

A Rehabilitative Ultrasound Imaging Investigation of Lateral Abdominal Muscle Thickness in Healthy Aging Adults

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ABSTRACT

Purpose: Rehabilitative ultrasound imaging (RUSI) is used to evaluate lateral abdominal muscle size and function during the abdominal drawing-in maneuver (ADIM), an exercise used to improve lumbar spine stability. Little is known about the size and performance of these muscles in healthy aging adults. The purpose of this study was to investigate, using RUSI, the size and symmetry of the lateral abdominal muscles bilaterally at rest and during the ADIM in healthy older adults and the reliability of these measurements. **Methods:** Three ultrasound images of the right and left lateral abdominal muscles were taken at rest and during the ADIM in 12 healthy older adults. Thickness of the transversus abdominis muscles (TrA), internal oblique (IO), and external oblique (EO) were measured for all images. Intraclass correlation coefficients were computed using model 3, form 1 (ICC_{3,1}). Two ratios of the abdominal muscles were calculated in the relaxed and contracted states. Paired t-tests were used to compare relaxed muscle thickness to contracted muscle thickness for all 3 muscles for each side. To test further for interactions of side and contractile state, 2 x 2 repeated measures ANOVAs were performed. Side-to-side differences in absolute and relative thickness were assessed with paired t-tests for the TrA and IO muscles. Absolute and relative side-to-side muscle symmetry indices were computed for each muscle at rest. **Results:** There was a significant difference in muscle thickness between the contracted and relaxed states for both the TrA and IO. There was no significant difference between left/right muscle thickness for the TrA or IO at rest or during the ADIM. The TrA nearly doubled in size while thickness of the IO + EO stayed relatively constant during the ADIM. Reliability for absolute muscle thickness was generally excellent: ICC_{3,1} ranged from 0.95 to 1.00 for intra-image reliability; 0.77 to 0.97 for inter-image reliability. **Conclusions:** These findings support symmetrical and preferential activation of the TrA during the ADIM in healthy older adults. Continued research

on the use of RUSI as a tool for both assessment and intervention in older adults is needed.

Key Words: ultrasound imaging, transversus abdominis, abdominal muscles

INTRODUCTION

Older adults are poorly represented in the literature on back pain. Yet, in individuals over 75 years of age back pain is the most commonly reported musculoskeletal problem and has the potential to impact function and rising health care costs.^{1,2} The prevalence of back pain in aging adults is uncertain, but the range is estimated between 13% and 49% with the frequency of severe back pain increasing with age.^{1,3} Approximately 27% of over 2,000 independent, well-functioning aging adults in the Health ABC study reported at least moderate LBP with the prevalence and severity of LBP independently associated with self-reported difficulty with functional tasks.⁴ Despite the high incidence and functional consequences, LBP in aging adults is poorly understood.

Altered trunk muscle performance is thought to be both a cause and consequence of LBP in younger adults. Expensive (MRI) and invasive (fine-wire EMG) techniques have identified a variety of changes in muscle recruitment: trunk muscle weakness,⁵ increased activity of the extensor muscles during trunk movements,⁶ delayed relaxation in response to unloading,⁷ and reduced activity during functional activities.⁸ Recently, ultrasound imaging (USI), a noninvasive technique, has demonstrated changes in the recruitment of the deep trunk muscles, transversus abdominis (TrA), and multifidus, as a consistent finding in individuals with LBP.^{9,10} Physical therapy that emphasizes preferential activation of the TrA and multifidus during active movement is theorized to improve lumbar spine stability and demonstrated to significantly decrease pain and prevent recurrence in younger individuals with LBP.¹¹⁻¹⁵ The generalizability of these findings or their relevance to aging adults is unknown.

The lateral abdominal muscles [transversus abdominis (TrA), internal oblique (IO) and external oblique (EO)] are theorized to control movement and provide stability to the trunk for functional activities.¹⁶⁻¹⁹ Specifically, the deep abdominal muscle, TrA, is implicated in the support and protection of the spine.¹⁰ The TrA is controlled independently of the other abdominal muscles and is activated early in a tonic manner prior to arm and leg movements^{9,16,20} and during locomotion.²¹ In contrast to healthy individuals, the TrA is less tonic,²¹ often delayed^{9,16,22} or reduced²³ in people with low back pain.

Several researchers have investigated lateral abdominal muscle size and function using ultrasound imaging.²³⁻²⁶ Ultrasound imaging is performed by physical therapists to evaluate muscle structure, form, and patterns of activation and does not

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require referral to a radiologist.²⁷ Because of its deep location and unique function, the TrA cannot be evaluated through traditional strength and endurance testing. Ultrasound imaging used in rehabilitation, known as rehabilitative ultrasound imaging (RUSI), has provided physical therapists with a tool to assess and train the TrA. Extensive research supports the reliability and validity of using RUSI in the measurement of muscle geometry, compared to other well-accepted techniques (ie, MRI and EMG).^{26,28-30} In addition to being able to assess geometric properties of muscles, RUSI has been a successful noninvasive technique in the measurement of muscle activation. Changes in ultrasound measurements of muscle thickness of the lateral abdominal muscles (including the TrA) have been correlated with increased EMG values during activity.³¹

The abdominal drawing-in maneuver (ADIM), a foundational exercise in trunk stabilization programs, is designed to facilitate a voluntary contraction of the TrA and has been shown to be an effective component in the management of low back pain.^{23,32-34} The ADIM is a gentle voluntary contraction of the lower abdominal wall performed by pulling the belly up and in towards the spine without moving the pelvis, ribcage, or spine. Optimal performance of the ADIM results in preferential thickening of the TrA bilaterally with minimal changes in combined EO and IO muscle thickness.^{23,26} Recently, researchers have demonstrated that delayed activation of the TrA in people with low back pain can be improved through training of repeated, isolated, voluntary TrA contractions using the ADIM.³⁵

Despite the high prevalence of back pain in aging adults, Rankin et al³⁶ is the only investigation of lateral abdominal muscle size and symmetry that included older subjects (ages 21-72 years); however, the subjects' mean age was only 40.6 years.³⁶ In younger adults researchers have demonstrated side to side symmetry of the lateral abdominal muscles at rest and during the ADIM^{24,25,36} and impaired muscle activation patterns in persons with low back pain.^{19,21,23} In aging adults little is known about the size, symmetry, and performance of the lateral abdominal muscles. The main purpose of this study was to describe, using RUSI, the size and symmetry of the lateral abdominal muscles, bilaterally, at rest and during the ADIM in healthy aging adults. The secondary purpose was to determine the reliability of these measurements.

METHODS

Subjects

Subjects were recruited by printed flyers and word of mouth from the community, local senior groups, and Alamance Regional Medical Center. Each subject volunteered to participate in this study and signed an informed consent form prior to participation. The study was approved by the Institutional Review Boards at Elon University and Alamance Regional Medical Center.

Thirty-six healthy aging adults initially volunteered for this study. Twelve subjects (9 women, 3 men), mean age 72 (S.D. 9.36) years, range 57-84 years, met the inclusion criteria and participated in the study. Seven subjects were independent community dwellers and 5 subjects lived in a minimal assistance retirement center. The mean body mass index of the subjects was 25.9 ± 2.96 kg/m². Exclusion criteria included

low back pain within the past 3 years resulting in either: (1) change in physical activity, (2) a need for medical care, or (3) lost days from work. Additional exclusion criteria were: a history of spinal, abdominal, or lower extremity surgery, respiratory or neurological disorders, structural scoliosis, urinary incontinence, BMI > than 30 kg/m², cardiac pacemaker, Mini-Mental State Exam³⁷ < 24, severe arthritis resulting in joint deformities of the hips, knees, or feet, and pain with weight bearing on either extremity.

Procedures

Using a slide presentation, each subject was instructed in the anatomy and ultrasound imaging of the abdominal muscles and the proper performance of the ADIM.^{23,31} The 5-minute slide presentation was created to familiarize subjects with the testing procedure. Then, each subject was positioned on a plinth in supine hook-lying with the head in midline, arms across the chest, and a bolster under the knees. To perform the ADIM each subject was taught to pull the lower abdomen up and in toward the spine at the end of exhalation and then, hold the contraction for 10 seconds while continuing to breathe normally and maintaining a neutral posture of the lumbar spine. Prior to testing on each side, the ADIM was practiced 3 times using RUSI for feedback. During ADIM practice the researchers provided verbal and tactile feedback to minimize substitution patterns and facilitate proper performance.

Following practice, ultrasound images of the lateral abdominal muscles were obtained at rest (relaxed state at the end of exhalation) and during the ADIM (contracted state). Three images were obtained in each state for each side, one side at a time. The order of imaged side was randomized using a table of random numbers. A 3-minute rest was provided between practice and testing, as well as between sides, to minimize potential effects of fatigue.²³ The time to acquire all images was 30 minutes. Ultrasound images were taken using the Aquila system (Biosound Esaote, Indianapolis, IN) with a 5 MHz curvilinear array transducer. The transducer was placed in a transverse plane halfway between the ASIS and the lower ribcage along the anterior axillary line (Figure 1). The location of the transducer was further standardized by positioning the hyperechoic interface between the TrA and the thoracolum-



Figure 1. Ultrasound Transducer Location

bar fascia on the far left side of the image. One researcher positioned the transducer to optimize the quality of the image and the second researcher captured the image at the end of the subject's exhalation at rest and during the ADIM for all subjects. Stored images were measured using Image J, version 1.38, Oct 2006, provided by NIH. A single researcher, blinded to the subject's identity, measured the thickness of the EO, IO, and TrA for all images, as described by Teyhen et al.²³ Figure 2 illustrates ultrasound images of the left lateral abdominal muscles.

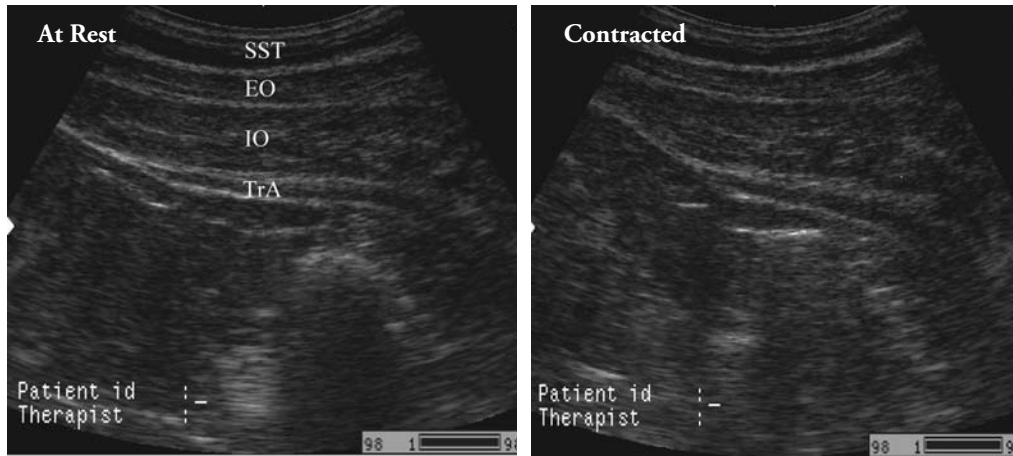


Figure 2. Ultrasound Images of the Lateral Abdominal Muscles – 84 Year Old Male. Subcutaneous Tissue (SST), Internal Oblique (IO), External Oblique (EO), Transversus Abdominis (TrA)

Data Analysis

Computations of ratios and contraction indices were performed with Microsoft Excel (v.2003). SPSS for Windows (v.13.0) was used for statistical analysis, with level of significance set at 0.05 for all statistical tests.

Intraclass correlation coefficients were computed using model 3, form 1 ($ICC_{3,1}$). Separate ICCs were computed for each muscle for each side and each state (relaxed and contracted). Intra-image reliability was computed using 3 repeated measurements taken from the first of 3 successive images. Inter-image reliability was computed using a single measurement taken from each of the three images. Standard errors of measurement were computed with the formula: $SEM = SD\sqrt{1 - ICC}$. As part of the reliability analysis, systematic bias was tested using a one-way repeated measures analysis of variance (ANOVA), using the 3 repeated measurements from the first image as levels for the single factor. When the sphericity assumption was violated, a conservative correction to degrees of freedom was made using the Greenhouse-Geisser method.

The mean thickness of each muscle was computed using a single measurement taken from each of the 3 images at rest and during contraction. Paired t-tests were used to compare mean relaxed muscle thickness to mean contracted muscle thickness for all 3 muscles. These tests were performed separately for right and left sides. To test further for interactions of side and contractile state, 2 x 2 repeated measures ANOVAs were performed for muscles showing significant changes in thickness between relaxed and contracted states. Contraction ratios (relaxed muscle thickness/contracted muscle thickness) were calculated for the TrA and for the EO + IO to quantify the change of muscle thickness with contraction. TrA contraction ratio was computed

as TrA contracted/TrA relaxed. EO + IO contraction ratio was computed as EO + IO contracted / EO + IO relaxed.

Side-to-side differences in absolute and relative (thickness of each muscle expressed as a percentage of total muscle thickness) thickness were assessed with paired t-tests for the TrA and IO muscles. Absolute side-to-side muscle symmetry (% difference between sides) was computed for each muscle at rest. Absolute symmetry was defined by the formula: $([(largest/smallest\ value) \times 100] - 100)$, after defining whether the right side or the left side had the largest average thickness across the 3 images.²⁶

RESULTS

Complete sets of images were obtained from 11 of the 12 patients. Measurements could not be obtained from unreadable images from 1 patient for 1 of 3 repeated images for 3 of the 12 combinations of muscle, side, and contractile state. For these 3 combinations, 2 images were used instead of 3 for computations of averages. Also for these 3 combinations, data from 11 patients instead of 12 were used for computations of ICCs.

Descriptive statistics for muscle thickness and results of paired t-tests comparing relaxed to contracted states are provided in Table 1. Average muscle thickness for TrA and IO muscles was greater when contracted than when at rest ($p=0.03$). Average percent increase in TrA muscle thickness from relaxed to contracted states was 62% on the left side; 61% on the right side. Average percent increase in IO muscle thickness from relaxed to contracted states was 27% on the left side; 29% on the right side. Thickness in EO muscles did not change appreciably between relaxed and contracted states ($p=0.14$). Contraction ratios were 1.76 and 1.65 for the TrA, and 1.19 and 1.16 for the EO + IO, left and right respectively (Table 2).

Average muscle thickness in the sample was greater in the IO muscle, both for relaxed and contracted states, than for either the TrA or EO muscles. For both TrA and IO muscles the 2 x 2 repeated measures ANOVAs yielded statistically significant main effects for contractile state ($p=0.02$), but no significant main effects for side ($p = 0.55$) and no significant side x state interaction effects ($p = 0.82$; Figures 3 & 4). Intra-image reliability for absolute muscle thickness was excellent: $ICC_{3,1}$ ranged from 0.95 to 1.00 across the 12 combinations of muscle, side, and contractile state (Table 3). Inter-image reliability for absolute muscle thickness was somewhat lower: $ICC_{3,1}$ ranged from 0.77 to 0.97 across the 12 combinations (Table 4). All point estimates of reliability were statistically significant ($p < 0.001$). Standard errors of measurement were quite small, ranging from 2 to 8 mm (Tables 3, 4).

Results for side-to-side symmetry for absolute and relative muscle thickness are summarized in Tables 5, 6. Average side-to-side differences for absolute and relative muscle thickness at rest ranged from 14% to 17%. None of the side-to-side differences were statistically significant ($p = 0.29$).

Table 1. Descriptive Statistics for Averaged Measures of Absolute Muscle Thickness

Muscle	Side	State	Mean (cm)	SD (cm)	Minimum (cm)	Maximum (cm)	p-value*
TrA	Left	Relaxed	0.56	0.15	0.36	0.91	<0.001
TrA	Left	Contracted	0.91	0.23	0.59	1.31	
TrA	Right	Relaxed	0.54	0.15	0.33	0.85	<0.001
<i>TrA</i>	<i>Right</i>	<i>Contracted</i>	<i>0.88</i>	<i>0.24</i>	<i>0.64</i>	<i>1.34</i>	
IO	Left	Relaxed	1.13	0.40	0.60	1.82	0.030
IO	Left	Contracted	1.43	0.72	0.67	3.11	
IO	Right	Relaxed	1.10	0.30	0.71	1.77	0.019
<i>IO</i>	<i>Right</i>	<i>Contracted</i>	<i>1.42</i>	<i>0.51</i>	<i>0.82</i>	<i>2.59</i>	
EO	Left	Relaxed	0.79	0.21	0.48	1.28	0.143
EO	Left	Contracted	0.85	0.22	0.51	1.27	
EO	Right	Relaxed	0.84	0.23	0.52	1.22	0.249
<i>EO</i>	<i>Right</i>	<i>Contracted</i>	<i>0.80</i>	<i>0.23</i>	<i>0.49</i>	<i>1.11</i>	

Descriptive statistics are based on averaged scores across 3 images from 12 subjects, except for results in italics above: unreadable images for 1 patient (for 1 of the 3 repeated images) resulted in only 2 images to average for these 3 results for 1 of the 12 subjects.
 Abbreviations: TrA, Transversus Abdominis; IO, Internal Oblique; EO, External Oblique
 * p-values from paired t-tests comparing relaxed means to contracted means for TrA and IO muscles.

Table 2. Contraction Ratio Data. Values Represent Mean (SD)

Contraction Ratio	Left	Right
TrA	1.76 (0.40)	1.65 (0.33)
EO + IO	1.19 (0.21)	1.16 (0.21)

TrA Contraction Ratio = TrA contracted/ TrA relaxed
 EO + IO contraction Ratio = EO + IO contracted/ EO + IO relaxed

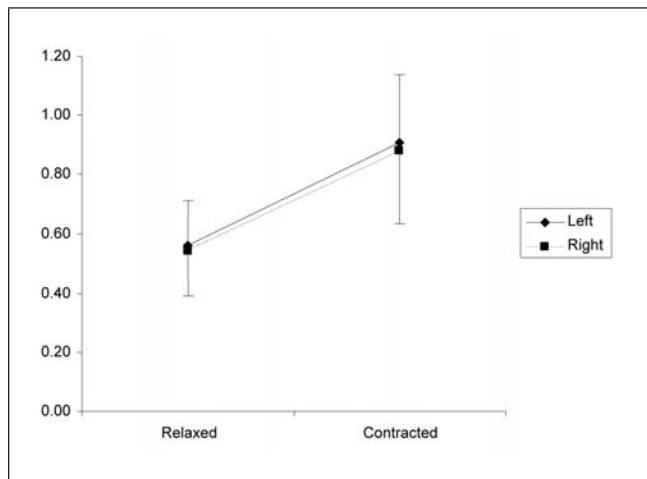


Figure 3. Interaction Plot Showing Effects of Side and Contractile State for the Transversus Abdominis Muscle

DISCUSSION

This study provides descriptive data on the size and symmetry of the lateral abdominal muscles and reliability of those measures in a sample of healthy aging adults. Consistent with our expectations in healthy aging adults, the size and symmetry of the lateral abdominal muscles at rest and during the ADIM are comparable to healthy, younger adults.^{24,25,36}

Absolute Muscle Thickness

The absolute TrA muscle thickness at rest and during the ADIM is consistent with other studies. In this study the bilateral TrA values at rest, 5.4-5.6(1.5) mm (mean ± SD), are similar to values previously reported. In a study of 123 healthy adults, Rankin et al³⁶ reported bilateral TrA values at rest of between 5.4 to 5.7(1.1) mm for men with mean age of 40.6(14.1) years, and between 3.9 to 4.4(0.8) mm for women with mean age of 33.8(12.7) years. In a study of 17 young, adult males aged 27.7(5.6) years, Springer et al²⁴ reported TrA values at rest of 5.0(0.9) mm. Total abdominal muscle thickness values at rest between 24.8 (5.2) mm and 24.8 (5.5) mm are comparable to findings by Springer et al²⁴ of between 20.9 (5.5) mm to 21.5 (5.9) mm. During the ADIM the TrA thickness values between 8.8 (2.4) mm to 9.1 (2.3) mm are also similar to those reported by Springer et al,²⁴ between 8.6 (2.2) mm to 8.7 (2.1) mm. In addition, total lateral abdominal muscle thickness during the ADIM between 31.0 (7.3) mm to 31.9 (8.1) mm is comparable to findings by Springer et al²⁴ of between 26.0 (8.2) mm to 26.5 (8.0) mm. The small differences in reported TrA values at rest and during ADIM may be accounted for by variations in subjects' age or ultrasound transducer location.

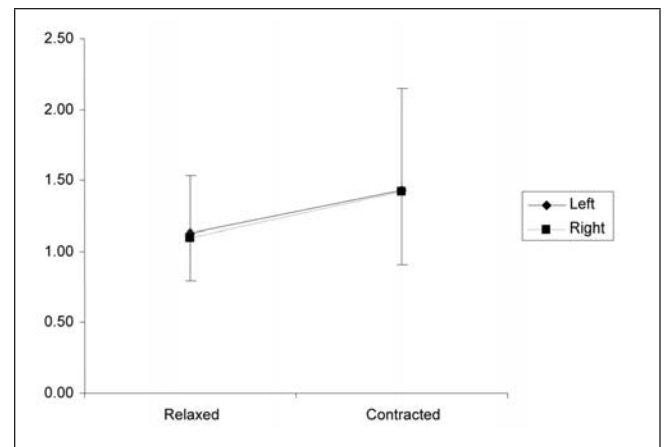


Figure 4. Interaction Plot Showing Effects of Side and Contractile State for the Internal Oblique Muscle

The pattern of descending order of absolute and relative muscle thickness at rest reported in this study bilaterally, IO > EO > TrA, is consistent with Rankin et al.³⁶ Previous research has shown this pattern is independent of gender and side (left versus right) or measurement location in the middle abdominal region.³⁰ Observation of variation from this normal pattern may be a simple screening tool useful in clinical evaluation of trunk muscle atrophy or hypertrophy.^{30,36}

Side-to-Side Comparisons

Evaluation of lateral abdominal muscle symmetry may be useful in the presence of unilateral pathology in aging adults. A comparison of this study's percent differences side-to-side

Table 3. Intra-image Reliability Coefficients for Bilateral Abdominal Muscles in Relaxed and Contracted States

Muscle	Side	State	ICC _(3,1)	95% Confidence Interval		SEM (cm)
				Lower Bound	Upper Bound	
TrA	Left	Relaxed	0.98	0.95	0.99	0.02
TrA	Left	Contracted	0.97	0.92	0.99	0.04
TrA	Right	Relaxed	0.97	0.92	0.99	0.03
<i>TrA</i>	<i>Right</i>	<i>Contracted</i>	<i>0.99</i>	<i>0.97</i>	<i>1.00</i>	<i>0.03</i>
IO	Left	Relaxed	0.99	0.99	1.00	0.03
IO	Left	Contracted	1.00	0.99	1.00	0.05
IO	Right	Relaxed	0.99	0.98	1.00	0.02
<i>IO</i>	<i>Right</i>	<i>Contracted</i>	<i>0.97</i>	<i>0.93</i>	<i>0.99</i>	<i>0.08</i>
EO	Left	Relaxed	0.98	0.95	0.99	0.03
EO	Left	Contracted	0.98	0.95	0.99	0.03
EO	Right	Relaxed	0.99	0.98	1.00	0.02
<i>EO</i>	<i>Right</i>	<i>Contracted</i>	<i>0.95</i>	<i>0.88</i>	<i>0.98</i>	<i>0.05</i>

Intraimage reliability coefficients are based on averaged scores across 3 images from 12 subjects, except for results in italics above: unreadable images for 1 patient (for 1 of the 3 repeated images) resulted in only 2 images to average for these 3 results for 1 of the 12 subjects.

Table 4. Inter-image Reliability Coefficients for Bilateral Abdominal Muscles in Relaxed and Contracted States

Muscle	Side	State	ICC _(3,1)	95% Confidence Interval		SEM (cm)
				Lower Bound	Upper Bound	
TrA	Left	Relaxed	0.86	0.68	0.95	0.01
TrA	Left	Contracted	0.77	0.51	0.92	0.03
TrA	Right	Relaxed	0.92	0.81	0.97	0.01
<i>TrA</i>	<i>Right</i>	<i>Contracted</i>	<i>0.82</i>	<i>0.58</i>	<i>0.94</i>	<i>0.02</i>
IO	Left	Relaxed	0.97	0.93	0.99	0.02
IO	Left	Contracted	0.95	0.88	0.98	0.03
IO	Right	Relaxed	0.93	0.83	0.98	0.02
<i>IO</i>	<i>Right</i>	<i>Contracted</i>	<i>0.88</i>	<i>0.71</i>	<i>0.96</i>	<i>0.03</i>
EO	Left	Relaxed	0.94	0.85	0.98	0.02
EO	Left	Contracted	0.85	0.65	0.95	0.03
EO	Right	Relaxed	0.94	0.85	0.98	0.02
<i>EO</i>	<i>Right</i>	<i>Contracted</i>	<i>0.88</i>	<i>0.70</i>	<i>0.96</i>	<i>0.03</i>

Interimage reliability coefficients are based on averaged scores across 3 images from 12 subjects, except for results in italics above: unreadable images for 1 patient (for 1 of the 3 repeated images) resulted in only 2 images to average for these 3 results for 1 of the 12 subjects.

generates similar findings to those reported by Rankin et al.³⁶ In aging adults the side to side mean differences were 15.07% (9.91%) for the TrA and 14.08% (10.46%) for the IO. Rankin et al³⁶ reported a range of side-to-side mean differences for the TrA (15.9% to 21.0%) and IO (17.3% to 21.9%) in males and females, respectively.

Relative thickness at rest for all 3 muscles demonstrated near perfect symmetry similar to previous research.^{24,36} We found a

Table 5. Absolute Muscle Thickness and Difference Side to Side at Rest*

Muscle	Left Side (cm)	Right Side (cm)	Difference Side to Side (%)†	p-value*
TrA	0.56 ± 0.15	0.54 ± 0.15	15.07 ± 9.91	0.595
IO	1.13 ± 0.40	1.10 ± 0.30	14.08 ± 0.46	0.543
EO	0.79 ± 0.21	0.84 ± 0.23	17.10 ± 4.03	0.286

Abbreviations: TrA, transversus abdominis; IO, internal oblique; EO, external oblique
 Values are expressed as mean ± SD
 See text for symmetry formula used to calculate % difference side to side
 † Mean side-to-side difference computed as the average of all individual side-to-side differences
 * P-values from paired t-tests comparing left side thickness scores to right side thickness scores

Table 6. Relative Muscle Thickness of the TrA, IO, EO and Difference Side to Side at Rest*

Muscle	Left Side (%)	Right Side (%)	Difference Side to Side (% + SD)†	p-value*
TrA	23 ± 3	22 ± 4	13.97 ± 8.24	0.549
IO	45 ± 9	44 ± 7	7.08 ± 6.80	0.663
EO	33 ± 8	34 ± 7	13.10 ± 3.13	0.327

Abbreviations: TrA, transversus abdominis; IO, internal oblique; EO, external oblique
 Values are presented relative to total muscle thickness of the lateral abdominal muscles and expressed as mean
 † Mean side-to-side difference computed as the average of all individual side-to-side differences
 * P-values from paired t-tests comparing left side thickness scores to right side thickness scores

mean (SD) relative thickness at rest for the TrA of 22% to 23% (3% to 4%). Relative TrA muscle thickness during the ADIM was 28% to 29% (5%), the first report of relative TrA muscle thickness during the ADIM in aging adults. In healthy, young, adult males Springer et al²⁴ found the mean (SD) relative thickness at rest of the TrA to be 20.1% (3.4%) and the relative muscle thickness during the ADIM to be 34.0% to 34.5% (6.6% to 7.2%). Similar to Rankin et al³⁶ who reported less than 2% and Springer et al²⁴ who reported 3.5%, this study reports a mean difference side-to-side of 1% for relative thickness at rest of the TrA.

In this sample of healthy aging adults, performance of the ADIM resulted in a significant symmetrical (left versus right) increase in the thickness of the TrA (p < 0.001) and IO (p = .03). The ADIM resulted in preferential activation of the TrA bilaterally, as demonstrated in previous studies.^{23,26,38} Preferential activation of the TrA has been defined as a 2-fold or 100% increase in the TrA muscle thickness during the ADIM (TrA contraction ratio ≥ 2.0), with the EO + IO muscle thickness staying relatively constant (EO + IO contraction ratio ~ 1.0).²³ In this study the average percent increase in TrA muscle thickness was left side (62%) and right side (61%). However, the mean TrA contraction ratios for left of 1.76 (0.40) and right of 1.65 (0.33) sides were less than the mean TrA contraction ratio of 2.27 (0.89) previously reported in a younger population.²³ The difference in the TrA contraction ratio between aging and younger adults may reflect an age-related decrease in

muscle activation. The mean EO + IO contraction ratios for the left and right sides were approximately 1.0. While the measured changes in TrA muscle thickness from relaxed to contracted states were smaller in aging adults than younger adults,^{23,26,38} the comparative lack of change in the EO & IO muscle thickness supports symmetrical, preferential activation of the TrA during the ADIM. In this study, average percent increase in IO muscle thickness from rest to contracted states was 27% on the left side, 29% on the right side. An increased thickness of the IO during the ADIM is consistent with findings reported by other researchers, illustrating that the ADIM does not activate the TrA in isolation.^{26,38} The authors found no other investigations reporting percent change of TrA or IO thickness of aging adults while performing the ADIM.

Reliability of Measures at Rest and During Contraction

This investigation examined reliability of measurements on both sides of the abdomen at rest and during ADIM. Repeated measurements of the same image demonstrated high ICC values and very low SEMs similar to those reported in previous studies.^{26,30} As expected, ICC values for measurements of the muscles at rest were slightly higher than the ICC values during the performance of the ADIM. Since the ADIM is a voluntary contraction, measures during contraction may show more variability than measures taken at rest.²⁶

LIMITATIONS

The major limitation of this research is the small sample size. The stringent exclusion criteria which limited the number of subjects may also limit the generalizability of the findings. Additionally, performance of the lateral abdominal muscles during the ADIM may not be representative of those muscles during functional activity.

CONCLUSION

The results of the current study expand on other investigations of lateral abdominal muscle thickness during the ADIM. Rehabilitative ultrasound imaging abdominal muscle thickness measurements at rest and during the ADIM are reliable in a healthy, aging population. These findings support symmetrical and preferential activation of the TrA during the ADIM in healthy aging adults. Low back pain is one of the most disabling and therapeutically challenging conditions adversely affecting aging adults, yet there is a limited body of research dedicated to assessing trunk muscle performance in this age group. Further research is indicated to examine the use of RUSI in aging adults for the evaluation and intervention of LBP.

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