Changes in Muscle Thickness Across Positions on Ultrasound Imaging in Participants With or Without a History of Low Back Pain

Mark A. Sutherlin, PhD, ATC, CSCS*; Matthew Gage, PhD, ATC†; L. Colby Mangum, PhD, ATC‡; Jay Hertel, PhD, ATC, FNATA‡; Shawn Russell, PhD‡; Susan A. Saliba, PhD, PT, ATC, FNATA‡; Joseph M. Hart, PhD, ATC, FNATA, FACSM‡

*Kinesiology Department, SUNY Cortland, NY; †Department of Health Professions, Liberty University, Lynchburg, VA; ‡Department of Kinesiology, University of Virginia, Charlottesville

Context: Injury-prediction models have identified trunk muscle function as an identifiable factor for future injury. A history of low back pain (HxLBP) may also place athletes at increased risk for future low back pain. Reduced muscle thickness of the lumbar multifidus (LM) and transversus abdominis (TrA) has been reported among populations with clinical low back pain via ultrasound imaging in multiple positions. However, the roles of the LM and TrA in a more functional cohort and for injury prediction are still unknown.

Objectives: To (1) assess the reliability of LM and TrA ultrasound measures, (2) compare changes in muscle thickness across positions between persons reporting or not reporting HxLBP, and (3) determine the ability to distinguish between groups.

Design: Cross-sectional study.

Setting: Research laboratory.

Patients or Other Participants: Participants were 34 people who did not report HxLBP (age = 22 ± 7 years, body mass index = 23.7 ± 2.7) and 25 people who reported HxLBP (age = 25 ± 10 years, body mass index = 24.0 ± 3.2).

Main Outcome Measure(s): Muscle thickness and changes in muscle thickness of the LM and TrA as shown on ultrasound imaging.

Results: Intraclass correlation coefficients ranged from 0.641 to 0.943 for all thickness measures and from 0 to 0.693 for all averaged thickness modulations bilaterally. Participants who reported HxLBP had voluntarily reduced TrA thickness modulations compared with those not reporting HxLBP ($P = .03$), and the testing position influenced TrA thickness modulations ($P < .01$). No differences were observed for LM thickness modulations between groups or positions ($P > .05$). A tabletop cutoff value of 1.32 had a sensitivity of 0.640 and a specificity of 0.706, whereas a seated cutoff value of 1.18 had a sensitivity of 0.600 and a specificity of 0.647.

Conclusions: In participants reporting HxLBP, TrA thickness modulations were lower and both tabletop and seated thickness modulations were able to distinguish reported HxLBP status. These findings suggest that TrA muscle function may be altered by HxLBP.

Key Words: transversus abdominis, lumbar multifidus, activation ratio

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Key Points

- Participants with a history of low back pain had smaller changes in transversus abdominis muscle thickness during the abdominal drawing-in maneuver in the tabletop and seated positions.
- No differences were observed in lumbar multifidus muscle thickness during the abdominal drawing-in maneuver.

Injury from sport participation is common among athletes.[1] Because of the large number of participants at risk for injury, sports medicine research focusing on identifying risk factors for injury prevention continues to grow.[2–6] Although injuries to the low back or lumbar spine are not the most frequently reported injury during athletic participation,[1] a 1-year prevalence of more than 50% of adolescent athletes has been demonstrated.[7] These numbers support data from elite athletes who reported back pain over a previous 1-year time span; most of their pain was located in the lumbar region.[8] In conjunction with the number of athletes reporting low back pain, a history of low back pain (HxLBP) in athletes has been shown to increase the future

risk of low back pain injury between 3- and 6-fold, depending on when an athlete reported pain.[9] This could lead to recurrent episodes of low back injury and pain that impede sport participation by these individuals.

Changes in function of the lumbar multifidus (LM)[10–13] and transversus abdominis (TrA)[10,14–17] have been reported between individuals with and without low back pain. As these muscles have been noted to contribute to local stabilization of the spine,[18] any disruption of normal muscle function could compromise the integrity of the spine, placing it at risk for undue stress or injury. Sports medicine researchers and clinicians can use ultrasound imaging to visualize and measure the properties and function of the

deeper muscles.[19,20] Ultrasound imaging has been used to identify potential neuromuscular dysfunction related to low back pain by showing changes in muscle thickness.[10–12,14–16] Assessing changes in muscle thickness between contracted and resting states reveals a person's ability to modulate muscle thickness using a voluntary or involuntary contraction. Although an unloaded tabletop measure has traditionally been used to assess changes in muscle thickness,[10–12,14,15] additional measures have been used during simulated[16] and actual weight-bearing positions.[11,14] As the muscle function of the LM and TrA may be influenced by the testing position, learning about the roles of both muscles across multiple positions could provide clinicians with a better understanding of LM and TrA muscle function and low back pain.

Smaller changes in muscle thickness have been reported for the LM in the tabletop position[10,12] and larger thickness changes in the standing position.[11] Comparisons of LM function in these assessments have involved both a contralateral arm reach[10,11] and an isolated sustained contraction.[12] Similarly, smaller changes in TrA thickness have been seen among persons with low back pain in tabletop,[10,14,15] seated,[14] and standing positions.[14] Volitional contractions for the TrA include an isolated muscle contraction using either the abdominal drawing-in maneuver[10,14] or the abdominal hollowing strategy.[15] However, the abdominal drawing-in maneuver has been theorized to co-contract the LM in combination with the isolated TrA contraction.[21] Evidence supporting co-contraction of the LM during the abdominal drawing-in maneuver during contractions in multiple positions using electromyography was reported.[22] Therefore, it may be possible to assess the function of both the LM and TrA during an abdominal drawing-in maneuver using ultrasound.

Translating thickness modulations from previous ultrasound findings is challenging when considering the implications of these measures in people with low back pain. Earlier assessments of TrA muscle function have consisted of instruction[10,14,15] along with corrective[10] or ultrasound biofeedback on proper TrA application.[14] The use of biofeedback could constitute a learning effect and allow individuals to improve or develop strategies to increase thickness modulations. A single session of exercise biofeedback may influence thickness modulations,[23] which could limit the ability of ultrasound thickness modulations to distinguish between groups. Providing necessary but minimal instructions to perform the abdominal drawing-in maneuver could allow ultrasound thickness modulations to be used as a diagnostic measure to identify low back pain. Also, all previous studies[11,12,14,15] have focused on samples of populations with clinical[10] or chronic low back pain.

Current prediction models suggest that LM size[6]; subjective assessment instruments for low back pain[2,3]; muscle endurance testing of the trunk, pelvic region, and thigh[2,3]; trunk displacement and repositioning[24]; and a HxLBP[24] all predict future injuries. Additionally, isolated muscle training with ultrasound imaging has been shown to reduce the number of games missed due to injury.[25] The ability to voluntarily modulate the LM or TrA could also be an outcome measure that contributes to these injury-prediction models. Establishing a measure that could be part of an injury-assessment screening would potentially allow more use of ultrasound imaging in the sports medicine setting. However, before thickness modulation assessments can be incorporated into injury-assessment models, a better understanding of the changes in LM and TrA muscle function is needed.

The purpose of our study was to assess the reliability of a single ultrasound measurement of the LM and TrA muscles and to compare the ultrasound thickness modulations of the LM and TrA during the abdominal drawing-in maneuver in multiple positions. We hypothesized that participants with a self-reported HxLBP would exhibit smaller thickness modulations of both muscles in all positions compared with participants who did not have HxLBP. Furthermore, we hypothesized that changes in muscle thickness would become smaller as functional tasks progressed and that thickness modulations could be used to identify the participant's group.

METHODS

The current design was a cross-sectional study to observe ultrasound thickness modulations during a single session and was approved by the University of Virginia Institutional Review Board. The dependent variables were the LM and TrA changes in muscle thickness and receiver operating curve (ROC) characteristics, including the area under the curve, sensitivity and specificity, predictive values, and likelihood ratios. The independent variables were group at 2 levels (participants with HxLBP and those without HxLBP) along with testing position at 4 levels (tabletop, seated, standing, and walking). All participants provided written consent before testing.

Participants

Volunteers between the ages of 18 and 64 years with either HxLBP consisting of at least 1 episode in the previous 6 months as well as either 3 episodes in the previous 3 years or 5 episodes across their lifetime or no lifetime HxLBP were eligible to participate. An episode of *low back pain* was defined as pain between the lowest rib and the gluteal folds that altered or limited participation in normal levels of daily, recreational, or physical activity, with periods of symptom resolution before and after the episode of pain. Volunteers were excluded if they reported a lower extremity injury in the previous 6 weeks or had a history of ligament reconstruction surgery. Volunteers who self-reported a spinal fracture or surgery, intervertebral disc injury, or pain exceeding 80 mm out of 100 mm on a visual analog scale or radiating pain past the knee or who were currently pregnant or within 6 months postpartum were also excluded. Additionally, any participant who could not maintain the testing positions or who had a skin infection, open wound, or subcutaneous tissue thickness that prevented ultrasound thickness measures was excluded.

Instruments

Patient-reported outcomes were collected using the Roland-Morris Disability Questionnaire,[26] Oswestry Disability Index (version 2.1a),[27] Tampa Scale for Kinesiophobia,[28] and Fear Avoidance Beliefs Questionnaire.[29] Pain was reported on a 100-mm visual analog scale, and activity levels were reported using the Godin Leisure Time

Exercise Questionnaire[30] and a modified Tegner Activity Scale,[31] with low back pain as the limiting factor.

Imaging was accomplished using an ultrasound device (model LOGIQ Book XP; GE Medical Systems, Waukesha, WI) with an 8-MHz linear transducer[23,32] and a Gait Trainer 3 treadmill (Biodex Systems Inc, Shirley, NY) for all walking trials.[32] Image J software (version 1.41o; National Institutes of Health, Bethesda, MD) was used to measure muscle thickness, and Excel software (version 14.7.7; Microsoft Corp, Redman, WA) was used for all calculations.

Testing Procedures

Interested participants provided written consent and then received an overview of the study procedures and were screened for eligibility. Eligible participants were randomized to the starting muscle and side for ultrasound imaging.[32] All ultrasound measurements started with the participants in the tabletop position and progressed to walking measures.[32] Resting ultrasound measures were taken at the end of normal expiration, whereas contracted measures were collected during the abdominal drawing-in maneuver immediately after normal expiration. Walking measures were taken during the ipsilateral heel strike on the treadmill with and without the abdominal drawing-in maneuver. Three resting and 3 contracted measures were recorded for each muscle, side, and position, for a total of 96 images per participant.

Tabletop Measures. Participants were initially positioned prone for the LM imaging or supine with a foam bolster placed under the knees for tabletop TrA imaging. For the LM, the ultrasound transducer was positioned longitudinally at the fourth and fifth lumbar vertebral level.[32] A water-soluble solution was applied to the skin, and the transducer was rotated until the zygapophysial joints were visible on the ultrasound image.[23,33]

For the TrA measures, the ultrasound transducer was placed on the lateral portion of the abdomen approximately 10 cm from the umbilicus.[32,34] A water-soluble transmission gel was applied directly to the skin along with an identification marking at the edge of the ultrasound transducer for subsequent measures. The transducer was adjusted until the lateral abdominal wall muscles were visible on the image and parallel at rest.

Abdominal Drawing-in Maneuver. The abdominal drawing-in maneuver was used for all contracted measures. Participants were allowed no more than 3 practice trials without biofeedback before testing. Verbal instructions were given to all participants to bring the umbilicus toward the spine at the end of normal expiration.[35] During contracted measures, participants were asked to complete and maintain the abdominal drawing-in maneuver until the image was captured.

Functional Positions. For the seated measures, participants were instructed to sit up straight on a backless stool with the hips and knees bent to approximately 90°.[32] Standing measures were collected in bipedal stance with the participant's feet approximately shoulder-width apart; walking measures were collected with participants walking at a self-selected comfortable pace.[32] An adjustable elastic wrap (Chattanooga Nylatex Wraps, DonJoy, Vista, CA) secured the transducer to an open cell foam pad directly on the skin and was used to maintain transducer positioning during the walking trials.[32]

Data Processing

All images were saved and exported for processing by a single assessor with more than 2 years of ultrasound experience at the initiation of the study. A single measurement was recorded per image, normalized to body mass index, and averaged across the 3 trials for the resting and abdominal drawing-in conditions for each muscle and testing position. Thickness measures for the LM were obtained vertically from the most superficial portion of the fifth lumbar vertebra to the inferior portion of the superior fascial border. Muscle thickness measures for the TrA occurred at the thickest point, which was visually determined by the assessor as the distance between the deep and superficial fascial borders perpendicular to the muscle fiber orientation. Thickness modulations for both muscles were calculated based on previous methods[36] and reported as the TrA contraction ratio. This was calculated by taking the ratio of the normalized average contracted thickness measures during the abdominal drawing-in maneuver to the normalized averaged resting values for each muscle. This procedure was repeated bilaterally and for each additional position for both the LM and TrA. A global measure of muscle function was then obtained and used for all comparisons by averaging the thickness modulations bilaterally for the LM and TrA muscles in each position.

Statistical Analysis

A power analysis was conducted using G*Power statistical software (version 3.1.5.1; Heinrich Heine Universitat Dusseldorf, http://gpower.hhu.de).[37] Previous findings[14] indicated that a minimum of 25 participants per group was needed to detect group differences based on a large effect size (Cohen d > 0.8) between groups, α level of .05, and power of 0.80. Demographic data were compared using independent-samples *t* tests and Mann-Whitney *U* tests. Two-way random intraclass correlation coefficients (ICCs [3,1]) were conducted to assess intrarater reliability for resting and contracted muscle thickness. Additional 2-way random intraclass correlation coefficients (ICCs [3,k]) were administered to assess the averages between left and right thickness modulations for a single global measure of muscle function. Reliability measure interpretations were determined using previously reported cutoff scores: <0.4, *poor*; 0.4 to 0.59, *moderate*; 0.6 to 0.75, *good*; and >0.75, *excellent*.[38] The standard error of measurement (SEM, equation 1)

$$SEM = SD \times \sqrt{1 - ICC} \qquad (1)$$

and minimal detectable difference (MDD, equation 2)

$$MDD_{95} = 1.96 \times SEM \times \sqrt{2} \qquad (2)$$

were also calculated for averaged bilateral thickness modulations.[39] Separate 2-way repeated-measures analyses of variance were conducted (group by position) for both the LM and TrA thickness modulations. Post hoc tests for position were conducted using least significant difference comparisons, and effect sizes with 95% confidence intervals (CIs) were interpreted using the Cohen d. The ROC curves were then administered for group thickness-modulation main effects across each position. Sensitivity, specificity, positive and negative prediction values, and likelihood ratios were then calculated based on the cutoff scores from the ROC curve

Table 1. Intrarater Reliability of Resting and Contracted Muscle Thickness: Intrarater Intraclass Correlation Coefficient (95% Confidence Interval)

Muscle	Position			
	Tabletop	Seated	Standing	Walking
Lumbar multifidus				
Resting	0.935 (0.913, 0.952)	0.937 (0.915, 0.954)	0.943 (0.924, 0.959)	0.867 (0.825, 0.902)
Contracted	0.928 (0.904, 0.947)	0.917 (0.889, 0.939)	0.921 (0.895, 0.942)	0.870 (0.829, 0.904)
Transversus abdominis				
Resting	0.766 (0.699, 0.823)	0.779 (0.715, 0.834)	0.765 (0.697, 0.822)	0.641 (0.551, 0.722)
Contracted	0.767 (0.701, 0.824)	0.725 (0.650, 0.790)	0.720 (0.644, 0.787)	0.660 (0.573, 0.738)

analysis. All statistical analyses were performed using SPSS (version 23.0; IBM Corp, Armonk, NY).

RESULTS

Seventy-three participants from a university community originally consented to the study. Of these, 14 were removed based on the current inclusion and exclusion criteria. A total of 59 participants were included in the analyses: 34 people without reported HxLBP (24 women and 10 men, age = 22 ± 7 years, height = 169.0 ± 9.2 cm, mass = 68.3 ± 13.3 kg, body mass index = 23.7 ± 2.7) and 25 people with reported HxLBP (16 women and 9 men, age = 25 ± 10 years, height = 171.2 ± 8.0 cm, mass = 70.2 ± 11.1 kg, body mass index = 24.0 ± 3.2).

Age, height, mass, body mass index ($P > .05$), Tegner Activity Scale (no HxLBP: median = 7, range, 3–10; HxLBP: median = 7, range, 3–9; $P = .79$), and total score on the Godin Leisure Time Activity scale (no HxLBP: 67 ± 33; HxLBP: 69 ± 45; $P = .87$) did not differ between groups. Participants with HxLBP had higher pain levels (no HxLBP: 0 ± 1 mm; HxLBP: 15 ± 14 mm; $P < .001$) and increased scores on the Roland-Morris Disability Questionnaire (no HxLBP: 0 ± 0; HxLBP: 2 ± 1; $P < .001$), Oswestry Disability Index 2.1a (no HxLBP: 0% ± 1%; HxLBP: 10% ± 7%; $P < .001$), Fear-Avoidance work subscale (no HxLBP: 0 ± 0; HxLBP: 6 ± 6; $P < .001$), physical activity subscale (no HxLBP: 1 ± 3; HxLBP: 9 ± 5; $P < .001$), and total scores (no HxLBP: 1 ± 3; HxLBP: 19 ± 10; $P < .001$) as well as on the Tampa Scale for Kinesiophobia (no HxLBP: 24 ± 7; HxLBP 31 ± 6; $P < .001$).

Reliability Measures. Intrarater reliability across 3 images consisted of ICC values above 0.867 for the LM and 0.641 for the TrA measures in all positions (Table 1). When averaged bilaterally, ICC values ranged from 0 to 0.351 for the LM thickness modulations (Table 2) and 0.419 to 0.693 for the TrA thickness modulations (Table 3). Averaging bilateral measures produced SEMs that were 0.061 or lower and 0.321 and under, respectively, for the LM and TrA individually; MDDs ranged from 0.114 to 0.169 and from 0.422 to 0.889 for the LM and TrA thickness modulations, respectively (Tables 2 and 3).

Lumbar Multifidus. No differences were observed in LM thickness modulations between participants with or without HxLBP ($F_{1,57} = 0.155$, $P = .70$, observed power = 0.07). Additionally, there were no differences between testing positions ($F_{3,171} = 1.071$, $P = .36$, observed power = 0.29) or group-by-position interactions ($F_{3,171} = 0.126$, $P = .95$, observed power = 0.07; Table 2).

Transversus Abdominis. Participants without HxLBP showed a greater ability to modulate TrA muscle thickness using the abdominal drawing-in maneuver ($F_{1,57} = 5.217$, $P = .03$, effect size = −0.56, 95% CI = −1.08, −0.03; observed power = 0.61; Table 3). There was also a significant main effect for position among all participants ($F_{3,171} = 10.986$, $P < .01$, observed power = 0.99, Table 3) but no group-by-position interaction ($F_{3,171} = 1.706$, $P = .17$, observed power = 0.44). Greater thickness modulations occurred in the tabletop position (1.37 ± 0.25) compared with the seated (1.21 ± 0.23, $P < .01$, effect size = −0.67, 95% CI = −1.04, −0.30) or standing (1.16 ± 0.22, $P < .01$, effect size = −0.89, 95% CI = −1.27, −0.51) testing positions but not during walking (1.29 ± 0.30, $P = .06$). Additionally, walking thickness modulations were greater than standing TrA thickness modulations ($P < .01$, effect size = −0.49, 95% CI = −0.86, −0.13).

Ultrasound Diagnostic Characteristics

Both tabletop and seated TrA thickness modulations predicted group based on HxLBP. The area under the curve was 0.693 (95% CI = 0.557, 0.829; $P = .01$) for the tabletop position and 0.686 (95% CI = 0.549, 0.823; $P = .02$) for the seated position. Tabletop muscle thickness modulations with a cutoff value of 1.32 had a sensitivity of 0.640, a specificity of 0.706, a positive predictive value of 62%, and a negative predictive value of 73%. Using a cutoff value of 1.18, seated muscle thickness modulations had a sensitivity of 0.600, a specificity of 0.647, and positive and negative prediction values of 56% and 69%, respectively. Participants with TrA thickness modulations below the identified thresholds had positive likelihood ratios of 2.2 for the tabletop and 1.7 for the seated measures and negative likelihood ratios of 0.46 for the tabletop and 0.59 for the seated TrA thickness modulations.

DISCUSSION

The current results indicate that our individual ultrasound imaging measurements were reliable (Table 1); the average single measure used for comparisons had lower reliability (Tables 2 and 3) but could still distinguish between groups (Table 3). Using the abdominal drawing-in maneuver, participants with HxLBP were not able to modulate muscle thickness of the TrA as well as participants without HxLBP. Additionally, we found that TrA thickness modulations varied across positions and that participants with a thickness modulation below a cutoff modulation score of 32% from baseline in the tabletop position and 18% in the seated position were 2.2 times (tabletop) and 1.7 times (seated) more likely to occur in participants with HxLBP compared with those who did not have HxLBP. These

Table 2. Lumbar Multifidus Thickness Modulations, Reliability and Measurement Error

Position	Intraclass Correlation Coefficient	95% Confidence Interval	Standard Error of Measurement	Minimal Detectable Difference	Group Thickness Modulations (Mean ± SD)	
					Healthy	Self-Reported History of Low Back Pain
Tabletop	0.351	0, 0.614	0.057	0.158	1.03 ± 0.06	1.02 ± 0.05
Seated	0.345	0, 0.612	0.041	0.114	1.02 ± 0.04	1.01 ± 0.03
Standing	0	0, 0.272	0.061	0.169	1.01 ± 0.04	1.01 ± 0.04
Walking	0.335	0, 0.606	0.049	0.136	1.01 ± 0.04	1.01 ± 0.05

findings support our hypothesis that people with HxLBP have altered neuromuscular properties of the TrA muscle.

These results are interesting as the participants with HxLBP had pain levels of less than 20 mm on a visual analog scale as well as minimal self-reported disability and fear-avoidance scores, which indicates that they were not clinically disabled at the time of testing. This suggests that people who reported only a previous history of pain may have already had neuromuscular alterations that could predispose them to additional injury. This theory is supported by elite athletes with low back pain who had decreased TrA muscle function,[17,40] and smaller changes in muscle thickness support earlier findings between healthy people and those with low back pain.[10,14,15] We also observed these differences without forms of biofeedback training as used in previous studies.[10,14] However, the current findings should be interpreted with some caution. Our SEM indicates that although a statistical difference was present between participants with and those without HxLBP, the mean difference between groups was just outside the SEM for the tabletop position and within the SEM for all other positions. Increased error in the current measure was expected as we did not provide feedback for the abdominal drawing-in maneuver; in addition, we took the visually thickest points for each measure and averaged them bilaterally for a global measure of muscle function. The increased error in the TrA thickness modulations may also be a result of multiple modulation strategies of the TrA. As the muscle thickness modulation calculations depend on both resting and contracted measures across trials, the use of multiple modulation strategies could have a direct effect on the average of the 3 trials, thereby increasing the variance in the measure.

By limiting the ability of participants to develop a strategy through feedback or a training session, we were able to quantitatively determine if they had reduced TrA muscle function using the abdominal drawing-in maneuver. The ability of the ROC curve in both tabletop (area under the curve = 0.693) and seated (area under the curve = 0.686) positions to distinguish group may allow TrA muscle thickness modulations to be used in a manner similar to a diagnostic test to determine if people have the ability to voluntarily increase TrA thickness. The positive predictive values described earlier indicate that when a person has a TrA thickness modulation below the current tabletop and seated cutoff scores, the chances of HxLBP are 62% and 56%, respectively. These values suggest that the current TrA thickness modulation cutoff scores may be only slightly better in determining group membership than the flip of a coin, with the tabletop position being better at identifying HxLBP with a cutoff score of 1.32 or less than a 33% increase from baseline values. When looking at the negative predictive values, we see that the tabletop and seated TrA thickness modulations had 73% and 69% chances, respectively, of identifying an individual without HxLBP when he or she exceeded the current cutoff scores and may be of greater importance. The addition of likelihood ratios allows for clinical interpretations in these participants: those who failed to meet the threshold values were either 2.2 or 1.7 times more likely, respectively, to have HxLBP depending on testing position. These findings could allow clinicians to use TrA thickness modulations as a potential physiological outcome measure to quantify HxLBP and help identify people who are unable to modulate TrA muscle thickness.

This was the second study to directly compare TrA thickness modulations across positions.[14] The current findings suggest that muscle function of the TrA depends on the testing position, which contradicts previous results.[14] One potential explanation for the different results is that participants were given biofeedback before testing in the earlier study.[14] As we[23] previously reported that a single exercise session was enough to affect TrA muscle function, adding biofeedback training before testing may have allowed participants to adapt a modulation strategy that could be implemented across each position. For the current study, we wanted to observe TrA muscle function without the influence of a potential learning effect from a biofeedback response to improve the ability to contract the muscle. Our findings suggest that participants may have used a variety of strategies or were unable to use the strategy applied during tabletop measures to the additional

Table 3. Transversus Abdominis Thickness Modulations, Reliability and Measurement Error

Position	Intraclass Correlation Coefficient	95% Confidence Interval	Standard Error of Measurement	Minimal Detectable Difference	Group Thickness Modulations (Mean ± SD)	
					Healthy	Self-Reported History of Low Back Pain[a]
Tabletop	0.693	0.483, 0.817	0.158	0.438	1.44 ± 0.24	1.28 ± 0.23
Seated[b]	0.419	0.036, 0.652	0.219	0.607	1.28 ± 0.24	1.12 ± 0.19
Standing[b,c]	0.650	0.416, 0.791	0.152	0.422	1.17 ± 0.24	1.15 ± 0.19
Walking	0.330	0, 0.603	0.321	0.889	1.32 ± 0.33	1.25 ± 0.27

[a] Main effect between groups ($P < .05$).
[b] Less than tabletop thickness modulations ($P < .05$).
[c] Less than walking thickness modulations ($P < .05$).

testing positions. However, these differences might also reflect changes in resting muscle thickness during gravity-dependent positions. If resting muscle thickness increased to support the external stress of gravity, then thickness modulations as a result of the abdominal drawing-in maneuver might be smaller due to increased resting thickness values. Therefore, increased resting thickness from tabletop to gravity-dependent positions, a reduced ability to increase TrA thickness during the abdominal drawing-in maneuver across positions, or a combination of these factors may have contributed to the differences between testing positions in the current study.

For this study, we only looked at the ability of a single outcome measure to detect differences between groups. Previous injury models[2,3,24] have used a multifactorial approach and followed athletes longitudinally to determine which factors best predicted injury. These earlier models have included combinations of subjective assessments associated with low back pain[2,3]; endurance testing of the trunk, pelvic region, and thigh[2,3]; and trunk proprioception and displacement[24] along with HxLBP status.[24] We believe our findings indicate that a voluntary thickness modulation might assess something different from these factors and could be an addition to previously reported models. Although we did not find evidence to support LM thickness modulations with the abdominal drawing-in maneuver, inclusion of the LM has been reported[6] and may still provide additional value to these models.

Limitations to the current study include the HxLBP participants selected, the method used to measure muscle thickness, and the reliability of the calculated measures. The sample was a younger cohort of people with HxLBP. Understanding potential neuromuscular alterations earlier in younger people may allow for intervention strategies to maintain their current lifestyle or identify those affected by low back pain earlier. We decided to select the visually thickest point on the ultrasound image as we theorized that it would allow more sports medicine clinicians to use ultrasound imaging for muscle function assessments without extensive specialized training. As part of this study, we wanted to evaluate the tradeoff between the ability to institute this specific ultrasound measure clinically and the error associated with the current measure for potential recommendations regarding use in sports medicine. The ICC values for the resting and contracted LM and TrA measures were all above 0.641 and could be interpreted as good based on the current cutoff score interpretations. However, when we calculated muscle thickness modulations and averaged the left and right sides for a single global measure of LM and TrA muscle function, only the TrA tabletop (ICC = 0.693) and standing (ICC = 0.650) positions still achieved good reliability. Because our main findings occurred in the tabletop position, this application may still provide information about differences in TrA muscle function between participants with and those without HxLBP. Additionally, we were not blinded to group assignment during testing. However, ultrasound images were recorded only during testing and then exported and measured at a later date, so this potential limitation was minimized.

The abdominal drawing-in maneuver was also used to assess LM thickness modulations. Based on the low ICC values and small changes in thickness during the abdominal drawing-in maneuver, this method may not be sensitive enough or it may not be an appropriate measure to detect changes across positions or between persons with and those without HxLBP. The use of the contralateral arm lift has been used to detect group differences[10,11] and may better represent LM muscle function without adding too much time to the participant's evaluation; thus, it should be considered in the future. Measuring LM muscle function across multiple vertebral segments rather than at a single location may also provide clarity about LM function among people with HxLBP.[10–12] Earlier researchers have reported differences between the fifth lumbar and the first sacral level in both the prone[10] and standing positions.[11] The use of an elastic belt during the walking trials and image capture during heel strike were also potential limitations to the current study. Lumbopelvic supports may provide a tactile feedback response and influence trunk and abdominal muscle thickness.[41] Additionally, the variability of the transducer during the gait cycle may have had a direct influence on thickness measures and may have affected thickness calculations, as indicated by the lower intrarater reliability for resting and contracted muscle thickness values (Table 1).

In conclusion, we observed decreased TrA thickness modulations in participants with HxLBP compared with those who did not have HxLBP, as well as across testing positions. Based on the current findings, we recommend the tabletop position to test TrA function because of the reliability of the measure and its ability to detect group differences. These results may also help clinicians understand how testing position influences muscle thickness and thickness modulations when using ultrasound imaging. Additional research focusing on other LM muscle function tests and longitudinal studies to determine if these measures can identify injury risks associated with TrA muscle function should be considered.

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REFERENCES

1. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42(2):311–319.
2. Wilkerson GB, Colston MA. A refined prediction model for core and lower extremity sprains and strains among collegiate football players. *J Athl Train*. 2015;50(6):643–650.
3. Wilkerson GB, Giles JL, Seibel DK. Prediction of core and lower extremity strains and sprains in collegiate football players: a preliminary study. *J Athl Train*. 2012;47(3):264–272.
4. Hammes D, Aus der Funten K, Bizzini M, Meyer T. Injury prediction in veteran football players using the Functional Movement Screen. *J Sport Sci*. 2016;34(14):1371–1379.
5. Gribble PA, Terada M, Beard MQ, et al. Prediction of lateral ankle sprains in football players based on clinical tests and body mass index. *Am J Sports Med*. 2016;44(2):460–467.
6. Hides JA, Stanton WR, Mendis MD, Franettovich Smith MM, Sexton MJ. Small multifidus muscle size predicts football injuries. *Orthop J Spors Med*. 2014;2(6):2325967114537588.
7. Schmidt CP, Zwingenberger S, Walther A, et al. Prevalence of low back pain in adolescent athletes—an epidemiological investigation. *Int J Sport Med*. 2014;35(8):684–689.

8. Schulz SS, Lenz K, Buttner-Janz K. Severe back pain in elite athletes: a cross-sectional study on 929 top athletes of Germany. *Eur Spine J*. 2016;25(4):1204–1210.

9. Greene HS, Cholewicki J, Galloway MT, Nguyen CV, Radebold A. A history of low back injury is a risk factor for recurrent back injuries in varsity athletes. *Am J Sports Med*. 2001;29(6):795–800.

10. Kiesel KB, Underwood FB, Mattacola CG, Nitz AJ, Malone TR. A comparison of select trunk muscle thickness change between subjects with low back pain classified in the treatment-based classification system and asymptomatic controls. *J Orthop Sports Phys Ther*. 2007;37(10):596–607.

11. Sweeney N, O'Sullivan C, Kelly G. Multifidus muscle size and percentage thickness changes among patients with unilateral chronic low back pain (CLBP) and healthy controls in prone and standing. *Man Ther*. 2014;19(5):433–439.

12. Wallwork TL, Stanton WR, Freke M, Hides JA. The effect of chronic low back pain on size and contraction of the lumbar multifidus muscle. *Man Ther*. 2009;14(5):496–500.

13. Hides J, Gilmore C, Stanton W, Bohlscheid E. Multifidus size and symmetry among chronic LBP and healthy asympotomatic subjects. *Man Ther*. 2008;13(1):43–49.

14. Miura T, Yamanaka M, Ukishiro K, et al. Individuals with chronic low back pain do not modulate the level of transversus abdominis muscle contraction across different postures. *Man Ther*. 2014;19(6):534–540.

15. Pulkovski N, Mannion AF, Caporaso F, et al. Ultrasound assessment of transversus abdominis muscle contraction ratio during abdominal hollowing: a useful tool to distinguish between patients with chronic low back pain and healthy controls? *Eur Spine J*. 2012;21(suppl 6):S750–S759.

16. Hides JA, Belavy DL, Cassar L, Williams M, Wilson SJ, Richardson CA. Altered response of the anterolateral abdominal muscles to simulated weight-bearing in subjects with low back pain. *Eur Spine J*. 2009;18(3):410–418.

17. Hides JA, Boughen CL, Stanton WR, Strudwick MW, Wilson SJ. A magnetic resonance imaging investigation of the transversus abdominis muscle during drawing-in of the abdominal wall in elite Australian Football League players with and without low back pain. *J Orthop Sports Phys Ther*. 2010;40(1):4–10.

18. Colston MA. Core stability, part I: overview of the concept. *Int J Athl Train Ther*. 2012;17(1):8–13.

19. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P. Rehabilitative ultrasound imaging of the abdominal muscles. *J Orthop Sports Phys Ther*. 2007;37(8):450–466.

20. Whittaker JL, Teyhen DS, Elliott JM, et al. Rehabilitative ultrasound imaging: understanding the technology and its applications. *J Orthop Sports Phys Ther*. 2007;37(8):434–449.

21. Richardson C, Hodges P, Hides J. *Therapeutic Exercise for Lumbopelvic Stabilization: A Motor Control Approach for the Treatment and Prevention of Low Back Pain*. 2nd ed. New York, NY: Churchill Livingstone; 2004.

22. Matthijs OC, Dedrick GS, James CR, et al. Co-contractive activation of the superficial multifidus during volitional preemptive abdominal contraction. *PM R*. 2014;6(1):13–21.

23. Partner SL, Sutherlin MA, Acocello S, Saliba SA, Magrum EM, Hart JM. Changes in muscle thickness after exercise and biofeedback in people with low back pain. *J Sport Rehabil*. 2014;23(4):307–318.

24. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med*. 2007;35(7):1123–1130.

25. Hides JA, Stanton WR, Mendis MD, Gildea J, Sexton MJ. Effect of motor control training on muscle size and football games missed from injury. *Med Sci Sorts Exerc*. 2012;44(6):1141–1149.

26. Roland M, Morris R. A study of the natural history of back pain. Part I: development of a reliable and sensitive measure of disability in low-back pain. *Spine*. 1983;8(2):141–144.

27. Fairbank JC. Why are there different versions of the Oswestry Disability Index? *J Neurosurg Spine*. 2014;20(1):83–86.

28. Vlaeyen JW, Kole-Snijders AM, Boeren RG, van Eek H. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. *Pain*. 1995;62(3):363–372.

29. Waddell G, Newton M, Henderson I, Somerville D, Main CJ. A Fear-Avoidance Beliefs Questionnaire (FABQ) and the role of fear-avoidance beliefs in chronic low back pain and disability. *Pain*. 1993;52(2):157–168.

30. Godin G, Shephard RJ. A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci*. 1985;10(3):141–146.

31. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985;198:43–49.

32. Mangum LC, Sutherlin MA, Saliba SA, Hart JM. Reliability of ultrasound imaging measures of transverse abdominis and lumbar multifidus in various positions. *PM R*. 2016;8(4):340–347.

33. Kiesel KB, Uhl TL, Underwood FB, Rodd DW, Nitz AJ. Measurement of lumbar multifidus muscle contraction with rehabilitative ultrasound imaging. *Man Ther*. 2007;12(2):161–166.

34. Henry SM, Westervelt KC. The use of real-time ultrasound feedback in teaching abdominal hollowing exercises to healthy subjects. *J Orthop Sports Phys Ther*. 2005;35(6):338–345.

35. Richardson CA, Jull GA. Muscle control-pain control. What exercises would you prescribe? *Man Ther*. 1995;1(1):2–10.

36. Teyhen DS, Miltenberger CE, Deiters HM, et al. The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. *J Orthop Sports Phys Ther*. 2005;35(6):346–355.

37. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175–191.

38. Djordjevic O, Djordjevic A, Konstantinovic L. Interrater and intrarater reliability of transverse abdominal and lumbar multifidus muscle thickness in subjects with and without low back pain. *J Orthop Sports Phys Ther*. 2014;44(12):979–998.

39. Portney LG, Watkins MP. *Foundations of Clinical Research Applications to Practice*. Vol 3. Upper Saddle River, NJ: Pearson Prentice Hall; 2009.

40. Hides J, Stanton W, Freke M, Wilson S, McMahon S, Richardson C. MRI study of the size, symmetry and function of the trunk muscles among elite cricketers with and without low back pain. *Br J Sports Med*. 2008;42(10):809–813.

41. Rostami M, Noormohammadpour P, Sadeghian AH, Mansournia MA, Kordi R. The effect of lumbar support on the ultrasound measurements of trunk muscles: a single-blinded randomized controlled trial. *PM R*. 2014;6(4):302–308.

Address correspondence to Mark A. Sutherlin, PhD, ATC, CSCS, Kinesiology Department, SUNY Cortland, PO Box 2000, Cortland, NY 13045. Address e-mail to mark.sutherlin@cortland.edu.