correlated with the activation of GMax, Hamstring, LM and LES muscle activation. So, our study controlled the lordotic angle of lumbar which all participants had a normal lumbar lordosis while lumbar hyperlordosis was excluded.

The result showed the lunge exercise in three directions are the most activation in gluteal and hamstring muscles when compared with wall squat because of single leg weight bearing. While the wall squat position is a double leg weight bearing. There is a lack of study of back and abdominal muscles activation in forward lunge, transverse lunge, sideway lunge and wall squat position. This study found that lunge in three directions, forward lunge was the least activation of LES activation due to neutral position of spine. Unlike sideway lunge which had trunk bent forward, so more activations of back muscles were evident. Moreover, wall squat position was higher activated of LM muscle rather than forward lunge and transverse lunge. It was possible that this position had to activate back muscles against the wall. For TrA/IO muscle activations, there were no difference among 4 positions. These four positions were in trunk upright which abdominal muscles were needed slightly.

In this study, the %MVIC of lunge in 3 directions and wall squat were less than the previous study (21). This difference might be due to the previous study investigated in the first 3 seconds after heel contact the floor, which are the gluteal and hamstring muscles contracted eccentrically. Contrast in this study, which determined in the last 3 seconds at ending position, which the muscles were in isometric contraction.

There were some limitations in this study. First, our results could not be generalized to other populations because all the participants in the study were healthy young individuals. Therefore, the differences in muscle activity among four positions should not be confirmed in symptomatic individuals or athletes. Second, our study design aimed to measure muscle activity in static position which would limit the interpretation of muscle activation during dynamic control.

Conclusions

This study examined the EMG signal amplitude of the GMax, GMed, LES, LM, TrA/IO, ST and BF muscles during performing lunge in three directions or wall squat positions. The results indicated that lunge in three directions had similar magnitude of activation of gluteal and hamstring muscles that were considerably suitable for strengthening purposes. However, sideway lunge was also shown high activations in both LM and LES muscles, while forward lunge position found the lowest activation in LES muscle. Wall squat had the lowest in gluteal and hamstring muscles activation but high activation in LM and LES muscles. Therefore, wall squat could be prescribed if back muscles strengthening program is considered.

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