Changes in lateral abdominal muscles’ thickness immediately after the abdominal drawing-in maneuver and maximum expiration

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ABSTRACT

All lateral abdominal muscles contract more strongly during maximum expiration than during the abdominal drawing-in maneuver (ADIM). However, little is known about which of the lateral abdominal muscles is activated during maximum expiration. Thus, the purpose of this study is to quantify changes in the thickness of the lateral abdominal muscles immediately after the ADIM and maximum expiration. The thickness of the transverse abdominis (TrA), internal oblique (IO), and external oblique (EO) muscles was measured by ultrasound imaging in 30 healthy men before and after the ADIM and maximum expiration. After the ADIM, there was no significant change in the thickness of the lateral abdominal muscles. After maximum expiration, the thickness of the TrA muscle significantly increased, and there was no significant change in the thickness of the IO and EO muscles. Thus, maximum expiration may be an effective method for TrA, rather than IO and EO, muscle training.
INTRODUCTION

Core stability is defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities (Kibler et al. 2006). All trunk muscles, including abdominal as well as back muscles, contribute to core stability (Cholewski & Van Vliet 2002). The relative contribution of each muscle group continually changes throughout an athletic task (Zazulak et al. 2007). The abdominal musculature serves as a vital component of the core; in particular, the transverse abdominis (TrA) muscle has been referenced in the literature. Contracting the TrA muscle increases intra-abdominal pressure and the tension of the thoracolumbar fascia, an important structure that connects the lower limbs (via the gluteus maximus muscle) to the upper limbs (via the latissimus dorsi muscle). It helps to form a ring around the abdomen that consists of thoracolumbar fascia posteriorly, the abdominal fascia anteriorly, and the oblique muscles laterally (Kibler et al. 2006), thus creating a stabilizing “corset” effect. There are some exercises to strengthen the superficial abdominal muscles (Escamilla et al. 2006). However, little is known about effective method of introducing hypertrophy of the TrA. Specific, isolated exercise for strengthening the TrA might be required.

The abdominal drawing-in maneuver (ADIM) is commonly used in lumbar stabilization training programs (O’Sullivan et al. 1998; Richardson et al. 2002). This maneuver is designed to activate the TrA muscle while minimally contracting the internal oblique (IO) and external oblique (EO) muscles (Urquhart et al. 2005). The abdominal muscles, including the TrA, are the most powerful muscles of expiration. The abdominal muscles are activated differentially: the TrA is the most active, the IO and EO of intermediate activity, and the rectus abdominis muscle is the least active expiratory muscle during resting ventilation (Abe et al. 1996). A recent study reports that the lateral abdominal muscles may contract more strongly during maximum expiration than during the ADIM (Ishida et al. 2012). However, the study does not
clarify which of the lateral abdominal muscles is activated during maximum expiration. Exercise is known to produce changes in the amount and distribution of water in skeletal muscle. Submaximal exercise increases total muscle water content, primarily in the extracellular space, while more strenuous exertion leads to increases in intracellular water (Sjøgaard et al. 1985). Therefore, measurements of change in cross-sectional area (CSA) may determine the degree of recruitment of each abdominal muscle during exercise. The abdominal muscles are too large to allow measurement of their CSA using ultrasound imaging (USI), so muscle thickness is measured (Hodges et al. 2003). USI measurements correlate well with those made using magnetic resonance imaging (Hides et al. 2006). To the best of our knowledge, differences in the thickness of the lateral abdominal muscles pre and post ADIM and maximum expiration have not been studied previously. Thus, the purpose of this study was to quantify changes in the thickness of the lateral abdominal muscles immediately after the ADIM and maximum expiration.

METHODS

Subjects

Thirty male volunteers participated in this study. Exclusion criteria were a history of low back pain, known neuromuscular disease, and participation in competitive sports more than 3 times a week. Subjects’ age, height, and weight (mean ± standard deviation values) were 20.2 ± 3.7 years, 170.7 ± 6.1 cm, and 65.1 ± 11.1 kg, respectively. The protocol for this study was approved by the Ethics Committee of the Kawasaki University of Medical Welfare. Each subject provided his written informed consent prior to participation.

Materials

B-mode real-time USI of the lateral abdominal wall were captured, stored, and measured using an
Aloka SSD-3500SX ultrasound console (Aloka Co. Ltd., Tokyo, Japan) with a 10-MHz linear-array transducer. Conductive gel was placed between the transducer and the subject's skin. The transducer was then placed transversely across the abdominal wall along a line midway between the inferior angle of the rib cage and the iliac crest on the right side of the body (Ferreira et al. 2004). The position was adjusted to ensure that the medial edge of TrA was approximately 1 cm from the medial edge of the image when the subject was relaxed (Ferreira et al. 2004). A custom-made holder was designed to enable hands-free application of the ultrasound transducer, which could maintain the inward pressure of the weight of the transducer and holder and allow the use of a linear-motion guide, the THK Miniature Linear Guide (RSR7; THK Co. Ltd., Tokyo, Japan) (Ishida & Watanabe 2012) (Fig. 1).

Procedure

Subjects were positioned supine with arms crossed over the chest and each hand over the contralateral shoulder. The following tasks were performed on separate days with a 1-week interval: (1) the ADIM; and (2) maximum expiration with an open airway. The order of the 2 tasks was chosen at random. A total of 12 images (3 at end of resting inspiration before ADIM, 3 at the end of resting inspiration after ADIM, 3 at the end of resting inspiration before maximum expiration, and 3 at the end of resting inspiration after maximum expiration) were captured. Prior to data collection, subjects were instructed on how to perform each task. Verbal instructions for the ADIM were “draw your belly inward and upward while breathing normally, then hold the contraction for 10 s, 10 times, with a 10-s rest period” (Richardson et al. 1999). The ADIM task was performed with “light” effort, which is equivalent to a rating of 2 on the Borg scale (Urquhart et al. 2005). The ADIM is generally difficult even for healthy subjects (Richardson et al. 2002); therefore, during practice trials, the subjects watched the ultrasound monitor for visual feedback (Jhu et al. 2010). Feedback was also provided to the participants by the experimenter. Verbal instructions for the
maximum expiratory task were as follows: “breathe out from the end of resting expiration to maximum expiration level over 10 s, 10 times, with a 10-s rest period, and do not use the brace pattern.” The brace pattern is a position that specifically leads to contraction of all abdominal muscles in individuals performing an isometric bracing action (Kennedy 1980). The maximum expiration was performed with “almost maximal” effort, which is equivalent to a rating of 10 on the Borg scale (Borg 1982). The ADIM was more difficult to perform than the maximum expiratory task. Therefore, the subjects practiced the former task 3 times and maximum expiration 1 time. Subjects could see the USI during the practice trials of the tasks as well as during data collection for the 2 tasks.

**Data Analysis**

One therapist performed all the analyses of the USI. The thickness of each of the 3 muscles (TrA, IO, and EO muscles) was measured at the center line of the image. The average of the 3 trials was used for analysis. Percent changes from before tasks were calculated as \([\frac{\text{after} - \text{before tasks}}{\text{before tasks}} \times 100\%]\) for the TrA, IO, and EO muscles.

SPSS 16.0J for Windows was used for all statistical analyses. The reliability of the 3 measured values was assessed using intra-class correlation coefficients (ICC 1, 3) \((n = 30)\). The standard error of measurement \((SEM = SD_{pool} \times \sqrt{1-ICC})\) and the minimal detectable change for a 95% confidence interval \((MDC = SEM \times \sqrt{2} \times 1.96)\) were calculated (Kiesel et al. 2007). The paired t-test was used to determine differences between before and after tasks. The level of significance was set at \(p < 0.05\).

**RESULTS**

The intra-examiner reliability of thickness of the lateral abdominal muscles is shown in Table 1. The ICCs of all indices were 0.99.
The thickness and percent change of the lateral abdominal muscles are shown in Table 2. After the ADIM, there was no significant change in the thickness of the lateral abdominal muscles. After maximum expiration, the thickness of the TrA muscle significantly increased, and there was no significant change in the IO and EO muscles. The mean difference between before and after maximum expiration was greater than the SEM, though that was less than the MDC in the thickness of the TrA muscle.

**DISCUSSION**

Previous studies have reported a range of ICC values for measurement of lateral abdominal muscle thickness at rest using USI (range, 0.98–0.99) (Mew 2009; Rankin et al. 2006). The ICC values for the lateral abdominal muscles in this study (0.99) were similar to those in previous studies. The methods used in this study may have contributed to the high intra-rater reliability. Specifically, the experimental setup may have positively influenced the reliability values. The location of the transducer holder was fixed, which allowed repeat testing under same instrument conditions using the same position, orientation, and inward pressure of the transducer before and after the task (Ishida & Watanabe 2012).

This study was conducted to quantify the changes in the thickness of the lateral abdominal muscles before and after the ADIM and maximum expiration. Strenuous exertion leads to great increase in intracellular water, therefore more strenuous exercise will increase the thickness of the muscles immediately after exercise (Sjøgaard et al. 1985). Low exertion leads to a little increase in intracellular water, therefore low exertion exercise won’t increase the thickness of the muscles (Ploutz-Snyder et al. 1995). In this study, the observation of a selective increase in TrA muscle thickness (5.4%) after maximum expiration suggests that the TrA muscle may exhibit stronger contraction during maximum expiration than the IO and EO muscles. The impact of this change might be negligible because the mean difference between before and after maximum expiration was not greater than the MDC in the thickness of the TrA muscle.
muscle. However, this mean difference was not measurement error: the mean difference between before and after the maximum expiration was greater than the SEM of the thickness of the TrA muscle. In addition, the lack of an observed increase in IO and EO muscle thickness after maximum expiration and in lateral abdominal muscle thickness after the ADIM suggests that there may not be enough contraction of the muscles to increase its thickness during that task. A previous study suggested increased water content of skeletal muscle in active muscle compared to inactive muscle (Ploutz-Snyder et al. 1995). Dilation of the resistance vessels in muscle occurs almost instantaneously with the onset of contraction (Shepherd 1968). The decrease in oxygen tension, the increase in carbon dioxide tension and lactic acid concentration, the increase in extracellular potassium, and the release of adenosine compounds from skeletal muscle cells, each of which is capable of causing some dilation, may together produce dilation proportional to the intensity of the exercise (Shepherd 1968). Previous experiments designed to assess the sources of various capillary driving pressures in stimulated muscle have demonstrated that only small-molecule osmotic pressure can adequately explain the fluid shift into muscle during contraction (Watson et al. 1993). It was proposed that accumulation of lactate, Na⁺, and phosphate produced by contracting muscle causes an increased interstitial osmolality that pulls water through water-only pathways across the capillary wall, thereby increasing osmotic water flow into the muscle and leaving an increased concentration of plasma solutes (Watson et al. 1993). In this study, some combination of these in the TrA, compared to IO and EO muscles, can explain the observation of selective increases in TrA muscle thickness after maximum expiration. A previous study demonstrated 9% and 5% increases in vasti and adductor muscle group CSA in each thigh, respectively, immediately following barbell squat exercise consisting of 6 sets of 10 repetitions with a load that induced failure within each set (Ploutz-Snyder et al. 1995). There were no changes in hamstring and rectus femoris CSA in that study (Ploutz-Snyder et al. 1995). This suggest that even if muscle contraction is moderate to high level, the resultant increase in muscle thickness is
small, and low-level muscle contraction does not produce a change in muscle thickness. This may be consistent with our results. The limitations of this study were difficulty normalizing lateral abdominal muscle activity to maximal voluntary contraction during tasks. To the best of our knowledge, relation between percentage of muscles contraction during exercise and immediately after percent change in the thickness of the muscle have not been studied previously. Future research should validate the USI findings of this study by assessing muscle activation with fine-wire EMG during tasks (Urquhart et al. 2005).

The results of this study indicate that maximum expiration may be an effective method for training the TrA muscle rather than IO and EO muscles. Training of isolated voluntary activation of TrA should be performed by doing the ADIM (O’Sullivan et al. 1998; Richardson et al. 2002). However, the ADIM is not suitable for strengthening of the TrA. Previous study suggested that factors related to the greater metabolite changes during training resulted in greater increases in isometric strength and muscle CSA (Schott et al. 1995). Maximum expiration might have possibility of long term effect of the TrA hypertrophy. Maximum expiration is an easy method to introduce and would be effective in combination with other trunk-stabilization and trunk-strengthening programs that target the deep abdominal muscles. Further study is necessary to quantify the additive effect of maximum expiration on deep abdominal muscles during core exercise.

**SOURCE OF FUNDING**

No external funding was received for this study.

**CONFLICT OF INTEREST**

There is no conflict of interest.
References


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transversus abdominis muscles, sacroiliac joint mechanics, and low back pain. Spine 27(4): 399-405


<table>
<thead>
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<th></th>
<th>ADIM</th>
<th>maximum expiration</th>
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<tbody>
<tr>
<td></td>
<td>ICC (1,3)</td>
<td>SEM*</td>
<td>MDC*</td>
</tr>
<tr>
<td>TrA</td>
<td>before</td>
<td>0.99</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.99</td>
<td>0.1</td>
</tr>
<tr>
<td>IO</td>
<td>before</td>
<td>0.99</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.99</td>
<td>0.2</td>
</tr>
<tr>
<td>EO</td>
<td>before</td>
<td>0.99</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.99</td>
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### Table 2 The means ± SD for abdominal muscle thickness and percent change

<table>
<thead>
<tr>
<th></th>
<th>before (mm)</th>
<th>after (mm)</th>
<th>difference (mm)</th>
<th>percent change (%)</th>
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<tbody>
<tr>
<td><strong>ADIM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TrA</td>
<td>3.3 ± 0.7</td>
<td>3.3 ± 0.8</td>
<td>0.0</td>
<td>1.1 ± 8.1</td>
</tr>
<tr>
<td>IO</td>
<td>10.0 ± 2.2</td>
<td>9.9 ± 2.2</td>
<td>0.1</td>
<td>-1.0 ± 5.1</td>
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<tr>
<td>EO</td>
<td>6.9 ± 1.8</td>
<td>6.8 ± 1.8</td>
<td>0.1</td>
<td>-2.0 ± 5.3</td>
</tr>
<tr>
<td>maximum expiration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TrA</td>
<td>3.4 ± 1.0</td>
<td>3.6 ± 1.0*</td>
<td>0.2</td>
<td>5.4 ± 8.2</td>
</tr>
<tr>
<td>IO</td>
<td>9.9 ± 1.9</td>
<td>10.1 ± 1.9</td>
<td>0.1</td>
<td>1.5 ± 5.4</td>
</tr>
<tr>
<td>EO</td>
<td>6.8 ± 1.6</td>
<td>6.9 ± 1.5</td>
<td>0.0</td>
<td>0.6 ± 6.4</td>
</tr>
</tbody>
</table>

*: *p* < 0.01. ADIM: abdominal drawing-in maneuver. TrA: transverse abdominis. IO: internal oblique. EO: external oblique.
A custom-made holder was designed to enable hands-free application of the ultrasound transducer, which could maintain the inward pressure of the weight of the transducer and holder and allow the use of a linear-motion guide, the THK Miniature Linear Guide (RSR7: THK Co. Ltd., Tokyo, Japan).