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The Use of Ultrasound Imaging of the Abdominal Drawing-in Maneuver in Subjects With Low Back Pain

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Study Design: Randomized controlled trial among patients with low back pain (LBP).
Objectives: (1) Determine the reliability of real-time ultrasound imaging for assessing activation of the lateral abdominal muscles; (2) characterize the extent to which the abdominal drawing-in maneuver (ADIM) results in preferential activation of the transverse abdominis (TrA); and (3) determine if ultrasound biofeedback improves short-term performance of the ADIM in patients with LBP.
Background: Ultrasound imaging is reportedly useful for measuring and training patients to preferentially activate the TrA muscle. However, research to support these claims is limited.
Methods and Measures: Thirty patients with LBP referred for lumbar stabilization training were randomized to receive either traditional training (n = 15) or traditional training with biofeedback (n = 15). Ultrasound imaging was used to measure changes in thickness of the lateral abdominal muscles. Differences in preferential changes in muscle thickness of the TrA between groups and across time were assessed using analysis of variance.
Results: Intrarater reliability measuring lateral abdominal muscle thickness exceeded 0.93. On average, patients in both groups demonstrated a 2-fold increase in the thickness of the TrA during the ADIM. Performance of the ADIM did not differ between the groups.
Conclusion: These data provide construct validity for the notion that the ADIM results in preferential activation of the TrA in patients with LBP. Although, the addition of biofeedback did not enhance the ability to perform the ADIM at a short-term follow-up, our data suggest a possible ceiling effect or an insufficient training stimulus. Further research is necessary to determine if there is a subgroup of patients with LBP who may benefit from biofeedback. *J Orthop Sports Phys Ther 2005;35:346-355.*

Key Words: *lumbar stabilization, real-time ultrasound imaging, therapeutic exercise, transverse abdominis*

Training of the transverse abdominis (TrA) and lumbar multifidus muscles is believed to be an important component in the rehabilitation of patients with low back pain (LBP).[17,19,26,37,38,42] Using fine-wire electromyography (EMG), Hodges et al[24,25,27,28] demonstrated that TrA activation occurs prior to limb movement, independent of movement direction, in asymptomatic adults. However, activation of the TrA prior to movement was delayed in patients with LBP.[26] The relationship between the presence of LBP and a delay in TrA muscle activation suggests that the TrA muscle may be important for normal motor control during active movement.[24-26,42]

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Brooke Army Medical Center and Wilford Hall Medical Center's Institutional Review Board approved the protocol for this study. The opinions or assertions contained here in are the private views of the Authors and are not to be construed as official or as reflecting the views of the Departments of the Army, Air Force or Defense. There has been no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.
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The abdominal drawing-in maneuver (ADIM) is commonly used as a foundational component of lumbar stabilization training programs.[38,41,42] This maneuver is designed to facilitate coactivation of the TrA and multifidus muscles to stabilize the trunk prior to limb movement. Rehabilitation focused on preferential activation of the deep trunk muscles (TrA and multifidus) during active movement has been theorized to improve the stability of the lumbar spine and has been found to significantly decrease symptoms associated with LBP.[6,37,42,43] Patients with LBP prescribed exercises for the deep trunk muscles have also been shown to experience fewer episodes of recurrent LBP.[17,37]

One potential limitation of lumbar stabilization programs is that training patients to perform the ADIM can be difficult and time consuming.[37] Although supplementary strategies, such as tactile cueing, quadruped positioning, pelvic floor muscle activation, and pressure gauges, previously have been used to enhance a patient's ability to preferentially activate the deep trunk muscles,[3,5,41] scant evidence exists to support their use.

Electromyography (EMG) techniques have traditionally been used to characterize activation of the lateral abdominal muscles. Fine-wire EMG has been successfully used to measure activation of the TrA during active movement of the extremities[24-28]; however, the invasiveness of the procedure, combined with the difficulty recording from a muscle positioned adjacent to the abdominal cavity, preclude its routine use in the clinical setting. Surface EMG is similarly limited for a different reason, primarily due to its inability to differentiate TrA muscle activity from that of the internal oblique (IO).[29,35] These limitations indicate that EMG may not be the optimal biofeedback tool for use in the clinical setting.

Ultrasound imaging is a noninvasive method that allows both the clinician and patient to observe changes in muscle thickness of the lateral abdominal muscles during the ADIM. These changes in muscle thickness are considered to be indicators of muscle activation.[32,41] Ultrasound imaging has been shown to be a reliable and valid technique to measure changes in muscle geometry.[1,2,4,13,31,33,34,44] In particular, ultrasound images are associated with the measurements obtained from more traditional techniques (ie, MRI, manual muscle testing, EMG).[8-10,14,18,23,30,36] Furthermore, direct assessment of changes in muscle geometry minimizes the measurement error associated with EMG, primarily elimination of the potential for cross-talk from surrounding musculature.[39] These perceived advantages of ultrasound have fostered its use as a biofeedback tool in clinical practice. Dietz et al[13] found that ultrasound imaging could be used to assess and improve the activation of the levator ani muscle in women suffering from urinary incontinence. In relation to low back exercise programs, the validity of using a change in muscle thickness as an indicator of muscle activation has been validated using EMG studies.[23,36] Specifically, changes in muscle thickness of the TrA[23,36] and the IO[23] represented changes in muscle activation, while the effects of changes of the external oblique (EO) remain less understood.[23]

Although ultrasound biofeedback has been suggested as a useful method to assist patients in learning to contract the lateral abdominal muscles,[32,41] there is a need to objectively determine whether ultrasound imaging is useful to improve preferential activation of the TrA (based on changes in muscle thickness) during the ADIM. Therefore, the purposes of this study were (1) to determine the reliability of real-time ultrasound to measure changes in lateral abdominal muscle thickness, (2) to characterize the extent to which the ADIM results in preferential activation of the TrA, and (3) to determine if biofeedback improves the short-term performance of the ADIM in patients with LBP.

METHODS

Subjects

A convenience sample of 30 subjects (12 women) (Figure 1) was recruited by physical therapists from 2 military medical centers (Brooke Army Medical Center and Wilford Hall Medical Center) in San Antonio, TX. The study was approved by the joint Brooke Army Medical Center and Wilford Hall Medical Center Institutional Review Board. All subjects provided consent to their participation and the rights of the subjects were protected. Subjects included active-duty military members or Department of Defense health care beneficiaries who were 18 to 45 years of age and who had been seeking treatment for their LBP within the previous 3 months. Subjects with significant neurologic involvement (myotomal weakness, diminished reflexes, or impaired sensation), previous exposure to lumbar stabilization training, history of lumbar surgery, or presence of spinal deformity were excluded. Subjects that were unable to tolerate the test positions (quadruped, seated, supine, and hook-lying) were also excluded.

Procedure

Ultrasound Measurements Ultrasound measurements were obtained with the subject in the supine hook-lying position and the examiners on the left side of the subject, using the Sonosite 180 Plus (Sonosite, Inc, Bothell, WA), with a 2- to 5-MHz curvilinear array.[23,41] The transducer was placed in a transverse plane just superior to the left iliac crest along the axillary line.[41] To standardize the location of the transducer, the hyperechoic interface between the

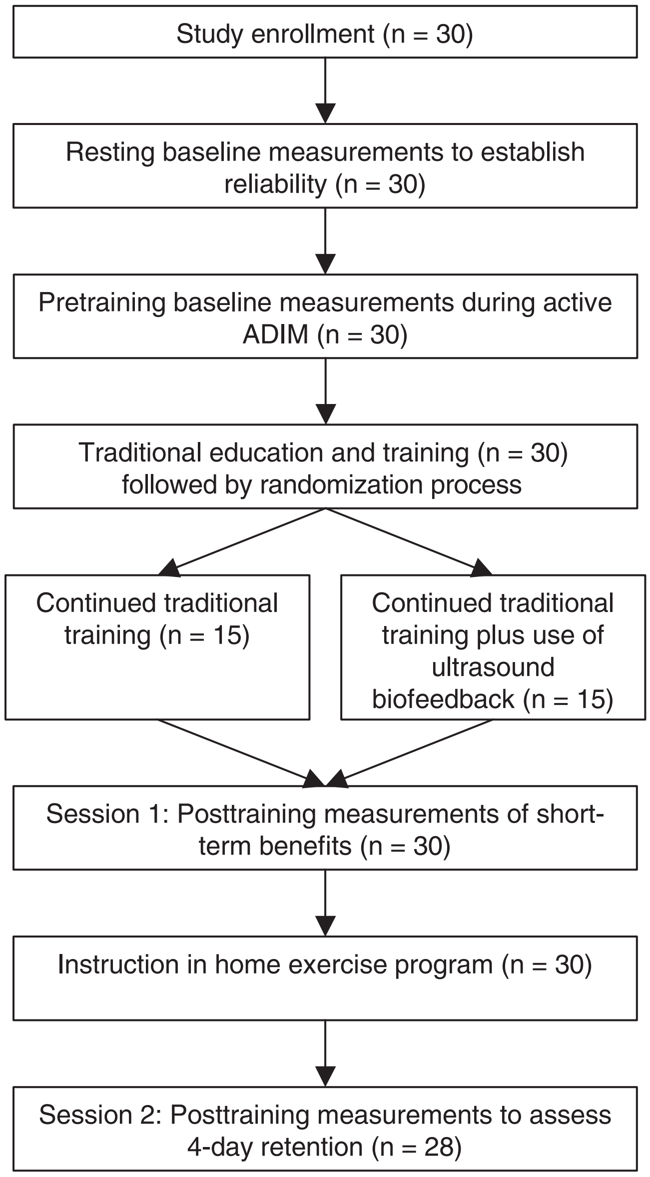

FIGURE 1. Flow chart of study design. (ADIM, abdominal drawing-in maneuver.)

TrA and thoracolumbar fascia was positioned in the far right side of the ultrasound image (Figure 2). The angle of the transducer was then adjusted to optimize visualization of the image. By standardizing the image location using visualized anatomical landmarks rather than superficial skin markers, the reliability testing more closely simulated the clinical setting.

To control for the influence of respiration,[7,20-22] subjects were given standardized instructions to perform the ADIM as they exhaled. The images were collected directly at the end of the exhalation, as determined by visual inspection of the abdominal content.

All measurements were obtained with the transducer in the same location. TrA thickness was measured between the superficial and deep borders of the muscle, as visualized by the hyperechoic fascial lines (Figures 2 and 3). Total lateral abdominal muscle thickness was measured from the superior border of the deep TrA fascia to the deep border of the superior EO fascia. Total lateral abdominal muscle thickness refers to the thickness of the 3 lateral abdominal muscles (TrA, EO, and IO).

To minimize bias, a team of 2 examiners performed the ultrasound measurements. One examiner positioned the transducer and optimized the quality of the image, but was blinded to the actual measurement values. A second examiner blinded to group assignment recorded the results of all measurements. The examiners consisted of physical therapy students who were provided a 3-hour training session in the measurement procedures by an investigator (D.S.T.) experienced with the use of ultrasound imaging in the assessment of lumbar spine musculature.

Reliability Analysis Resting images of the TrA and the total lateral abdominal muscle thickness were first obtained with the subject in the supine hook-lying position (Figure 2). Two measurements were recorded on a single image to determine the error associated with the measurement of the lateral abdominal muscle thickness from the ultrasound image (intraimage, intrarater reliability). A second resting image of the TrA and the total lateral abdominal muscle thickness was measured to establish the reliability and measurement error associated with the procedures used to obtain standardized image location and measurements from 2 separate ultrasound images (interimage, intrarater reliability).

Baseline Assessment of the ADIM To determine the baseline performance of the patient's ability to perform the ADIM prior to training, subjects were instructed to contract their abdominals by bringing their belly button up and in towards their spine. No other instruction or tactile cues were provided. Pretraining contracted images of the TrA and the total lateral abdominal muscle thickness (Figure 3) were obtained based on a single pretraining contraction using the previously described procedures.

Initial Training Session After baseline measurements were obtained, all subjects received an education session and training in the ADIM (Figure 1). The training session consisted of the exercise being performed in 3 postures: quadruped, seated, and supine hook-lying. Subjects that received traditional training with ultrasound biofeedback (biofeedback group) were provided the visual biofeedback of the ADIM during the seated and supine postures.

The introductory education session included visualization of anatomic diagrams of the core stabilizing muscles, descriptions of the anticipatory contraction of the TrA muscle in healthy controls,[24,25] and the delay that occurs in those with LBP.[26] All subjects were instructed how to perform the ADIM according to the procedures described by Richardson et al.[41] A total of 5 contraction attempts, each with a 10-second hold, were performed in each of the 3 positions.

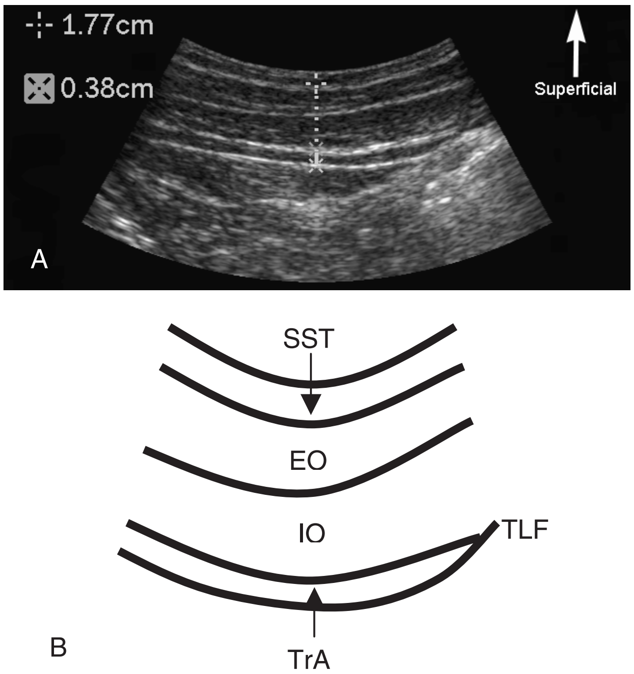

FIGURE 2. (A) Sonogram of lateral abdominal muscles at rest. The muscle thickness of the 3 lateral abdominal muscles, transverse abdominis (TrA), internal oblique (IO), and external oblique (EO) is identified as the length of the solid and dotted line (1.77 cm). The thickness of the TrA muscle is identified as the solid line (0.38 cm). (B) Diagrammatic drawing of the resting image: TrA, IO, EO, superficial soft tissue (SST), and thoracolumbar fascia (TLF). (Video available at www.jospt.org)

Tactile and verbal instructions were provided to all subjects in each position. Training in the quadruped position was performed first because it has been described as the easiest position to learn the ADIM secondary to gravitational pull on the abdominals.[41]

After the training in quadruped, patients were then randomly assigned to receive further instruction using traditional training or traditional training with biofeedback in the ADIM. The randomization scheme was performed prior to the initiation of the study, using sealed, sequentially numbered envelopes that corresponded to the patient's study identification number. For patients in the biofeedback group, additional training was provided to familiarize patients in how to view the ultrasound image in real-time prior to the exercise instruction in the seated and supine hook-lying positions. Approximately 5 minutes of biofeedback was provided to optimize performance of the ADIM, defined as maximal preferential activation of the TrA. Five minutes was selected based on research by Dietz et al[13] in the use of ultrasound biofeedback for instruction of pelvic floor contractions and clinical feasibility. Patients in the traditional training group were provided similar verbal and tactile feedback to optimize performance but without the use of ultrasound (visual) biofeedback. Total treatment time between groups was similar to mitigate the potential for an attention effect to occur.

Assessment of the Short-Term Benefits of Ultrasound Biofeedback After a 3-minute rest period, posttraining measurements were performed using the previously described procedures. All subjects performed the ADIM 3 more times in the supine hook-lying position without being able to observe the ultrasound image. The first 2 were practice contractions and the last contraction was used to obtain measurements for the immediate posttraining abdominal muscle ratios. Subjects were unaware which contraction was being measured.

Retention Testing At the end of the first session, all subjects received instruction on the home exercise program and were asked to return in approximately 4 days for retention testing. The home exercise program consisted of 3 different versions of the ADIM, based on the work by Hagins et al.[15] The positioning in the first 2 exercises (supine hook-lying with a 0.9-kg book on the subject's abdomen and quadruped) was incorporated into the home exercise program to provide external cues (the weight of the book and gravitational pull, respectively) during the performance of the ADIM. The third exercise position (supine hook-lying without a book) was incorporated into the home exercise program because it was identical to the testing procedure. Patients were instructed to hold each contraction for 10 seconds

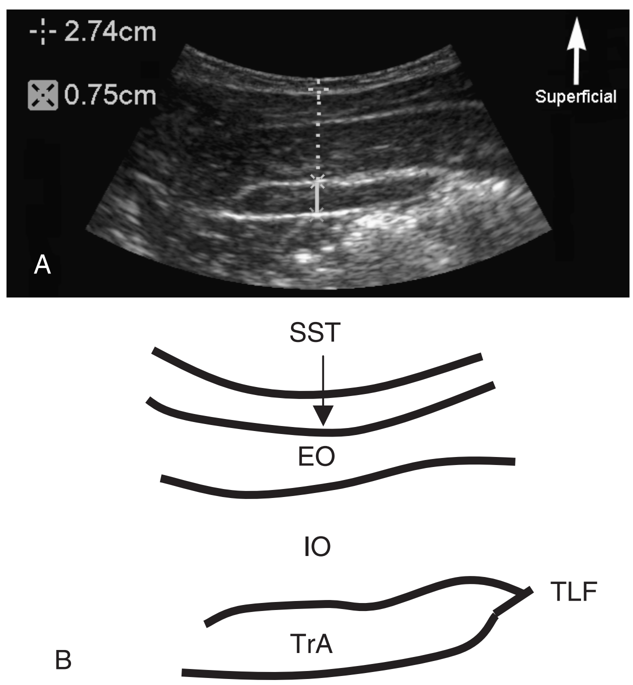

FIGURE 3. (A) Sonogram of lateral abdominal muscles during the abdominal drawing-in maneuver. The muscle thickness of the 3 lateral abdominal muscles, transverse abdominis (TrA), internal oblique (IO), and external oblique (EO) is identified as the length of the solid and dotted line (2.74 cm). The thickness of the TrA muscle is identified as the solid line (0.75 cm). (B) Diagrammatic drawing of the lateral abdominals during the abdominal drawing-in manuever: TrA, IO, EO, superficial soft tissue (SST), and thoracolumbar fascia (TLF). (Video available at www.jospt.org)

and to perform each version of the ADIM 3 times per session, at 2 sessions per day, for a total of 18 repetitions per day. All 3 positions emphasized proper breathing. Subjects were given an exercise log to record compliance. Subjects returned for follow-up testing approximately 4 days later (range, 3-7 days; mean ± SD, 4.3 ± 1.1 days), and the patient's ability to perform the ADIM was reassessed using the same procedures that were used at baseline.

Statistical Analysis

Three ratios were calculated based on the relaxed and contracted states of the abdominal muscles. The muscular thickness of the TrA (equation 1) and the EO + IO muscles (equation 2), while contracted, were normalized based on the resting-thickness values. These contraction ratios were calculated to assess relative change of muscle thickness of these 2 muscle groups. Based on pilot work using trained individuals, we expected at least a 2-fold increase in the TrA muscle thickness during the ADIM (TrA contraction ratio $\geq$2.0), with the EO + IO muscle thickness staying relatively constant (EO + IO contraction ratio, ~1.0). These values were used to define preferential activation of the TrA during the ADIM a priori.

Equation 1:

$$TrA\ contraction\ ratio = \frac{TrA\ contracted}{TrA\ rest}$$

Equation 2:

$$EO + IO\ contraction\ ratio = \frac{EO + IO\ contracted}{EO + IO\ rest}$$

A preferential activation ratio (equation 3) was calculated to determine the relative coactivation of the TrA to the EO and IO muscle group. This value measured the difference in the proportion of muscle thickness of the TrA relative to the total lateral abdominal muscle thickness at both the rested and contracted states. The difference between these 2 ratios represents the relative change in the proportion of the TrA relative to the total lateral abdominal muscle thickness. In which a higher value represents a contraction with the majority of change in muscle thickness occurring in the TrA, while a lower or negative value represents greater relative change in muscle thickness of the EO + IO musculature.

Equation 3:

$$Preferential\ activation\ ratio = \frac{TrA\ contracted}{TrA + EO + IO\ contracted} - \frac{TrA\ rest}{TrA + EO + IO\ rest}$$

Two versions of intrarater reliability were calculated. First, to determine the reliability of an examiner's ability to consistently identify the correct landmark references with the on-screen measurement calipers, the same examiner performed repeated measurements of the same image after resetting the calipers (ie, intraimage reliability). Secondly, to measure the additional error associated with variations in the placement of the array and pressure applied to the soft tissue, repeated measurements of 2 separate images were obtained (interimage reliability). Although all repeated measures were recorded by the same examiner, the potential for recall bias was controlled by blinding the examiner to the results of each measurement. Both reliability measures were calculated for the TrA and lateral abdominal muscles (IO + EO + TrA) in the relaxed state using the intraclass correlation coefficient ($ICC_{3,1}$). Response stability was calculated using the coefficient of variation method error (CV_{ME}) and standard error of the measurement (SEM).

A mixed-model repeated-measures analysis of variance (ANOVA) was used for between- and within-subjects comparisons of TrA preferential activation. Independent variables were the repeated-measures factor-time with 3 levels (pretraining, posttraining, and follow-up) and group with 2 levels (traditional training group and biofeedback group). The level of significance was set a priori to be 0.05. All data were analyzed using SPSS Version 10.1 (SPSS, Inc, Chicago, IL).

RESULTS

Of the 30 subjects initially enrolled in the study, 13 in the biofeedback group and 15 in the traditional training group completed treatment and both testing sessions. Two subjects from the biofeedback group were unable to return for the follow-up appointment because of non–study-related reasons. Data from these 2 subjects were excluded based on the intent to determine the efficacy of ultrasound imaging under ideal circumstances. Descriptive statistics for those enrolled in the study are provided in Table 1.

TABLE 1. Descriptive statistics. Values represent mean (SD), unless indicated otherwise.

Description	Traditional Training (n = 15)	Biofeedback Training (n = 13)
Age (y)	30.8 (10.1)	31.2 (7.5)
Height (cm)	170.7 (9.5)	169.5 (7.3)
Body mass (kg)	77.9 (14.1)	77.3 (8.2)
Oswestry score	19.3 (13.6)	22.6 (10.0)
Duration of symptoms (mo)	3.4 (2.4)	3.3 (2.4)
Number of exercise sessions	6.7 (2.2)	8.0 (1.7)
Men-women ratio (n)	11:4	7:6

TABLE 2. Interimage and intrarater reliability.

	Intraimage Reliability (n = 30)			Interimage Reliability (n = 9)		
	$ICC_{3,1}$, 95% CI	SEM (cm)	CV_{ME} (%)	$ICC_{3,1}$, 95% CI	SEM (cm)	CV_{ME} (%)
TrA	0.98 (0.96-0.99)	0.013	5	0.93 (0.75-0.99)	0.031	11
Total	0.99 (0.99-10.0)	0.018	5	0.97 (0.77-0.99)	0.087	14

Abbreviations: CV_{ME}, coefficient of variation method error; ICC, intraclass correlation coefficient; SEM, standard error of the measurment; TrA, thickness of the transverse abdominis muscle; total, total thickness of the lateral abdominal muscles.

TABLE 3. Muscle thickness of the TrA and EO+IO over time. Data are provided as mean (standard deviation). Baseline values represent the resting muscle thickness value. The values at pretraining, posttraining, and day 4 represent the thickness of the contracted muscle.

Time	Traditional Training (n = 15)	Biofeedback Training (n = 13)	Overall (n = 28)
TrA (cm)			
Baseline (rest)	0.21 (0.10)	0.21 (0.10)	0.21 (0.10)
Pretraining	0.44 (0.17)	0.44 (0.13)	0.44 (0.15)
Posttraining	0.43 (0.18)	0.47 (0.13)	0.45 (0.16)
Day 4	0.45 (0.22)	0.44 (0.20)	0.44 (0.20)
EO + IO (cm)			
Baseline (rest)	1.90 (0.43)	1.66 (0.49)	1.79 (0.46)
Pretraining	1.92 (0.39)	1.73 (0.56)	1.83 (0.48)
Posttraining	1.90 (0.32)	1.80 (0.54)	1.85 (0.43)
Day 4	1.94 (0.40)	1.77 (0.46)	1.86 (0.43)

Abbreviations: EO, external oblique; TrA, transverse abdominis; IO, internal oblique.

TABLE 4. Contraction and preferential activation ratio data. Values represent mean (SD).

Contraction Ratio/Time	Traditional Group (n = 15)	Biofeedback Group (n = 13)	Overall (n = 28)
TrA			
Pretraining	2.22 (0.68)	2.33 (1.11)	2.27 (0.89)
Posttraining	2.29 (1.10)	2.43 (0.91)	2.36 (1.00)
Day 4	3.00 (1.92)	2.28 (0.82)	2.66 (1.53)
EO + IO			
Pretraining	1.02 (0.09)	1.04 (0.10)	1.03 (0.10)
Posttraining	1.02 (0.17)	1.09 (0.15)	1.05 (0.16)
Day 4	1.09 (0.13)	1.08 (0.06)	1.09 (0.10)
Preferential activation			
Pretraining	0.08 (0.04)	0.09 (0.06)	0.09 (.05)
Posttraining	0.08 (0.06)	0.10 (0.05)	0.09 (.06)
Day 4	0.09 (0.05)	0.08 (0.04)	0.09 (.05)

The $ICC_{3,1}$ for intraimage (n = 30) and interimage (n = 9) intrarater reliability were all greater than 0.93 (Table 2). Further, response stability was calculated (SEM), which ranged from 0.013 to 0.087 cm (Table 2).

The mean values of muscle thickness for the TrA and EO + IO at rest and the mean change with contraction are provided in Table 3. The mean TrA contraction ratios resulted in greater than a 2-fold increase between the resting and contracted states at pretraining, posttraining, and follow-up (Table 4). Only a slight increase was observed in the contraction ratios of the EO + IO at pretraining, posttraining, and follow-up. The mixed-model ANOVA revealed no significant differences between preferential activation ratios of the biofeedback group and traditional training group for between-subjects (1 degree of freedom, F = 0.275, P = .605) or within-subjects (2 degrees of freedom, F = 0.013, P = .988) effects.

DISCUSSION

The intraimage and interimage intrarater reliability of the TrA and the lateral abdominal muscles measurements are considered good and clinically useful according to the classification system outlined by Portney and Watkins.[40] Further, the SEM, which ranged from 0.13 to 0.31 mm for the TrA, was consistent with prior error measurements from other accepted techniques, such as M-mode ultrasound (0.18-0.66 mm).[2,33] Therefore, ultrasound imaging is

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a noninvasive tool that can be reliably used in the clinical setting to quantify the thickness of the lateral abdominal muscles. Future researchers should measure interrater reliability to establish ultrasound imaging as a legitimate tool for assessing activation of the lateral abdominal muscles across raters.

Further refinement of the relationship between changes in muscle thickness measured with ultrasound imaging and more traditional techniques of assessment of muscular function is required. For example, the validity of using ultrasound imaging to assess the muscles of the pelvic floor has been extensively studied[8-14,34,39] and validated, based on strength testing with pressure perineometry[10] and more traditional testing for urinary incontinence.[9,14,34] Further, Peschers et al[39] concluded that only changes in muscle geometry measured with ultrasound imaging represented pure changes in muscular function secondary to the limitations of the other assessment tools (cross-talk limitations with EMG). Recently completed validation studies for the use of ultrasound imaging of the lateral abdominal muscles have also determined relationships between changes in thickness and changes in EMG values.[23,36] However, further investigation is required to determine the exact relationship between the change in muscle thickness and muscle activation (linear versus nonlinear relationships) and the limitations of this measurement approach as a tool to assess muscle activation.

According to the operational definition used for preferential activation, subjects in both groups were generally able to preferentially activate the TrA prior to training (TrA contraction ratio mean ± SD, 2.27 ± 0.89), with only minimal change in the EO + IO musculature (EO + IO contraction ratio mean ± SD, 1.03 ± 0.10). This occurred with minimal instruction ("Take a deep breath in and, as you exhale, pull your belly button up and in towards your spine").[41] The relative lack of change in the EO + IO muscle thickness, compared to the measured changes in the TrA muscle thickness, at all 3 testing periods validates the theoretical rationale for using the ADIM as a foundational component to lumbar stabilization programs to preferentially activate the TrA (Figure 4).

The results of this study failed to support the hypothesis that patients with LBP who received a single episode of supplemental biofeedback would demonstrate significant short-term improvements in the ability to preferentially activate the TrA after training. Based on previous literature,[26] it was expected that subjects with LBP would have difficulty preferentially activating the TrA prior to training, yet this was not the case. The lack of difference between training methods may be explained in part by the fact that patients in both groups could preferentially activate the TrA prior to training and the suggested nonlinear nature of muscle thickness changes during contraction.[23] Both of these factors may have lead to a ceiling effect, which may have limited the ability of ultrasound imaging to detect improvements after training. However, it is also possible that our inability to detect a benefit from ultrasound biofeedback could be attributed to a treatment program that provided a suboptimal training stimulus. Finally, it is possible that the lack of a treatment effect may be at least partially attributable to a failure in isolating the subgroup of patients most likely to benefit from biofeedback. These patients would presumably be patients who have difficulty activating the TrA at baseline, thus are, theoretically, potential candidates for lumbar stabilization training.

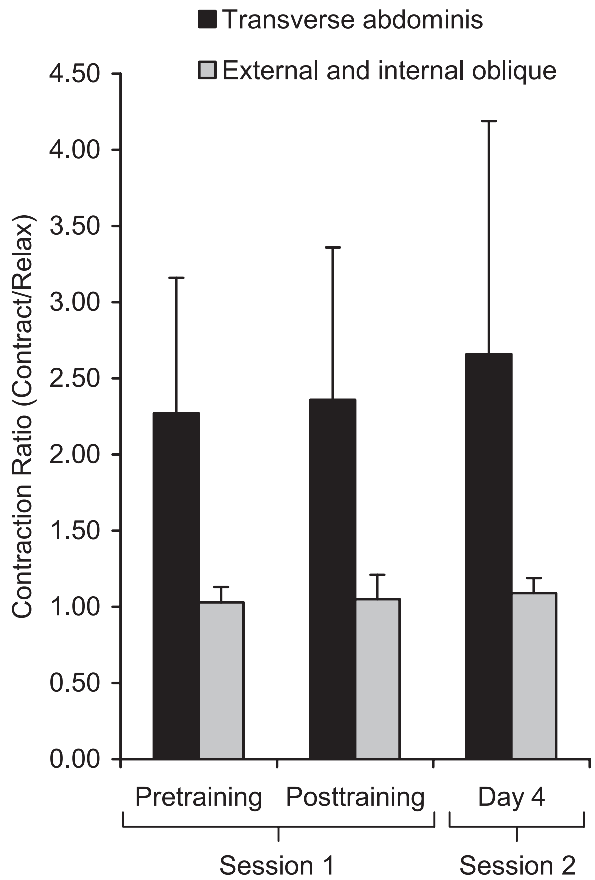

FIGURE 4. Mean ratio data for the transverse abdominis (TrA) contraction ratio and external and internal oblique (EO + IO) contraction ratio are shown. The ratio of contracted/resting for the TrA and the EO + IO for all subjects was averaged for each test period (pretraining, posttraining, and day 4).

The lack of short-term improvement in the ability to contract the TrA muscle contrasted with the purported benefits of ultrasound biofeedback for the lateral abdominal muscles[32,41] and evidence of benefits from ultrasound biofeedback for the pelvic floor muscles.[13] Based on the contradictory results of this study, it is important to explore why this discrepancy exists. Based on an anticipated effect size of 0.7 before the study began, a sample size of 30 subjects provided adequate power ($>.80$) to achieve statistical significance at an alpha level equal to .05. The actual

TABLE 5. Comparison of subjects that met the CPR* and those that did not meet the CPR† for pretraining measurements.

	Positive CPR Group (n = 9)	Negative CPR Group (n = 21)
TrA contraction ratio	2.00 (0.61), 1.09-2.93	2.40 (0.94), 1.35-5.00
EO+IO contraction ratio	1.06 (0.11), 0.94-1.21	1.00 (0.09), 0.84-1.16
Preferential activation ratio	0.07 (0.04), 0.01-0.13	0.10 (0.05), 0.03-0.22

Abbreviations: EO, external oblique; IO, internal oblique; TrA, transverse abdominis.
*Clinical predication rule (CPR) by Hicks et al.[16]
†Values represent mean (standard deviation), range.

effect size was only 0.28. However, it seems reasonable to suspect that the lack of a treatment effect may be at least partially attributable to a failure in isolating the subgroup of patients most likely to benefit from biofeedback training. These patients would presumably be patients who have difficulty activating the TrA at baseline, thus theoretically potential candidates for biofeedback training. Preliminary findings from secondary analyses of the data in this study appear to support this hypothesis.

Hicks[16] recently developed a clinical prediction rule to identify patients likely to benefit from lumbar stabilization exercise. The clinical prediction rule consists of 4 predictors: age less than 40 years, average straight-leg raise greater than 90°, a positive prone instability test, and presence of at least 1 aberrant movement during lumbar spine range of motion testing.[16] Patients with at least 3 out of 4 criteria present were more likely to experience a successful outcome than patients who did not satisfy the rule (positive likelihood ratio, 4.0). The authors of this research report did not attempt to explain the mechanism as to why these patients improved with lumbar stabilization exercise. However, given that a focus of the treatment approach was to improve activation patterns of the deep trunk muscles (TrA and multifidus), perhaps patients who have these factors present are the same individuals that might have difficulty activating the TrA at baseline.

Based on our inclusion of each of these variables as part of the standardized history and physical examination performed at baseline, we were able to retrospectively classify patients as to whether they were positive on the clinical prediction rule (at least 3 of the 4 findings present). The unequal distribution of subjects in each group (9 subjects met the rule versus 21 subjects did not meet the rule) limits the power of a direct comparison. However, the data suggest that subjects who met the rule were less able to increase the thickness of the TrA at baseline compared to subjects who did not meet the rule (Table 5). Future work is needed to confirm whether differences in one's ability to preferentially activate the TrA are based on one's status on the rule. If our preliminary findings can be substantiated, additional research could examine the efficacy of biofeedback in the subgroup of patients who are positive on the rule. An alternative option would be to establish a threshold that indicates the lack of the ability to increase the thickness of the TrA prior to training (perhaps less than 1.5), and then limit the inclusion criteria to these individuals. Ultimately, some combination of these approaches might be feasible. Limiting future study to a more homogeneous subgroup of patients who have difficulty performing the contraction at baseline with only minimal instruction ("Bring your belly button up and in towards the spine") would provide further insight into the clinical utility of ultrasound imaging in the management of low back disorders. Additionally, future research should address the effectiveness of lumbar stabilization training programs based on initial ultrasound measurements to determine if effectiveness of this intervention is influenced by the initial ability to perform the contraction.

CONCLUSION

Real-time ultrasound imaging is a noninvasive technique that can be reliably used to measure thickness. Importantly, the results of this study provide construct validity for the notion that the ADIM results in preferential activation of the TrA muscle and support its use as a foundational component for lumbar stabilization training programs. Additionally, our subjects could preferentially activate the TrA at baseline and the use of biofeedback or traditional exercise instruction did not prove to be beneficial for improving preferential activation of the TrA while performing the ADIM over a 4-day period. Future studies should measure the benefits of ultrasound biofeedback on subjects who have difficultly preferentially activating the TrA at baseline.

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