Effect of the abdominal draw-in manoeuvre in combination with ankle dorsiflexion in strengthening the transverse abdominal muscle in healthy young adults: A preliminary, randomised, controlled study

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Abstract

Objectives To compare the effect of the abdominal draw-in manoeuvre with the abdominal draw-in manoeuvre in combination with ankle dorsiflexion on changes in muscle thickness and associated muscle activity in abdominal muscles.

Design A preliminary, randomised, controlled study.

Setting University laboratory.

Participants Forty healthy adults (18 males, 22 females) were allocated at random to the experimental group [mean age (SD) 24 (1.6) years, n = 20] or the control group [mean age (SD) 24 (1.9) years, n = 20]. The experimental group performed the abdominal draw-in manoeuvre in combination with ankle dorsiflexion, and the control group performed the abdominal draw-in manoeuvre alone, five times a day.

Main outcome measures Ultrasonography and electromyography were used to determine the intervention-related changes in muscle activity and the thickness of abdominal muscles during the abdominal draw-in manoeuvre or the abdominal draw-in manoeuvre in combination with ankle dorsiflexion.

Results A significant difference was found in the thickness of the transverse abdominal muscle between the groups [mean difference 0.24 cm, 95% confidence interval (CI) 0.08 to 0.40, P = 0.005. On electromyography, a significant difference was demonstrated in the amplitude of the transverse abdominal muscle contraction between the two techniques in the experimental group (mean difference 68.76 mV, 95% CI 53.16 to 84.36, P = 0.000. The intra-class correlation coefficient (ICC 2,1) showed excellent test–retest reliability of ultrasound measurement of the abdominal muscles: 0.96 (95% CI 0.85 to 0.99) for the transverse abdominal muscle, 0.87 (95% CI 0.62 to 0.98) for the internal oblique muscle and 0.77 (95% CI 0.44 to 0.96) for the external oblique muscle.

Conclusions This is the first study to demonstrate the additive effect of ankle dorsiflexion on deep core muscle thickness and activity, thus contributing to existing knowledge about therapeutic exercise for the effective management of low back pain.

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Keywords: Ultrasonography; Reliability; Abdominal draw-in manoeuvre; Irradiation; Transverse abdominis

Introduction

The abdominal draw-in manoeuvre (ADIM) is commonly used during core stabilisation techniques to restore neuromuscular control in the core stabilisation musculature of athletes with sports injuries. The manoeuvre has also recently gained widespread acceptance in reducing symptoms in patients with low back pain [1,2]. Recent evidence on the conservative management of low back pain suggests that the restoration of neuromuscular control in the transverse abdominal (TrA) muscle, together with minimal contraction of other superficial oblique, internal and external abdominal muscles, is essential for effective treatment during the early stages of rehabilitation [3–5]. Previous studies have demonstrated that the use of the ADIM, in particular, is far more effective than the use of general core stabilisation techniques in improving the cross-sectional area of the TrA muscle [3,6,7]. Thus, core stabilisation techniques that incorporate the selective motor recruitment of the central core stabiliser, such as the TrA muscle, may be beneficial in the effective management of low back pain.

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A variety of core stabilisation techniques, including abdominal bracing, curl-ups, lateral bridges, wall squats and stabilisation exercises using a ball [7,8], are used in conjunction with or without ultrasound imaging [9–11], although outcome studies have failed to provide clinical evidence for the superiority of any particular technique. In addition, despite the fact that all of these stabilisation exercises have been used in the management of individuals with low back pain, it is difficult to reach a clinical decision about adopting any one of them because their therapeutic efficacy has yet to be demonstrated. For example, ascertaining the exact or underpinning therapeutic effect of core stabilisation techniques poses a significant challenge because these techniques are often incorporated into static and dynamic neuromuscular or strengthening regimens [3,5,12]. Such combinations can potentially confound the results about which type of core stabilisation technique is more effective for the selective recruitment of core stabilisers.

The irradiation technique, a form of proprioceptive neuromuscular facilitation, has been conventionally used to selectively increase the number of active motor unit recruitment involved or weakened in the neuromuscular response [13,14]. Irradiation is defined as the increasing spread and strength of the response to the stimulation (resistance) [13–16], and possibly results from stimulus (resistance)-induced temporal or spatial summation [17]. It is also possible that the irradiation technique may empower or stimulate the deep target TrA muscle selectively through the application of resistance to the relatively stronger ankle dorsiflexors when used in combination with the ADIM, thus further augmenting lumbar spinal stability. Research is needed to determine the motor control mechanisms underpinning the therapeutic effects of the irradiation technique, which has important clinical ramifications for the prevention and management of lumbar spinal instability. This study was undertaken to determine the additive effect of a combination of ankle dorsiflexion and the ADIM on lumbar stabilisation and abdominal muscle motor control patterns in healthy young adults. Lumbar stabilisation and the motor control patterns in abdominal muscles were determined by measuring muscle thickness and muscle activity using ultrasound and electromyography (EMG), respectively, in experimental and control groups. The basic hypothesis was that the selective increase in size and amplitude in the TrA muscle would be greater in the experimental group (which performed both the ADIM and ankle dorsiflexion) compared with the control group (which performed the ADIM alone).

Methods

Design

The participants were allocated at random into the experimental group or the control group. The investigators responsible for assessing the outcomes were unaware of an individual’s group assignment. Random allocation was implemented using the conventional randomisation directory method in which a random number table was used to produce one code card for each participant, who then picked a card to receive his or her group assignment. Experiment blinding success was evaluated by asking the outcome assessors which intervention they thought had been provided.

Participants

A convenience sample of 40 healthy young adults was recruited from a local university. All of the participants gave their informed consent, and the study protocol was approved by the university ethics and institutional review board. The participants, all of whom were free from any known medical problems, were allocated at random into the experimental group (n = 20) or the control group (n = 20). Those with any neuromusculoskeletal pathology or history of spinal surgery were excluded. The target sample size was estimated based on a power of 87% at α = 0.05 to detect large differences in effect size between the groups [18]. Table 1 presents the demographic characteristics of the participants.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Demographic data of participants (n = 40), expressed as mean (standard deviation).</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Experimental (n = 20)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>24 (1.6)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168 (8.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61 (12.0)</td>
</tr>
</tbody>
</table>

Intervention

Both groups performed an ultrasound-guided (visual feedback) ADIM for 30 minutes per day, 5 days per week over a 2-week period, with ankle dorsiflexion added in the experimental group. The success of the ADIM was assessed by monitoring muscle thickness using ultrasound, and irradiation was evaluated by monitoring the recruitment sequence of activation of the tibialis anterior, rectus femoris and TrA muscles of the right lower extremity.

During the ADIM, participants were asked to adopt a crook-lying position, and a pressure biofeedback unit set to range from 40 to 70 mmHg [19,20] was placed beneath their fifth lumbar vertebra to monitor lumbar movement during the measurement of ADIM performance. Participants were instructed to draw in their lower abdomen below the navel gently and gradually without moving their upper abdomen or spine, while maintaining a neutral pelvic position to attempt to keep the target pressure range (40 to 70 mmHg). They were then asked to dorsiflex their ankle joint against the resistance [with 50% maximal voluntary isometric contraction (MVIC) of the tibialis anterior] provided by a fixed-strap band. The irradiation or propagation order of muscle recruitment or the sequential activation of the tibialis anterior, rectus femoris
Fig. 1. Electromyogram (EMG) measurement of muscle activity. Raw EMG data are shown for a representative subject from the experimental group, who performed the abdominal draw-in manoeuvre (ADIM) in combination with ankle dorsiflexion. The five vertical solid lines indicate the time at which an automatic auditory cue from the EMG software was sequentially given for the ADIM, tibialis anterior (TA) contraction, rectus femoris (RF) contraction, transverse abdominal (TrA) contraction, and release (or rest), respectively.

and TrA muscles was closely assessed through real-time EMG.

Ultrasound imaging

A Logiq sonography system (α 200, Samsung-GE Medical Systems Inc., Seongnam, Korea) with a 7.5-MHz linear transducer was used to assess muscle thickness and to provide accurate visual feedback during the intervention. The thicknesses of the abdominal muscles, including the internal oblique and external oblique muscles, were obtained.

The participants were asked to adopt a relaxed crook-lying position [19]. Their hip and knee joints were positioned between 40 and 80 degrees to reduce the lumbar lordosis. The inferior borders of the rib cage and iliac crest on the right side were palpated as reference points [21]. Ultrasound gel (AQUASONIC® 100, Parker Inc., Orange, NJ) was applied to the transducer head, which was transversely positioned 25 mm anteromedial to the midway point between the 12th rib and the iliac crest [21,22]. The transducer head was manoeuvred until the sharpest images of the lateral abdominal muscles (external oblique, internal oblique and TrA muscles) were obtained [23]. Three scans were taken on the right side of the abdominal muscles in their relaxed state in reference to a predetermined benchmark. The scanning location at the pre-test was marked on a transparent sheet for the post-test to ensure identical placement throughout the entire experiment [24]. To control for the potential influence of respiration on muscle thickness, the images were consistently acquired at the end of expiration, which was determined through visual inspection of the ultrasound image [21]. The image data acquired were stored, and muscle thickness (cm) was measured using an on-screen caliper. The thicknesses of all three muscles were defined by drawing a vertical reference line that was located 2.5 cm from the left edge (the muscle–fascia junction) of the TrA [21]. An immediate readout of the muscle thickness was displayed on the screen and stored for further analysis. Data that were unacceptable due to movement artefact were discarded, and the scan was then repeated. Based on this protocol, a test–retest reliability study was conducted to determine the degree of reliability between the pre- and post-tests of ultrasound measurements of abdominal muscle size in normal young adults, including those of the external oblique, internal oblique and TrA muscles. Intra-class correlation coefficient (ICC) statistical analysis revealed good to excellent ICCs ranging from 0.77 to 0.97.

Electromyography

A surface EMG with a WEMG-8-type cable (Laxtha Inc., Daejeon, Korea) was used to record the onset times and amplitudes of the contractions of the tibialis anterior, rectus femoris and TrA muscles. These measurements were only collected for the experimental group to determine whether sequential activation of these muscles occurred during ankle dorsiflexion (Fig. 1). During data analysis, the amplitude data were used to evaluate the meaningful changes in the selective motor control patterns of the TrA, whereas the onset time data were simply used to monitor the firing sequence (i.e. TrA → tibialis anterior → rectus femoris → augmented TrA). To reduce skin impedance, each participant’s skin was shaved, sanded and cleaned, and electrode gel was applied. If the measured impedance was greater than 5 kΩ, the electrode was removed and the skin preparation procedure was repeated. A pair of active electrodes (inter-electrode distance = 2.0 cm) was placed over the tested muscle bellies
Table 2
Comparison of muscle thickness (cm) in the transverse abdominal, internal oblique and external oblique muscles between the experimental and control groups.

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>Control</th>
<th>P-value</th>
<th>Mean difference (95% CI) cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse abdominal</td>
<td>0.86 (0.31)</td>
<td>0.62 (0.16)</td>
<td>0.005*</td>
<td>0.24 (0.08 to 0.40)</td>
</tr>
<tr>
<td>Internal oblique</td>
<td>0.79 (0.19)</td>
<td>0.92 (0.29)</td>
<td>0.092</td>
<td>−0.13 (−0.29 to 0.02)</td>
</tr>
<tr>
<td>External oblique</td>
<td>0.42 (0.12)</td>
<td>0.46 (0.16)</td>
<td>0.973</td>
<td>−0.00 (−0.09 to 0.09)</td>
</tr>
</tbody>
</table>

The experimental group performed the abdominal draw-in manoeuvre in combination with ankle dorsiflexion, whereas controls performed the abdominal draw-in manoeuvre alone. CI, confidence interval.

* Independent t-test revealed a significant difference between the two groups.

parallel [25], and a reference electrode was positioned over the lateral ankle malleolus. Telescan 2.89 software (Laxtha Inc.) was used to acquire EMG signals at a sampling frequency of 1024 Hz and to process them with a 60-Hz notch filter. The root mean square EMG amplitude for the TrA muscle was calculated for 2 seconds (4 to 6 seconds duration, interval 1) during the ADIM and for 2 seconds (13 to 15 seconds, interval 4) during the ADIM in combination with ankle dorsiflexion (Fig. 1). The sequential activation of tibialis anterior, rectus femoris and TrA muscle activities was displayed on a computer monitor. Participants were instructed to sustain 30% MVIC of the TrA muscle during the ADIM, followed by 50% MVIC of the tibialis anterior, rectus femoris and TrA muscles during ankle dorsiflexion, and then to rest for 5 seconds. An automatic auditory cue was used to trigger each contraction event, which lasted for 3 seconds over a 20-second period (Fig. 1).

Data analysis

Standard statistical analysis included computation of the means and standard deviations, an independent sample t-test or paired two-tailed t-test, and ICC analysis [22]. The independent t-test was used to assess the mean differences in muscle thickness between the experimental and control groups. The paired t-test was used to examine the mean difference in the EMG amplitude of the TrA muscle between pre- and post-intervention in the experimental group. ICC analysis and a Bland and Altman test [2,26] were used to examine the test–retest reliability of the ultrasound measurements of abdominal muscle thickness. Repeated-measures analysis of variance, ICC = (2,1) (two-way random, single measure), was undertaken and the 95% confidence interval (CI) of the difference between the two measurements was calculated [27,28]. Bland and Altman plots, including the mean difference and the limits of agreement, were calculated to provide an estimate of the error between repeated measurements [26] using MedCalc for Windows Version 10.4. (MedCalc Software, Mariakerke, Belgium) Statistical Package for the Social Sciences Version 12.0 (SPSS Inc., Chicago, IL, USA) was used, with statistical significance set at P<0.05.

Results

Ultrasound imaging data

The independent t-tests consistently revealed a significant difference in the thickness of the TrA muscle between the groups (mean difference = 0.24 cm, 95% CI 0.08 to 0.40 cm, P = 0.005), which indicates that the combination of the ADIM and ankle dorsiflexion was more effective in improving selective recruitment of the TrA muscle than the ADIM alone (Table 2). However, no significant difference in the thickness of the internal oblique muscle (−0.13 cm, 95% CI −0.29 to 0.02 cm, P = 0.092) or the external oblique muscle (−0.00 cm, 95% CI −0.09 to 0.09 cm, P = 0.937) was found between the two groups. This finding suggests that the thickness of the internal oblique muscle in the experimental group had a tendency to decrease, which in turn further supports the selective motor control of the core abdominal muscles. The thickness measurements (cm) of the TrA, internal oblique and external oblique muscles in the experimental and control groups are shown in Fig. 2.

Test–retest reliability

The test–retest reliability ICC (2,1) revealed ICCs of 0.96 (95% CI 0.85 to 0.99), 0.87 (95% CI 0.62 to 0.98) and 0.77 (95% CI 0.44 to 0.96) for the TrA, internal oblique and external oblique muscles, respectively. The Bland and Altman plots showed that the mean differences and the 95% limits of agreement in the TrA, internal oblique and external oblique
Fig. 3. Bland and Altman plot showing the reliability of ultrasound measurement for the thickness of the transverse abdominal muscle imaged in two abdominal draw-in manoeuvre interventions. The middle line shows the mean difference. The 95% upper and lower limits of agreement represent 2 standard deviations above and below the mean difference.

Fig. 4. Bland and Altman plot showing the reliability of ultrasound measurement for the thickness of the internal oblique muscle imaged in two abdominal draw-in manoeuvre interventions. The middle line shows the mean difference. The 95% upper and lower limits of agreement represent 2 standard deviations above and below the mean difference.

Fig. 5. Bland and Altman plot showing the reliability of ultrasound measurement for the thickness of the external oblique muscle imaged in two abdominal draw-in manoeuvre interventions. The middle line shows the mean difference. The 95% upper and lower limits of agreement represent 2 standard deviations above and below the mean difference.

Discussion

This study is the first to investigate the augmented effect of the ADIM and ankle dorsiflexion on selective motor control and muscle thickness in core muscles. As anticipated, the data show that a combination of the ADIM and ankle dorsiflexion is significantly more effective in improving selective motor recruitment and associated thickness of the TrA muscle than the ADIM alone.

The ultrasound imaging data are consistent with previous findings investigating the effect of core stabilisation on muscle thickness during the ADIM. The thickness of the TrA muscle during the ADIM was approximately 0.77 cm in a previous study [29], whereas in the present study, the thickness of the TrA muscle increased by approximately 0.86 cm during the combination of the ADIM and ankle dorsiflexion, and by 0.62 cm during the ADIM alone (39% increase). In contrast, the thickness of the internal oblique and external oblique muscles tended to decrease during the combination of ADIM and ankle dorsiflexion, although the mean differences failed to reach statistical significance. These findings further indicate that ankle dorsiflexion in combination with the ADIM may have produced spatial and temporal summation, and selectively stimulated the deep target TrA muscle against the resistance, thus leading to augmented core stability or stiffness.

The present EMG findings show that the amplitude of the root mean square EMG data during the ADIM in combination with ankle dorsiflexion (139.97 mV) increased by approximately 200% compared with that of the ADIM alone (71.21 mV). Recent research examining the relation-

**Table 3**

<table>
<thead>
<tr>
<th></th>
<th>ADIM + AD mV</th>
<th>P-value</th>
<th>Mean difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TrA muscle</td>
<td>139.97(48.16)</td>
<td>&gt;0.001</td>
<td>68.76(53.16 to 84.36)</td>
</tr>
</tbody>
</table>

ADIM, abdominal draw-in manoeuvre; ADIM + AD, abdominal draw-in manoeuvre in combination with ankle dorsiflexion; CI, confidence interval.

* A paired t-test revealed a significant difference in the experimental group.
ship between muscle activity and the change in thickness of the TrA muscle during the ADIM using fine-wire EMG and ultrasound imaging reported a similarly strong correlation ($R^2 = 0.87$, $P < 0.001$) [22]. Neurophysiologically, it can be extrapolated that such augmented and selective improvement in muscle activity may have been the result of energy overflow or propagation from the tibialis anterior (distal) muscle to the TrA (central) muscle via a long and elastic anterior fascia connection [14–16] when ankle dorsiflexion was added to the ADIM, which was observed in a sequential EMG activation pattern. In fact, there is a growing body of evidence to show that core stability can be further strengthened when the ‘central’ core exercise is combined with ‘distal’ upper or lower extremity exercises (i.e. dead bug, one-leg bridging and stability ball bridging) [5,6,30,31].

Certainly, these results have important clinical implications, as they show that ADIM training is beneficial for selective recruitment of the TrA muscle and its central mechanism of action on the lumbopelvic region, and that the mechanism of a deep musculofascial corset can be further augmented by ankle dorsiflexion. Previous evidence on the clinical management of low back pain suggests that support and protection of the spine is essential to stiffen the lumbosacral joint during selective core stabilisation training of the TrA muscle, thereby minimising clinical complaints about low back pain and lumbar spinal instability [32].

When considering the ICCs, the test–retest reliability data demonstrate excellent results, suggesting a good degree of repeatability between the repeated US measurements. However, the Bland and Altman limits of agreement are wider than the differences found between groups, which suggests that the measurements may be subject to consequential error. Previous studies have reported a relatively poor degree of reliability [10,29,33,34], although the reliability in this study may have been improved by the use of a transparent sheet and static position measurement which attempted to control for error associated with the inconsistent location of ultrasound applications and movement artefacts, where other studies have used washable skin markers and dynamic conditions. It is tentatively suggested that abdominal muscle thickness measurements obtained by ultrasound can be reasonably accurate and reliable, within the limits defined by the Bland and Altman analysis. With further refinement, these measurements may provide a good measure for the assessment of intervention-related morphological changes and associated motor control mechanisms. Several shortcomings were identified in this research, which could be considered to enhance a more robust and large-scale clinical study in the future. First, this research represents a preliminary experiment intended to investigate the immediate effect of the ADIM in combination with ankle dorsiflexion in healthy subjects. Therefore, it invites future research that examines the long-term effect of the intervention in both normal and pathological populations, such as those suffering from low back pain. Second, the mechanism of action in the deep multifidus muscles, which is synchronously orchestrated in harmony with the deep abdominal muscles, the TrA, for core stability, was not measured. It would be of great interest to probe the mechanism of action in these muscles [35]. Finally, the results of this study cannot be generalised because the sample was limited to young, healthy adults. Thus, at this time, the technique discussed here cannot be said to provide an optimal strategy for training TrA muscle control. Nevertheless, the findings on the core technique make an important contribution to the existing body of knowledge on the therapeutic exercise of abdominal muscles in patients with acute low back pain for whom the current ADIM is not easily applicable due to their severe impairments such as pain and weakness.

Conclusions

This study provides empirical evidence to show that the ADIM combined with ankle dorsiflexion is useful in enhancing muscle activity and associated morphological changes in the TrA muscle. It offers clinical insights into the additive effect of ankle dorsiflexion in selectively stimulating the TrA muscle, and suggests that it may be used as an alternative core stabilisation technique for the management of patients with low back pain.

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Conflict of interest: None declared.

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