Sys Rev Pharm 2022; 13(4): 219-224
A multifaceted review journal in the field of pharmacy
E-ISSN 0976-2779 P-ISSN 0975-8453 / DOI: 10.31858/0975-8453.13.4.219-224

Research Article

Effects of the Abduction Resistance of the Hip Joint during Bridge Exercise in Patients with Chronic Back Pain: A Cross-Over Study

Myoung Kwon Kim*
Department of Physical Therapy, College of Rehabilitation Sciences, Daegu University, Jillyang, Republic of Korea

Article History: *Submitted: 08.03.2022* *Accepted: 29.03.2022* *Published: 05.04.2022*

ABSTRACT

Purpose: This study examined the effects of the levels of resistance on the muscle activities around the hip and spine during bridge exercise with hip abduction resistance in patients with chronic back pain.

Methods: A cross-over study design was used. Twenty subjects with low back pain were enrolled in this study. The subjects performed bridge exercise with hip abduction resistances (20 mmHg, 40 mmHg, and 60 mmHg). An elastic band was used to provide resistance. The surface electromyography device was used to measure the activity of the erector spinae, biceps femoris, gluteus maximus, and gluteus medius. The Root Mean Square (RMS) was calculated and the EMG signals collected were normalized to the percentage Maximal Voluntary Isometric Contraction (%MVIC). One way repeated measures ANOVA was applied to examine the differences.

Results: The muscle activity of the gluteus maximus and gluteus medius increased significantly with increasing resistance level. There was significant difference of muscle activity in biceps femoris with resistance level between 20 mmHg and 40 mmHg, but there was no significant difference in other resistance levels. There was no significant difference according to resistance level in the erector spinae. The muscle activity ratios of the gluteus medius/erector spinae and gluteus maximus/erector spinae increased significantly with increasing resistance strength.

Conclusion: The different levels of abduction resistance for hip abduction during bridge exercise will help activate the gluteus maximus selectively in patients with chronic back pain.

Keywords: Hip joint, Low back pain, Muscle strength

***Correspondence:** Myoung Kwon Kim, Department of Physical Therapy, College of Rehabilitation Sciences, Daegu University, Jillyang, Republic of Korea, E-mail: skybird-98@hanmail.net

INTRODUCTION

Low back pain is a common musculoskeletal disorder (Kuijer W, *et al.*, 2006; Manusov EG, 2012), and it has been estimated that 65% to 90% of the adult population experience chronic low back pain (Wand BM and O'Connell NE, 2008). Patients with low back pain show reduced walking ability, balance control, and proprioception, compared to healthy individuals (Baker DI, *et al.*, 2005). Several studies have reported an relationship between abnormal hip mechanics and changed hip muscle performance and various lower extremity and lower back conditions (Bishop BN, *et al.*, 2018; Powers CM, 2010; Sims KJ, *et al.*, 2002).

The gluteus medius is the major abductor of the hip, and the gluteus maximus is the major extensor of the hip that is also involved in hip abduction and external rotation (Bishop BN, *et al.*, 2018; Lyons K, *et al.*, 1983; Neumann DA, 2010). Many studies reported that the weakness of gluteus maximus and gluteus medius cause abnormal compensatory motion, such as altered hip and knee positioning and abnormal muscle activation (Bishop BN, *et al.*, 2018; Powers CM, 2010; Mok NW, *et al.*, 2007; Page P, *et al.*, 2011; Sahrmann S, *et al.*, 2017; Selkowitz DM, *et al.*, 2013). The result of this change in mechanics can lead to numerous musculoskeletal problems, including a variety of painful conditions of the lower back (Bishop BN, *et al.*, 2018). A weak gluteus maximus and gluteus medius have been recognized to be associated with chronic lower back pain (Bishop BN, *et al.*, 2018; Cooper NA, *et al.*, 2016; Larivière C, *et al.*, 2010; McKeon MD, *et al.*, 2006). Therefore, several studies suggested that strengthening the gluteus maximus as well as neuromuscular retraining exercises are necessary for rehabilitation and preventing low back pain (Kang SY, *et al.*, 2013; Khanna AJ, *et al.*, 2006; Mooney V, *et al.*, 2001).

Studies recommended side bridge, wall squat, forward step-up, quadruped upper and lower extremity lift, standing hip abduction (weight bearing on the target/opposite extremity), and side-lying hip abduction to activate the gluteal muscles (Selkowitz DM, *et al.*, 2013; Arokoski JP, *et al.*, 1999; Ayotte NW, *et al.*, 2007; Bolgla LA and Uhl TL, 2005; Ekstrom RA, *et al.*, 2007; McBeth JM, *et al.*, 2012). In addition, previous authors examined the effects of exercises that activate the gluteus maximus and gluteus medius (Selkowitz DM, *et al.*, 2013; Bolgla LA and Uhl TL, 2005; Distefano LJ, *et al.*, 2009; Philippon MJ, *et al.*, 2011; Reiman MP, *et al.*, 2012). For specific strengthening of the gluteus maximus and gluteus medius while decreasing the activities of the tensor fascia latae and lumbar extensor, previous studies used surface electromyography during specific exercises in various positions (Distefano LJ, *et al.*, 2009; Philippon MJ, *et al.*, 2011); weight bearing hip abduction exercise (Bolgla LA and Uhl TL, 2005); and elastic resistance on the knee, ankle, and foot (Cambridge ED, *et al.*, 2012; Youdas JW, *et al.*, 2014). Gluteus muscle setting exercise, forward bending leg lifts, and quadruped leg raise were recommended for strengthening the gluteus maximus (Kisner C, *et al.*, 2017). Bridge exercise with hip abduction has been shown to be effective in strengthening the gluteus maximus (Kang SY, *et al.*, 2016). Bridging with 30° hip abduction can be recommended as an effective method to selectively facilitate gluteus maximus activity, minimize compensatory elector spinae activity, and decrease the anterior pelvic tilt angle (Kang SY, *et al.*, 2016).

Although previous studies have reported that it is advantageous to selectively activate gluteus maximus according to the angle of hip abduction during bridge exercise, no study has examined the selective activation of gluteus maximus and gluteus medius according to the different levels of abduction resistance on the hip.

Many patients with low back pain have weakness of the gluteus maximus (Bishop BN, *et al.*, 2018; Cooper NA, *et al.*, 2016;

Larivière C, *et al.*, 2010; McKeon MD, *et al.*, 2006). If there is a change of the gluteus maximus activation, we can recommend the hip abduction resistance during bridge exercise. Therefore, the aim of the study was to determine the effects of the levels of resistance on the muscle activities around the hip and spine during bridge exercise with hip abduction resistance in patients with chronic back pain.

MATERIALS AND METHODS

Participants

Twenty adult females in their 20s to 30s, who have chronic back pain, were included in this study. All subjects agreed voluntarily to participate in this experiment. Prior to the start of the study, all subjects understood its content and signed an informed consent form. This study complied with the ethical standards of the declaration of Helsinki and was approved by the Research Ethics Committee of Daegu University (1040621-201811-HR-007-02). The subjects were required to meet the following criteria for inclusion in the study: (1) a patient diagnosed with chronic back pain and low back pain lasting for more than three months; (2) no history of low back surgery due to orthopedic problems; (3) no malformations or fractures of the spine on radiographs; (4) no sensory dysfunction, vestibular disorders, nervous system disorders, respiratory diseases, musculoskeletal disorders in the legs, or neck problems, and not wearing orthosis; and (5) not having performed regular or systematical exercise during daily activities for the last three years.

Experimental procedures

This is a cross-over study design conducted to compare the muscle activities according to the level of resistance during hip abduction with general bridge exercises. In order to minimize a bias of the resistance level, randomization was needed. To randomize the order of applying resistance, sealed envelopes were prepared in advance and marked inside with A, B, or C representing 20 mmHg, 40 mmHg, and 60 mmHg. A third party who was unaware of the study performed the randomization. Before and after the intervention, Physician 1, who was blinded to the order of applying resistance of the subjects, assessed the subject characteristics and all outcome measures. The interventions were performed in a closed room by Physician 2, who was not involved in the subject assessment. Both physicians were instructed not to communicate with the subjects about the study goals or treatments. *Figure 1* shows flow diagram of the study. The sample size for this study was calculated using the G* Power program 3.1.0 (G power program Version 3.1, Hein-rich-Heine-University Du¨sseldorf, Du¨sseldorf, Germany). Based on data from a pilot study, the estimated sample size required to obtain a minimum power of 80% at a significant alpha level of 95% was 16. Accordingly, 20 subjects were recruited to account for a potential dropout rate of 20%.

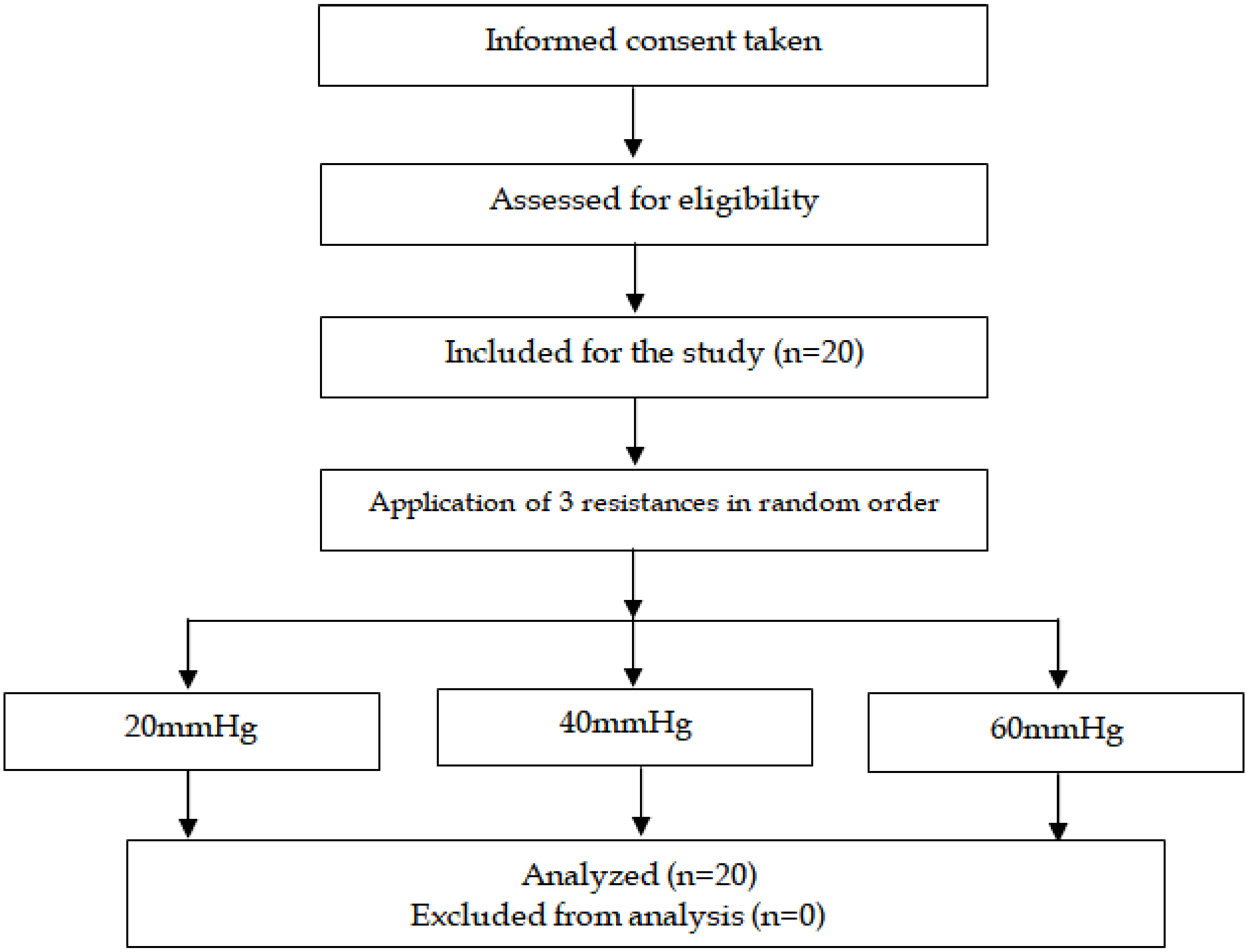

Figure 1: Study flowchart

Intervention

To compare the muscle activities at three different resistances (20 mmHg, 40 mmHg, and 60 mmHg) during hip abduction with general bridge exercise, a Theraband Elastic Band (Hygienic Corporation, Akron, Ohio) was used to provide resistance on the hip abduction (Tonley JC, *et al.*, 2010). A green color Thera-band was used in the study. The length of the Thera-band was 60 cm (Page P, 2000). A biofeedback device (Pressure Biofeedback Unit, Chattanooga, USA) was used to determine the amount of the resistance of the hip abduction during bridge exercise. Experimenter put a biofeedback device next to the subject's knee joint. Subjects performed bridge exercise with the resistance of hip abduction (20 mmHg, 40 mmHg, and 60 mmHg) given by the Thera-band.

The experiment was conducted over three days, and the subjects performed one of three interventions to prevent a learning effect. In this study, the bridge exercise was performed by the general method currently used for most patients (Youdas JW, *et al.*, 2015). The bridge exercise was performed in the following sequence. Before the bridge exercise, abdominal drawing-in maneuver with biofeedback device was performed in order to prevent an excessive lumbar flexion caused by contraction of the rectus abdominis. In the starting position of the bridge, therapist asked subjects to pull their tummy button toward their spine and hold the position 5 second during exhalation with maintaining 70 mmHg pressure. The subjects commenced the bridge exercise lying in the supine position with the knees bent 90°, arms away from the body at approximately 30°, and the palms facing downward on the floor. The feet were placed flat on the floor, shoulder-width apart, and the pelvis was put in a neutral position. The subjects were then instructed to lift their hips off the floor at a hip extension angle of 0° and knee flexion angle of 90° (Lehman GJ, *et al.*, 2005). The biofeedback device was placed on the subject's left knee joint. Subjects were educated about bridge exercises for 10 minutes before the experiment, and each position was performed for seven seconds and three repetitions. In addition, feedback was continuously given to the subjects during the experiment to ensure that the subjects performed each posture accurately.

Outcome measures

The surface electromyography device (TeleMyoDTS, Noraxon Ins, Az, USA) was used to measure the activity of the erector spinae, biceps femoris, gluteus maximus, and gluteus medius during hip abduction with the bridge exercise. EMG data were collected and analyzed on the left leg. The centers of the EMG electrodes were kept at a distance of 2 cm, and the EMG electrodes were attached parallel to muscle fibers to obtain EMG signals with the least possible noise. At the point of attachment, hair was first removed using a disposable razor, followed by rubbing off dead skin cells to reduce the skin resistance, and foreign substances were removed with alcohol swabs (Marshall PW and Murphy BA, 2005). For normalization of the EMG data, a Maximum Voluntary Isometric Contraction (MVIC) was performed for each muscle and the EMG amplitude was recorded. To measure the activity of the gluteus maximus, the subjects were instructed to perform hip extension with knee flexion 90° in the prone position. At this time, the resistance was applied to the posterior part of the femur, and the subjects were required to withstand the resistance (Willcox EL and Burden AM, 2013). To measure the gluteus medius, the subjects were instructed to bend the hip and knee on the lower side in the side-lying position and lift the leg on the upper side. At this time, the subjects were required to withstand the manual resistance applied to the ankle (Boren K, *et al.*, 2011).

To measure the biceps femoris activity, the subjects performed knee flexion in the prone position against manual resistance applied to the ankle (Chan MK, *et al.*, 2017; Hislop H, *et al.*, 2013). For erector spinae activity, the subjects were asked to raise the trunk against resistance in the prone position while the lower extremities were stabilized firmly on the table (Ansari B, *et al.*, 2018). The mean value of the EMG signal was obtained using measurements for three seconds, excluding measurement data of the first and last one second.

Interventions using 20 mmHg, 40 mmHg, and 60 mmHg resistances were performed and repeated it three times. The mean values were used to determine the %MVIC value. A five-minute break was given between tests to prevent muscle fatigue (Cram JR, *et al.*, 1998).

According to resistance levels, we compared the result values (gluteus maximus, gluteus medius, biceps femoris, erector spinae, gluteus medius/erector spinae, and gluteus maximus/erector spinae) and identified changes with increasing the level of resistance. To calculate the ratio, gluteus medius/erector spinae*100 and gluteus maximus/erector spinae*100 were used.

Data processing

Data were analyzed using SPSS version 22.0 (SPSS Inc. Chicago, IL) for Windows software. The Shapiro-Wilk test was used for the normality test. The subjects' general characteristics were analyzed using descriptive statistics. One way repeated measures ANOVA was performed to examine differences between the groups, and the LSD test was used as a post-hoc test to examine the within-group differences. The level of significance was set at $p<0.05$.

RESULTS

Table 1 lists the general characteristics of the subjects.

There was significant difference of muscle activity in gluteus maximus with resistance level (20 mmHg and 40 mmHg, $p<0.05$; 20 mmHg and 60 mmHg, $p<0.05$; 40 mmHg and 60 mmHg, $p<0.05$). There was significant difference of muscle activity in gluteus medius with resistance level (20 mmHg and 40 mmHg, $p<0.05$; 20 mmHg and 60 mmHg, $p<0.05$; 40 mmHg and 60 mmHg, $p<0.05$) *(Table 2).*

There was significant difference of muscle activity in biceps femoris with resistance level between 20 mmHg and 40 mmHg ($p<0.05$), but there was no significant difference between 20 mmHg and 60 mmHg ($p>0.05$), and also 40 mmHg and 60 mmHg ($p>0.05$). There was no significant difference according to resistance level in the erector spinae (20 mmHg and 40 mmHg, $p>0.05$; 20 mmHg and 60 mmHg, $p>0.05$; 40 mmHg and 60 mmHg, $p>0.05$) *(Table 2).*

There was significant difference of the muscle activity ratios of the gluteus medius/erector spinae (20 mmHg and 40 mmHg, $p<0.05$; 20 mmHg and 60 mmHg, $p<0.05$; 40 mmHg and 60 mmHg, $p<0.05$). There was significant difference of the muscle activity ratios of the gluteus maximus/erector spinae (20 mmHg and 40 mmHg, $p<0.05$; 20 mmHg and 60 mmHg, $p<0.05$; 40 mmHg and 60 mmHg, $p<0.05$) *(Table 3).*

Table 1: General characteristics of the subjects

Variable	Values
Age (year)	24.0 ± 2.8[a]
Height (cm)	161.5 ± 3.2
Weight (kg)	54.1 ± 5.31
Body mass index (kg/m^2)	20.7 ± 1.8
Gender (male/female)	0/20

Note: [a]Mean ± SD

Table 2: Comparison of the muscle activities according to the resistance strength

Muscle	20 mmHg	40 mmHg	60 mmHg	p
Gluteus maximus	15.14 ± 8.8$^{\alpha}$	24.19 ± 12.26	35.24 ± 13.72	0.00*
Gluteus medius	16.81 ± 12.63	30.15 ± 17.68	52.06 ± 20.89	0.00*
Biceps femoris	26.26 ± 21.3	22.64 ± 17.8	21.53 ± 20.42	0.75
Erector spinae	48.01 ± 18.31	46.42 ± 16.25	49.12 ± 15.6	0.87
Note: $^{\alpha}$Mean ± SD, *Statistical significance $p<0.05$				

Table 3: Comparison of muscle activity ratios according to the resistance strength

Ratio	20 mmHg	40 mmHg	60 mmHg	p
Gluteus medius/Erector spinae	0.32 ± 0.2$^{\alpha}$	0.72 ± 0.75	1.0 ± 0.53	0.00*
Gluteus maximus/Erector spinae	0.35 ± 0.23	0.61 ± 0.43	0.79 ± 0.36	0.00*
Note: $^{\alpha}$Mean ± SD, *Statistical significance $p<0.05$				

DISCUSSION

This study examined the muscle activities around hip and spine during bridge exercise with hip abduction resistance in patients with chronic back pain. The key research finding is that different levels of abduction resistance for hip abduction during bridge activated the gluteus maximus selectively in patients with chronic back pain.

The muscle activity of the gluteus maximus increased significantly with increasing resistance level of hip abduction. A previous study reported that the activity of the gluteus maximus could be increased selectively by performing 30° hip abduction during hip joint extension (Kang SY, *et al.*, 2013). These results show that hip abduction can selectively facilitate gluteus maximus activity and hip abduction can increase the activity of the gluteus maximus. Motor unit recruitment refers to the activation of additional motor units to accomplish an increase in contractile strength in a muscle (Lundy-Ekman L, 2013). The control of muscle is realized at the level of the motor unit (Lundy-Ekman L, 2013; Potvin JR and Fuglevand AJ, 2017). According to the neural mechanisms called the Henneman's size principle, the higher the recruitment, the stronger the muscle contraction will be. Motor units are generally recruited in the order of weakest to strongest as the contraction increases (Potvin JR and Fuglevand AJ, 2017; Henneman E, 1957; Henneman E and Mendell LM, 2011; Henneman E, *et al.*, 1965). Therefore, when the resistance of the hip abduction is increased, the recruitment of the muscle fibers of the gluteus maximus should be increased to maintain contraction against hip abduction resistance.

The muscle activity of the gluteus medius increased significantly with increasing resistance level of hip abduction. A previous study examined the effects of various gluteus medius strengthening exercises and found that of the 11 types of exercises, additional hip joint abduction exercise resulted in the highest activation of the gluteus medius (Selkowitz DM, *et al.*, 2013). The middle portion of the gluteus medius is an abductor, and the gluteus maximus is an extensor and external rotator (Neumann DA, 2010; Selkowitz DM, *et al.*, 2013). A previous study reported that hip abduction exercise with elastic resistance around thighs produced significantly greater activation in both the gluteus medius and gluteus maximus relative to the TFL (Bishop BN, *et al.*, 2018). According to the size principle (Henneman E, 1957; Henneman E and Mendell LM, 2011; Henneman E, *et al.*, 1965), activation of the gleuteus medius also should be increased to maintain a contraction against hip abduction resistance. Because gluteus medius is highly activated during hip abduction resistance exercise, the recruitment of the gluteus medius increased with increasing resistance of hip abduction.

There was significant difference of muscle activity in biceps femoris with resistance level between 20 mmHg and 40 mmHg, but there was no significant difference between 20 mmHg and 60 mmHg, and also 40 mmHg and 60 mmHg. A study reported that as the extension angle was increased during prone hip extension exercise, the gluteus maximus activity was increased and the biceps femoris activity was decreased significantly (Kang SY, *et al.*, 2013).

The result of this study that the activity of the gluteus maximus increased with increasing abduction resistance strength of the hip joint was attributed to the reduced activity of the biceps femoris. In addition, although decrease in the mean muscle activity was greater at an abduction resistance strength of 60 mmHg than at 20 mmHg or 40 mmHg, the post-hoc test revealed no significant difference. These results can be explained by a high standard deviation due to the small sample size.

The muscle activity of the erector spinae showed no significant difference when comparing the value measured at an abduction resistance strength of 60 mmHg with those at 20 mmHg and 40 mmHg. A study reported that there were no significant differences in the muscle activity of the erector spinae during bridge exercises on various unstable support surfaces (Imai A, *et al.*, 2010). These results can be explained by the fact that the abdominal drawing-in maneuver suppressed the unnecessary activity of muscles around the spine (Shurley JP and Newman JK, 1965). In this study, the abdominal drawing-in maneuver was used to decrease the unnecessary muscle activities during bridge exercise. The level of the hip abduction resistance may not have affected the activity of erector spinae because the bridge exercise with hip abduction resistance was not targeted at the erector spinae.

The gluteus medius/erector spinae muscle activity ratio was significantly higher at the resistance strength of 60 mmHg than at the resistance strength of 20 mmHg, and was significantly higher at 40 mmHg than at 20 mmHg. Similarly, the gluteus maximus/erector spinae muscle activity ratio was significantly higher at 60 mmHg than at 20 mmHg, and at 40 mmHg than at 20 mmHg. A previous study reported that bridging with hip abduction can facilitate gluteus maximus selectively, minimize compensatory ES muscle activity (Kang SY, *et al.*, 2016). Given these findings, it was assumed that increased activity of gluteus maximus is related to decreased muscle activity of elector spinae during bridging with hip abduction.

Based on these findings, different levels of hip abduction resistance during bridge exercise can be used to activate the gluteus maximus selectively and decrease the activation of unnecessary muscles in chronic back pain patients. This study had some limitations. First, it was difficult to generalize the findings of this study because the study was aimed at females in their 20s to 30s. Second, the long-term effects of the bridge exercise with hip abduction resistance were not observed. Finally, this study could not identify the effects of the core muscles and the interactions between muscles around the trunk, pelvic, hip, and lower extremity. Further studies will be needed to determine the long-term effects, the difference between genders, and the activities of more muscles.

CONCLUSION

The purpose of the study was to determine the effects of the levels of resistance on the muscle activities around the hip and spine during bridge with hip abduction resistance in patients with chronic back pain. The use of different levels of abduction resistance for hip abduction during bridge exercise will help to activate the gluteus maximus selectively in chronic back pain patients. Therefore, if abduction resistance of the hip joint is added to the existing method of bridge exercise for chronic back pain patients, it will be helpful for the selective activation of the gluteus maximus.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT, Ministry of Science and ICT) (No. NRF-2021R1F1A1052333).

REFERENCES

1. Kuijer W, Brouwer S, Preuper HS, Groothoff JW, Geertzen JH, Dijkstra PU. Work status and chronic low back pain: Exploring the International Classification of Functioning, Disability and Health. Disabil Rehabil. 2006; 28(6): 379-388.
2. Manusov EG. Evaluation and diagnosis of low back pain. Prim Care. 2012; 39(3): 471.
3. Wand BM, O'Connell NE. Chronic non-specific low back pain-subgroups or a single mechanism? BMC Musculoskelet Disord. 2008; 9(1): 1-5.
4. Baker DI, King MB, Fortinsky RH, Graff IV LG, Gottschalk M, Acampora D, *et al.* Dissemination of an evidence-based multicomponent fall risk-assessment and-management strategy throughout a geographic area. J Am Geriatr Soc. 2005; 53(4): 675-680.
5. Bishop BN, Greenstein J, Etnoyer-Slaski JL, Sterling H, Topp R. Electromyographic analysis of gluteus maximus, gluteus medius, and tensor fascia latae during therapeutic exercises with and without elastic resistance. Int J Sports Phys Ther. 2018; 13(4): 668.
6. Powers CM. The influence of abnormal hip mechanics on knee injury: A biomechanical perspective. J Orthop Sports Phys Ther. 2010; 40(2): 42-51.
7. Sims KJ, Richardson CA, Brauer SG. Investigation of hip abductor activation in subjects with clinical unilateral hip osteoarthritis. Ann Rheum Dis. 2002; 61(8): 687-692.
8. Lyons K, Perry J, Gronley JK, Barnes L, Antonelli D. Timing and relative intensity of hip extensor and abductor muscle action during level and stair ambulation: an EMG study. Phys Ther. 1983; 63(10): 1597-1605.
9. Neumann DA. Kinesiology of the hip: A focus on muscular actions. J Orthop Sports Phys Ther. 2010; 40(2): 82-94.
10. Mok NW, Brauer SG, Hodges PW. Failure to use movement in postural strategies leads to increased spinal displacement in low back pain. Spine. 2007; 32(19): 537-543.
11. Page P, Frank C, Lardner R. Assessment and treatment of muscle imbalance: The Janda approach. J Orthop Sports Phys Ther. 2011; 41(10): 799-800.
12. Sahrmann S, Azevedo DC, van Dillen L. Diagnosis and treatment of movement system impairment syndromes. Braz J Phys Ther. 2017; 21(6): 391-399.
13. Selkowitz DM, Beneck GJ, Powers CM. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? Electromyographic assessment using fine-wire electrodes. J Orthop Sports Phys Ther. 2013; 43(2): 54-64.
14. Cooper NA, Scavo KM, Strickland KJ, Tipayamongkol N, Nicholson JD, Bewyer DC, *et al.* Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. Eur Spine J. 2016; 25(4): 1258-1265.
15. Larivière C, RA DS, Arsenault AB, Nadeau S, Plamondon A, Vadeboncoeur R. Specificity of a back muscle exercise machine in healthy and low back pain subjects. Med Sci Sports Exerc. 2010; 42(3): 592-599.
16. McKeon MD, Albert WJ, Neary JP. Assessment of neuromuscular and haemodynamic activity in individuals with and without chronic low back pain. Dyn Med. 2006; 5(1): 1-8.
17. Kang SY, Jeon HS, Kwon O, Cynn HS, Choi B. Activation of the gluteus maximus and hamstring muscles during prone hip extension with knee flexion in three hip abduction positions. Man Ther. 2013; 18(4): 303-307.
18. Khanna AJ, Reinhardt MK, Togawa D, Lieberman IH. Functional outcomes of kyphoplasty for the treatment of osteoporotic and osteolytic vertebral compression fractures. Osteoporos Int. 2006; 17(6): 817-826.
19. Mooney V, Pozos R, Vleeming A, Gulick J, Swenski D. Exercise treatment for sacroiliac pain. Orthopedics. 2001; 24: 29-32.
20. Arokoski JP, Kankaanpää M, Valta T, Juvonen I, Partanen J, Taimela S, *et al.* Back and hip extensor muscle function during therapeutic exercises. Arch Phys Med Rehabil. 1999; 80(7): 842-850.
21. Ayotte NW, Stetts DM, Keenan G, Greenway EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. J Orthop Sports Phys Ther. 2007; 37(2): 48-55.
22. Bolgla LA, Uhl TL. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. J Orthop Sports Phys Ther. 2005; 35(8): 487-494.
23. 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.
24. McBeth JM, Earl-Boehm JE, Cobb SC, Huddleston WE. Hip muscle activity during 3 side-lying hip-strengthening exercises in distance runners. J Athl Train. 2012; 47(1): 15-23.
25. Distefano LJ, Blackburn JT, Marshall SW, Padua DA. Gluteal muscle activation during common therapeutic exercises. J Orthop Sports Phys Ther. 2009; 39(7): 532-540.
26. Philippon MJ, Decker MJ, Giphart JE, Torry MR, Wahoff MS, Laprade RF. Rehabilitation exercise progression for the gluteus medius muscle with consideration for iliopsoas tendinitis: An *in vivo* electromyography study. Am J Sports Med. 2011; 39(8): 1777-1786.
27. Reiman MP, Bolgla LA, Loudon JK. A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. Physiother Theory Pract. 2012; 28(4): 257-268.
28. Cambridge ED, Sidorkewicz N, Ikeda DM, McGill SM. Progressive hip rehabilitation: The effects of resistance band placement on gluteal activation during two common exercises. Clin Biomech. 2012; 27(7): 719-724.
29. Youdas JW, Adams KE, Bertucci JE, Brooks KJ, Nelson MM, Hollman JH. Muscle activation levels of the gluteus maximus and medius during standing hip-joint-strengthening exercises using elastic-tubing resistance. J Sport Rehabil. 2014; 23(1): 1-1.

30. Kisner C, Colby LA, Borstad J. Therapeutic exercise: Foundations and techniques. FA Davis. 2017.
31. Kang SY, Choung SD, Jeon HS. Modifying the hip abduction angle during bridging exercise can facilitate gluteus maximus activity. Man Ther. 2016; 22: 211-215.
32. Tonley JC, Yun SM, Kochevar RJ, Dye JA, Farrokhi S, Powers CM. Treatment of an individual with piriformis syndrome focusing on hip muscle strengthening and movement reeducation: A case report. J Orthop Sports Phys Ther. 2010; 40(2): 103-111.
33. Page P. Clinical force production of Thera-Band® elastic bands. J Orthop Sports Phys Ther. 2000; 30: 47-48.
34. Youdas JW, Hartman JP, Murphy BA, Rundle AM, Ugorowski JM, Hollman JH. Magnitudes of muscle activation of spine stabilizers, gluteals, and hamstrings during supine bridge to neutral position. Physiother Theory Pract. 2015; 31(6): 418-427.
35. Lehman GJ, Hoda W, Oliver S. Trunk muscle activity during bridging exercises on and off a swissball. Chiropr Osteopat. 2005; 13(1): 1-8.
36. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil. 2005; 86(2): 242-249.
37. Willcox EL, Burden AM. The influence of varying hip angle and pelvis position on muscle recruitment patterns of the hip abductor muscles during the clam exercise. J Orthop Sports Phys Ther. 2013; 43(5): 325-331.
38. 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.
39. Chan MK, Chow KW, Lai AY, Mak NK, Sze JC, Tsang SM. The effects of therapeutic hip exercise with abdominal core activation on recruitment of the hip muscles. BMC Musculoskelet Disord. 2017; 18(1): 1-1.
40. Hislop H, Avers D, Brown M. Daniels and Worthingham's muscle Testing-E-Book: Techniques of manual examination and performance testing. Elsevier Health Sciences. 2013.
41. Ansari B, Bhati P, Singla D, Nazish N, Hussain ME. Lumbar muscle activation pattern during forward and backward walking in participants with and without chronic low Back pain: An Electromyographic study. J Chiropr Med. 2018; 17(4): 217-225.
42. Cram JR, Kasman GS, Holtz J. Introduction to Surface Electromyography. Aspen Publishers. 1998.
43. Lundy-Ekman L. Neuroscience-E-Book: Fundamentals for Rehabilitation. Elsevier Health Sciences. 2013.
44. Potvin JR, Fuglevand AJ. A motor unit-based model of muscle fatigue. PLoS Comput Biol. 2017; 13(6): 1005581.
45. Henneman E. Relation between size of neurons and their susceptibility to discharge. Science. 1957; 126(3287): 1345-1347.
46. Henneman E, Mendell LM. Functional organization of motoneuron pool and its inputs. Compr Physiol. 2011; 423-507.
47. Henneman E, Somjen G, Carpenter DO. Functional significance of cell size in spinal motoneurons. J Neurophysiol. 1965; 28(3): 560-580.
48. Imai A, Kaneoka K, Okubo Y, Shiina I, Tatsumura M, Izumi S, *et al.* Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. J Orthop Sports Phys Ther. 2010; 40(6): 369-375.
49. Shurley JP, Newman JK. Spondylolysis in American football players: Etiology, symptoms, and implications for strength and conditioning specialists. Strength Cond J. 2016; 38(5): 40-51.