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ORIGINAL RESEARCH

TRANSVERSUS ABDOMINIS ACTIVATION AND TIMING IMPROVES FOLLOWING CORE STABILITY TRAINING: A RANDOMIZED TRIAL

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ABSTRACT

Background: Patients with non-specific low back pain (LBP) often present with a decrease in transversus abdominis (TrA) muscle activation and delayed onset of contraction with extremity movements, potentially contributing to recurrent LBP. Core stability is required for extremity movement and if the timing of when the TrA contracts is not corrected patients may continue to experience LBP.

Hypothesis/Purpose: The purpose of this study was to assess the effects of a four-week core stability rehabilitation program on TrA activation ratio and when the TrA initiates contraction during upper extremity movements in subjects with and without LBP. It was hypothesized that those with LBP would experience greater changes in TrA activation and onset of contraction by the TrA compared to the healthy group.

Study Design: Randomized Clinical Trial

Methods: Forty-two participants volunteered (21 healthy and 21 LBP). Ultrasound imaging measured the TrA activation ratio and time of initial contraction of the TrA during upper extremity movement into flexion. Half of the healthy and LBP participants were assigned to the exercise group. Participants reported twice a week to the athletic training facility to complete an exercise progression of three exercises. After four weeks, all participants returned to have TrA activation and timing measured again.

Results: Pertaining to demographics, there were no differences between the healthy and LBP participants. There was a group interaction for both TrA activation ratio ($p = .049$) and onset of initial contraction ($p = .008$). Those in the exercise group showed an increase in TrA activation ratio (1.85 ± 0.09) compared to the control group (1.79 ± 0.08), as well as an improvement in the onset of contraction (2.07 ± 0.08 seconds) compared to the control group (2.23 ± 0.09 seconds) after the four-week rehabilitation program. Strong effect sizes for TrA activation ratio (0.71 [0.06-1.35]) and initial onset of TrA contraction (-1.88 [-2.63 - -1.11]) were found indicating clinical differences related to the interventions.

Conclusion: TrA activation and timing were altered following a four-week core stability program in people with and without LBP. Clinicians should consider incorporating these exercises for improving the function of the TrA.

Level of Evidence: Therapy, level 2b

Key words: core stabilization exercises, low back pain, ultrasound imaging

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INTRODUCTION

Low back pain (LBP) is one of the leading reasons people seek medical advice in the United States.[1] With a high recurrence rate of over 60%,[2-4] the cause of LBP, as well as effective treatment practices, need to be at the forefront of clinical practice. Clinical spinal instability has been considered to be an important cause for recurrent LBP.[1,5] It is believed to be caused by the loss of spinal motion leading to pain and neurologic dysfunction,[5] such as that of weak or delayed activation of core musculature.[6-12]

Stability of the spine involves three subsystems: active, passive, and neural control.[1] The active system incorporates the muscles surrounding the spine that produce the forces necessary for stability. The passive system incorporates non-contractile tissues, such as ligaments, that provide stability at the end ranges of motion. The neural system receives afferent information from the trunk and extremities and sends efferent signals for muscle activation and motor patterns for spinal stability. As muscle tone and motor patterns improve, spinal stability should also be enhanced, decreasing LBP.[1,13]

One of the core muscles addressed during rehabilitation that addresses spinal stability is the transversus abdominis (TrA), as it has been shown to atrophy following an episode of LBP.[6] This muscle acts as a corset and is activated prior to extremity movement in order to increase stiffness of the spine for stability.[14,15] Individuals with LBP have a decrease in TrA activation measured via real-time ultrasound,[16] as well as delayed muscle activation.[17] It has been proposed that patients with LBP be screened using clinical prediction rules for LBP.[18-21] Of the four classifications, patients that fall in the stabilization category are believed to have altered motor patterns resulting in excessive segmental movements of the spine.[22] The treatment for people in this category is isolated contraction and co-contraction of the deep stabilizing muscles (TrA and multifidus) and strengthening the large spinal stabilizers (erector spinae and obliques) . Exercises that have been shown to activate the TrA the best are the abdominal drawing in maneuver (ADIM), the side-bridge, and quadruped exercises.[12] While these exercises have been shown to increase TrA activation, it is unknown if changes in muscle activation affect when the TrA “turns on” or becomes activated with movement.

To measure TrA activation and timing, diagnostic ultrasound imaging can be used to view the muscle in real time.[23] Ultrasound imaging (USI) has been shown to be as reliable as MRI in measuring muscle activation.[24,25] Most ultrasound machines also have a movie feature that allows an examiner to capture muscle activation during movement. Therefore, the purpose of this study was to assess the effects of a four-week core stability rehabilitation program on TrA activation ratio and when the TrA initiates contraction during upper extremity movements in subjects with and without LBP. It was hypothesized that those with LBP would experience greater changes in TrA activation and onset of contraction by the TrA compared to the healthy group.

METHODS

Subjects

Forty-two participants volunteered to be in the study, with 21 participants reporting LBP. The other half were healthy, never having experienced LBP. Demographics are presented in Table 1. Exclusion criteria for the LBP group included any injury to the body in the prior six weeks, except low back pain; previous abdominal or lumbar surgery; pregnancy; balance disorders; or an Oswestry Disability Index (ODI)[26] score greater than 40%. To be in the healthy group, exclusion criteria was the same except participants could not have any injury to the body in the prior six weeks or an ODI score higher than 0%. The study was approved by the Institutional Review Board and all subjects signed informed consent and the rights of subjects were protected.

Ultrasound Imaging

A Terason t3000 M-series portable ultrasound system (Teratech, Burlington, MA) with an 8-15MHz linear array measured TrA activation and onset of contraction by the TrA during upper extremity movement into flexion. Prior to exercise assignment, all participants met with the lead investigator who was blinded to group allocation. The lead investigator performed all the ultrasound imaging and has utilized these techniques for seven years. The patient was supine in the hook lying position with the abdomen exposed. Ultrasound gel was applied to the transducer and placed over the right abdomen superior to the iliac crest, in the midaxillary line, in

Table 1. *Demographics*

	Age	Height	Weight	ODI Score
Healthy (n=20)	23.2 ± 1.8 years	67.38 ± 0.74 cm	72.43 ± 2.87 Kg	0%
LBP (n=19)	21.7 ± 0.4 years	66.42 ± 0.81 cm	68.76 ± 2.59 Kg	13.1 ± 1.5%
Exercise (n=19)	21.2 ± 0.5 years	66.29 ± 0.93 cm	69.47 ± 3.14 Kg	7.4 ± 1.9%
Control (n=20)	23.7 ± 1.7 years	67.50 ± 0.60 cm	71.75 ± 2.33 Kg	5.4 ± 1.7%

LBP= low back pain; ODI= Oswestry Disability Index

a transverse position.[11,27,28] To standardize position of the TrA on the ultrasound screen, the medial edge of the TrA was visualized on the far right of the screen. Three resting images were captured at the end of exhalation to limit the effect of respiration on muscle thickness.[29] Next, the participant was instructed to perform an ADIM. The instructions were to "breathe in, breathe out, and when near maximal exhalation, draw your belly button to your spine". During the contraction, an image was recorded. This was repeated two more times.

For the movie portion, the participant and transducer was positioned in the same location as above. Using a stop watch, a three second count down was given before the participant started moving the left arm overhead for a two second count. As the arm was returning to the starting position, the right arm was moving overhead for a two second count. The pattern continued until the movie finished recording. The movie began to be captured at the beginning of the three second count down and a 10 second clip was recorded.

Exercise Protocol

Half of the LBP and half of the healthy participants were randomly assigned to the exercise protocol using a random number generator. The four-week rehabilitation protocol consisted of the participants meeting with one of the other investigators twice a week in the athletic training facility. If the participant was in the control group, they were instructed to maintain their daily activities of living and return four weeks later.

Three exercises were chosen (ADIM, side-bridge, and quadruped) and the level of difficulty increased each week, pain permitting. For the ADIM, 3 sets of 10 contractions, with a 10 second hold and 15 second rest, was used. The cue to the patient was "breathe in, breathe out, and when near maximal exhalation, draw your belly button to your spine". During week 1, the patient was in the hook-lying position and only performed the ADIM. During week 2, the arms were moved overhead in an alternating pattern, every two seconds during the contraction phase. During week 3, the legs lifted off the table in an alternating pattern, every two seconds during the contraction phase. During week 4, the opposite arm and leg moved over head/lifted off the table in an alternating pattern, every two seconds during the contraction phase, (Figure 1).

For the side-bridge exercise, the patient started by lying on their right side, with the weight-bearing elbow flexed and both knees flexed. The patient was instructed to perform an ADIM, then lift into a

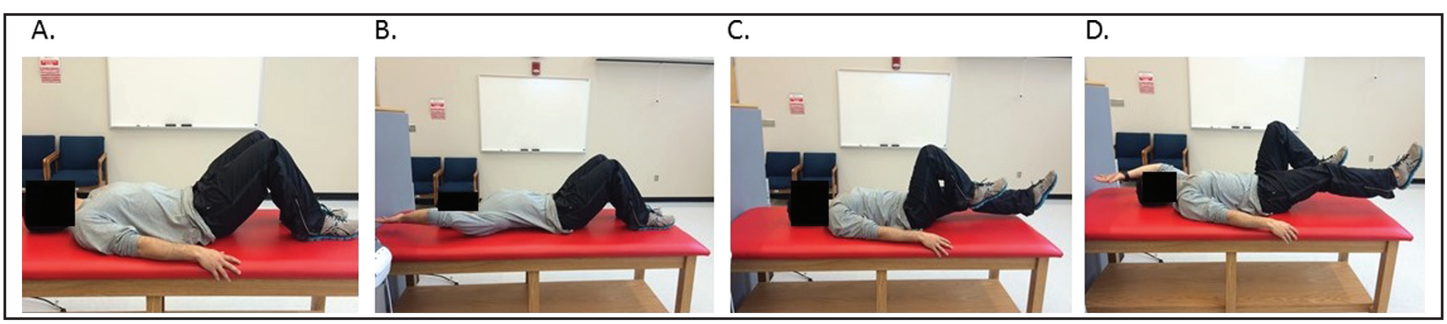

Figure 1. *Weekly progression of the abdominal drawing-in maneuver (ADIM) exercises. A = Week 1: Hooklying with ADIM B = Week 2: Hooklying with ADIM and alternating arms, C = Week 3: Hooklying with ADIM and alternating legs and D = Week 4: Hooklying with ADIM and alternating opposite arm and leg.*

side plank position with the elbow and knees flexed, keeping the hip and shoulder in line. The position was held for 10 seconds, with a 15-second rest. Then the patient switched to the left side and performed the same half version of the side-bridge. This was repeated three times. During week 2, the elbow remained bent, but the knees were extended. During week 3, the elbow was straight and the knees bent. During week 4, both the elbow and knees were extended (Figure 2).

Lastly, for the quadruped exercise, the patient began in quadruped. Keeping a flat back, the patient performed the ADIM, holding the contraction for 10 seconds. This was repeated two more times, with 15 seconds rest between contractions. During week 2, the arms were extended out front in an alternating pattern every two seconds during the contraction phase. During week 3, the legs were extended behind the patient in an alternating pattern every two seconds, during the contraction phase. During week 4, the opposite arm and leg were extended at the same time in an alternating pattern, every two seconds (Figure 3).

For all exercises, the number of repetitions stayed the same, but the difficulty increased if the patient was ready to progress to the advanced level.

Procedures

Participants entered the athletic training facility wearing athletic clothing. After signing informed consent, inclusion/exclusion criteria were reviewed. If the subject met the LBP group qualification, the ODI was completed. Healthy subjects also completed the ODI to make sure the score was 0. Next, ultrasound imaging was completed. The lead investigator left the room and the subject was assigned to either the exercise or control group. Those in the exercise group began with the exercises that day. Those in the control group did not report back until four weeks later. A home exercise program was not prescribed and the participants were asked not to do exercises outside of the study. At the end of the four weeks, those in the exercise group reported to the athletic training facility 24 hours after the last rehabilitation session. The same ultrasound images were recorded again by the lead investigator.

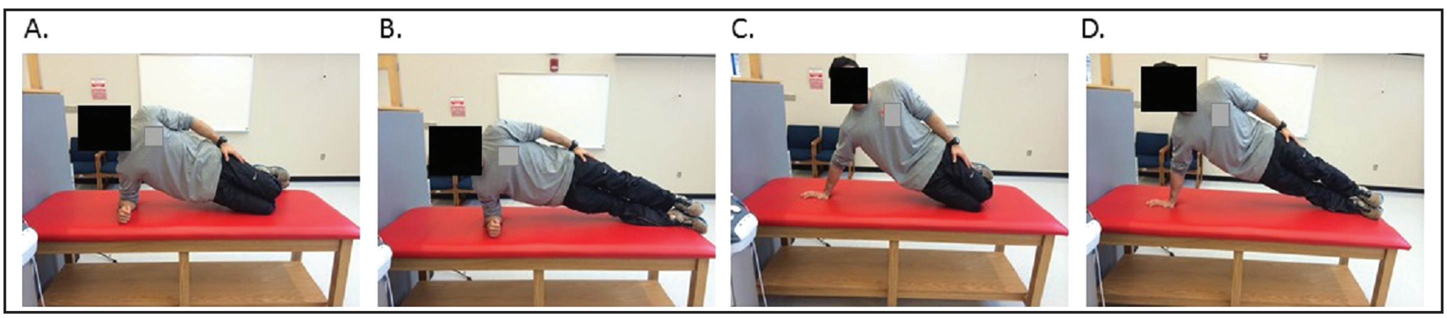

Figure 2. *Weekly progression of the side-bridge exercise. A = Week 1: half side plank with elbows and knees flexed, B = Week 2: full side plank with elbow flexed, C = Week 3: half side plank with elbow straight and D = Week 4: Fill side plank with elbow straight.*

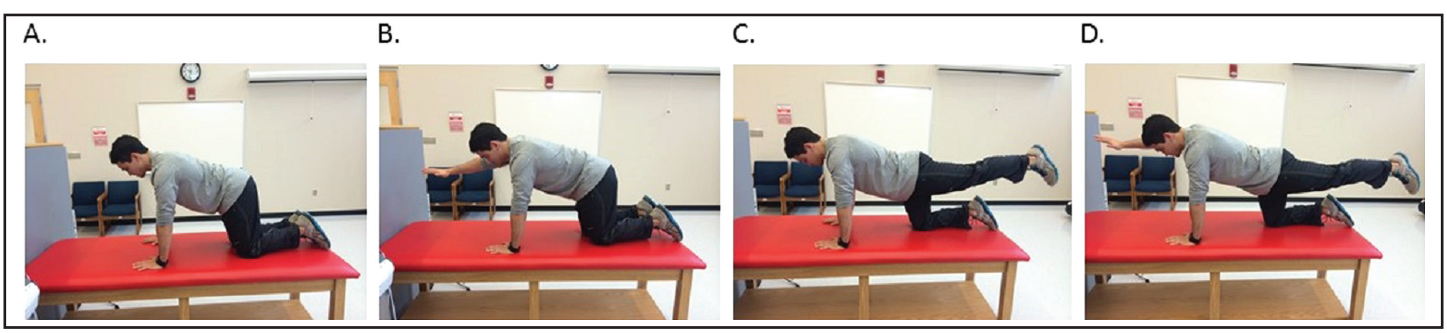

Figure 3. *Weekly progression of the quadruped exercise. A = Week 1: Quadruped with ADIM, B = Week 2: Quadruped with ADIM and alternating arms, C = Week 3: Quadruped with ADIM and alternating legs and D = Week 4: Quadruped with ADIM and alternating opposite arm and leg.*

DATA REDUCTION

TrA Activation

TrA activation was measured using a ratio from the following equation as it has been well documented in the literature.[12,34,35,49,52]

$$\frac{\text{Thickness of TrA during ADIM}}{\text{TrA thickness at rest}}$$

If the ratio was a 2, that indicated the TrA thickness doubled during the contraction portion of the ADIM.[12] The ratio was used to standardized activation across all participants. Two participants were excluded from data analysis, as they represented outliers in the data.

TrA Timing

The recording was analyzed using slow motion ultrasound in order to observe when the TrA began to contract. This was indicated by when the most medial portion of the TrA started to retract laterally. Since image depth alters the transducer MHz used, the frames captured per second varied, with the average being around 20 frames per seconds. Frames could be advanced one at a time to find the frame where the contraction began. The timing of the frame was converted to seconds using the ultrasound software. One subject was excluded from data analysis due to video data not being captured.

Data Analysis

Two 2x2x2 ANOVAs were used to determine the effect of group (exercise and control) and condition (LBP and healthy) on TrA activation and TrA timing following a four-week rehabilitation protocol (baseline and four-weeks). Alpha was set *a priori* at $\alpha = .05$. Cohen's d effect sizes were calculated to interpret clinical meaningfulness.

RESULTS

All descriptive data for subjects and outcomes are presented in Tables 1 and 2.

There were no significant group by condition interactions for TrA activation ($p = .424$) or timing ($p = .609$). However, there were significant group interactions for TrA activation ($p = .049$) and timing ($p = .008$), indicating those in the exercise group increased TrA activation and improved timing compared to the control group. Strong effect sizes for TrA activation (0.71 (0.06-1.35)) and TrA timing (-1.88 (-2.63 - -1.11)) were found further indicating the results show clinical differences beyond measurement variability. Means and standard deviations are presented in Table 2.

DISCUSSION

According to the results of the study, people are able to increase the activation and decrease timing of the TrA, regardless of having LBP or not. With effect sizes being strong, it is further indicated that TrA muscle function improved in those that participated in the exercise program. It appears that four-weeks is long enough to see changes, however this length of time may be too short to see maximum effectiveness. With the initiation of muscular training programs, neural changes present at about 4-6 weeks and strength gains are not seen until 6-8 weeks.[30] It is likely the positive findings at four weeks improved neural function of the TrA, however, the effects on LBP were not assessed.

The exercises chosen have been previously identified to activate the TrA.[12,27,31-33] The side-bridge

Table 2. *Transversus Abdominis Activation and Timing Following a Four-Week Core Stability Program*

	TrA Activation* Baseline	TrA Activation 4-Weeks	TrA Timing† Baseline	TrA Timing 4-Weeks
Exercise (n=19)	1.58 ± 0.07	1.85 ± 0.09‡	2.34 ± 0.07 sec	2.07 ± 0.08 sec‡
Control (n=20)	1.74 ± 0.08	1.79 ± 0.08	2.22 ± 0.08 sec	2.23 ± 0.09 sec

TrA= Transversus Abdominis

*Activation (expressed as mean ± SD) is the ratio of TrA thickness change from a resting to contracted position during the abdominal drawing-in maneuver calculated as contracted state/resting state.

†Timing was determined as the point when the TrA began contracting when the arm was brought overhead after a three-second wait period.

‡ Significant difference between the control group (p≤.05)

exercise was reported to be the most challenging, especially in subjects that had previous shoulder injuries. Exercises were not progressed if the subject reported pain or could not perform the exercise correctly. While there are a variety of exercise prescriptions for core stability, this progression was chosen to focus on exercises where limb movements could be added. In addition, these exercises were chosen to decrease loads placed on the lumbar spine,[31-33] allow arm movement without increased muscle activation of the lateral abdominal muscles,[12] and target muscle activation of the TrA[27]. By progressing the exercises over a four-week time period, the subjects were able to focus on contracting the TrA prior to limb movement utilizing more functional movement patterns. Since arm movement was the activity during post-testing, subjects were accustomed to contracting the TrA prior to movement from the exercise protocol, resulting in improved activation and initial onset of contraction.

Previous authors have indicated that people with LBP have a delay in activation of the TrA, contributing to spinal instability, as measured via EMG.[10,14] The results of this study do not support the delay in activation observed in people with LBP, but this may be due to the younger age of the participants and/or pain was not severe enough to seek medical advice. ODI scores on average were 13% (range 4-28%) which falls in the minimal disability category where people are coping with everyday activities of daily living, and where treatment is generally not needed.[26] In the future, ODI scores should fall in the 20-40% range where conservative treatment is suggested. This may result in greater differences between groups at baseline. There are conflicting repors regarding TrA activation being lower in people with LBP.[7,34-36] Studies that enrolled a young, active population have not shown these differences.[34,35] Thus, the population chosen and level of disability should be considered in future research.

There has been considerable use of USI to measure TrA muscle activation.[8,27,34,35,37-57] Measurement error is minimal compared to other methods, such as EMG, as crosstalk from surrounding musculature does not exist.[32] However, there has been limited use of USI to determine muscle contraction timing. Fine wire EMG has the ability to assess muscular timing, but it is invasive and can be challenging to determine if the wire is in the correct muscle.[7,17,58,59] USI provides a non-invasive way to observe muscle contraction in real time. While it may not be the most accurate method to measure timing, this technology is clinically relevant and could be used by clinicians to assess the progress of their patients. The hooklying position that the USI was captured in could also be changed in the future to accommodate for and assess the TrA during more dynamic movement. A study by Mangum et al.[49] indicated acceptable to excellent reliability in seated, standing, and walking positions during USI of the TrA ($ICC_{3,k}$ = 0.553-0.737), however, the hook-laying position showed superior reliability ($ICC_{3,k}$ = 0.903). That was why this position was chosen for this study.

Limitations

Several limitations need to be reported for this study. First, the population consisted of collegiate-aged people that were not classified as disabled by their LBP. The ODI may not be the best instrument for a physically active population experiencing LBP to quantify disability. Second, the measurement of initial onset of TrA contraction was subjective to the investigator analyzing the frames of the movie. Movement by the subject and movement of the probe can indicate false readings of contraction. Third, two researchers led the exercise sessions. While the same researcher followed the same patient through the exercises, inconsistencies in instructions and verbal cueing across subjects may have occurred.

CONCLUSION

In both healthy and LBP participants that completed the four-week rehabilitation protocol, increases in TrA activation and improvement in TrA timing were found. In this study, a change of almost two tenths of a second may be the difference needed to stabilize the spine before extremity movement, at least in an anticipated task. The participants were able to activate the TrA almost one second prior to limb movement. However, it is unknown how these participants would respond to an unanticipated task and how quickly the TrA would contract. The participants were able to prepare the spine for overhead movement, even though they were not given instruction to do so. Core stability is necessary for any type of movement and should be incorporated during rehabilitation of any injury.

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