Electromyographic Analysis of Transversus Abdominis and Lumbar Multifidus Using Wire Electrodes During Lumbar Stabilization Exercises

Lumbar stabilization exercises (LSEs) are commonly used for the treatment of low back pain and improvement of athletic performance. O’Sullivan et al reported that LSEs for patients with lumbar spondylolysis or spondylolisthesis were more effective than conventional conservative treatment. Recently, Rasmussen-Barr et al also demonstrated that LSEs for patients with recurrent low back pain seemed more effective than daily walks in improving disability and health parameters. It has also been documented that LSEs are effective not only for disorders of the lumbar region but also for prevention of lower extremity injuries. Zazulak et al have reported that deficient trunk core stability was a risk factor for anterior cruciate ligament injury in female athletes.

In addition to injury treatment and prevention, LSEs may improve athletic performance. Butcher et al reported that LSEs significantly increased vertical takeoff velocity in athletes. Sato et al also demonstrated the effectiveness of LSEs for improving performance.

Muscle function in the neutral zone is important for stabilization of the lumbar spine. Bergmark classified the trunk muscles into a local and a global system to understand how the muscular system acts on the stability of the lumbar spine. The local muscle system includes the deeper muscles, which have their origin or insertions either directly or indirectly on the lumbar vertebrae. This system directly provides lumbar segmental stabilization. The transversus abdominis and lumbar multifidus are examples of local muscles. The global muscle system includes those muscles that do not directly attach to the lumbar vertebrae, such as the rectus abdominis and external oblique muscles. The global muscles generate a large torque across multiple segments and control trunk movement. It has been reported that increased vertebral stiffness by coactivation of the local and global

**STUDY DESIGN:** Experimental laboratory study.

**OBJECTIVES:** To measure trunk muscle activity using wire electrodes during lumbar stabilization exercises and to examine if more effective exercises to activate the deep trunk muscles (local muscles) exist.

**BACKGROUND:** Lumbar stabilization exercises are performed to improve motor control of trunk muscles. However, the magnitude of activation of local muscles during lumbar stabilization exercises is not clear.

**METHODS:** Nine healthy men with no history of lumbar spine disorders participated in the study. Fine-wire electrodes were inserted into the transversus abdominis (TrA) and lumbar multifidus, bilaterally. In addition, surface electrodes were attached to the rectus abdominis, external obliques, and erector spinae, bilaterally. Electromyographic signal amplitude was measured during the following exercises: elbow-toe, hand-knee, back bridge, side bridge, and curl-up. Two-way analyses of variance were used to compare muscle activity level among exercises and between sides for each muscle.

**RESULTS:** The exercise showing the greatest activity level for the TrA was elbow-toe exercise with contralateral arm and leg lift. In addition, for the TrA, a significant side-to-side difference in activation level was demonstrated for 7 of the 11 exercises that were performed. The activity level of the multifidus was greatest during the back bridge exercises. The curl-up exercise generated the highest activity level for the rectus abdominis and the back bridge, with single-leg lift exercises generating the highest erector spinae activity.

**CONCLUSIONS:** The exercises investigated in this study resulted in a wide range of effort level for all 5 muscles monitored. Many of the exercises also resulted in an asymmetrical (right versus left side) activation level for a muscle, including the TrA. J Orthop Sports Phys Ther 2010;40(11):743-750. doi:10.2519/jospt.2010.3192

**KEY WORDS:** EMG, erector spinae, low back, lumbar spine

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muscles is important in improving the stability of the lumbar spine. Although conventional trunk muscle training has focused mainly on global muscles, LSEs are intended to train the motor control of both the local and global muscles.

LSEs include various procedures such as abdominal-hollowing, pelvic-tilting, and bridge exercises. Bridge and 4-point kneeling exercises are often performed using a combination of posture and support surface changes. These exercises are widely performed in clinical and athletic rehabilitation, and many studies have been conducted to examine their effects. Kavcic et al reported that 4-point kneeling with contralateral arm and leg lift is the most effective exercise for improving trunk stability. Stevens et al reported that coactivation of the trunk and hip muscles was observed during 4-point kneeling exercise. It has also been reported that performing curl-up on an unstable surface using a Swiss ball increases abdominal muscles activity, and that coactivation of the abdominal muscles was observed with machine training using the Torso Track or Ab Slide.

However, few studies have examined deep trunk muscle activity during LSEs using intramuscular electromyographic (EMG) electrodes. Because the purpose of LSEs is to train motor control of local muscles, it is necessary to determine the type of LSEs that is effective for promoting local muscle activity. The purpose of this study was therefore to measure trunk muscle activity during LSEs using a combination of superficial and wire electrodes, and to determine if there are exercises that are more effective to activate local muscles in contrast to global muscles.

METHODS

Subjects

INE HEALTHY MEN (MEAN ± SD age, 24.1 ± 0.8 years; height, 170.4 ± 4.8 cm; body mass, 62.2 ± 4.6 kg), without low back pain at the time of the experiment, participated. Exclusion criteria included history of lumbar spine disorder, neurological disorder, or spinal surgery. All subjects were former athletes who had previously performed abdominal or back exercises; however, they had not performed regular stabilization exercises. The purpose and protocol of the study was explained and each participant signed an informed consent form prior to participation. The study was approved by the Ethics Committee of the University of Tsukuba.

Electromyography

EMG signal of selected musculature of the trunk was recorded using a combination of intramuscular fine-wire and surface electrodes. EMG signal of the transversus abdominis (TrA) and the lumbar multifidus (MF), bilaterally, was recorded using fine-wire bipolar electrodes fabricated from 2 strands of urethane-coated stainless-steel wire (diameter, 0.05 mm; Unique Medical Co, Ltd, Tokyo, Japan). The fine wire was threaded into hypodermic needles (23 gauge × 60 mm), with 2 mm of urethane removed and tips bent back to form 1- and 2-mm hooks. Wire electrodes were sterilized via autoclave (HighClave HVE-50; Hirayama Manufacturing Corp, Saitama, Japan) at 121°C for 20 minutes. Electrodes were inserted into the TrA (approximately midway between the rib cage and the iliac crest) and MF (approximately 2 cm lateral to the L5 spinous process), bilaterally, under the guidance of ultrasound imaging (FIGURE 1). Once the electrodes reached the targeted muscle, they were stimulated using electrical stimulation, and muscle contraction was confirmed by ultrasound imaging.

Before the surface electrodes were attached, the skin was rubbed with a skin abrasive and alcohol to reduce the skin impedance to below 2 kΩ. Pairs of disposable Ag/AgCl surface electrodes (Vitrode F-150S; Nihon Kohden Corporation, Tokyo, Japan) were bilaterally attached, parallel to the muscle fibers, with a center-to-center distance of 2 cm, to the following muscles: rectus abdominis (RA, 3 cm lateral to the umbilicus), the external obliques (EO, midway between the costal margin of the ribs and the iliac crest, approximately 45° to the horizontal), and erector spinae (ES, 3 cm lateral to the L3 spinous process). A reference electrode was placed over the sternum.

Procedure

For normalization of the EMG data, a maximum voluntary contraction (MVC) was performed for each muscle while the EMG signal was recorded. The MVC for the RA was obtained when doing a partial sit-up with knees flexed and manual resistance applied to the shoulders toward trunk extension. For the EO, the subjects performed an oblique sit-up, attempting to move the resisted shoul-
der toward the opposite flexed knee. The abdominal-hollowing task, performed in a sitting position, was used to establish the MVC of the TrA. The MVC for the MF and ES were obtained with the subjects doing trunk extension in a prone position, with manual resistance applied to the upper thoracic area. Manual resistance was applied gradually, until a maximum effort was reached, then held for 3 seconds. Each MVC test was performed once, with a brief rest between the testing of each muscle.

EMG signal was recorded during the following exercises (Figure 2): elbow-toe, elbow-toe with contralateral arm and leg lift, hand-knee with contralateral arm and leg lift, back bridge, back bridge with single leg lift, side bridge, side bridge with left leg lift, and curl-up. The elbow-toe exercise involved subjects making a prone bridge on their elbows and toes, then horizontally lifting their right arm and left leg. This exercise was also performed with the combination of left arm and right leg. The hand-knee with contralateral arm and leg lift exercise was performed in the 4-point kneeling position, with the subjects lifting the right arm and left leg horizontally. This exercise was also performed with the combination of left arm and right leg. For the back bridge exercise, subjects lifted the pelvis in the supine position until 0° of hip flexion was reached, then extended the right or left leg. The side bridge exercise was performed by supporting the body with the right elbow and foot and lifting the left leg to reach a horizontal position. The curl-up was performed in the supine position, with hands behind the head and the knees flexed to approximately 90°. Subjects lifted their heads and shoulders until their scapulae were off the floor. Each subject practiced each exercise once before the experimental task. Normal breathing patterns were maintained throughout the exercises. For all exercises except the curl-up, subjects were instructed on assuming a neutral lumbar spine position. Once the neutral spine position was reached, the exercise position was held for 3 seconds. Subjects were allowed to rest for about 30 seconds between exercises.

**EMG Data Analysis**

All EMG signals were amplified 1000 times using an amplifier (MEG-6116, JB-640J; Nihon Kohden Corporation). The sampling frequency was 1,000 Hz. The raw data were band-pass filtered between 20 to 500 Hz and full-wave rectified using analysis software (BIMUTAS-Video; Kissei Comtec Co, Ltd, Nagano, Japan). The root-mean-square was calculated for 1 second, while the posture was stable, during each exercise. The root-mean-square during the exercise was normalized as a percentage of the greatest root-mean-square obtained over a 1-second period during the MVC test (%MVC).
Elbow-toe with right arm and left leg lift
Elbow-toe with right arm and left leg lift
Side bridge
Side bridge
Back bridge with left leg lift
Back bridge with left leg lift
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Hand-knee with left arm and right leg lift
Hand-knee with left arm and right leg lift
Back bridge with single leg lift, and side bridge with left leg lift (P < .05) (FIGURE 3). For the right TrA, the elbow-toe with right arm and left leg lift exercise produced the highest activity level (mean ± SD, 41.8% ± 20.2% MVC). For the left TrA, the elbow-toe with left arm and right leg lift exercise produced the highest activity level (50.6% ± 28.4% MVC). Statistically significant differences for the right and left TrA between these exercises and the remaining 10 are indicated in FIGURE 3.

**Results**

Descriptive data (mean ± SD) for each muscle for each exercise performed in this study are displayed in FIGURES 3 through 7.

**Transversus Abdominis** There was a statistically significant interaction between sides and exercises (P < .001). Pairwise comparisons indicated a significant side-to-side difference in TrA muscle activation for the following exercises: elbow-toe with contralateral arm and leg lift, hand-knee with contralateral arm and leg lift, back bridge with single leg lift, and side bridge with left leg lift (P < .05) (FIGURE 3). For the right TrA, the elbow-toe with right arm and left leg lift exercise produced the highest activity level (mean ± SD, 41.8% ± 20.2% MVC). For the left TrA, the elbow-toe with left arm and right leg lift exercise produced the highest activity level (50.6% ± 28.4% MVC). Statistically significant differences for the right and left TrA between these exercises and the remaining 10 are indicated in FIGURE 3.

**Multifidus** There was no significant interaction between sides and exercises (P = .34). The main effect for the overall difference between right and left side was significant (P < .001). For the exercise main effect, the back bridge with right leg lift exercise produced the highest activity level for the average of the right and left side (mean ± SD, 51.7% ± 34.0% MVC), which was significantly greater than all the other exercises except for the back bridge and back bridge with left leg lift exercises (P < .05, FIGURE 4).

**Rectus Abdominis** There was no significant interaction between sides and exercises (P = .50). The main effect for the overall difference between right and left sides was significant (P < .001). For the exercise main effect, the back bridge with right leg lift exercise produced the highest activity level for the average of the right and left side (mean ± SD, 51.7% ± 34.0% MVC), which was significantly greater than all the other exercises except for the back bridge and back bridge with left leg lift exercises (P < .05, FIGURE 4).
left side was significant \( (P<.001) \). For the exercise main effect, the curl-up exercise produced the highest activity level for the average of the right and left sides (mean ± SD, 43.8% ± 14.3% MVC), which was significantly greater than the other exercises except for the elbow-toe, elbow-toe with right arm and left leg lift, and elbow-toe with left arm and right leg lift exercises \( (P<.05, \text{FIGURE 5}) \).

**External Oblique** There was a significant interaction between sides and exercises \( (P<.001) \). Pairwise comparisons indicated that significant side-to-side differences in EO muscle activation existed for the following exercises: side bridge and side bridge with left leg lift \( (P<.05) \) (FIGURE 6).

For the right EO, the elbow-toe with left arm and right leg lift exercise produced the highest activity level (mean ± SD, 87.0% ± 36.1% MVC). For the left EO, the elbow-toe with right arm and left leg lift exercise produced the highest activity level (mean ± SD, 92.6% ± 43.2% MVC). Statistically significant differences for the right and left EO between these exercises and the remaining 10 are indicated in FIGURE 6.

**Erector Spinae** There was a significant interaction between sides and exercises \( (P<.001) \). Pairwise comparisons indicated that significant side-to-side differences in ES muscle activation existed for the following exercises: the elbow-toe with right arm and left leg lift, back bridge with right leg lift, back bridge with left leg lift, side bridge, and side bridge with left leg lift \( (P<.05, \text{FIGURE 7}) \). For the right ES, the back bridge with right leg lift exercise produced the highest activity level (mean ± SD, 45.0% ± 20.3% MVC). For the left ES, the back bridge with left leg lift exercise produced the highest activity level (mean ± SD, 39.0% ± 16.8% MVC). Statistically significant differences for the right and left ES between these exercises and the remaining 10 are indicated in FIGURE 7.

**DISCUSSION**

We measured trunk muscle activity using intramuscular and surface electrodes during various LSEs to examine which exercise would be most effective to activate each muscle. Some LSEs, such as the abdominal hollowing exercise, are performed with the intent of activating local muscles only without increasing global muscle activity.\(^{29}\) On the other hand, other exercises, such as the bridge exercises, are high-load LSEs that involve recruitment of the local and global muscles. In this study we examined the trunk muscle activity during high-load LSEs. While other researchers have used surface EMG to measure trunk
muscle activity during similar exercises, in this study fine-wire intramuscular electrodes were used for the TrA and MF. The results show that TrA activity was the greatest during the elbow-toe with contralateral arm and leg lift (mean ± SD, 41.8% ± 20.2% MVC for the right TrA and 50.6% ± 28.4% MVC for the left TrA). It is noteworthy that the exercises with arm and leg lift produced asymmetrical activation of the TrA. This finding is consistent with the data by Allison et al, who reported asymmetry of the feed-forward TrA activity during an arm-raising task. These data would indicate that the TrA is activated in an asymmetrical manner during asymmetric LSSEs, which accounted for 7 of the 11 exercises included in the study. Despite their level of difficulty, none of the exercises generated an activation level of the TrA above 60% of its MVC, which was established using an abdominal hollowing exercise. Giving some indications that activation of the TrA may be better achieved through low-load exercises focusing on motor learning and control.

MF activity was the greatest during 3 variations of the back bridge. Ekstrom et al have also documented that MF activity measured by surface EMG was high during a back bridge exercise. The need to extend the spine against gravitational forces when performing a bridge in a supine position likely accounts for this higher activity level. Previous researchers have reported that the MF functions as a lumbar spine extensor and controls lumbar segmental stability, 2 functions likely required during the back bridge exercises.

RA activity was the greatest during the curl-up exercise. Other researchers have documented that the activity level of the RA during a curl-up exercise was approximately 50% of MVC, which is similar to the results obtained in this study. The highest bilateral symmetrical level of activation of the EO was seen during the elbow-toe exercises, with the highest levels when the contralateral arm and leg were lifted off the supporting surface, likely reflecting the role of the EO to help control trunk rotation. Despite a lack of statistical significance, it is noted that the activation of the EO on the side of the leg that was lifted was slightly higher for the 2 exercises with arm and leg lifts. In a previous study, Lehman et al reported EO activity levels of approximately 45% MVC during the elbow-toe exercise, a value significantly lower than in the current study. Significant asymmetry of EO activation was measured with the 2 side bridge exercises, where the body was supported by the right arm and foot, with the higher activation level noted for the right EO, the side of support. This would be consistent with the need to more specifically activate and shorten the muscles on the right side of the lumbar spine. Ekstrom et al reported that EO activity levels on the side of the supporting extremities for the side bridge was an average of 69% ± 26% MVC. This compares to approximately 80% MVC for the right EO, the supporting side, in this current study. On the left side, the nonsupporting side, the activity level was about 20% MVC, demonstrating a large asymmetrical activation level of the EO for this exercise.

The general pattern of activation for the ES is in many respects similar to what was observed for the EO. Relatively high bilateral activation of the ES is noted with the 3 variation of back bridge exercises. Also, similar to what was noted with the EO, while not statistically significant, a higher activity level for the ES was noted on the side of the leg that is lifted. Activation of the ES during the side bridge is also very asymmetrical, with much higher activation (approximately 30% MVC) on the side in contact with the supporting surface, as compared to approximately 10% MVC for the opposite side. The results are similar to those of previous studies.

Overall, the activity of the abdominal muscles (TrA, RA, and EO) was greater during exercises performed in a prone position, either using elbow-toe or hand-knee combination for support. The asymmetry in base of support created by lifting the contralateral arm and leg also created some asymmetry in activation of the musculature, with a higher activity level on the side of the lower extremity being lifted for the EO and on the side of the upper extremity lifted for the RA and TrA. This interesting finding deserves the attention of future studies. Cocontraction of the abdominal muscles occur during the elbow-toe exercises, including the TrA, which is activated to more than 45% MVC during the elbow-toe with contralateral arm and leg lift. Cocontraction of the abdominal muscles has been reported to increase postero-anterior spinal stiffness. Therefore, the elbow-toe with contralateral arm and leg lift may be effective to enhance lumbar spinal stability. However, Rodebold et al have reported that patients with low back pain increase global muscle activity. Therefore, as mentioned earlier, exercises to train the isolated contraction of the local muscles, such as the abdominal-hollowing exercise, may be better when a therapist conducts the therapeutic exercises for patients with excessive global muscle activation.

Overall, the exercises performed in the supine position generated a higher activity level of the MF and ES, as compared to those performed in the prone position. So, those exercises may be better suited to focus on the posterior trunk musculature. The back bridge with single-leg lift produced the greatest MF and ES activity and is considered to effectively induce cocontraction of back muscles. Stevens et al have also reported that the cocontraction of MF and ES occurred with the back bridge exercises, a similar result.

Finally, the greatest amount of side-to-side asymmetry in activation of the lumbar and spinal musculature was observed with the 2 side bridge exercises with support on the right elbow and foot. For all 5 muscles, the activation level was higher on the right side for these 2 exercises, but the amount...
of asymmetry differed quite noticeably across the 5 muscles. The muscle with the greatest amount of asymmetry was the EO, with approximately 80% MVC for the right side versus 30% for the left side. The ES also showed a statistically significant amount of asymmetry between sides (right side, approximately 30% MVC; left side, 10% MVC). The side-to-side differences for the TrA were approximately 30% MVC on the right versus 15% on the left, which was statistically significant only for the side bridge exercise with left leg lift. For the RA and the MF, Figures 4 and 5 also show this consistent side-to-side difference that, while not significant (likely due to the small number of subjects in the study), should be noted for future investigation.

For this study, the following points should be considered as limitations. Similar to a previous study,1 the number of subjects in this study was kept low due to the invasive nature of using intramuscular wire electrodes. It may have been more optimal to collect data for several repetitions of each exercise as opposed to a single repetition. This would have been similar to previous studies.9,35,37 EO activity was high during almost all of the exercises performed in this study, which may indicate that maximum EO activity was not precisely measured during the MVC task, despite using a method similar to that used in a previous study.7

CONCLUSION

Our results showed that the exercise that greatly activated the transversus abdominis was elbow-toe with contralateral arm and leg lift, and the exercises which greatly activated the multifidus were back bridge exercises. Overall, the exercises investigated in this study resulted in a wide range of effort level for all 5 muscles monitored. Many of the exercises also resulted in an asymmetrical (right versus left side) activation level for a muscle, including the transversus abdominis.

KEY POINTS

**FINDINGS:** All exercises generated activation of all muscles that were monitored; but preferential activation for the abdominal muscles was seen with the exercises performed in a prone position and preferential activation of the spinal musculature was seen with exercises performed in the supine position. Side-to-side asymmetry of muscle activation, with greater activation on the side providing support, was seen with the side bridge exercises.

**IMPLICATION:** Despite the isometric and stabilization nature of these exercises, significant asymmetry in side-to-side muscle activation was noted for some muscles for many of these exercises.

**CAUTION:** Results related to the ability to activate the lumbar and abdominal musculature should not be directly interpreted as clinically effective to reduce back pain.

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**RESEARCH REPORT**


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