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Original Article

EMG Activity in the Abdominal Muscles and the Kinematics of the Lumbar Spine during Unilateral Upper-limb Resistance Exercises under Stable and Unstable Conditions

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Abstract. [Purpose] We investigated the effects of unstable conditions on the electromyographic (EMG) activity of the rectus abdominis (RA) and the transverse abdominis–internal oblique (TrA-IO) muscles, and lumbar kinematics during unilateral upper-limb resistance exercises using elastic tubing bands. [Subjects] Twelve healthy males were recruited. [Methods] The subjects performed isometric left shoulder abduction using an elastic tubing band in a sitting position on a chair, and on a Swiss ball. During this exercise, EMG activities of the RA and TrA-IO were recorded using a wireless EMG system, and a three-dimensional motion analysis system monitored lumbar kinematics. Differences in EMG activities of the RA and TrA-IO, the ratio of TrA-IO to RA activity, and lumbar kinematics were compared between the stable and unstable conditions using the paired *t*-test. [Results] Under the unstable condition, the EMG activities of both muscles were significantly greater than that under the stable condition; however the ratio of TrA-IO to RA activity did not significantly differ between the conditions. The lumbar angle significantly differed only in the coronal plane. [Conclusions] These findings indicate that trunk posture should be considered when performing exercises under unstable conditions.

Key words: Swiss ball, Abdominal muscles, Electromyography

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INTRODUCTION

Low-back pain is a common musculoskeletal disorder, and many clinicians have tried to improve trunk stability to prevent and treat low-back pain[1, 2)]. Trunk stability is provided by global muscles, including the rectus abdominis (RA), external oblique (EO), internal oblique (IO), and erector spinae (ES), and local muscles, such as the transverse abdominis (TrA) and multifidus[3, 4)]. The RA is subclassified as a global mobilizer muscle that produces mobility, and the IO as a global stabilizer that produces stability through eccentric control[4)]. Thus, selective activation of the IO or the combined action of the TrA and IO (TrA-IO) with respect to the RA is emphasized during trunk stabilization exercises for the effective improvement of trunk stability[5–7)].

Recent studies have suggested upper-limb resistance exercises increase trunk muscle activity[1, 8)]. In a previous study, upper-limb resistance exercises using elastic tubing bands were found to change electromyographic (EMG) activity in the abdominal muscles according to the direction of shoulder movements[8)]. Moreover, Mullington et al.[9)] showed that shoulder abduction facilitated contralateral abdominal muscle activity. It has been hypothesized that upper-limb resistance exercises may require greater activity of the trunk muscles to maintain an upright trunk posture[1)].

To maximize the effects of various trunk stability exercises, clinicians often use unstable surface conditions (e.g., a Swiss ball)[2, 7)]. Previous studies have shown significantly greater EMG activity in the abdominal muscles during curl-up and trunk bridge exercises under unstable versus stable conditions[2, 10)]. However, other studies have reported no significant differences in EMG activities in abdominal muscles between stable and unstable conditions[11, 12)]. The differences among studies may result from incomplete information on trunk kinematics, as changes in trunk posture can influence abdominal muscle activity[13)].

Although the need to measure trunk kinematics during exercises under unstable conditions has been previously noted[10)], the information available on trunk kinematics is limited. Moreover, it is unclear whether the EMG activity of the abdominal muscles during upper-limb resistance exercise is influenced by surface conditions. Thus, the aim of this study was to investigate the effects of surface conditions on abdominal muscle activity and the kinematics of the lumbar spine during unilateral upper-limb resistance exercises.

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SUBJECTS AND METHODS

Twelve healthy males (mean age: 24.25 ± 1.69 years, mean height: 174.31 ± 4.25 cm, and mean weight: 67.25 ± 5.52 kg) were recruited for this study. All the subjects were right-hand dominant. Individuals who experienced low-back pain and shoulder pain or had a history of surgery in the upper or lower extremities were excluded. All participants provided their written informed consent prior to participation, and this study was approved by Inje University Ethics Committee for Human Investigations.

To record EMG activity of the RA and TrA-IO muscles, a surface EMG system (Delsys Inc., Boston, MA, USA) was used to collect data at a sampling rate of 1,000 Hz, with a bandwidth of 20–450 Hz. Before the electrodes were attached, the skin was shaved and cleaned with an alcohol swab. The electrodes were attached the right side along the direction of the muscle fibers at 2 cm lateral to the umbilicus for the RA, and at the midpoint between the anterior superior iliac spine (ASIS) and pubic tubercle for the TrA-IO[7]. The recorded raw data were converted to root mean square (RMS) data. After electrode attachment, maximum voluntary isometric contraction (MVIC) of each muscle was measured, as described by Kendall et al[14]. MVIC was measured for 5 s, and data from the middle 3 s were used for calculations. The MVIC trials were repeated twice for each muscle, and the mean value of the two trials was used for the normalization of muscle activity.

A VICON motion-analysis system (VICON Motion System, Ltd., Oxford, UK) with eight MX-T10 cameras was used to monitor lumbar kinematics. Reflective markers were attached to the first and second lumbar spinous processes and bilateral sides of the second lumbar spinous process to construct the lumbar spine, and three reflective markers were placed on the ASIS, posterior superior iliac spine (PSIS), and the midpoint of the bilateral PSISs for the pelvic segment. Three-dimensional lumbar kinematics were used to calculate the movement of the lumbar spine segment with respect to the pelvic segment using the Cardan angle. Positive values were defined as lumbar extension in the sagittal plane, left side bending in the coronal plane, and right rotation in the transverse plane.

In the present study, a blue elastic tubing band with a medium level of resistance (Thera-Band, Hygenic Corporation, USA) was used to provide resistance during unilateral upper-limb resistance exercises. All subjects sat on a chair (stable surface) or a Swiss ball (unstable surface) at the same height as the chair, and the elastic tubing band was placed under the buttocks. A goniometer was used to confirm 90° of hip and knee flexion when subjects were in the sitting position. To minimize differences in the amount of resistance among subjects, the length of the elastic tubing band was normalized to the height of the subjects. Subjects gripped the elastic tubing band at a point at the level of the left acromion in the sitting position. All subjects performed 180° of left shoulder abduction and then held the position for 5 s under the stable and unstable conditions, which were employed at random.

The mean EMG activity of the RA and TrA-IO and the ratio of TrA-IO to RA activity during the middle 3 s of isometric shoulder abduction were calculated for analyses. The mean values of the lumbar angle in the sagittal, coronal, and transverse planes during the middle 3 s of isometric shoulder abduction were analyzed using Nexus software (ver. 1.7; VICON Motion System, Ltd.). Differences in EMG activities of the RA and TrA-IO, the ratio of TrA-IO to RA activity, and the three-dimensional lumbar kinematics during unilateral upper-limb resistance exercise were compared between the stable and unstable conditions using the paired t-test. Statistical analyses were performed using PASW Statistics software (ver. 18.0; SPSS, Inc., Chicago, IL, USA), with a significance level of 0.05.

Table 1. Electromyographic (EMG) activity of the rectus abdominis (RA) and transversus abdominis–internal oblique (TrA-IO) on the right side during left upper-limb resistance exercise on stable and unstable surfaces

Muscle	Mean ± SD (%MVIC)	
	Stable surface	Unstable surface
RA	6.64 ± 7.37	7.39 ± 8.42*
TrA-IO	6.00 ± 5.34	6.69 ± 5.85*
TrA-IO/RA	1.25 ± 0.90	1.42 ± 1.25

MVIC, maximum voluntary isometric contraction. *$p < 0.05$

Table 2. Three-dimensional kinematic data of the lumbar spine during left upper-limb resistance exercise on stable and unstable surfaces

Plane	Mean ± SD (°)	
	Stable surface	Unstable surface
Sagittal	−11.27 ± 6.94	−11.37 ± 7.74
Coronal	3.89 ± 3.38	1.90 ± 3.39*
Transverse	−5.00 ± 4.18	−5.55 ± 3.37

*$p < 0.05$

RESULTS

RA ($p = 0.045$) and TrA-IO ($p = 0.038$) activities were significantly greater under the unstable condition than under the stable condition; however, the ratio of TrA-IO to RA activity was not significantly different between the two conditions ($p = 0.181$). The lumbar angle significantly differed between the stable and unstable conditions only in the coronal plane ($p = 0.003$). There was no significant difference in lumbar angle in the sagittal ($p = 0.897$) or transverse ($p = 0.252$) plane between the two conditions (Tables 1, 2).

DISCUSSION

We demonstrated the influence of unstable conditions on EMG activities of the RA and TrA-IO, and on the ratio of TrA-IO to RA activity, as well as on three-dimensional lumbar kinematics during unilateral upper-limb resistance exercise. The findings of the present study show that the unstable condition facilitated contralateral abdominal muscle activity; however, the contribution of TrA-IO activity relative to that of RA (the ratio of TrA-IO to RA) was not influenced by condition. Compared with the stable condition, the unstable condition induced significantly greater right bending of the lumbar spine during isometric left shoulder abduction using the elastic tubing band.

Unstable conditions are commonly recommended in the literature to increase abdominal muscle activity[1, 15]. Among the abdominal muscles, TrA-IO is crucial for improving trunk stability[4]. In particular, selective activation of the stabilizer muscles is important in maintaining proper trunk alignment during limb movements[16]. Thus, clinicians should consider whether unstable conditions increase not only TrA-IO activity but also the contribution of TrA-IO to global mobilization (e.g., the RA)[5–7]. In this study, RA and TrA-IO muscle activity increased significantly under the unstable condition compared to the stable condition. It has been reported that activity in the contralateral trunk muscles is increased to control trunk movement produced by reactive force during upper-limb movement[17]. It is considered that unstable conditions place greater demands on the abdominal muscles in the control of trunk movement during unilateral upper-limb resistance exercise, increasing EMG activity in both the RA and TrA-IO. However, the ratio of TrA-IO to RA activity was not significantly different between the unstable and stable conditions. Considering the role of the stabilizer muscles such as the TrA-IO in keeping an upright trunk posture during limb movements[4, 16], the lack of a significant difference in the ratio of TrA-IO to RA between stable and unstable conditions may reflect a lack of control over trunk movements.

Our lumbar kinematic findings support the absence of a significant difference in the ratio of TrA-IO to RA between the two conditions. In the present study, the unstable condition resulted in greater right bending of the lumbar spine during isometric left shoulder abduction than under the stable condition. Because shoulder abduction involves movement in the coronal plane[13], the lumbar kinematics may be influenced only in the coronal plane. Furthermore, the unstable condition makes it difficult to control right bending of the trunk during left shoulder abduction, leading to significant changes in lumbar kinematics and no significant difference in the ratio of TrA-IO to RA during left upper-limb resistance exercises under the unstable condition.

Several limitations of this study should be considered. First, all subjects performed only left shoulder abduction. Future studies should include right shoulder abduction and bilateral shoulder abduction. Second, EMG activity was only monitored in the contralateral RA and IO in this study. It would be useful if future studies also included other trunk muscles, such as the EO and ES. Finally, the present study did not examine the effects of differences in resistance on trunk muscle activity and lumbar kinematics during unilateral upper-limb resistance exercises.

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