Journal of Sport Rehabilitation, 2021, 30, 754-759
https://doi.org/10.1123/jsr.2020-0031

Human Kinetics
ORIGINAL RESEARCH REPORT

Electromyographic Analysis of Hip and Trunk Muscle Activity During Side Bridge Exercises in Subjects With Gluteus Medius Weakness

Kyung-eun Lee, Seung-min Baik, Chung-hwi Yi, Oh-yun Kwon, and Heon-seock Cynn

Context: Side bridge exercises strengthen the hip, trunk, and abdominal muscles and challenge the trunk muscles without the high lumbar compression associated with trunk extension or curls. Previous research using electromyography (EMG) reports that performance of the side bridge exercise highly activates the gluteus medius (Gmed). However, to the best of our knowledge, no previous research has investigated EMG amplitude in the hip and trunk muscles during side bridge exercise in subjects with Gmed weakness. ***Objective:*** The purpose of this study was to examine the EMG activity of the hip and trunk muscles during 3 variations of the side bridge exercise (side bridge, side bridge with knee flexion, and side bridge with knee flexion and hip abduction of the top leg) in subjects with Gmed weakness. ***Design:*** Repeated-measures experimental design. ***Setting:*** Research laboratory. ***Patients:*** Thirty subjects (15 females and 15 males) with Gmed weakness participated in this study. ***Intervention:*** Each subject performed 3 variations of the side bridge exercise in random order. ***Main Outcome Measures:*** Surface EMG was used to measure the muscle activities of the rectus abdominis, external oblique, longissimus thoracis, multifidus, Gmed, gluteus maximus, and tensor fasciae latae (TFL), and Gmed/TFL muscle activity ratio during 3 variations of the side bridge exercise. ***Results:*** There were significant differences in Gmed ($F_{2,56} = 110.054$, $P < .001$), gluteus maximus ($F_{2,56} = 36.416$, $P < .001$), and TFL ($F_{2,56} = 108.342$, $P < .001$) muscles among the 3 side bridge exercises. There were significant differences in the Gmed/TFL muscle ratio ($F_{2,56} = 20.738$, $P < .001$). ***Conclusion:*** Among 3 side bridge exercises, the side bridge with knee flexion may be effective for the individuals with Gmed weakness among 3 side bridge exercises to strengthen the gluteal muscles, considering the difficulty of the exercise and relative contribution of Gmed and TFL.

Keywords: electromyography, muscle activity, stabilization, weakness

Gluteal muscle strength and endurance are important for injury prevention, normalizing gait pattern and posture, reducing pain, and building up athletic performance.[1,2] The gluteus medius (Gmed) plays a role in maintaining a level of the pelvis and preventing hip adduction during single-limb support. In particular, the posterior fibers of the Gmed contribute to preventing femoral internal rotation during single-limb support.[1,3] Lateral hip pain, knee osteoarthritis, patellofemoral pain, and chronic lower back pain may occur in subjects with Gmed weakness.[4,5]

Previous research using electromyography (EMG) has reported that the side bridge exercise highly activates the Gmed.[6,7] Side bridge exercises strengthen the hip and trunk muscles and challenge the trunk muscles without the high lumbar compression associated with trunk extension or curls.[8,9] Many studies examined the effect of side bridge exercises on hip and trunk muscle activity in patients with various conditions.[6,7,10,11] Boren et al[10] reported that the side bridge exercise with hip abduction showed the highest percentage of maximal voluntary isometric contraction (%MVIC) for Gmed activation (103% MVIC) in healthy subjects. However, the side bridge exercise with hip abduction is very challenging, and it is important to consider the functional demands and dosage when selecting exercises for muscle training and strengthening. Youdas et al[9] quantified the EMG activity of rectus abdominis (RA), external oblique (EO), lumbar multifidus (MF), longissimus thoracis (LgT), and Gmed to understand the activation of trunk and hip muscles during side bridge exercises to facilitate clinical decision making. According to the role in stabilization exercises, the trunk muscles could be divided into local and global muscles.[12] The MF, local muscles, are directly attached to the lumbar vertebrae and provide segmental stability of the lumbar spine.[13] The LgT, RA, and EO, global muscles, produce the large torque across multiple segments and act as a prime mover of the trunk.[13] McGill and Karpowicz[11] examined the muscle activity of the RA, EO, and erector spinae to quantify the degree of difficulty of the various side bridge exercises and provide guidance for clinical application. They also reported that the side bridge exercise with knee flexion decreased trunk muscle activity, making it less challenging.

People with Gmed weakness often compensate by using tensor fasciae latae (TFL) as a hip abductor muscle to a greater extent. This may result in hypertonicity and tightness in the iliotibial band.[14] Overactive TFL can cause patella lateral tilt and translation through the connection with the iliotibial band. This movement may lead to lateral knee pain and patellofemoral maltracking.[15] As such, considering the relative contribution of the TFL and Gmed to the side bridge exercise is clinically important, particularly in subjects with Gmed weakness.

To the best of our knowledge, no previous research has investigated EMG amplitude in hip and trunk muscles during side bridge exercise in subjects with Gmed weakness. Therefore, the purpose of this study was to investigate change in EMG activity in the RA, EO, LgT, MF, Gmed, gluteus maximus (Gmax), and TFL, and Gmed/TFL muscle activity ratio during 3 side bridge exercises (side bridge [SB], side bridge with knee flexion [SBK], and side bridge with knee flexion and hip abduction of the top leg [SBKH]) in subjects with Gmed weakness. It was hypothesized

Lee and Baik are with the Department of Physical Therapy, The Graduate School, Yonsei University, Seoul, South Korea. Yi, Kwon, and Cynn are with the Department of Physical Therapy, College of Health Science, Yonsei University, Wonju, Gangwon, South Korea. Yi (pteagle@yonsei.ac.kr) is corresponding author.

that the EMG activity of the Gmed, Gmax, and TFL muscles would be increased in SBKH compared with SB and SBK; the activity of RA, EO, LgT, and MF muscles would be increased in SBKH and decreased in SBK compared with SB.

Method

Subjects

G*Power software (version 3.0.10; Franz Faul, University of Kiel, Kiel, Germany) was used to calculate the sample size ($\alpha = .05$, power = 0.8, effect size [ES] = 0.25) of 28. Thirty subjects with Gmed weakness participated in this study (age = 23.76 [2.42] y, height = 168.30 [7.65], mass = 62.45 [14.03], 15 females, 15 males). Subjects were between 18 and 40 years of age. Inclusion criteria required that the subject be able to perform the SB exercises without pain. The exclusion criteria were a history of spinal dislocation or fracture, shoulder tendinopathy, bursitis, impingement, adhesive capsulitis, or acute lower back pain and current neuromuscular pain, numbness, or tingling of the lower extremities or back.[9] Gmed weakness was detected using the manual muscle test.[16] Subjects were positioned in the side-lying position on a table. The lower leg was flexed for stability and comfort, and the test-side leg (upper leg) was aligned with the trunk. The test-side leg was abducted at the hip to 50% of full range of motion. The investigator's hand was placed 10 cm proximal to the lateral femoral epicondyle of the test-side leg. The subject performed an isometric hold for 5 seconds against resistance to downward force. The investigator provided verbal commands to facilitate maximal performance and to avoid hip flexion, hip medial rotation, or pelvic hiking of the test-side leg by recruitment of the TFL or quadratus lumborum. Muscle strength was graded as 0 to 5 by manual muscle testing. A grade of 3 or less was defined as Gmed weakness. If Gmed weakness was bilateral, the weaker side was the test side in this study. The Yonsei University Wonju Institutional Review Board approved the protocol for this study, and each subject gave informed consent prior to participation.

Instrumentation

Surface EMG. Surface EMG data were collected from Noraxon TeleMyo DTS (Noraxon Inc, Scottsdale, AZ) and analyzed using Noraxon MyoResearch 1.10 XP software (Noraxon Inc). The EMG signals were amplified, band-pass filtered between 10 and 450 Hz, and the sampling rate was 1000 Hz. Data were collected from the Gmed, Gmax, TFL, RA, EO, LgT, and MF on the tested side. The mean value of 3 trials was used for data analysis. The skin was shaved and scrubbed with alcohol to reduce impedance of the EMG signal. Two Ag/AgCl surface electrodes were placed over the mid-position of the muscle belly. For the Gmed muscle, 2 electrodes were placed parallel to the muscle fiber over the proximal third of the distance between the iliac crest and the greater trochanter.[17] For the Gmax muscle, 2 electrodes were placed between the trochanter and the sacral vertebrae in the middle of the muscle at an oblique angle at the level of the trochanter or slightly above.[17] For the TFL muscle, 2 electrodes were placed parallel to the muscle fibers approximately 2 cm below the anterior superior iliac spine.[17] For the RA muscle, 2 electrodes were placed 3 cm apart, parallel to the muscle fibers of the RA, so that they were located over the muscle belly approximately 2 cm lateral to and across from the umbilicus.[17] For the EO muscle, 2 electrodes were placed lateral to the RA and directly above the anterior superior iliac spine, halfway between the crest and the ribs at a slightly oblique angle so that they ran parallel to the muscle fibers.[17] For the LgT muscle, 2 electrodes were placed 2 cm lateral to the T9 spinous process parallel to the muscle mass.[9] For the MF muscle, 2 electrodes were placed 2 cm lateral to the lumbosacral junction.[9]

Maximal voluntary isometric contractions (MVICs) were collected to normalize the EMG data of each muscle in the manual muscle test position.[18] To measure the MVIC of the Gmed muscle,[18] the subject was positioned in the side-lying position with the test-side up and the bottom hip flexed for stability and comfort. The test-side leg was abducted approximately 50% of the full range of hip abduction and performed with the hip in neutral in the sagittal plane and with a slight lateral hip rotation. The investigator applied downward force to the ankle while maintaining the hip position. To measure the MVIC of the Gmax muscle with the subject in the prone position with knee flexion at 90°, the investigator applied resistance to the posterior thigh to the hip extension.[18] To measure the MVIC of the TFL muscle,[18] the investigator applied downward resistance to the ankle in the direction of the hip extension while the subject flexed the hip slightly with the knee extended in the supine position. To measure the MVIC of the RA muscle,[18] the investigator applied resistance to the shoulders with the subject in the partial fetal position with the feet secured. To measure the MVIC of the EO muscle,[18] the subject performed an oblique curl up and the investigator applied resistance at the shoulder. To measure MVIC of the LgT and MF muscles,[18] in the prone position, the subjects extended the trunk to end range and the investigator applied resistance to the upper thoracic area. The process for measuring MVIC was performed twice for each muscle for 5 seconds, with a 3-minute rest between contractions. The mean values of the middle 3 seconds were used for data analysis.

3D Motion Analysis System. A 3D motion analysis system (Noraxon Research MyoMotion; Noraxon Inc) was used to monitor the trunk in neutral alignment and the compensatory movement of the hip during the side bridge exercise. The sensors were attached to the pelvis (the bony area of the sacrum), lower thoracic region (the mid-back at approximately the L1/T12), and thigh of the non-test-side leg (the lower quadrant of the quadriceps and the area of lowest belly muscle displacement in motion).

Experimental Procedures

Before undertaking the 3 side bridge exercises, subjects were instructed by the investigator about the standardized position of the exercises and familiarized with the exercises for around 20 minutes. The subjects performed each exercise 3 times, with a 5-minute rest between each exercise. Three exercises were performed in a random order using the random number generator feature in Microsoft Excel software (Microsoft Corp, Redmond, WA).

Side Bridge Exercise. As shown in Figure 1, for the SB, the subject was positioned in the side-lying position with the test-side down and the test-side leg (lower leg) extended. The test-side elbow joint was positioned directly below the shoulder, with the upper arm perpendicular to the floor. To stabilize the shoulder, the top hand was positioned over the lower side of the deltoid and the arm drawn across the chest. The top foot was placed on top of the lower foot. The subject supported their body weight on the lower elbow and feet while lifting the hips to assume the bridge position. The investigator ensured that the length of the body created a straight line, and the subject looked straight ahead during the exercise (Figure 1).[10,11]

Side Bridge Exercise With Knee Flexion. As shown in Figure 2, for SBK, the subject was positioned in the side-lying position test-side down with knee flexion at 90°. The test-side elbow joint was positioned directly below the shoulder with the upper arm perpendicular to the floor. To stabilize the shoulder, the top hand was positioned over the lower side of the deltoid and the arm drawn across the chest. The top foot was stacked on top of the lower foot. Then, the subject supported their body weight on the lower elbow and knee while lifting the hips to assume the bridge position. The investigator ensured that the length of the body created a straight line, and the subject looked straight ahead during the exercise (Figure 2).[11]

Side Bridge Exercise With Knee Flexion and Hip Abduction. As shown in Figure 3, for SBKH, the subject was positioned in the side-lying position test-side down with knee flexion at 90° and hip abduction of the top leg to 50% of the full range of motion. The test-side elbow joint was positioned directly below the shoulder with the upper arm perpendicular to the floor. To stabilize the shoulder, the top hand was positioned over the lower side of the deltoid and the arm drawn across the chest. The top foot was stacked on top of the lower foot. Then, the subject supported their body weight on the lower elbow and knee while lifting the hips to assume the bridge position. The investigator ensured that the length of the body created a straight line, and the subject looked straight ahead during the exercise.[11] If the angle of hip abduction of the top leg exceeded 5° to the standard position in the sagittal plane, the data were regarded as deviations and discarded.[16]

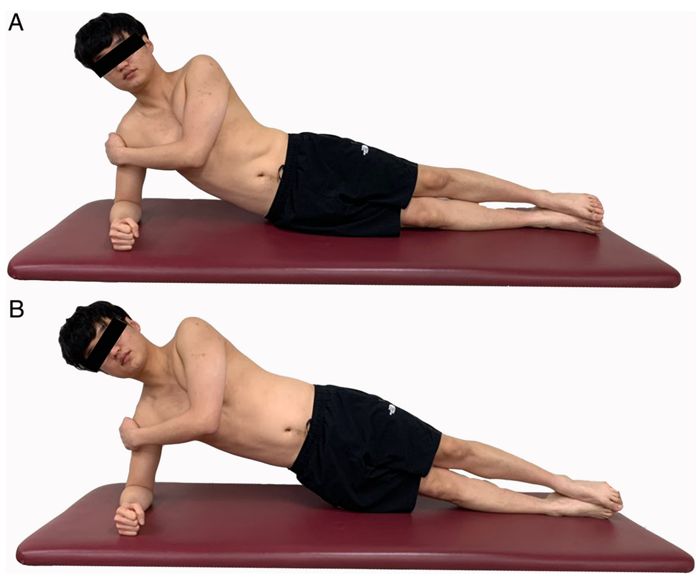

Figure 1 — Side bridge exercise. (A) Starting position and (B) bridging position.

Statistical Analysis

Statistical Package for Social Science software (version 25.0, SPSS; IBM Corp, Armonk, NY) was used for statistical analysis. A one-sample Kolmogorov–Smirnov test was performed for testing the normality of data distribution. One-way repeated analyses of variance with one within-subjects factor (exercise type: SB, SBK, and SBKH) were used to determine the effects of the side bridge exercises on the hip and trunk muscles. Level of significance was set at $\alpha = .05$. If significant differences were detected in analyses of variance, the Bonferroni correction was performed ($\alpha = .05/3 = .017$). The ES was represented by Cohen d to identify meaningful changes between interventions.

Results

There were significant differences in RA ($F_{2,56} = 30.764$, $P < .001$), EO ($F_{2,56} = 12.241$, $P < .001$), LgT ($F_{2,56} = 21.086$, $P < .001$), MF ($F_{2,56} = 19.910$, $P < .001$), Gmed ($F_{2,56} = 110.054$, $P < .001$), Gmax ($F_{2,56} = 36.416$, $P < .001$), and TFL ($F_{2,56} = 108.342$, $P < .001$) muscles among the 3 side bridge exercises (Table 1). The activity of the RA was significantly greater in SB than SBK ($P < .001$, ES = 8.243) and SBKH ($P < .001$, ES = 8.142). The activity of the EO was significantly greater in SB than SBK ($P < .001$, ES = 7.622) and also significantly greater in SBKH than SBK ($P = .004$, ES = 4.312). The activity of the LgT was

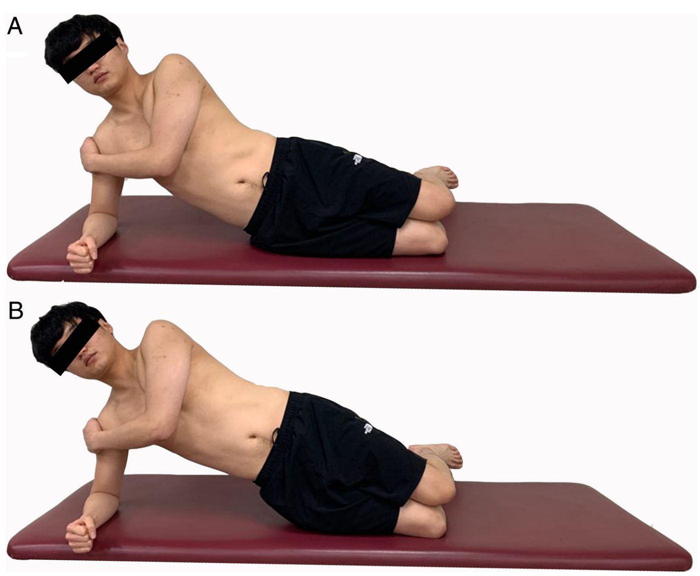

Figure 2 — Side bridge exercise with knee flexion. (A) Starting position and (B) bridging position.

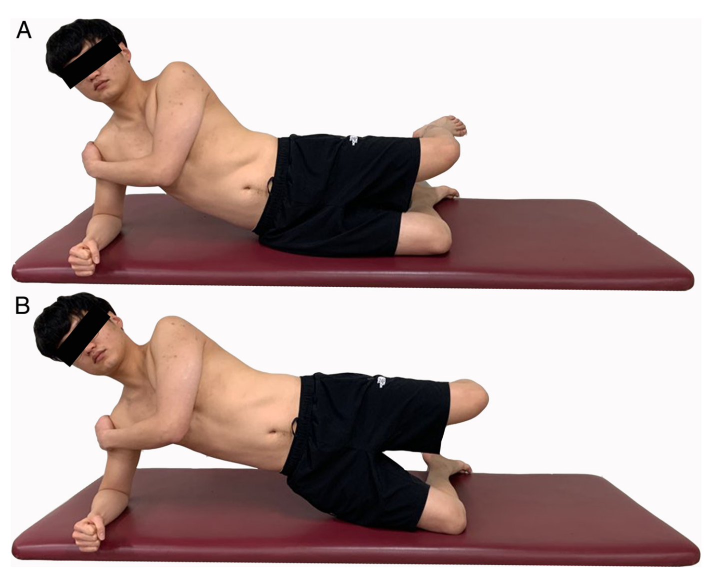

Figure 3 — Side bridge exercise with knee flexion and hip abduction. (A) Starting position and (B) bridging position.

Table 1 Comparison of Muscle Activities During the 3 Side Bridge Exercises (Unit: %MVIC)

Muscles	SB	SBK	SBKH	F	P
RA	34.62 (22.55)*,**	23.70 (16.45)	21.77 (15.12)	30.764	<.001
EO	94.09 (44.53)*	64.12 (36.49)**	78.31 (47.57)	14.241	<.001
LgT	47.87 (27.48)*,**	35.10 (22.59)	31.86 (23.67)	21.086	<.001
MF	51.31 (24.87)*,**	43.94 (16.53)**	64.82 (27.95)	19.910	<.001
Gmed	44.79 (20.96)**	39.05 (19.41)**	70.91 (21.38)	110.054	<.001
Gmax	32.42 (21.45)**	32.28 (18.02)**	52.68 (25.18)	36.416	<.001
TFL	27.44 (21.61)*,**	22.10 (21.92)**	61.65 (32.34)	108.342	<.001
Gmed/TFL ratio	2.57 (1.72)*,**	4.45 (3.73)**	1.48 (0.93)	20.738	<.001

Abbreviations: EO, external oblique; Gmax, gluteus maximus; Gmed, gluteus medius; LgT, longissimus thoracis; MF, lumbar multifidus; %MVIC, percentage of maximal voluntary isometric contraction; RA, rectus abdominis; SB, side bridge exercise; SBK, side bridge exercise with knee flexion; SBKH, side bridge exercise with knee flexion and hip abduction; TFL, tensor fasciae latae. Note: Values are presented as mean (SD).
*Significant difference with SBK. **Significant difference with SBKH.

significantly greater in SB than SBK ($P < .001$, ES = 6.396) and SBKH ($P < .001$, ES = 7.027). The activity of the MF was significantly greater in SB than SBK ($P = .011$, ES = 3.748) and also significantly greater in SBKH than SB ($P = .001$, ES = 5.116) and SBK ($P < .001$, ES = 7.956). The activity of the Gmed was significantly greater in SBKH than SB ($P < .001$, ES = 16.825) and SBK ($P < .001$, ES = 18.045). The activity of the Gmax was significantly greater in SBKH than SB ($P < .001$, ES = 9.773) and SBK ($P < .001$, ES = 10.132). The activity of the TFL was significantly greater in SB than SBK ($P < .001$, ES = 5.730) and also significantly greater in SBKH than SB ($P < .001$, ES = 14.150) and SBK ($P < .001$, ES = 15.609).

There were significant differences in the Gmed/TFL muscle ratio ($F_{2,56} = 20.738$, $P < .001$). The ratio was significantly greater in SBK than SB ($P = .001$, ES = 5.201) and SBKH ($P < .001$, ES = 7.219). The significance was greater in SBKH than SB ($P = .001$, ES = 5.276).

Discussion

The purpose of this study was to examine changes in hip and trunk muscle activity and Gmed/TFL muscle activity ratio during 3 side bridge exercises in subjects with Gmed weakness. It was hypothesized that the EMG activity of the Gmed, Gmax, and trunk muscles would increase in SBKH, and the EMG activity of the TFL would be decreased and Gmed/TFL muscle activity ratio would be increased in SBK compared with other SB exercises.

In all trunk muscles (RA, EO, LgT, and MF), activity was significantly lower in SBK than SB. In previous studies,[11,19] the activity of the RA, EO, and back extensors were lower during the side bridge exercises with the knees flexed than during the side bridge exercises with the leg extended. This indicates that knee flexion influences the trunk muscles during side bridge exercise. Knee flexion provides a large base of support and short lever arm to the trunk muscles, thus requiring comparatively lower activation of the trunk muscles during side bridge exercise.

The activity of the RA and LgT was significantly greater in SB than SBKH. There was no significant difference between the 2 during SBK and SBKH. These results were consistent with previous research,[13] which reported that there was no significant difference in activity of the RA during side bridge exercise with and without hip abduction in the knee extended position. The RA is a global stabilizer and a prime mover in the trunk that does not support the spine segmentally.[12,20] The LgT is also a global stabilizer. It spans the lumbar spine, controlling displacements of the torso.[12,21] This may explain why, in the current study, hip abduction did not influence the activity of RA or LgT during the bridge exercises. Considering the results of the previous study[13] and this study, the hip abduction during side bridge exercise does not influence the EMG activity of the RA and LgT regardless of knee flexion and extension.

The activity of the EO was greater during SBKH than SBK. While the EO is also a global stabilizer of the trunk muscles, the EO showed different activity than the other global stabilization muscles (RA and LgT). This indicates that hip abduction of the nontest side may influence the activity of the EO during bridge exercise. The activity of the MF was greater in SBKH than SB and SBK. The MF, which is a deep segmental muscle attached to the spine, was previously demonstrated to be influential in stabilizing the lumbar spine.[22] Therefore, the MF is important for lumbar stabilization as a segmental stabilizer. In an early study,[12] the additional load by unbalanced lower limb movement may produce the activity of the back extensor like MF to maintain the spinal stability. Thus, the increase of MF activation suggests that hip abduction of the top leg in SBKH may affect lumbar stability. Instability of the lumbar spine during SBKH may have contributed to the increased activity of the MF and EO found in the current study. In many stabilization exercises,[23] the EO is activated with the paraspinal muscles at the L5 level. It is difficult to contract the local stabilizer independently from the EO.[23]

In the current study, the activity of Gmed, Gmax, and TFL was significantly greater during SBKH than SB and SBK. To the best of our knowledge, no previous studies have examined the activity of Gmed, Gmax, and TFL during side bridge exercises. Therefore, it is impossible to compare the results of the current study to other studies. The results of the present study indicate that the hip abduction of the top leg may influence the activity of the hip muscles. The Gmed and TFL muscles are the primary hip abductors, and the superior fibers of the Gmax act as a hip abductor.[24] The side bridge exercise with hip abduction, which is performed in the side-lying position, enhances activation down the closed kinetic chain. The abducted hip of the top leg may lead to higher activity of the hip muscles because of the increased load of the test-side hip muscles to maintain the bridge position.

There were no significant differences between activity of the Gmed or Gmax during SB and SBK. This indicates that knee flexion did not influence the activity of these muscles. However, the activity of the TFL was significantly greater in SB than SBK, suggesting that knee flexion during the side bridge exercise affects the activity of the TFL. The TFL is attached at the iliotibial band that inserts on the lateral border of the patella, the lateral retinaculum, and Gerdy's tubercle of the tibia.[25] A previous study[14] reported that people with Gmed weakness often compensate with the TFL. Results of the current study show that trunk activity was lower in SBK compared with SB, which indicates that SBK was the least challenging exercise. This might lead to a decreased tendency for substitution with the TFL during SB in subjects with Gmed weakness.

The ratio of Gmed/TFL was significantly greater in SBK than SB and SBKH. The activity of the Gmed was significantly greater in SBKH than SB and SBK. However, the activity of the TFL was significantly lower in SBK than SB and SBKH. Thus, among the 3 side bridge exercises, SBK showed preferential activity of Gmed over the TFL. For the subjects with Gmed weakness, SBK may be an effective exercise considering the relative contribution of Gmed and TFL.

Many publications suggest that the physiotherapist consider the demands on the muscle and the level of difficulty when selecting an exercise for the patient.[9,11] Regarding the %MVIC of each muscle, SBK was the easiest among the 3 exercises. The results of the current study suggest that SB was the challenging exercise for each trunk muscle (RA, EO, LgT, and MF). Thus, SB may be difficult for individuals with Gmed weakness to perform. As an alternative to SB, SBK may be suitable for individuals with Gmed weakness.

This study had several limitations. First, the important stabilizers (the transversus abdominis and quadratus lumborum) were not recorded during the side bridge exercises. Second, the participants were all young subjects. Therefore, the findings may not be generalizable to the wider population. Third, subjects without Gmed weakness were not measured in this study. Finally, this study had a cross-sectional study design. In future, a longitudinal study would be useful to determine the long-term effects of the different side bridge exercises used in this study for the subjects with Gmed weakness.

Conclusion

This research analyzed the muscle activity of the hip and trunk in subjects with Gmed weakness during 3 side bridge exercises. The activity ratio of Gmed/TFL was significantly increased in SBK compared with SB and SBKH. The activity of trunk muscles was lowest in SBK. Considering the difficulty of the exercise and the relative contribution of Gmed and TFL, SBK may be an effective exercise for individuals with Gmed weakness.

Acknowledgments

This study was supported by the "Brain Korea 21 FOUR Project", the Korean Research Foundation for Department of Physical Therapy in the Graduate School of Yonsei University.

References

1. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc*. 2004;36(6):926–934. doi:10.1249/01.MSS.0000128145.75199.C3
2. Nelson-Wong E, Flynn T, Callaghan JP. Development of active hip abduction as a screening test for identifying occupational low back pain. *J Orthop Sports Phys Ther*. 2009;39(9):649–657. doi:10.2519/jospt.2009.3093
3. Grimaldi A. Assessing lateral stability of the hip and pelvis. *Man Ther*. 2011;16(1):26–32. doi:10.1016/j.math.2010.08.005
4. Cichanowski HR, Schmitt JS, Johnson RJ, Niemuth PE. Hip strength in collegiate female athletes with patellofemoral pain. *Med Sci Sports Exerc*. 2007;39(8):1227–1232. doi:10.1249/mss.0b013e3180601109
5. Hinman RS, Hunt MA, Creaby MW, Wrigley TV, McManus FJ, Bennell KL. Hip muscle weakness in individuals with medial knee osteoarthritis. *Arthritis Care Res*. 2010;62(8):1190–1193. doi:10.1002/acr.20199
6. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther*. 2007;37(12):754–762. doi:10.2519/jospt.2007.2471
7. Ebert JR, Edwards PK, Fick DP, Janes GC. A systematic review of rehabilitation exercises to progressively load the gluteus medius. *J Sport Rehabil*. 2017;26(5):418–436. doi:10.1123/jsr.2016-0088
8. McGill S, Juker D, Kropf P. Quantitative intramuscular myoelectric activity of quadratus lumborum during a wide variety of tasks. *Clin Biomech*. 1996;11(3):170–172. doi:10.1016/0268-0033(95)00056-9
9. Youdas JW, Boor MMP, Darfler AL, Koenig MK, Mills KM, Hollman JH. Surface electromyographic analysis of core trunk and hip muscles during selected rehabilitation exercises in the side-bridge to neutral spine position. *Sports Health*. 2014;6(5):416–421. doi:10.1177/1941738114539266
10. 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;6(3):206–223.
11. McGill SM, Karpowicz A. Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. *Arch Phys Med Rehabil*. 2009;90(1):118–126. doi:10.1016/j.apmr.2008.06.026
12. Arokoski JP, Valta T, Airaksinen O, Kankaanpää M. Back and abdominal muscle function during stabilization exercises. *Arch Phys Med Rehabil*. 2001;82(8):1089–1098. doi:10.1053/apmr.2001.23819
13. Okubo Y, Kaneoka K, Imai A, et al. Electromyographic analysis of transversus abdominis and lumbar multifidus using wire electrodes during lumbar stabilization exercises. *J Orthop Sports Phys Ther*. 2010;40(11):743–750. doi:10.2519/jospt.2010.3192
14. Fredericson M, Wolf C. Iliotibial band syndrome in runners. *Sports Med*. 2005;35(5):451–459. doi:10.2165/00007256-200535050-00006
15. Merican AM, Amis AA. Iliotibial band tension affects patellofemoral and tibiofemoral kinematics. *J Biomech*. 2009;42(10):1539–1546. doi:10.1016/j.jbiomech.2009.03.041
16. Lee JH, Cynn HS, Kwon OY, et al. Different hip rotations influence hip abductor muscles activity during isometric side-lying hip abduction in subjects with gluteus medius weakness. *J Electromyogr Kinesiol*. 2014;24(2):318–324. doi:10.1016/j.jelekin.2014.01.008
17. Criswell E. *Cram's Introduction to Surface Electromyography*. 2nd ed. Burlington, MA: Jones & Bartlett Learning; 2010.
18. Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. *Muscles: Testing and Function With Posture and Pain.* 5th ed. Baltimore, MD: Williams & Wilkins; 2005.
19. Escamilla RF, Lewis C, Pecson A, Imamura R, Andrews JR. Muscle activation among supine, prone, and side position exercises with and without a Swiss ball. *Sports Health*. 2016;8(4):372–379. doi:10.1177/1941738116653931

20. Johnson B. The functions of the individual muscles in the lumbar part of the spinae muscle. *Electrography*. 1970;10(1):5–21.
21. Beneck GJ, John WS, Shelby D. Postural cueing to increase lumbar lordosis increases lumbar multifidus activation during trunk stabilization exercises: electromyographic assessment using intramuscular electrodes. *J Orthop Sports Phys Ther*. 2016;46(4):293–299. doi:10.2519/jospt.2016.6174
22. Panjabi MM. The stabilizing system of the spine. Part II, neutral zone and instability hypothesis. *J Spinal Discod*. 1992;5(4):390–397. doi:10.1097/00002517-199212000-00002
23. Arokoski JP, Valta T, Kankaanpää M, Airaksinen O. Activation of lumbar paraspinal and abdominal muscles during therapeutic exercises in chronic low back pain patients. *Arch Phys Med Rehabil*. 2004;85(5):823–832. doi:10.1016/j.apmr.2003.06.013
24. Neumann DA. Kinesiology of the hip: a focus on muscular actions. *J Orthop Sports Phys Ther*. 2010;40(2):82–94. doi:10.2519/jospt.2010.3025
25. Martens M, Libbrecht P, Burssens A. Surgical treatment of iliotibial band friction syndrome. *Am J Sports Med*. 1989;17(5):651–654. doi:10.1177/036354658901700511