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Research Article

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Effect of Changes in Knee Angle and Weight-Shifting of the Sole on the Lower Extremity Muscle Activity during the Bridge Exercise

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| Abstract |

PURPOSE: This study examined the effect of changes in the knee angle and weight shifting of the sole on the activity of the lower extremity muscles during bridge exercise.
METHODS: The subjects of this study included 20 healthy adult women (mean age 29.8 ± 4.32). The subjects performed the bridge exercise under three weight-shifting conditions general bridge (GB), hindfoot press bridge (HPB), and fore-foot bridge (FPB) and at two knee angles (90° and 60°). During the bridge exercise, the activity of the quadriceps femoris (rectus femoris, vastus medialis oblique, and vastus lateralis) and biceps femoris muscles were measured using an electromyography sensor.
RESULTS: In the quadriceps femoris, the muscle activity of HPB and FPB was significantly higher than that of the GB at knee angles of 90° and 60° ($p < .05$). In the biceps femoris, the muscle activity increased significantly in the order of GB < HPB < FPB, and the knee angle increased significantly at 60° rather than at 90° ($p < .05$). There was no significant difference according to the knee angle in all muscles except for the biceps femoris.
CONCLUSION: These findings suggest that the weight-shifting bridge of sole bridge exercise was more effective in increasing the activation of the lower extremity muscles than the GB.

Key Words: Bridge exercise, EMG, Lower extremity muscle activity, Weight-shifting

Ⅰ. Introduction

Bridge exercise is the most common closed chain strengthening exercise to improve the stability of the trunk and lower extremity muscles [1]. For stability, coordinating all the trunk and lower extremity muscles surrounding the lumbar region is a key [2]. The bridge exercise aims to increase the stability of the spine and pelvis during the functional postures and movements, strengthen the muscles, and restore control and balance of muscles and movements [3]. Trunk and lower extremity treatments should be combined because they involve joint movements that help

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muscle strength, endurance, intrinsic water-soluble function, and bone atrophy prevention at the early stages of rehabilitation [4].

Previous studies on bridge exercise focused mainly on muscle activity according to the joint angle of the lower extremity and the supporting surface [5-7]. As the knee angle decreased, the biceps femoris, vastus medialis, and lateralis muscles contributed significantly to the stability of the knee joint during the bridge exercise, and the activity of the vastus medialis muscle increased compared to the rectus femoris muscle. Therefore, this study set the experiment at 90° and 60°, which had the highest muscle activity ratio of the lower limbs muscles in previous studies.

Jung [8] compared the effect of the ground-pressing bridge exercise and the standard bridge exercise, finding that the pressing bridge exercise was effective in strengthening the erector spinae, gluteus maximus, semitendinosus, rectus femoris, and gastrocnemius muscles. Hong et al. [9] showed that higher muscle activity and the change in muscle endurance could be induced in bridge exercise using unstable ground and various supporting surfaces. This suggests that bridge exercise is related to the pelvis and the feet in terms of the activation of the muscles that move the pelvis and that the effect of the bridge exercise varied according to the change in the movement of the feet. In the stance phase when walking, the force on the ground increases as the weight shifts from the heel to the forefoot. The weight-shifting bridge exercise can contribute to the prior learning of muscles related to gait motion. On the other hand, there have been few studies on the changes in the knee joint and the weight shifting of the sole.

Building on previous studies, the present study analyzed the effects of changes in the knee angle and weight shifting of the sole on the activity of the lower extremity muscles during bridge exercise.

Table 1. General Characteristics of the Subjects (M ± SD)

Characteristics	Subjects
Gender (female)	20[a]
Age (year)	29.8 ± 4.32
Weight (kg)	57.41 ± 4.56
Height (cm)	164.4 ± .03
Body mass index (kg/m²)	18.29 ± 1.48

M ± SD: Values are expressed as mean ± standard deviation
[a]Values are presented as numbers.

Ⅱ. METHODS

1. Subjects

The subjects included 20 healthy adult women who read the consent form and agreed voluntarily to participate in the experiment. The subjects with the balance ability and joint working range were required to perform the bridge exercise. The study experiment was conducted after being reviewed by the Bioethics Review Committee of Korea University (KUIRB-2021-0249-01). The general characteristics of the subjects were as follows (Table 1).

2. Procedures

This study had a crossover design. The subjects included 20 healthy adult women who read the consent form and agreed voluntarily to participate in the experiment. The experimental procedures are illustrated in Fig. 1.

1) Posture and method of starting the bridge exercise

As for the starting posture of the bridge exercise, the subjects were asked to lay on their back, look at the ceiling, and place both hands comfortably on the ground. They were instructed to spread their feet shoulder-width apart to control their knee angles at 90° and 60° using a goniometer. The ankle angle was controlled by placing the second toe and tibial tuberosity in a vertical line. The trunk and femur were also in a vertical line so that the hip joint angle was 0° to extend the hip (Fig. 2).

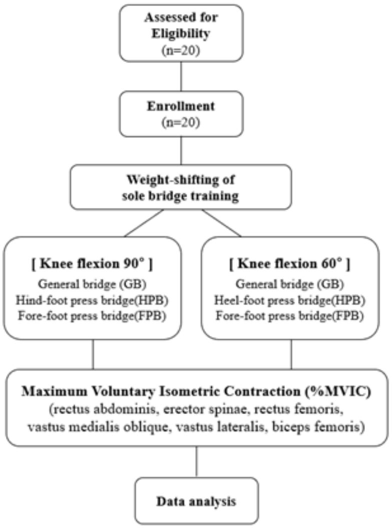

Fig. 1. Schematic representation of the experimental procedure.

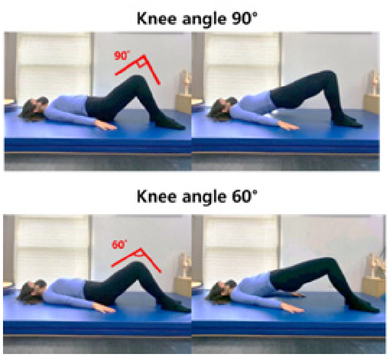

Fig. 2. Bridge exercise (knee flexion 90°/60°).

The experiment included the general bridge without pressing the ground with the sole (GB), hindfoot press bridge while pressing the ground with the hindfoot (HPB), and forefoot press bridge while pressing the ground with the forefoot (FPB). The hindfoot refers to the calcaneus, and the forefoot refers to the metatarsals and phalanges (Fig. 3). The study measured the activity of the lower extremity muscles.

All exercises were repeated three times for five seconds each, and the muscle activity data for three seconds except for one second each at the early and late stages were used

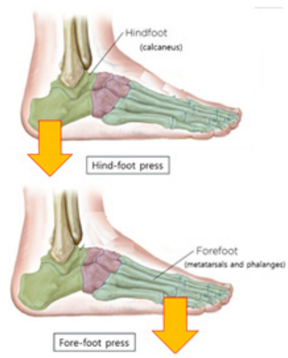

Fig. 3. Weight shifting of the sole.

for analysis. The experimental sequence was randomized using a random number table. A one-minute rest was taken with a five-second interval to prevent muscle fatigue during the exercise. An examiner with more than four years of experience as a trainer and who received training in measuring equipment conducted all measurements.

2) Pressing bridge exercise

Before starting the experiment, the ground pressing exercise that changed the weight shifting of the sole was performed for pre-adaptation. The exercise had the same posture as the starting position of the bridge exercise; the foot was placed on the balance pad, and the knee was bent at 90° and 60°.

The examiner controlled the ankle angle with a goniometer and instructed the participant to press the balance pad (BALANCE PAD, AIREX, Switzerland) as much as possible with the forefoot or hindfoot to measure the depth of pressing. The average value of the balance pad depth was calculated by repeating it three times for more than five seconds to increase the reliability of the measured values [10]. The exercise was performed for each knee angle 10 times for 30 minutes. A three-minute rest was provided between each measurement to prevent muscle fatigue.

3. Equipment

The study used a Delsys Trigno Wireless EMG (Delsys

Table 2. Placement Position of the Electrode on Each Muscle

		Muscle placement position
Lower extremity	biceps femoris	at 50% on the line between the ischial tuberosity and the laterality and the lateral epicondyle of the tibia.
	rectus femoris	at 50% on the line from the anterior spina iliac superior to the superior part of the patella
	vastus medialis oblique	at 80% on the line between the anterior spina iliac and the joint space in front of the anterior border of the medial ligament.
	vastus lateralis	at 2/3 on the line from the anterior spina superior to the lateral side of the patella.

Trigno Wireless EMG, Delsys Inc., U.S.A) operating wirelessly.

The sampling rate of the EMG signal was set to 1000 Hz, with a band stop filter of 60 Hz and a bandpass filter of 10-500 Hz. All signals were treated with the root mean square (RMS). All electrodes for surface electromyography were attached to the subject's dominant muscle in parallel with the direction of the muscle fiber [11]. The body hair on the attachment sites was removed using a disposable razor to reduce the skin resistance to the surface EMG signal. The electrode was placed after wiping the attachment sites with an alcohol swab to remove body oil [12]. Four muscles of the lower extremity muscles (biceps femoris, rectus femoris, vastus medial muscle, and vastus lateralis muscles) were measured to investigate the difference in muscle activity according to the changes in knee angle and weight shifting of the sole during the bridge exercise. The attachment used the method suggested by the SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscle). Table 2 lists the electrode attachment sites.

For the activity of each muscle, the maximal voluntary isometric contraction (%MVIC) was measured to normalize the EMG signals. For each measurement posture, the biceps femoris, rectus femoris, vastus medial muscle, and vastus lateralis muscles were measured individually using the manual muscle test [13]. The study normalized and analyzed the maximum voluntary isometric contraction percentage (% maximal voluntary isometric contraction, %MVIC) with the mean value of the muscle activity data for the middle three seconds, excluding one second at the beginning and the end, among the values measured for five seconds after the start command. A three-minute rest was provided between each measurement to prevent muscle fatigue of the subjects [14].

4. Statistical data analysis

The study analyzed the general characteristics of the subjects by calculating the mean and standard deviation using descriptive statistics. The difference in the activity according to the changes in the knee angle (90° and 60°) and weight shifting of sole conditions (GB, HPB, and FPB) during the bridge exercise was compared using the two-way repeated measurement ANOVA. In the case of knee angle and weight shifting of the sole conditions having an interaction effect, an independent t-test and one-way ANOVA with Bonferroni's correction were performed. The Statistical Package for the Social Science (SPSS version 25, IBM Corporation, USA) was used at the .05 significance level (α).

Ⅲ. RESULTS

1. Results of muscle activity of the rectus femoris

In the rectus femoris, the GB, HPB, and FPB at the

Table 3. Results of Repeated Measure Two-way ANOVA for Lower Extremity Muscles EMG According to the Changes in knee Angle and Weight Shifting of the Sole

muscle	knee angle	foot condition			Source	p-value
		GB	HPB	FPB		
RF	90°	7.84 ± 3.86	10.10 ± 4.38[a]	10.29 ± 4.38[a]	knee flexion	.271
					weight-shifting	.001*
	60°	7.96 ± 2.41	8.86 ± 2.42[a]	9.76 ± 3.4[a]	knee flexion xweight-shifting	.100
VMO	90°	18.73 ± 9.96	25.43 ± 10.48[a]	27.30 ± 14.21[a]	knee flexion	.700
					weight-shifting	.010*
	60°	19.71 ± 9.71	23.96 ± 10.92[a]	25.44 ± 11.96[a]	knee flexion xweight-shifting	.576
VL	90°	12.32 ± 4.19	17.97 ± 5.26[a]	20.96 ± 8.28[a]	knee flexion	.596
					weight-shifting	.000*
	60°	13.43 ± 7.77	16.34 ± 9.7[a]	18.83 ± 9.02[a]	knee flexion xweight-shifting	.117
BF	90°	21.06 ± 12.15[bc]	36.32 ± 21.04[ac]	51.75 ± 31.79[ab]	knee flexion	.000*
					weight-shifting	.000*
	60°	38.02 ± 18[†bc]	49.94 ± 26.9[†ac]	57.75 ± 29[†ab]	knee flexion xweight-shifting	.049*

Mean ± Standard deviation (%MVIC), RF: rectus femoris, VMO: vastus medialis oblique, VL: vastus lateralis, BF: biceps femoris

Knee angle: Knee flexion 90°, Knee flexion 60°, Weight-shifting: GB- general Bridge, HPB- Hind-foot Press Bridge, FPB- Fore-foot Press Bridge

Weight-shifting: GB- general bridge, HPB- hindfoot press bridge, FPB- fore-foot press bridge, †Statistically significant at knee flexion ($p < .05$)

[a,b,c]Significant difference with GB, HPB, FPB ($p < .05$), *: Statistically significant at the level of $p < .05$.

knee angle of 90° ($F(1.4, 26.1) = 10.91$, $p < .01$) and 60° ($F(2, 38) = 6.2$, $p < .01$) showed a statistically significant difference in the order of GB < HPB, FPB. There was no significant difference between the two knee angles and no significant difference in the interaction effect of the knee angle and the weight shifting of the sole ($p > .05$).

2. Results of muscle activity of the vastus medialis oblique

In the vastus medialis oblique, GB, HPB, and FPB at knee angles of 90° ($F(2, 38) = 6.01$, $p < .05$) and 60° ($F(2, 38) = 5.34$, $p < .05$) showed a significant difference in the order of GB < HPB, FPB. No significant difference in the interaction effect of the knee angle and the weight shifting of the sole was observed between the two knee angles ($p > .05$).

3. Results of muscle activity of the vastus lateralis

In the vastus lateralis, the GB, HPB, and FPB at knee angles of 90° ($F(1.2, 22) = 16.75$, $p < .01$) and 60° ($F(2, 38) = 9.06$, $p < .01$) showed a significant difference in the order of GB < HPB, FPB. No significant difference in the interaction effect of the knee angle and the weight shifting of the sole was observed between the two knee angles ($p > .05$).

4. Results of muscle activity of the biceps femoris

In the biceps femoris, GB, HPB, and FPB at knee angles of 90° ($F(1.2, 23.2) = 23.44$, $p < .01$) and 60° ($F(2, 38) = 25.02$, $p < .01$) showed a significant difference in the order of GB < HPB < FPB. The difference in knee angle was statistically significantly higher at 60° than at 90° in GB, HPB, and FPB ($F(1,19) = 30.93$, $p < .05$), and the interaction effect was also significant ($F(1.4, 25.7) = 3.96$, $p < .05$) in Table 3.

Ⅳ. DISCUSSION

These results showed that the weight-shifting bridge exercise increased the activity of the lower extremity muscles more than the general bridge exercise. As the moment arm length of the knee joint angle increased, the increased muscle activity generated a greater torque, playing an important role in optimizing the muscle activation. Hirose and Tsuruike suggested that the knee flexion force should be increased as the horizontal distance from the knee (leverage) to the foot (effort point) increased [15].

Kitamura reported that the forward shift COP resulted in higher loads for the "posterior muscles". In this study, given the change in the increase in difficulty due to weight-shifting of the sole, it can be used as an application of muscle strengthening exercise using the increase in activity of the biceps femoris and the learning process for the vastus medialis and lateralis muscles [16]. Although the angle of the ankle did not change, the increase in the flexion and rotational force of the knee due to the force of pressing the sole appeared to affect the biceps femoris. Some reported the effect of the bridge exercise according to knee joint angle on the lower extremity muscle activity [17]. They found that the quadriceps femoris knee joint angle decreased to 120°, 90°, 60°, and 45°, whereas the biceps femoris the muscle activity increased as the angle was decreased. For the opposite activity, the muscle activity increased with increasing angle. In this study, the quadriceps muscle activity was higher at 90° than at the knee flexion angle of 60° during the selective ground pressing bridge exercise, and the knee flexor activity was higher at 60° than at the knee flexion angle of 90°, showing similar results to the previous studies. The quadriceps femoris is the most important muscle among the muscles around the knee joint and an agonist of the knee joint extension action. It provides stability to the lower extremity, especially the stability of the knee joint when standing or walking [18]. Hortobágyi et al. [19] emphasized the need to improve the control and balance of the biceps femoris and the quadriceps muscles.

Therefore, these results suggest that bridge exercise with weight shifting of the sole could enhance lower extremity stabilization. In addition, this study can provide the basic material necessary to construct selective exercise instructions and programs during bridge exercise.

This study had some limitations. First, because the study subjects were healthy adult females, care should be taken when generalizing the study results to the elderly and people with musculoskeletal disorders. Therefore, future studies should be conducted on the elderly and patients experiencing various clinical symptoms. Second, although the pressing bridge exercise was performed in the pre-experimental training, it was difficult to identify the degree of ground pressing during the experiment because of a lack of appropriate measurement tools, which calls for future studies. Third, the activity of the muscle around the ankle, which might be affected by the weight-shifting bridge exercise, was not measured. Moreover, it was impossible to consider all the muscles involved during the bridge exercise. Future studies will need to identify various relevant muscles and their changes when applying an intervention for 3~4 weeks.

Ⅴ. CONCLUSION

Weight shifting of the sole during the bridge exercise can be more effective in increasing the activation of the lower extremity muscles than general bridge exercises.

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References

[1] Kisner C, Colby LA. Therapeutic Exercise: Foundations and Techniques (4th ed). Philadelpia. F.A. Davis Company. 2002.

[2] Stuart M McGill, Sylvain Grenier, Natasa Kavcic, et al. Coordination of Muscle Activity to Assure Stability of the Lumbar Spine. J Electromyogr Kinesiol. 2003;13(4):353-9.

[3] CA Richardson, GA Jull. Muscle Control-Pain Control. What Exercises Would You Prescribe?. Man Ther. 1995. 1(1):2-10.

[4] Shumway-Cook A, Anson D, Haller S. Postural sway biofeedback: Its effect on reestablishing stance stability in hemiplegic patients. Arch Phys Med Rehabil. 1988;69(6):395-400.

[5] Gyeongseok Yu. Influence of the Knee Angles on the Electromyographic Activities and Fatigue of the Ankle Muscles in Healthy Subjects. Master’s degree. Yong-in University. 2005.

[6] Kim kyung-hwan, Rae-Joon Park, Jang Jun Hyeok, et al. The Effect of Trunk Muscle Activity on Bridging Exercise According to the Knee Joint Angle. J Korean Soc Phys Med. 2010;5(3):405-12.

[7] Choi jung-tae. Effects of bridge exercise with different ankle joint angles on trunk and lower limbs muscles’ activities. Master’s degree. Korea University. 2015.

[8] Jung Moon-Kyun, Kyung-Hwan Kang. The effect of bridge exercise with pressing ground on activation of lower body muscle and trunk muscle. Journal of Sport and Leisure Studies. 2017;68:593-600.

[9] Hong young-joo, Oh-yun Kwon, Chung-hwi Yi, et al. Effects of the support surface condition on muscle activity of abdominalis and erector spinae during bridging exercises. PTK 2010;17(4):16-25.

[10] Jung KS, Kim YS, In TS. Effects of the support surface condition on muscle activity of trunk muscles during balance exercises in patients with stroke. JKPT. 2015;27(4):196-200.

[11] Cram, Jeffrey R, Glenn S, et al. Introduction to surface electromyography (1st ed). Aspen publishers, 1998.

[12] Hermens HJ, B Freriks, C Disselhorst-Klug, et al. Development of recommendations for semg sensors and sensor placement procedures. J Electromyogr Kinesiol. 2000;10(5):361-74.

[13] FP Kendall, EK McCreary, PG Provance, et al. Muscle testing and function with posture and pain (5th ed). Philadelphia. Lippincott Williams & Wilkins Publisher. 2005.

[14] D’hooge R, Hodges P, Tsao H, et al. Altered trunk muscle coordination during rapid trunk flexion in people in remission of recurrent low back pain. J Electromyogr Kinesiol. 2013;23(1):173-81.

[15] Hirose, Norikazu, Masaaki Tsuruike. Differences in the electromyographic activity of the hamstring, gluteus maximus, and erector spinae muscles in a variety of kinetic changes. J Strength Cond Res. 2018;32(12): 3357-63.

[16] Tetsuro Kitamura, Akira Kido, Yukako Ishida, et al. Muscle activity pattern with a shifted center of pressure

during the squat exercise. J Sports Sci Med. 2019;18(2):248-52.

[17] Kim Kyung-hwan, Kyong-il Ki, Hye-jin Yoon. The effect of lower extremity muscle activity on bridging exercise according to the knee joint angle. KPNFA. 2011;9(1):21-9.

[18] GL Soderberg, TM Cook. An electromyographic analysis of quadriceps femoris muscle setting and straight leg raising. Phys Ther. 1983;63(9):1434-8.

[19] Tibor Hortobágyi, Lenna Westerkamp, Stacey Beam, et al. Altered hamstring-quadriceps muscle balance in patients with knee osteoarthritis. Clin Biomechanics (Bristol, Avon). 2005;20(1):97-104.