Effects of Different Hip Rotations on Gluteus Medius and Tensor Fasciae Latae Muscle Activity During Isometric Side-Lying Hip Abduction

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Context: Gluteus medius (Gmed) weakness is associated with some lower-extremity injuries, including iliotibial band friction syndrome and patellofemoral pain syndrome.1-5 Thus, clinicians use several hip-abduction-strengthening exercises such as side-lying hip abduction (SHA), single-leg stance, lateral band walk, and sideways hop exercises.6,7 Among many Gmed-strengthening exercises, a standard SHA exercise has been advocated, because this exercise can be performed early in the rehabilitation program to generate proper neuromuscular control and strength as an open-chain exercise; later, the exercise can progress to more functional exercises such as single-leg-stance exercises.7,8 Synergistic muscles such as the quadratus lumborum9 and tensor fasciae latae (TFL)8 may be activated during SHA. A previous study10 demonstrated that use of a pressure biofeedback unit (Chattanooga Group, Inc, Hixson, TN) during SHA could decrease quadratus lumborum activity and increase Gmed activity. However, there is no reported method to avoid excessive TFL muscle activity.

Objectives: To compare Gmed and TFL muscle activity and the Gmed:TFL muscle-activity ratio during SHA exercise with 3 different hip rotations. Design: The effects of different hip rotations on Gmed, TFL, and the Gmed:TFL muscle-activity ratio during isometric SHA were analyzed with 1-way, repeated-measures analysis of variance. Setting: University research laboratory. Participants: 20 healthy university students were recruited in this study. Interventions: Participants performed isometric SHA: frontal SHA with neutral hip (frontal SHA-N), frontal SHA with hip medial rotation (frontal SHA-MR), and frontal SHA with hip lateral rotation (frontal SHA-LR). Main Outcome Measures: Surface electromyography measured the activity of the Gmed and the TFL. A 1-way repeated-measures analysis of variance assessed the statistical significance of Gmed and TFL muscle activity. When there was a significant difference, a Bonferroni adjustment was performed. Results: Frontal SHA-MR showed significantly greater Gmed muscle activation than frontal SHA-N (P = .000) or frontal SHA-LR (P = .015). Frontal SHA-LR showed significantly greater TFL muscle activation than frontal SHA-N (P = .002). Frontal SHA-MR also resulted in a significantly greater Gmed:TFL muscle-activity ratio than frontal SHA-N (P = .004) or frontal SHA-LR (P = .000), and frontal SHA-N was significantly greater than frontal SHA-LR (P = .000). Conclusions: Frontal SHA-MR results in greater Gmed muscle activation and a higher Gmed:TFL muscle ratio.

Keywords: hip abductor, surface electromyography, synergistic muscles, frontal-plane exercise

Gluteus medius (Gmed) weakness is associated with some lower-extremity injuries, including iliotibial band friction syndrome and patellofemoral pain syndrome.1-5 Thus, clinicians use several hip-abduction-strengthening exercises such as side-lying hip abduction (SHA), single-leg stance, lateral band walk, and sideways hop exercises.6,7 Among many Gmed-strengthening exercises, a standard SHA exercise has been advocated, because this exercise can be performed early in the rehabilitation program to generate proper neuromuscular control and strength as an open-chain exercise; later, the exercise can progress to more functional exercises such as single-leg-stance exercises.7,8 Synergistic muscles such as the quadratus lumborum9 and tensor fasciae latae (TFL)8 may be activated during SHA. A previous study10 demonstrated that use of a pressure biofeedback unit (Chattanooga Group, Inc, Hixson, TN) during SHA could decrease quadratus lumborum activity and increase Gmed activity. However, there is no reported method to avoid excessive TFL muscle activity.

People with Gmed weakness may compensate by activating the TFL to perform SHA.9,11 When the TFL is activated to compensate for a weak Gmed, the TFL may become dominant, compared with the Gmed, from repeated use. A dominant TFL can contribute to pain in the hips, in the lower back, and in the lateral area of the knees.1,11 In particular, the posterior fibers of the Gmed manage excessive internal hip rotation and abduction during walking or running, according to a person’s gait.12,13 However, the TFL is an internal rotator and abductor of the hip. Consequently, when excessive internal rotation occurs in a gait or movement pattern, the TFL may become dominant as a hip abductor.5 Excessive TFL activation can also exert a lateral force on the patella,14,15 which has been related to patellofemoral pain syndrome.16 In particular, during SHA, a dominant TFL can cause the hip to flex relative to the frontal plane. There is currently no way to assess for TFL dominance; even dominant TFL could influence lower-extremity injuries. The shortness test of the iliotibial band would only be used for assuming TFL dominance.

A previous study17 investigated SHA during hip lateral rotation (LR), with the rationale that having the hip laterally rotated would activate the Gmed and minimize
the TFL, which is a medial rotator. However, the results contradicted the rationale; TFL muscle activity increased, whereas Gmed muscle activity decreased in SHA with the hip laterally rotated. TFL muscle activity increased because the SHA position, with the hip laterally rotated, pulls the hip into extension and places the TFL line of action in a more anterior position to the hip joint center, compared with that of the Gmed. Thus, the TFL might contract more against gravity than the Gmed during SHA with LR of the hip. There appear to be no studies on the effect of hip medial rotation (MR) on Gmed and TFL activation during SHA. Therefore, examination of Gmed and TFL activation with hip MR during SHA will provide valuable, new information.

The purpose of this research was to determine the effects of different hip rotations in the transverse plane on Gmed and TFL muscle activity during isometric SHA by using a pressure biofeedback unit to investigate both the muscle activity and the Gmed:TFL muscle-activity ratio: frontal SHA with neutral hip (frontal SHA-N), frontal SHA with hip MR (frontal SHA-MR), and frontal SHA with hip LR (frontal SHA-LR). The hypothesis was that Gmed muscle activity would increase, that TFL muscle activity would decrease, and that the Gmed:TFL muscle-activity ratio would be greater in frontal SHA-MR than with the other exercises.

**Methods**

**Design**

Participants attended a 1-hour testing session at the university. Frontal SHA exercise (with N, MR, and LR) and muscles (Gmed, TFL) were the independent variables, and surface electromyography (EMG) was the dependent variable.

**Participants**

G-power software provided power analyses. A necessary sample size of 7 participants was calculated from data obtained from a pilot study of 7 participants to achieve a power of .80 and an effect size of 0.51 (calculated by partial η² of .207 from the pilot study), with an α level of .05. The current study had 20 participants. Table 1 presents information about the participants. A soccer-ball-kicking exercise established the dominant leg for each participant.

Participants had to be between 18 and 30 years of age, free from past or current inflammatory arthritis or lower-extremity and back dysfunction, and able to maintain 5 seconds of isometric SHA. Exclusion criteria included past or present musculoskeletal, neurological, or cardiopulmonary diseases that could interfere with SHA. In addition, shortness of the iliotibial band was excluded by the modified Ober test. In this test, a normal iliotibial band stretches when the hip adducts beyond 10°. If the iliotibial band is short, it does not allow the test leg to drop toward the table beyond 10°. Overweight or obese candidates were excluded because fatty tissue acts as a low-pass filter for electrical signals. The terms *overweight* and *obesity* were defined as having a body-mass index >25. The study protocol was approved by the local university human studies committee. Before the study, participants read and signed a written consent form.

**Instrumentation**

A Tele-Myo DTS EMG instrument with a wireless telemetry system (Noraxon, Inc, Scottsdale, AZ, USA) collected EMG data. The sampling rate was 1000 Hz. A digital band-pass filter (Lancosh FIR), between 20 and 450 Hz, filtered the raw signals. Root-mean-square values were calculated with a moving window of 50 milliseconds, and Myo-Research Master Edition 1.06 XP software analyzed the EMG data.

**Procedures**

Before testing, participants jogged around a gym for 5 minutes at a submaximal speed to warm up and to reduce possible discomfort while performing SHA exercises. The pressure biofeedback unit was placed between the treatment table and the participant’s lumbar spine in the side-lying position. The pressure biofeedback unit provides visual feedback to prevent unwanted changes in body position during SHA exercises; used effectively, it can decrease substitution from the quadratus lumborum, increase activity of the Gmed, and prevent excessive lateral tilt of the lumbopelvic region in the frontal plane. Familiarization was necessary, however, because participants were unfamiliar with using a pressure biofeedback unit during SHA exercises. The principal investigator (J.H.L.) instructed participants on its use with consistent verbal cues. Participants had to observe the analog gauge of the pressure biofeedback unit to maintain the determined target pressure during hip abduction. The pressure biofeedback unit was inflated until the pressure reached 40 mmHg, and then the participant and the principal investigator (J.H.L.) monitored pressure changes during the SHA exercises to ensure that pressure was maintained between 35 and 45 mmHg. Pressure changes of 5 mmHg from the target pressure were allowed to accommodate changes induced by breathing. Each participant was pain free and comfortable with use of the pressure biofeedback unit after the familiarization period.

### Table 1 Participant Characteristics, Mean (SD), N = 20

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>22.3 (1.9)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>168.7 (7.2)</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>65.5 (12.4)</td>
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<td>Body-mass index, kg/m²</td>
<td>22.9 (3.1)</td>
</tr>
<tr>
<td>Hip-abduction passive range of motion, °</td>
<td>29.8 (5.1)</td>
</tr>
</tbody>
</table>
Frontal SHA-N. For frontal SHA-N, Participants were positioned side-lying on the treatment table; the upper trunk and pelvis were aligned in a straight line. The bottom-side leg could be flexed at both the hip and knee joints for comfort and stability. The participant was asked to keep the pelvis neutral in the sagittal and horizontal planes by full contact against the wall; the principal investigator (J.H.L.) monitored this visually. A wooden target bar was placed at 50% of the hip abduction’s maximal range of motion, accommodating the range of motion of each participant. Thus, the test leg was abducted to 50% of the maximal range of motion with knee extension until the lateral aspect of the distal tibia (above the lateral malleolus) touched the target bar, maintained in the position for 5 seconds, and then slowly returned to the starting position. The target pressure on the pressure biofeedback unit was monitored during this 5-second period. The participant was instructed to contact the posterior heel on the wall and to abduct the hip of the test leg so that the posterior heel slid up the wall to ensure SHA in the frontal plane (Figure 1). If the posterior heel lost contact with the wall during frontal SHA-N, the data were discarded. The participants were not allowed to try again.

Frontal SHA-MR. Frontal SHA-MR was performed in the same way as frontal SHA-N, except that the hip joint was in MR. Participants were instructed to rotate the hip of the test leg medially and to point the toes and patella comfortably as far downward as possible. The principal investigator (J.H.L.) palpated the greater trochanter of the test leg to confirm hip MR. The participant was asked to slide the medioposterior heel against the wall while performing frontal SHA-MR until the posterolateral aspect of the distal tibia (above the lateral malleolus) touched the target bar. If the medioposterior heel lost contact with the wall during frontal SHA-MR, the data were discarded (Figure 2).

Frontal SHA-LR. Frontal SHA-LR was performed in the same way as the frontal SHA-N, except that the hip joint was in LR. Participants were instructed to rotate the hip of the test leg laterally and to point their toes and patella comfortably as far upward as possible. The principal investigator (J.H.L.) palpated the greater trochanter of the test leg to confirm hip LR of the test leg. The participant was asked to slide the lateroposterior heel against the wall while performing frontal SHA-LR until the anterolateral aspect of the distal tibia (above the lateral malleolus) touched the target bar. If the lateroposterior heel lost contact with the wall during frontal SHA-LR, the data were discarded (Figure 3).

EMG Data Collection. Electrodes were placed over the midsection of the muscle bellies, as in previous research evaluating the gluteal muscles and detailed by Rainoldi et al. For the Gmed muscle, electrodes were placed directly superior to the greater trochanter of the femur, one-third of the distance between the iliac crest and the greater trochanter of the femur. For the TFL muscle, electrodes were placed 2 cm inferior, and slightly lateral, to the anterosuperior iliac spine. Electrode sites were prepared by shaving hair from the immediate vicinity of the muscle belly and cleansing the skin with isopropyl alcohol applied with a sterile gauze pad to reduce impedance to the EMG signal and to allow for proper electrode fixation. Proper placement of the electrodes was confirmed by viewing the participants completing 5 repetitions of SHA. Electrode contacts were checked before all contractions.

Maximal voluntary isometric contraction (MVIC) in the standard manual-muscle-test position was used for normalization of the Gmed and the TFL. Participants performed for 5 seconds at MVIC with a 10-second...
rest between contractions and a 3-minute rest between muscles tested. To obtain the MVIC for the Gmed, participants lay on their sides with the test leg up and the bottom hip and knee flexed for stabilization. The test leg was abducted to approximately 50% of hip abduction, and the hip was positioned in slight extension and LR. An investigator applied a downward force at the ankle while stabilizing the hip with the other hand. To obtain MVIC values for the TFL, the participants lay supine with the hip flexed and medially rotated maximally with the knee extended. The investigator applied force at the ankle in the direction of hip extension. Investigators measured the MVIC for Gmed and TFL muscles twice and used the mean value from the 2 trials for data analysis. The collected EMG amplitudes for Gmed and TFL muscles during each exercise were expressed as a percentage of the mean MVIC (%MVIC).

Data on the muscle activity of the Gmed and the TFL were collected during the SHA exercises in the frontal plane (SHA-N, SHA-MR, and SHA-LR) in randomized order by drawing lots, as exercise order may be associated with learning effects or fatigue. Each SHA was performed at a comfortable speed. EMG data were collected for 5 seconds during the isometric phase and were calculated from the average of the middle 3 seconds of each exercise to reduce any starting or ending effect or skin–electrode connecting element.22,26 Participants performed 3 trials under each SHA condition, with a 3-minute rest between exercises.27 The mean value was used for data analysis.28

Statistical Analysis

PASW Statistics 18 software (SPSS, Chicago, IL) was used to perform all statistical analyses. Kolmogorov–Smirnov Z-tests were performed to assess the normality of the distribution. A 1-way, repeated-measures analysis of variance was used to assess the statistical significance of Gmed and TFL muscle activity and the Gmed:TFL muscle-activity ratio during SHA exercises with different hip rotations (frontal SHA-N, frontal SHA-MR, frontal SHA-LR). Statistical significance was set at .05. If a significant difference was found, a Bonferroni adjustment was performed (with $\alpha = .05/3 = .017$). The effect size was calculated using the pooled standard deviation.

Results

Gmed and TFL Muscle Activity

The results indicated significant differences among hip-abduction exercises for Gmed activity ($F_{2,29} = 11.452, P = .000$, effect size = 0.888), TFL activity ($F_{2,29} = 6.117, P = .006$, effect size = 0.650), and Gmed:TFL muscle-activity ratio ($F_{2,29} = 10.517, P = .000$, effect size = 0.851). Frontal SHA-MR showed significantly greater Gmed muscle activation than did frontal SHA-N (MVIC, $P = .000$, effect size = 0.664) and frontal SHA-LR ($P = .015$, effect size = 0.467; Figure 4). Frontal SHA-LR showed significantly greater TFL muscle activation than did frontal SHA-N ($P = .002$, effect size = 0.623; Figure 4).

Figure 4 — Comparison of muscle activity in the gluteus medius and the tensor fasciae latae among different hip rotations during side-lying hip-abduction (SHA) exercises. Abbreviations: SHA-N, SHA with neutral hip; SHA-MR, SHA with hip medial rotation; SHA-LR, SHA with hip lateral rotation. *Significant difference by Bonferroni adjustment ($P < .017$).
Gluteus Medius and Tensor Fasciae Latae Activation

Gmed:TFL Muscle-Activity Ratio

The Gmed:TFL muscle-activity ratio was significantly greater for frontal SHA-MR than for frontal SHA-N ($P = .004$, effect size = 0.526) and for frontal SHA-LR ($P = .000$, effect size = 0.881), and it was significantly greater for frontal SHA-N than for frontal SHA-LR ($P = .001$, effect size = 0.704; Table 2, Figure 5).

Discussion

The purpose of this study was to investigate whether Gmed and TFL muscle activity and Gmed:TFL muscle-activity ratio would be different with respect to different hip rotations in the transverse plane (frontal SHA-N, frontal SHA-MR, and frontal SHA-LR) during SHA exercises. The Gmed is important as an abductor in the frontal plane,29,30 and it has a role as a hip medial rotator.31 To our knowledge, this is the first study to investigate and report the effects of the SHA-MR position on the muscle activity of the Gmed and TFL and the Gmed:TFL muscle-activity ratio during isometric SHA.

Gmed muscle activity was significantly greater in frontal SHA-MR than in frontal SHA-N (by 11.1%) and frontal SHA-LR (by 10.0%). These findings support the research hypothesis and agree with previous studies.30–32 Earl30 showed that hip abduction with MR exercise was significantly greater than hip abduction with LR exercise in Gmed muscle activity during single-leg stance. Schmitz et al32 also demonstrated that Gmed activation increased when external hip-rotation forces were increased, so they suggested that the Gmed was important as an internal rotor of the hip. In addition, O’Dwyer et al31 reported that anterior Gmed subdivision activity increased during hip abduction in the standing position and during MR in the prone position, although direct comparison of the finding to the current study is limited because the current study investigated the activity of the Gmed using only 1 set of electrodes, placed over the middle Gmed. TFL muscle activity was significantly greater in frontal SHA-LR than in frontal SHA-N (13.0%). TFL muscle activity in frontal SHA-LR was also greater, by 10.8%, than in frontal SHA-MR; however, this difference was not statistically significant. These findings did not support our research hypothesis that TFL muscle activity would decrease in frontal SHA-MR compared with the other hip positions during the SHA exercise examined. However, the findings revealed that frontal SHA-LR increased TFL muscle activity significantly compared with frontal SHA-N. McBeth et al8 compared Gmed and TFL muscle activity during hip abduction with LR and showed that Gmed muscle activity (53.0% ± 28.4% MVIC) was significantly less than TFL activity (70.9% ± 17.2% MVIC). The authors of that previous study used the concept of gravity in relation to the hip joint to explain the results; placing the hip joint in external rotation activated the TFL because gravity on the lower extremity would draw the hip joint into extension, challenging the TFL to sustain a neutral position. The position difference of the hip joint in the frontal SHA-MR, compared with

![Figure 5 — Comparison of muscle-activity ratio in the gluteus medius (Gmed) and the tensor fasciae latae (TFL) among different hip rotations during side-lying hip abduction (SHA) exercises. Abbreviations: SHA-N, SHA with neutral hip; SHA-MR, SHA with hip medial rotation; SHA-LR, SHA with hip lateral rotation. *Significant difference by Bonferroni adjustment ($P < .017$).]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frontal SHA-N</th>
<th>Frontal SHA-MR</th>
<th>Frontal SHA-LR</th>
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<tr>
<td>Gluteus medius</td>
<td>34.2 (11.8)a</td>
<td>45.3 (20.5)</td>
<td>35.3 (12.5)</td>
</tr>
<tr>
<td>Tensor fasciae latae</td>
<td>30.4 (20.0)</td>
<td>32.6 (24.5)</td>
<td>43.4 (16.6)</td>
</tr>
<tr>
<td>Gluteus medius:tensor fasciae latae ratio</td>
<td>1.6 (1.1)</td>
<td>2.0 (1.3)</td>
<td>0.9 (0.4)</td>
</tr>
</tbody>
</table>

Abbreviations: SHA-N, SHA with neutral hip; SHA-MR, SHA with hip medial rotation; SHA-LR, SHA with hip lateral rotation.

a Percentage of average maximal voluntary isometric contraction.
other exercises, may also explain the increased Gmed muscle activation in the current study. The possible mechanism for this finding may be that the Gmed was placed on the highest position in the cross-section (ie, in the transverse plane) of the upper thigh when isometric SHA-MR was maintained. Thus, the Gmed was in a favorable position to be activated to sustain isometric SHA-MR and to counterbalance the downward pull of gravity. Another mechanism for the finding could be that the Gmed counters the anterior roll of the pelvis in the transverse plane while maintaining frontal SHA-MR.

Frontal SHA-MR significantly increased the Gmed:TFL muscle-activity ratio, by 20% and 55%, respectively, compared with frontal SHA-N and frontal SHA-LR. Frontal SHA-N also significantly increased this ratio by 44% compared with frontal SHA-LR. These Gmed:TFL muscle-activity-ratio results support the research hypothesis and favor frontal SHA-MR over frontal SHA-N and frontal SHA-LR. Because no previous study has reported measurement of the Gmed:TFL activity ratio during SHA with different hip rotations, comparison of the results of this study with other work is impossible. However, by presenting the muscle-activity ratio of the Gmed to the TFL during SHA, this study demonstrates that frontal SHA-MR is the best exercise among the 3 frontal-SHA exercises for increasing the Gmed:TFL muscle-activity ratio. Reporting relative muscle activity rather than the absolute activity is advantageous because synergistic muscles work simultaneously and influence each other throughout movement.33,34 In particular, if the activity of 1 muscle decreases, the activity of the other increases to complete the same range of motion.35,36

However, this study has some limitations. First, generalizability is limited because healthy, young participants were recruited. The results might have been different if the study had employed participants with patellofemoral pain syndrome or iliotibial band syndrome or who had weak Gmeds and/or dominant TFLs. Second, this study was a cross-sectional study, so long-term effects of frontal SHA-MR cannot be determined. Third, crosstalk might have occurred between Gmed and TFL muscles, although the study took all precautions to maximize the reliability of the EMG signal. Fourth, although medial and lateral rotations of the test hip joint were ensured by palpation of the greater trochanter before SHA, and frontal plane SHA was validated by contact of the heel against the wall during SHA, kinematic data would have been preferable for confirmation of hip-joint position during frontal-plane SHA. Fifth, this study used the manual-muscle-test position for MVIC, as in a previous study.8 The manual-muscle-test position was similar to the SHA-MR for the TFL and the SHA-LR for the Gmed, respectively. Thus, the similarity of the manual-muscle-test position could have influenced the %MVIC measurements. Further studies should investigate the long-term effects of frontal SHA-MR on Gmed and TFL activity in participants with Gmed weakness and/or TFL dominance.

Conclusion

This study focused on investigating the effects of different hip rotations in the transverse plane on Gmed and TFL muscle activity and on the Gmed:TFL muscle-activity ratio during frontal-SHA exercise with a pressure biofeedback unit. Gmed muscle activity was significantly greater in frontal SHA-MR than in frontal SHA-N and frontal SHA-LR, and TFL muscle activity was significantly greater in frontal SHA-LR than in frontal SHA-N. The Gmed:TFL activity ratios in frontal SHA-MR were significantly greater than those in frontal SHA-N and frontal SHA-LR. Thus, frontal SHA-MR is the best exercise, among the 3 frontal-SHA exercises, for greater Gmed muscle activation and higher Gmed:TFL muscle-activity ratio.

Acknowledgments

The study protocol was approved by the institutional review board of Yonsei University Wonju Campus Human Studies Committee. All participants gave written informed consent before data collection began.

References

10. Cynn HS, Oh JS, Kwon OY, Yi CH. Effects of lumbar stabilization using a pressure biofeedback unit on muscle