

## Effects of the Support Surface Condition on Muscle Activity of Abdominalis and Erector Spinae During Bridging Exercises

**Young-ju Hong, B.H.Sc., P.T.**

Dept. of Rehabilitation Therapy, The Graduate School, Yonsei University

**Oh-yun Kwon, Ph.D., P.T.**

**Chung-hwi Yi, Ph.D., P.T.**

**Hye-seon Jeon, Ph.D., P.T.**

Dept. of Physical Therapy, College of Health Science, Yonsei University

**Jong-hyuck Weon, Ph.D., P.T.**

Dept. of Rehabilitation, Wonju Christian Hospital, Yonsei University

**Kyue-nam Park, M.Sc., P.T.**

Dept. of Rehabilitation Therapy, The Graduate School, Yonsei University

### Abstract

The aim of this study was to determine the muscle activity of the abdominalis and erector spinae during bridging and unilateral bridging exercises on the firm surface, the sit-fit, and the foam roll. Eighteen healthy young subjects were recruited for this study. Surface electromyographic (EMG) activities were recorded from the both sides of the rectus abdominalis, external obliques, internal obliques, and erector spinae muscles during bridging and unilateral bridging exercises. A one-way repeated analysis of variance was used to compare the EMG activity of each muscle according to the support surface condition. Differences in the EMG activities between the bridging and unilateral bridging exercises, and between the right and left side were assessed using a paired t-test. The study showed that the EMG activities of all of the muscles were significantly higher when the bridging exercise was performed using the foam roll or sit-fit than on the firm surface. The EMG activities of the right rectus abdominis, right external obliques, the right internal oblique, and both erector spinae were significantly higher during unilateral bridging exercise using the foam roll or the sit-fit than on the firm surface. The EMG activities of all of the muscles were significantly higher during the unilateral bridging exercise than during the bridging exercise. Based on these findings, performing the unilateral bridging exercise using the sit-fit or the foam roll is a useful method for facilitating trunk muscle strength and lumbar stability.

**Key Words:** Abdominal muscles; Bridging exercise; Electromyography; Erector spinae; Trunk stabilization exercise; Unstable support surface.

### Introduction

Low back pain (LBP) is common, with 60%~90% of the adult population being at risk of developing LBP at some point in their lifetime (Smeal et al, 2004). Of those who develop acute LBP, 30% develop chronic LBP (Khadilkar et al, 2005), which has a significant impact on functional status and occupational activities, and marked socioeconomic repercussions (Hagen et al,

2000; Philadelphia Panel, 2001; Strand et al, 2002). Chronic LBP is the most frequent cause of workers' compensation claims and a major reason for visits to healthcare professionals (Philadelphia Panel, 2001).

The trunk muscles provide core stability to the trunk, which allows the trunk to maintain a static posture even under the influence of destabilizing external torques (Akuthota and Nadler, 2004). LBP is caused by instability of the lumbar segment with

weakness of the trunk stabilizer muscles, and a lack of back muscle endurance (Hall and Brody, 2005; Neumann, 2002). Poor coordination of the muscle corset around the lumbar spine may also contribute to LBP (Andersson et al, 1997; Cholewicki and VanVliet, 2002). Panjabi (1992) introduced an innovative model of a spinal stabilization system. Spine stability is dependent on three subsystems: passive (spinal column), active(spinal muscles), and control (neural control). Lumbar spine stability can be achieved via coordinated force feedback from both the active and the passive structures, with appropriate levels of activation to the contracting muscles in order to balance any destabilizing force (Kavcic et al, 2004). It is therefore essential that stability is precisely controlled by lumbar and abdominal muscles to produce the stiffness required to optimize the loading on the lumbar spine, and to prevent overload injury (Arokoski et al, 2004). Lumbar stability is increased with abdominal and paraspinal muscle coactivation, which increases intra-abdominal pressure and produces an abdominal spring force (McGillet et al, 2003). The abdominal muscles serve as a vital component of the core. The internal oblique (IO) has a similar fiber orientation to the transverse abdominis, thus increasing the intra-abdominal pressure together with the transverse abdominis. Thus, the IO imparts functional stability to the lumbar spine (McGill, 2002). The external oblique (EO), the largest and most superficial of the abdominal muscles, acts as an evaluator of anterior pelvic tilt. It is recruited to enhance spine stability, generating lateral bending and twist torque of the trunk (Pool-Goudzwaard et al, 1998). The rectus abdominis (RA) is a paired, strap-like muscle of the anterior abdominal wall contraction of which predominantly causes flexion of the lumbar spine. The erector spinae (ES) in the lumbar region act on the lumbar spine via a long tendon that is attached to the pelvis. Contraction of the ES extends the trunk, a movement that is controlled largely by the opposing activity of the RA muscles. The role of the multisegmental back muscle is to

provide general trunk stabilization and to balance external loads, thereby helping to minimize the forces acting on the spine (Ebenbichler et al, 2001). The function and coordination of the muscles that stabilize the lumbar spine are often impaired in patients with LBP (Cholewicki and VanVliet, 2002).

During the past decade, many physical therapy rehabilitation interventions have been used in the management of LBP (Khadilkar et al, 2005). Exercises are effective in decreasing the intensity of LBP and the associated functional disability, and in improving back extension strength, mobility, and endurance (Hubley-Kozey and Vezina, 2000). Recently the focus of lumbar stabilization exercises has been on protecting the spinal joint structure from further repetitive microtrauma and restoring dynamic stability to the trunk (Stevens et al, 2006). The lumbar stabilization exercises include the so-called dying bug, quadruped, pelvic tilt, abdominal hollowing, and bridging exercises (Barnett and Gilleard, 2005; Hubley-Kozey and Vezina, 2002). The bridging exercise is commonly used for improving lumbopelvic stabilization. It is a comfortable and typically painless posture for improving the coordination of the trunk muscles (Hyde and Gengenbach, 2007; Lehman et al, 2005; Stevens et al, 2006). The use of unstable support surfaces increases muscle activity and coactivation for trunk and lumbar stability (Vera-Garcia et al, 2000). Unstable support surfaces such as gym balls, rollers, wobble boards, slings, and disks are often used for stability exercises (Akuthota and Nadler, 2004). According to a study by Marshall and Murphy (2005), performing tasks on a Swiss ball leads to the abdominal and spinal muscle activities being higher than those on a stable surface (Vera-Garcia et al, 2000). However, the Swiss ball has been the only type of unstable surface examined in previous studies. Trunk and ES EMG activities were recently investigated during bridging stabilization exercises, ball bridging exercises, and bridging exercises with leg movements (Stevens et al, 2006).

However, the EMG activities of the abdominal

muscles and ES during bridging and unilateral bridging exercises under different support surface conditions were not analyzed. Therefore, in the present study determined the effects of three different surface conditions (firm surface, sit-fit, and foam roll) on abdominal muscles and ES EMG activities during bridging and unilateral bridging exercises. We hypothesized that performing unilateral bridging exercise on the sit-fit and foam roll would increase the abdominal muscles and ES EMG activities compare with performing bridging exercise on the firm surface.

## Methods

### Subjects

A cohort of eighteen healthy young subjects (9 men and 9 women) without neurological, musculoskeletal, or cardiopulmonary diseases, or back or lower-limb pathology were recruited from the department of physical therapy, Yonsei University, Korea (Table 1). The subjects were assessed for their ability to perform the bridging exercise and unilateral bridging exercise without pain. To perform the unilateral bridging exercise, the dominant leg was identified as the leg chosen to forcefully strike a soccer ball (John and Matthew, 2010). The right side of legs was dominant in all subjects. Prior to the study, the principal investigator explained all of the procedures to the subjects in detail, and obtained their written informed consent to participate.

### Instruments

EMG data were collected using a Noraxon TeleMyo 2400 system<sup>1)</sup> and analyzed using MyoResearch Master Edition 1.06 XP software. The skin was prepared by shaving the hair and then rubbing it with sandpaper and an alcohol/water solution to decrease the skin impedance. Surface electrode pairs and the adhesive skin interfaces were separated by 2 cm. The reference electrode was attached to the right anterior superior iliac spine (ASIS).

The eight electrode sites on both sides were as follows: the RA (parallel to approximately 3 cm lateral and superior to the umbilicus, arranged along the longitudinal axis, over the muscle belly), IO (halfway between the ASIS of the pelvis and the midline, just superior to the inguinal ligament), EO (halfway between the ASIS of the pelvis and the inferior border of the rib cage at a slightly oblique angle, running parallel to the underlying muscle fibers), and lumbar ES (parallel to the spine, approximately 2 cm lateral to the L4~L5 spinous process for the lumbar ES, over the muscle belly) (Cram et al, 1998).

The raw signal was full-wave rectified and filtered using a Lancosh FIR digital filter. The band-pass filter was set between 20 and 500 Hz and the notch filter at 60 Hz. The sampling rate was 1000 Hz. The EMG data were processed into the root mean square (RMS) value, which was calculated from 300-ms windows of data points. For normalization of the EMG data, the mean RMS of three trials of 5-second maximal voluntary isometric contractions (MVICs) was calculated for each muscle. The manual muscle testing positions selected for the MVIC were those recommended by Kendall et al, (2005). For the testing of the bridging and unilateral bridging exercises, the EMG signal was collected for 5 seconds while the subject's pelvis was maintained level with the hip in a neutral position. The data for each trial are expressed as a percentage of the MVIC (%MVIC), and the mean value of three trials was used for analysis.

### Procedures

The exercises were performed using three different support surfaces: firm surface, sit-fit, and round

**Table 1.** General characteristics of subjects (N=18)

Characteristics	Mean±SD	Range
Age (yrs)	23.2±2.1	21~26
Body mass (kg)	61.3±9.9	46~81
Height (cm)	170.6±9.2	156~190

1) Noraxon TeleMyo 2400T, Noraxon Inc., Scottsdale, AZ, U.S.A.



**Figure 1.** Surface conditions. A: Firm surface, B: Sit-fit, C: Foam roll.

foam roll (Figure 1). The height of the 14 cm diameter foam roll was matched with the firm surface and sit-fit height. The subjects laid supine on the floor with their feet flat on the experimental surface. All subjects attended an orientation (practice) session that lasted at least 30 minutes before testing to familiarize themselves with the bridging and unilateral bridging exercises using the different support surface conditions. The start position of all exercises was hook-lying with the feet flat on the support surface. The positions of both the subject and the equipment were standardized by placing markers on the floor. Tests were performed in a random order. The bridging position was held for five seconds, and three trials were performed for each exercise. A 30-second rest period was allocated between the trials, and a 3-minute rest period was allocated between the different support surface conditions.

### **Bridging Exercise**

The subjects assumed a supine position on the floor with the head, upper trunk, and pelvis in a straight line. The knees were bent to  $60^\circ$  and the hands were placed onto the chest. The feet were placed shoulder-width apart on the support surface being tested. The subjects lifted their pelvis until the hip joint reached a neutral position (Figure 2). At the beginning of each exercise, a neutral lumbar spine position was determined by the examiner and the subjects were encouraged to hold this position during the course of the exercise. Feedback from the examiner was given in order to achieve a consistent spine and lower-limb posture during the bridging exercise.

### **Unilateral Bridging Exercise**

This testing procedure was similar to that of the

bridging exercise, except that the right knee joint was extended during the bridging exercise position (Figure 3), and also took place using the three different support surfaces. The target bar was placed at the level of  $0^\circ$  of knee extension, and subjects were instructed to extend their knee without hip adduction, abduction, or pelvic tilt until the tiptoe region of the right side touched the target bar.

### **Statistical Analysis**

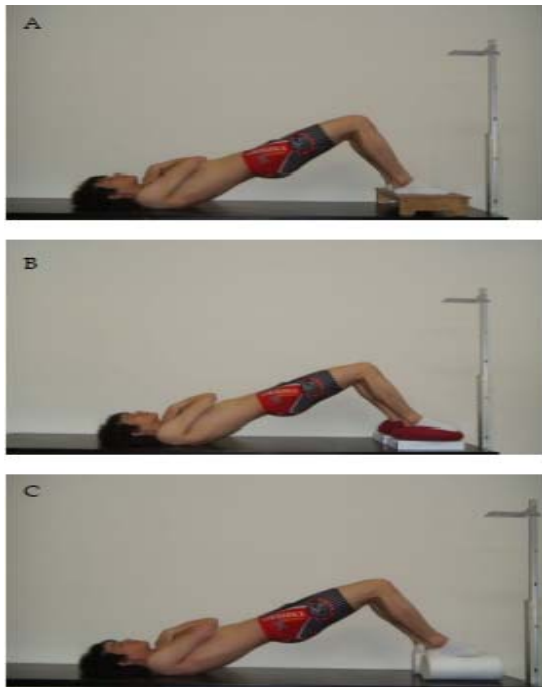
The data are expressed as mean $\pm$ standard deviation (SD) values. Repeated oneway analysis of variance (ANOVA) was used to compare the EMG activities of the abdominalis and ES according to the support surface condition. The Bonferroni's post-hoc test was used to determine the differences in EMG activities of the abdominalis and ES between the different support surface conditions. The significance of differences in the EMG activity between the bridging and unilateral bridging exercises, and between the right side and left side were assessed using a paired t-test. Data analysis was performed using SPSS version 12.0 software, and the level of statistical significance was set at .05.

## **Results**

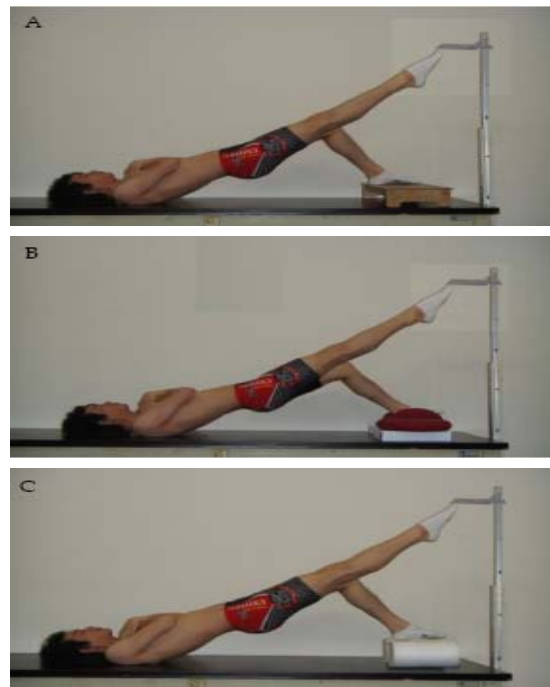
The EMG activities of all of the abdominalis and the ES differed significantly among the different support surfaces during the bridging exercise ( $p < .05$ ) (Table 2).

### **Comparison of EMG activities according to the support surface conditions during the bridging exercise**

Post-hoc testing revealed that the EMG activities of



**Figure 2.** Bridging exercise under the three different support surface conditions. A: Firm surface, B: Sit-fit, C: Foam roll.



**Figure 3.** Unilateral bridging exercise under the three different support surface conditions. A: Firm surface, B: Sit-fit, C: Foam roll.

both RAs, both EOs, and the right IO were significantly higher when performing the bridging exercise using the foam roll than when using the sit-fit. The EMG activities of both EOs, both IOs, and both ESs when performing the bridging exercise were significantly higher when using the foam roll than when using the firm surface. None of the muscle EMG activities when performing the bridging exercise differed significantly between using the firm surface and the sit-fit.

**Comparison of EMG activities according to the support surface conditions during the unilateral bridging exercise**

The EMG activities of the right RA, right EO, right IO, and both ESs differed significantly among the different support surfaces during the unilateral bridging exercise ( $p < .05$ ) (Table 2). Post-hoc testing revealed that the EMG activities of the left RA, both EOs, and the right IO when performing the unilateral bridging exercise were significantly higher when using the foam roll than

when using the sit-fit. The EMG activities of the right EO, right IO, and both ESs when performing the unilateral bridging exercise were significantly higher when using the foam roll than when using the firm surface. The EMG activity of the left ES when performing the unilateral bridging exercise was significantly higher when using the sit-fit than when using the firm surface ( $p < .05$ ). The EMG activity of each individual muscle was significantly higher during the unilateral bridging exercise than during the bridging exercise ( $p < .01$ ) (Table 2).

**Comparison of EMG activities between the right and left sides during the bridging exercise**

There was no significant difference in the EMG activity of each muscle between the right and the left sides during the bridging exercise (Table 3).

**Comparison of EMG activities between the right and left sides during the unilateral bridging exercise**

**Table 2.** Comparison of EMG activities according to the support surface conditions during the bridging and unilateral bridging exercise

Muscle	Bridging				Unilateral bridging			
	Firm Surface	Sit-Fit	Foam Roll	F	Firm Surface	Sit-Fit	Foam Roll	F
RRA	4.38±3.42 <sup>a</sup>	4.90±4.54	6.42±6.00	3.89	17.16±13.64	21.84±19.67	25.35±22.91	5.75*
LRA	4.30±3.48	4.40±3.42	6.69±6.29	5.53*	9.72±7.29	10.92±9.45	13.08±11.38	3.15
REO	4.96±4.20	5.60±3.78	8.72±6.98	10.21*	19.20±11.12	23.19±12.37	27.40±12.68	10.82*
LEO	5.60±4.06	5.93±3.62	9.93±7.22	10.82*	20.32±13.49	21.82±11.48	26.25±14.62	2.85
RIO	5.03±4.07	6.80±6.70	11.44±10.53	6.71*	32.09±22.70	37.55±23.83	46.38±27.64	7.35*
LIO	5.91±4.11	7.97±6.82	13.86±12.06	7.96*	26.13±21.82	31.61±22.15	37.46±27.23	3.21
RES	31.02±10.77	34.55±8.86	35.74±9.08	5.36*	3.15±14.43	50.11±11.99	52.90±11.25	10.31*
LES	32.27±10.14	35.35±8.01	37.25±7.76	7.66*	39.95±11.82	44.82±9.13	47.31±8.57	11.51*

<sup>a</sup>Mean±SD, \*p<.01.

R.:right, L.:left, RA: rectus abdominis, EO: external oblique, IO: internal oblique, ES: erector spinae.

**Table 3.** Comparison of EMG activities between the right and left sides during the bridging exercise and unilateral bridging exercise

Type of exercise	Muscle		Firm Surface	t	Sit-Fit	t	Foam Roll	t
Bridging exercise	RA	Rt	4.38±3.42 <sup>a</sup>	.16	4.90±4.54	.69	6.42±6.00	-.31
		Lt	4.30±3.48		4.40±3.42		6.69±6.29	
	EO	Rt	4.96±4.20	-1.06	5.60±3.78	-.56	8.72±6.98	-1.51
		Lt	5.60±4.06		5.93±3.62		9.93±7.22	
	IO	Rt	5.03±4.07	-1.26	6.80±6.70	-1.73	11.44±10.53	-1.28
		Lt	5.91±4.11		7.97±6.82		13.86±12.06	
	ES	Rt	31.02±10.77	-1.02	34.55±8.86	-.77	35.74±9.08	-1.36
		Lt	32.27±10.14		35.35±8.01		37.25±7.76	
Unilateral bridging exercise	RA	Rt	17.16±13.64	2.81**	21.84±19.67	3.05**	25.35±22.91	3.29**
		Lt	9.72±7.29		10.92±9.45		13.08±11.38	
	EO	Rt	19.20±11.12	-.74	23.19±12.37	.74	27.40±12.68	.50
		Lt	20.32±13.49		21.82±11.48		26.25±14.62	
	IO	Rt	32.09±22.70	1.73	37.55±23.83	1.49	46.38±27.64	1.95
		Lt	26.13±21.82		31.61±22.15		37.46±27.23	
	ES	Rt	43.15±14.4	2.12*	50.11±11.99	2.30*	52.90±11.25	2.10
		Lt	39.95±11.82		44.82±9.13		47.31±8.57	

<sup>a</sup>Mean±SD, \*p<.05, \*\*p<.01.

RA: rectus abdominis, EO: external oblique, IO: internal oblique, ES: erector spinae.

However, when performing the unilateral bridging exercise the EMG activity of the right RA was significantly higher than that of the left RA in all three

support surface conditions. The EMG activity of the right ES was also significantly higher than that of the left ES when performing the unilateral bridging ex-

ercise using the firm surface and the sit-fit (Table 3).

## Discussion

The stability of the lumbar spine requires both the passive stiffness provided by the osseous and ligamentous structures, and the active stiffness provided by muscles that are under the motor control of the central nervous system (Ebenbichler et al, 2001; McGill et al, 2003). The spinal structure plays a role, but damage to the spinal segments can be compensated by proper muscular function and adequate neural control, which is why exercise training is the mainstay of treatment to improve stabilization of the spine (Barr et al, 2005). Thus, trunk stabilization exercises are often used in the rehabilitation of individuals with LBP. Unstable surfaces have been commonly incorporated into trunk strengthening exercise regimes and recommended as a means of more effectively training the stability of the musculoskeletal system (Behm et al, 2005; Lehman et al, 2005). Numerous studies have documented increased trunk muscle activity during a variety of trunk muscle exercises on unstable surfaces such as gym balls, rollers, wobble boards, slings, and disks (Arokoski et al, 2001; Lehman et al, 2005; Mori, 2004; Stevens et al, 2006; Vera-Garcia et al, 2000).

The effects of three different support surface conditions on abdominalis and ES muscle activities during bridging and unilateral bridging exercises were examined in the present study. The EMG activities of both RAs, both EOs, and the right IO when performing the bridging exercise were significantly higher when using the foam roll than when using the sit-fit. In addition, the EMG activities of the both EOs, and both IOs when performing the bridging exercise using the foam roll were approximately two times higher than when using the firm surface. The EMG activities of the contralateral RA, both EOs, and ipsilateral IO when performing the unilateral bridging exercise were significantly higher when using

the foam roll than when using the sit-fit. Those of the ipsilateral EO, ipsilateral IO, and both ESs when performing the unilateral bridging exercise were significantly higher when using the foam roll than when using the firm surface. The EMG activity of the contralateral ES was significantly higher during the same exercise when using the sit-fit than when using the firm surface. The findings of this study thus demonstrate that when performing the bridging and unilateral bridging exercises, the EMG activities of the abdominalis and ES were significantly higher when using the sit-fit and foam roll (unstable surfaces) than when using the firm surface (stable surface). These increased abdominalis and ES EMG activities when using an unstable surface are in accordance with the findings of Arokoski et al (2001) and Vera-Garcia et al (2000). Vera-Garcia and his colleagues (2000) reported that the EMG activities of both RAs, EOs, and IOs were higher when performing exercises on a gym ball than when using a stable surface. This increased EMG activity was attributed to the increased need for spine and whole-body stability in order to reduce the threat of falling off the unstable surface. A more unstable support area requires more muscle activity to maintaining balance.

In the present study, the EMG activities of all of the abdominalis when performing bridging exercise were significantly higher when using the foam roll than when using the sit-fit. There are several possible explanations for this finding. First, the cylindrical shape of the foam roll provides a smaller contact area on the floor and moves easily from side to side; therefore, more challenging balancing reactions are required during bridging exercise when using foam roll than when using the sit-fit, with its flat lower surface (i.e. normal to the floor) (Creager, 2006). Second, the contact area between the subject's foot and the support surface of the foam roll is smaller than with the sit-fit. Finally, the smaller contact area between the foot and the foam roll may have resulted in a reduced somatosensory input, and thus a concomitant reduction in feedback, possibly causing

an increase in the EMG activities of the abdominalis (Shumway-Cook and Woollacott, 2001).

In this study, the EMG activities of the abdominalis and ES were significantly higher during the unilateral bridging exercise than during the bridging exercise. The contact area between the subject's feet and the support is smaller when performing the unilateral bridging exercise than when performing the bridging exercise. Thus, maintaining a neutral spine without rotation during the unilateral bridging exercise is a more challenging task, requiring more abdominalis contraction than the bridging exercise (Behm and Anderson 2006; Shumway-Cook and Woollacott 2001). Instability is induced not only by unstable surfaces, but also by destabilizing torque such as that resulting from the unbalanced movement of lifting a leg (Behm et al, 2005). Due to the instability of the unilateral bridging exercise, muscle crossing the abdominal area needs to cocontract more to maintain the unilateral bridging exercise without spine rotation, hip flexion, and pelvic tilt than in the bridging exercise. The weight of the lifted leg produces torque about spine rotation, hip flexion, and pelvic tilt. To counterbalance this rotation moment, the RA, EO, and IO muscles of the contralateral side contract to maintain trunk stability (Pool-Goudzwaard et al, 1998). This instability can be overcome by cocontraction of the abdominalis not by contraction of a particular muscle. Spinal stability can be maintained during the unilateral bridging exercise only by elevating the intra-abdominal pressure by simultaneously contracting all of the trunk muscles (Ebenbichler et al, 2001).

The major finding of this study was that the EMG activity of the right RA was significantly higher than that of the left RA during the unilateral bridging exercise in all three support surface conditions. In addition, the EMG activity of the right ES was significantly higher than that of the left ES during the unilateral bridging exercise using both the firm surface and the sit-fit. Both the RA and the EO muscles play a role in stabilizing the trunk and

pelvis (Mori, 2004). The EOs stabilize the trunk by preventing mediolateral rotation as a result of their attachment to the thoracolumbar fascia. On the other hand, the RA muscles have a more longitudinal action on the trunk, and are a better stabilizer of anteroposterior tilting of the pelvis (Neumann, 2002). Performing the unilateral bridging exercise activated the right RA, and the right ES, because the subjects were asked to maintain the static equilibrium of the body during the unilateral bridging exercise.

The weight of the lifted leg causes a hip extension moment. This should be counterbalanced by the activation of the hip flexors to maintain the neutral position of trunk. Increased hip flexor muscle activation will cause anterior pelvic tilt of the right side. Anterior pelvic tilt is prevented by contraction of the right RA. This may be why the activity of the right RA was greater during the unilateral bridging exercise than during the bridging exercise (Marshall and Murphy, 2005). The activation of the right ES may also be increased to counterbalance the activation of the right RA. The findings of this study should aid the design of new trunk stabilization exercises.

There were some limitations to this study. First, our results cannot be generalized to other populations because all of the subjects who participated in the study were healthy and young. Therefore, the effects of surface condition on trunk muscles during stabilizing exercises should be confirmed in a patient population. Second, the activities of the deep muscles that are considered to be trunk stabilizers, such as the transverse abdominis, multifidus, and pelvic floor muscles were not measured.

## Conclusion

The effects of the support surface condition on the EMG activities of the abdominalis and ES during bridging and unilateral bridging exercises were investigated. Overall, these exercises activated the abdominalis and ES more when they were performed



using the sit-fit and foam roll (the unstable surfaces) than when using the firm surface (the stable surface). In addition, the EMG activities of the abdominalis and ES were higher when performing the unilateral bridging exercise than during the bridging exercise.

## References

- Akuthota V, Nadler SF. Core strengthening. *Arch Phys Med Rehabil.* 2004;85:86-92.
- Andersson EA, Nilsson J, Ma Z, et al. Abdominal and hip flexor muscle activation during various training exercises. *Eur J Appl Physiol Occup Physiol.* 1997;75(2):115-123.
- Arokoski JP, Valta T, Airaksinen O, et al. Back and abdominal muscle function during stabilization exercises. *Arch Phys Med Rehabil.* 2001;82(8):1089-1098.
- Arokoski JP, Valta T, Kankaanpää M, et al. Activation of lumbar paraspinal and abdominal muscles during therapeutic exercises in chronic low back pain patients. *Arch Phys Med Rehabil.* 2004;85:823-832.
- Barr KP, Griggs M, Cadby T. Lumbar stabilization: Core concepts and current literature, Part 1. *Am J Phys Med Rehabil.* 2005;84(6):473-480.
- Barnett F, Gilleard W. The use of lumbar spinal stabilization techniques during the performance of abdominal strengthening exercise variations. *J Sports Med Phys Fitness.* 2005;45(1):38-43.
- Behm DG, Leonard AM, Young WB, et al. Trunk muscle electromyographic activity with unstable and unilateral exercises. *J Strength Cond Res.* 2005;19(1):193-201.
- Creager CC. *Therapeutic Exercises using Foam Rollers.* 7th ed. Berthoud, Executive Physical Therapy Inc, 2006.
- Cholewicki J, VanVliet JJ IV. Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions. *Clin Biomech (Bristol, Avon).* 2002;17(2):99-105.
- Cram JR, Kasman GS, Holtz J. *Introduction to surface Electromyography.* Gaithersburg, MD, Aspen Publishers, 1998.
- Ebenbichler GR, Oddsson LI, Kollmitzer J, Erim Z. Sensory-motor control of the lower back: Implications for rehabilitation. *Med Sci Sports Exerc.* 2001;33(1):1889-1898.
- Hagen KB, Holte HH, Tambs K, et al. Socioeconomic factors and disability retirement from back pain: A 1983-1993 population-based prospective study in Norway. *Spine.* 2000;25(19):2480-2487.
- Hall CM, Brody LT. *Therapeutic Exercise: Moving toward function.* 2nd ed. Philadelphia, Lippincott Williams and Wilkins, 2005.
- Hubleby-Kozey CL, Vezina MJ. Muscle activation during exercises to improve trunk stability in men with low back pain. *Arch Phys Med Rehabil.* 2002;83:1100-1108.
- Hyde TE, Gengenbach MS. *Conservative management of Sports Injuries.* 2nd ed. Sudbury MA, Jones and Bartlett Publishers, 2007.
- John R, Matthew KS. An investigation of lower-extremity functional asymmetry for non-preferred able-bodied walking speeds. *Int J Exerc Sci.* 2010;3(4):182-188.
- Kavicic N, Grenier S, McGill SM. Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises. *Spine.* 2004;29(20):2319-2329.
- Kendall FP, McCreary EK, Provance PG, et al. *Muscles: Testing and Function with Posture and Pain.* 5th ed. Baltimore, Lippincott Williams & Wilkins, 2005.
- Khadilkar A, Milne S, Brosseau L, et al. Transcutaneous electrical nerve stimulation for the treatment of chronic low back pain: A systematic review. *Spine.* 2005;30(23):2657-2666.
- Lehman GJ, Hoda W, Oliver S. Trunk muscle activity during bridging exercises on and off a Swiss ball. *Chiropr Osteopat.* 2005;13:14-21.
- Marshall PW, Murphy BA. Core stability exercises

- on and off a Swiss ball. *Arch Phys Med Rehabil.* 2005;86(2):242-249.
- McGill SM. *Low Back Disorders: Evidence-based prevention and rehabilitation.* 2nd ed. Champaign, IL, Human Kinetics, 2002.
- McGill SM, Grenier S, Kavcic N, et al. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kinesiol.* 2003;13(4):353-359.
- Mori A. Electromyographic activity of selected trunk muscles during stabilization exercises using a gym ball. *Electromyogr Clin Neurophysiol.* 2004;44(1):57-64.
- Neumann DA. *Kinesiology of the Musculoskeletal System.* 1st Ed. St. Louis, Mosby, 2002.
- Panjabi MM. The stabilizing system of the spine. Part I Function, dysfunction, adaptation, and enhancement. *J Spinal Disord.* 1992;5(4):383-389.
- Philadelphia Panel. Philadelphia Panel evidence-based clinical practice guidelines on selected rehabilitation interventions for low back pain. *Phys Ther.* 2001;81(10):1641-1674.
- Pool-Goudzwaard AL, Vleeming A, Stoeckart R, et al. Insufficient lumbopelvic stability: A clinical, anatomical and biomechanical approach to 'a-specific' low back pain. *Man Ther.* 1998;3:12-20.
- Shumway-Cook A, Woollacott M. *Motor Control: Theory and practical applications.* 2nd ed. Baltimore, Lippincott Williams & Wilkins, 2001.
- Smeal WL, Tyburski M, Alleva J, et al. Conservative management of low back pain, Part I. Discogenic/radicular pain. *Dis Mon.* 2004;50(12):636-669.
- Strand LI, Moe-Nilssen R, Ljunggren AE. Back performance scale for the assessment of mobility-related activities in people with back pain. *Phys Ther* 2002;82(12):1213-1223.
- Stevens VK, Bouche KG, Mahieu NN, et al. Trunk muscle activity in healthy subjects during bridging stabilization exercises. *BMC Musculoskelet Disord.* 2006;7:75-82.
- Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys Ther.* 2000;80(6):564-569.
- Vezina MJ, Hubley-Kozey CL. Muscle activation in therapeutic exercises to improve trunk stability. *Arch Phys Med Rehabil.* 2000;81(10):1370-1379.
- 
- 
- This article was received September 26, 2010, and was accepted November 2, 2010.