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Activation of Trunk Muscles during End-Inspiration of Abdominal Breathing: Comparison among Four Different Positions

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Abstract. [Purpose] The purpose of this study was to compare the activation of trunk muscles during end-inspiration of abdominal breathing among four different back exercise positions to investigate potential effects on the activation of trunk muscles. [Subjects] Sixty healthy male adults volunteered to participate in the study. [Methods] Each subject was instructed regarding abdominal breathing and the study procedure. While the maximal voluntary contraction and end-inspiration of abdominal breathing of individual muscles were being performed, the activity of the muscles was measured using surface electromyography. The activity of the muscles while performing end-inspiration of abdominal breathing was normalized to the percentage of maximal voluntary contraction (% MVC). [Results] Right and left erector spinae and external oblique showed significant differences among the positions between before and after end-inspiration of abdominal breathing(EIAB). The prone-on-elbows position demonstrated the greatest increase post-EIAB. [Conclusion] End-inspiration of abdominal breathing appears to be effective in the four different positions for activating the erector spinae and external oblique trunk muscles, but not rectus abdominis.
Key words: End-inspiration abdominal breathing, Maximal voluntary contraction, Four back exercise positions

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INTRODUCTION

Abdominal breathing is a form of breathing that can be taught as an exercise, and is mainly accomplished by the contraction and descent of the diaphragm. The diaphragm has three lumbar areas of origin, the L1-L3 lumbar body, the intervertebral disc and the anterior longitudinal ligament and inserts at the central tendon of the diaphragm. As the diaphragm descends, it pushes the internal abdominal organs downward and as a result, the volume of the thoracic cavity increases and intrapleural pressure decreases so that the air goes into the alveoli while the volume of the abdominal cavity decreases with an increase in Intra-Abdominal Pressure (IAP)[1,2)].

Most studies related to abdominal breathing[3–7)] have investigated the ventilation of healthy persons and patients with lung disease, as well as the saturated oxygen and inspiratory muscle function. Recently, though, Lewis[8)] suggested that the belly, the lower ribcage and the lower back are expanded during the inspiration of abdominal breathing because the diaphragm is connected to areas surrounding the lower ribcage and the L1, L2, L3 vertebral segments. The concept of breathing has been introduced as part of the therapeutic approach to musculoskeletal disorders such as low back pain[9)]. The importance of abdominal breathing is emphasized in yoga that alleviates and prevents low back pain related to muscle imbalance and in the core strengthening program that focuses on lumbar stabilization[10,11)]. Although abdominal breathing is used as part of yoga, core strengthening, Qigong[12)], and Tai Chi1[3)], the effect of end-inspiration of abdominal breathing (EIAB) on the activation of the trunk muscles has not been investigated with regard to physical therapy intervention for musculoskeletal disease such as low back pain. The ability of EIAB to affect the activation of the trunk muscles can be explained by 1) the rising IAP and the outward movement of the abdominal wall due to the descend of the diaphragm during inspiration, 2) the increase of spinal stiffness due to the rising IAP, and 3) the correlation with erector spinae muscles and spinal stiffness[14)]. The purpose of this study was to investigate the effect of EIAB on the activation of trunk muscles in healthy people among four positions for back exercise

SUBJECTS AND METHODS

Sixty healthy male volunteers were recruited for this study. Subjects were excluded from the study if they had: neurological disorders, history of back surgery within the last 3 years, or upper and lower orthopedic disorders within the last 3 years. Each subject was given an explanation of the purpose of this study, and signed a written, informed consent form before participating in the experiment. The experimental order of each position was assigned randomly to each subject using a computerized random allocation and subjects were asked to adopt abdominal breathing for one minute. Abdominal breathing is defined here as a method where the contraction of the diaphragm results in its downward displacement while the abdomen expands anteriorly during inspiration and the diaphragm rises to its original position while the abdominal girth decreases during expiration. The subjects were asked to hold their breath at end of inspiration of abdominal breathing (EIAB) for four seconds to measure activation of the trunk muscles with electromyography (EMG). Four back exercise positions were used for comparison of the activation of the trunk muscles: flexion of the right shoulder and the extension of the left leg in quadruped position, flexion of the left shoulder and the extension of the right leg in quadruped position, the prone position with back and arm extension and the prone position on the elbows with flexion of the elbows. In order to reduce skin resistance to the EMG signals, excessive hairs was removed from the skin, the corneum was removed by rubbing the skin with a piece of sandpaper, and the skin was cleaned with disinfectant alcohol. The surface bi-polar electrodes (Norotrodes; Myotronics-Noromed, Inc, USA), 2 mm wide, were attached 20 mm apart from center to center. The bi-polar active electrodes were attached parallel to the muscle fiber orientation and the reference electrodes were attached to the subject's iliac crest. The surface electrodes were attached at the following sites: the right and left erector spinae (ES) 3 cm to the left and right sides of the 3rd lumbar vertebra, the right rectus abdominis (RA), 3 cm lateral to the umbilicus, and the right external abdominal oblique (EO) located halfway between the anterior superior iliac spine and the inferior margin of the rib cage[15].

All EMG data were collected using MP150WSW (BIOPAC System Inc., USA). The EMG signals were bandpass filtered between 10 and 500 Hz. The sampling rate for the signals was set to 1 kHz. Collected data were processed using AcqKnowledge® Software Version 3.7 (BIOPAC System Inc., USA). During data collection, the raw recordings were monitored. Raw EMG data were full-wave rectified and processed using a root-mean-square algorithm to quantitatively calculate the amplitude of the EMG signals. The amplitudes were then normalized to the amplitudes obtained during MVC and the value was expressed as a percentage of MVC (% MVC). % MVC was calculated as (EMG value obtained in each position) divided by (EMG value obtained at MVC) × 100%.

The EMG value obtained at MVC was measured against manual resistance. The movements that could maximally activate individual muscles were determined to be trunk extensions for the right and left erector spinae (ES) in the prone position, trunk flexions for the RA in the supine position, and trunk rotations to the contralateral side for the EO in supine position[16]. The EMG value in each position was obtained while subjects performed the stated position, before and after EIAB. A time of four seconds was set for each EMG reading of the trunk muscles before and after EIAB. The first second was excluded and the remaining three seconds were used for the comparison. Three EMG trials were performed with one minute of rest between each position and with three minutes of rest before and after EIAB.

In this study, statistical analyses were performed using SPSS (v.12). Paired sample t-tests were used to compare % MVC of the trunk muscles in the four back exercise positions before and after EIAB. One-way repeated measures ANOVA was used to compare the differences in % MVC of the trunk muscles before and after EIAB of the different muscles among the four back exercise positions. The significance level (α) was 0.05.

RESULTS

The average age of the study subjects was 23.9 ± 3.54 years. Their average height was 175.0 ± 4.74, their average weight was 67.9 ± 7.32 kg, and their average BMI was 24.9 ± 4.1 kg/m2. In flexion of the right shoulder and extension of the left leg in the quadruped position, % MVC of the right and left ES and EO after EIAB were 37.9%, 38.7%, and 10.5%, respectively, as shown in Table 1. In flexion of the left shoulder and extension of the right leg in the quadruped position, % MVC of the right and left ES and EO after EIAB were 41.8%, 35.7%, and 11.8%, respectively, as shown in Table 2. In the prone position with back and arm extension, % MVC of the right and left ES and EO after EIAB were 30.4%, 33.2%, and 12.6%, respectively (Table 3). In the prone position on the elbows with flexion of the elbows, % MVC of the right and left ES and EO after EIAB were 35.2%, 35.6%, and 12.7%, respectively (Table 4). Right and left ES and EO had significant increases post-EIAB among the different positions, but RA did not show any significant differences between pre-and post-EIAB among the positions. In addition, the prone on the elbows position demonstrated the greatest increase post-EIAB as shown in Table 5.

DISCUSSION

In this study, in order to get an understanding of the effect of EIAB on the activity of the trunk muscles in healthy people, MVC of the trunk muscles including right and left ES, RA, and EO were measured before and after EIAB relative to back exercise positions using surface EMG and comparisons of the differences of the trunk muscles before and after EIAB among the four positions were made. In this study, two lumbar extensor muscles, right and left ES, were used because these muscles are muscles in which lumbar muscle weakness and functional weakness commonly occur related to back pain[17,18]. In addition, two abdominal muscles including RA and EO were selected because these muscles are essential for lumbar stabilization[19]. The internal abdominal oblique and the transversus abdominis muscles play a major role in spinal stabilization, but in this study, because EIAB was the intervention method,

Table 1. Comparison of MVC between pre- and post-EIAB in flexion of the right shoulder and extension of the left leg in the quadruped position.

Muscle	Pre EIAB	Post EIAB
Right ES*	30.9 ± 11.00	37.9 ± 13.90
Left ES*	33.2 ± 12.00	38.7 ± 13.00
RA	6.1 ± 3.10	7.0 ± 2.80
EO*	8.8 ± 2.20	10.5 ± 2.10

*Significant difference ($p<0.05$). Unit: % MVC. ES: erector spinae; RA: rectus abdominis; EO: external abdominal oblique.

Table 2. Comparison of MVC between pre- and post-EIAB in flexion of the left shoulder and extension of the right leg in the quadruped position.

Muscle	Pre EIAB	Post EIAB
Right ES*	36.60 ± 11.42	41.80 ± 15.25
Left ES*	31.60 ± 11.00	35.70 ± 13.24
RA	5.77 ± 3.05	6.80 ± 3.74
EO*	8.96 ± 2.67	11.86 ± 6.19

*Significant difference ($p<0.05$). Unit: % MVC. ES: erector spinae; RA: rectus abdominis; EO: external abdominal oblique.

Table 3. Comparison of MVC between pre- and post-EIAB in the prone position with back and arm extension.

Muscle	Pre EIAB	Post EIAB
Right ES*	12.23 ± 10.55	35.20 ± 15.56
Left ES*	12.61 ± 9.44	35.69 ± 15.42
RA	5.85 ± 3.98	7.20 ± 4.34
EO*	7.49 ± 4.30	12.77 ± 7.65

*Significant difference ($p<0.05$). Unit: % MVC. ES: erector spinae; RA: rectus abdominis; EO: external abdominal oblique.

Table 4. Comparison of MVC between pre- and post-EIAB in the prone position on the elbows with flexion of the elbows.

Muscle	Pre EIAB	Post EIAB
Right ES*	12.48 ± 12.02	30.44 ± 13.57
Left ES*	12.51 ± 11.08	33.21 ± 16.00
RA	5.68 ± 3.11	6.88 ± 4.33
EO*	8.37 ± 4.48	12.63 ± 5.97

*Significant difference ($p<0.05$). Unit: % MVC. ES: erector spinae; RA: rectus abdominis; EO: external abdominal oblique.

Table 5. Comparison of muscle activity in difference between pre- and post-EIAB among the four back exercise positions (N=60)

	Quadruped position 1	Quadruped position 2	Prone position 1	Prone position 2
Rt. ES*	7.00 ± 11.11	5.18 ± 10.84	17.96 ± 16.50	22.97 ± 16.45[a]
Lt. ES*	5.52 ± 8.76	4.11 ± 8.97	20.7 ± 17.12	23.08 ± 15.06[a]
RA	0.85 ± 3.91	1.03 ± 4.68	1.20 ± 5.44	1.34 ± 6.22
EO*	1.70 ± 2.50	2.89 ± 6.38	4.26 ± 7.84	5.28 ± 8.77[a]

*Significant difference ($p<0.05$). Unit: % MVC. ES: erector spinae; RA: rectus abdominis; EO: external abdominal oblique. Quadruped position 1: flexion of the right shoulder and extension of the left leg while in quadruped position; Quadruped position 2: flexion of the left shoulder and extension of the right leg while in quadruped position; Prone position 1: prone position with back and arm extension; Prone position 2: prone position on the elbows with flexion of the elbows. a Values within the same row are significantly different, $p<0.05$.

superficial muscles such as the rectus abdominis and external abdominal oblique rather than intermediate and deep muscles like the internal abdominal oblique and the transversus abdominis were expected to respond remarkably to EMG. So, these muscles were selected. Selection of RA and EO muscles was influenced by Hodges et al.[20] who suggested that increase in IAP is related to stiffness of the lumbar spine, and Bergmark's study[21] that concluded that EO contributed to the stability of the spine. In this study, after EIAB in position 1(flexion of the right shoulder and the extension of the left leg while in quadruped position), MVC of the right and left ES and EO increased by 7%, 5.5%, and 1.68%, respectively. MVC of RA showed no significant difference. It is possible that the reason the MVC of the right ES had a greater increase than that of the left ES is that most of the subjects were right-handed and that the subjects contracted the right ES more in order to maintain balance in the quadruped position while lifting the right shoulder and the left leg. It is also possible that RA showed less muscle activity than EO because RA does not work during EIAB, even though it is a muscle directly related to the stabilization of the lumbar spine. In the studies that compared activation of the muscles among back exercise positions, results for MVC before EIAB were similar to those of our present study. Callahan et al.[22] examined 13 normal persons with loading on the lumbar spine and the activity of the trunk muscles during flexion of the right shoulder and extension of left leg in the quadruped position. Activation of the left ES (25.5%) was higher than the activation of the right ES (19.4%) and in the same position, the activation of the abdominal muscles was low at 7% or lower. This activation was similar to our results before EIAB, but not after EIAB. In a study by Marshall and Murphy[23], during flexion of the right shoulder and extension of the left leg in the quadruped position over a ball, ES (33.99%) and EO (33.38%) muscles showed high activation while RA (5.3%) showed relatively low activation. The authors did not specifically mention use of abdominal breathing, but used a core strengthening exercise[11] that emphasized abdominal breathing. They reported high activity in the right ES and EO and low activity in RA, results which are similar to those of our present study. Low activation of RA may be related to the fact that RA works at the minimum in local stability in the quadruped position[24]. Following EIAB in position 2 (flexion of the left shoulder and the extension of the right leg while in quadruped position), MVC of the right and left ES and EO increased by 5.2%, 4.1% and 2.3%. MVC of RA showed no significant difference. The greater increase in MVC for the right ES as compared to the left ES may be because the subjects were right-handed, and balance was leaning toward the right side when they were flexing the left shoulder and extending the right leg; thus, more forces was applied to the right ES. It is also possible that the RA showed lower muscle activity than the EO because RA does not work during EIAB. Callahan et al.[22] reported the activation of the right ES was 28.4% and that of the left ES was 19.4% in subjects in the same position, with muscle activation higher on the right side, similar to the results of our present study. Regarding the activity of the abdominal muscles, Souza et al.[24] reported that activation of the EO (10.9%) was higher than that of the RA (3.0%). Their results are also similar to the results of the present study before EIAB, but they did not provide post-EIAB measures for comparison. The changes in the activation of the trunk muscles shown in the quadruped positions in this study could be related to be the fact that the erector spinae muscle is an accessory respiratory muscle which extends the vertebra column, allowing further elevation of the ribs during deep inspirations[25]. Also, although abdominal muscles are expiratory muscles, EO showed larger activation than the RA because EO works more strongly at the end stage of inspiration[26]. In addition, Ugalde et al.[27] studied activation of abdominal muscles during inspiration in normal persons and patients with myotonic muscular dystrophy (MMD) and reported that EO showed activation of around 8% and RA showed activation of 3% in inspiration with significant differences between the EO and RA similar to the results of the present study. In this study, in the prone position with back and arm extension during EIAB, the MVC of the right and left ES, and EO increased by 18.4%, 20%, and 4.3%, respectively. In addition, in the prone position on the elbows with flexion of the elbow during EIAB, the MVC of the right and left ES, and EO increased by 22.7%, 23.5%, and 5.3%, respectively. The RA showed no change between the two positions. The high activation of the right and left ES and EO in the prone on the elbows position with flexion of the elbow among the four positions may be the reason that IAP increases during EIAB in contact with floor and the increase in IAP greatly affects the right and left ES. Shirley et al.[14] indicated that the stiffness coefficient K was high at 17.94 in 50% inspiration compared to 50% expiration in prone positions. This result suggests high correlations between the force and displacement in inspiration. As for reasons why changes were shown in the activation of the trunk muscles in the prone positions, Campbell and Green[28] indicated that the activity of the diaphragm during inspiration is large and is associated with an increase in IAP. Their conclusion is supported by the results of McGill et al.[29] and Cholewiki et al.[30] who demonstrated that increased IAP stiffened the spine.

Limitations of this study include no measurement of respiratory parameters in the four different positions, the lack of gender variation among subjects as the subjects were only males. Further study of subjects with back pain is necessary to compare this type of intervention with other interventions for the patients with back pain and to investigate the effect of the various positions on abdominal activation in patients with back pain.

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