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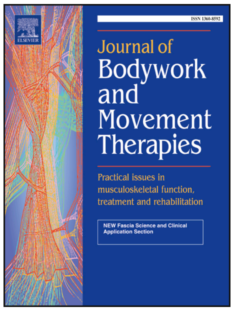

Reliability of ultrasound measurement of the lateral abdominal and lumbar multifidus muscles in individuals with chronic low back pain: a cross-sectional test-retest study

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Credit author statement

Soheila Abbasi: Conceptualization, Investigation, Methodology, Software and Roles/Writing – original draft. Mohammad Reza Hadian Rasanani: Funding acquisition, Project administration, Resources, Supervision and Writing – review & editing. Gholam Reza Olyaei: Project administration, Validation, Visualization and Writing – review & editing. Nastaran Ghotbi: Conceptualization, Data curation, Software and ***Writing – review & editing. Omid Rasouli: Formal analysis,*** Investigation, ***Methodology, Roles/Writing – original draft and Writing – review & editing.***

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TITLE PAGE

Reliability of ultrasound measurement of the lateral abdominal and lumbar multifidus muscles in individuals with chronic low back pain: a cross-sectional test-retest study

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Reliability of ultrasound measurement of the lateral abdominal and lumbar multifidus muscles in individuals with chronic low back pain: a cross-sectional test-retest study

ABSTRACT

Objectives: Ultrasound (US) imaging has been suggested to evaluate the morphology and function of trunk muscles; however, little is known about the reliability of the US measures in patients with chronic low back pain (CLBP). This study aimed to evaluate intrarater reliability of US imaging of the lateral abdominal and lumbar multifidus muscles in individuals with nonspecific CLBP.

Methods: In this cross-sectional study, intrarater within-day and between-day reliability of US measurements of the transversus abdominis, internal oblique, external oblique and lumbar multifidus (at the L3-L4, L4-L5, and L5-S1 levels) muscles were obtained on both sides. The resting and contracted thickness and contraction ratio of each muscle were measured in 21 individuals with nonspecific CLBP.

Results: All US measurements of the lateral abdominal and lumbar multifidus muscles demonstrated good to excellent within-day (Intraclass correlation coefficients (ICCs: 0.80–0.98) and between-day (ICCs: 0.80–0.97) reliability. The standard error of the measurement (SEMs) and minimal detectable change (MDCs) of the lateral abdominal muscles on both sides ranged 0.5–1.6 mm and 0.4–4.4 mm, respectively. The SEMs and MDCs of the LM muscles on both sides ranged 1.1-2.7 mm and 2.86 to 7.49 mm, respectively.

Conclusion: The findings indicate that US imaging has good to high intrarater *within- and between-day* reliability for assessing absolute thickness and contraction ratio of the trunk muscles on both right and left sides in patients with nonspecific CLBP. The vertical alignment of the US transducer is a reliable method for assessing the lateral abdominal muscles.

Keywords: Back pain; Muscle Contraction; Reproducibility; Trunk muscles; Ultrasonography

INTRODUCTION

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The lateral abdominal wall, i.e., the transversus abdominus (TrA), internal oblique (IO), and external oblique (EO) muscles, together with the lumbar multifidus muscle (LM), provide stability for the lumbar spine (Hodges, 2004). Automatic activities of these muscles are associated with the protective lumbar spine mechanism, which is impaired in individuals with chronic low back pain (CLBP) (Costa et al., 2009; Djordjevic et al., 2014; Rasouli et al., 2020). As one of the available instruments, ultrasound (US) imaging has been used by researchers and therapists to evaluate morphology of the trunk muscles in LBP (ShahAli et al., 2019). Moreover, muscle contraction ratio (contracted thickness/resting thickness) has been recently suggested as the estimation of muscle function (Caresio et al., 2015).

Clinical measurements should be reproducible and reliable. Accordingly, previous studies have investigated the reliability of US measurements of the abdominal and LM muscles in individuals with and without LBP (Arab et al., 2013; Djordjevic et al., 2014; Gibbon et al., 2017; Koppenhaver et al., 2009a; Tahan et al., 2014; Teyhen et al., 2011). However, they have used different methods such as target muscles, functional tasks, transducer direction, and site of scanning, which resulted in some gaps for using US to evaluate the trunk muscles (Costa et al., 2009; Hebert et al., 2009). First, previous studies mostly evaluated voluntary contractions of the abdominal muscles like abdominal drawing-in maneuver (ADIM) (Linek et al., 2014; Pulkovski et al., 2012) with very diverse reliability results. Only a few reliability studies have used an automatic task like active straight leg raise (ASLR) (Gibbon et al., 2017; Teyhen et al., 2011) (Koppenhaver et al., 2009c; Teyhen et al., 2009). However, none of them has studied the reliability in individuals with nonspecific CLBP. Second, the reliability has been evaluated only in one specific scanning site and transverse transducer alignment. Since the abdominal muscle thickness is not homogeneous, the reliability of more scanning sites needs to be evaluated (Niewiadomy & Szuscik, 2017; Rankin et al., 2006). In addition, a new vertical alignment of transducer was argued based on the morphology of the deep abdominal muscles and direction of the fascia on cadavers (Urquhart et al., 2005).

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The examiners have mostly placed transducer transversely just superior to the iliac crest or between the inferior angle of the rib cage and the iliac crest along the axillary line on the abdominal region. These studies reported a variety of results ranging from poor to excellent reliability (Arab et al., 2013; Teyhen et al., 2011). Despite the recommendation, only two studies have investigated vertical placement of transducer on the abdominal muscles, but studied only in healthy samples. They found that on this site with vertical transducer, all three abdominal muscles are relatively flat and well represented and their thicknesses are easier to measure vertically at the same point on one image (Niewiadomy & Szuscik, 2017; Rankin et al., 2006).

Third, to the best of our knowledge, none study has evaluated the reliability of US to measure the LM muscle thickness at different vertebral levels at rest and during automatic contractions in patients with nonspecific CLBP. Moreover, the reliability of the abdominal and LM muscles has been investigated on one side (mostly the right side), not both sides.

To address some of the mentioned gaps, this study aimed to evaluate intrarater within-day and between-day reliability of US in measuring thickness and contraction ratio of the LM (at three levels), TrA, IO, and EO muscles on both sides in individuals with nonspecific CLBP.

METHODS

Study design

This study employed a cross-sectional test-retest design to measure intrarater within-day and between-day reliability in individuals with nonspecific CLBP. The study was approved by the Human Ethics Committee at the Tehran University of Medical Sciences (Protocol code: IR.TUMS.FNM.REC.1399.041) and followed the Declaration of Helsinki. All participants were informed, and they signed a consent form before participation.

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Participants

Patients with nonspecific CLBP aged 25-55 years old participated in this study. All participants were referred from two public physical therapy clinics associated with the Tehran University of Medical Sciences from July 2017 to September 2018. The inclusion criteria were: Localized back pain between the 12th rib and the gluteal folds lasting more than three months and the ability to lie supine at least 20 minutes for US assessment and to perform ASLR and contralateral arm lift task (CALT). Exclusion criteria were history of sciatica or other radicular involvement, spinal surgery, nerve root compression or neurological deficits, diseases, pregnancy at the time of testing, lower extremity injuries rheumatic or neuromuscular diseases (Nourbakhsh & Arab, 2002).

In the current study, we used Visual Analogue Scale to assess the pain intensity (Hawker et al., 2011), Oswestry Disability Index (ODI) to evaluate the disability (Fairbank & Pynsent, 2000) and Tegner Activity Rating Scale to assess the activity level (Tegner & Lysholm, 1985).

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Apparatus and image processing

The lateral abdominal and LM muscles were imaged by a diagnostic ultrasound instrument set in two-dimensional B-mode (HS-2600, Honda Electronics Co, Japan). After data collection, actual muscle thickness was measured by Image J software (version 1.52p; National Institutes of Health, Bethesda, MD, USA). A physical therapist with 10 years of experience in musculoskeletal disorders and 1 year of US experience performed all examination and measurements.

Abdominal muscles

High-resolution US images of the abdominal muscle thickness on both sides were obtained using a 50 mm, 7.5 MHz linear transducer at rest and during contraction. Participants were positioned in crook lying (60º hip flexion) with a pillow under their head, and hands were resting on the chest. At first, required landmarks and transducer location was marked on the skin. The transducer was manually placed in the vertical alignment over the halfway along a line joining the ASIS to just below the ribcage in the mid-axillary line (Rankin et al., 2006).

The ASLR task was selected to record automatic contractions of the lateral abdominal muscles to avoid confounding factors such as participant’s ability to understand the command, motivation, fear of pain, and variability in performance (Teyhen et al., 2009). Accordingly, each participant was requested to raise the lower extremity 5cm from the bed without knee flexion in the crook lying position. The height of 5 cm was also marked on the wall. Before imaging, the operator lifted the participant’s lower extremity to the correct position (5cm) to familiarize the participant with the procedure. Furthermore, the contraction thickness of the abdominal muscles was recorded during ASLR. All abdominal images were frozen at the end of normal expiration and stored for later analysis.

The abdominal muscle thicknesses in all positions were measured as the distance between the superior border and inferior border of each muscle’s hyperechoic fascial lines by adjusting electronic on-screen calipers (Joseph et al., 2015). For standard placement of the measurement line, a perpendicular line through the center of the US image was adjusted.

Lumbar Multifidus

Longitudinal images of the LM muscle on both sides were obtained using a 70 mm, 5 MHz convex transducer at rest and during CALT at the L3-L4, L4-L5, and L5-S1 levels. Participants were placed in the prone position on a bed with a pillow beneath their abdomen to minimize the lumbar lordosis (Hides et al., 2008), and L5 spinous process was marked. The transducer was placed longitudinally and centrally on the lumbar spinous processes as described by before (Stokes et al., 2005). Then, the transducer was moved laterally, to maintain the transducer light facing cranially, so that a parasagittal image of the LM muscle could be seen.

CALT was previously used to evaluate the activation of LM (Kiesel et al., 2008; Kiesel et al., 2007). Each participant was instructed to “lift arm approximately 5 cm off the table” in prone lying while her/his upper limbs were repositioned overhead, elbows flexed to 90º and shoulders

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abducted to 120º as controlled using a goniometer. Beforehand, the height of 5 cm was marked on the wall. Participants performed a single CALT practice, which was given before the measurements being recorded. Contraction thickness of the LM muscle was measured during CLAT. All clear images were frozen and saved for later measurement.

The thickness of LM muscle in all positions was measured at the levels of L3-4, L4-5, and L5-S1 zygapophyseal joints using on-screen calipers. Linear measurements were conducted from the tip of the target zygapophyseal joint to the inside edge of the superior border of multifidus muscle (Wallwork et al., 2007).

Procedure

Testing muscles and conditions were randomly selected to avoid an order effect by picking up a number by the participants. In all tests, the rater alternated between the right and left sides to minimize participants' fatigue. Eventually, three images/measurements had been taken in each task for each muscle from each side, and the average of three images/measurements was used for further analysis. Three sessions were performed within three days; First, the examiner performed all measurements, and then, repeated the measurements after one hour in random order with the same procedure for within-day reliability. After three days, the same procedure was carried out randomly for between-day reliability.

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Statistical Analysis

Data were presented as means ± standard deviations (SDs). All statistical analyses were performed with SPSS Version 22. The normality of distribution for all variables was assessed using the one-sample Kolmogorov-Smirnov test. Side-to-side differences of the resting thickness of the lateral abdominal and LM muscles (only for the first assessment) were assessed using paired *t*-test with the statistical significance level of 0.05. Intrarater reliability (within-day and between-days) for the average of three measurements of thicknesses (resting and contracted thicknesses) and contraction ratio values of the abdominal (EO, IO, TrA) and LM (L3-L4, L4-

L5, L5-S1) muscles were analyzed by the intraclass correlation coefficient (ICC 3, 1; method: alpha, two-way mixed, consistency). Model 3 (ICC 3,1) was used due to the point that one judge evaluated the same population. The ICCs are classified as follows: <0.69 poor, 0.70–0.79 fair, 0.80–0.89 good, and 0.90–1.00 high correlation (Blesh, 1974). Standard error of measurement (SEM), and the minimal detectable change (MDC) for a 95% confidence interval were also calculated by the following formulas: $SEM = [pooled\ SD\ \sqrt{1 - ICC}]$, $MDC = [SEM \times z \times \sqrt{2}]$ (Weir, 2005).

RESULTS

Twenty-one patients with CLBP (7 men and 14 women) completed the testing. The overview of participant flow and data collection are shown in Figure 1.Demographics and clinical characteristics of the participants are summarized in Table 1. The participants were mainly females and had mild to moderate pain intensity and disability. Normal distribution was observed for all variables. No significant differences in resting thickness were found between the right and left sides in the abdominal or LM muscle.

<Fig 1 and Table 1 about here>

Muscle thickness and contraction ratio

Tables 2 shows muscle thicknesses (in mm) and contraction ratios at rest and during ASLR task for the lateral abdominal muscles on both sides in three different assessments. The smallest abdominal muscle thicknesses were seen at resting position (crook lying), and the highest values belonged to the contraction position (crook lying with ASLR). The smallest and highest contraction ratios belonged to the EO muscle.

<Table 2 about here>

Tables 3 shows muscle thicknesses (in mm) and contraction ratios at rest and during CALT task for the LM muscle on both sides in three different assessments. The smallest LM thicknesses were seen at resting position (prone lying) and the highest values related to the contraction

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position (prone lying with CLAT). Moreover, the smallest contraction ratio of the LM muscle belonged to LM at the L5-S1 level and the highest value related to LM at the L3-L4 level.

<Table 3 about here>

Reliability of ultrasound measurements

Table 4 shows both within-day (first and second assessment) and between-day reliability (second and third assessment) values of the US measurements of the lateral abdominal muscles on both sides. There were good to high within-day (ICC= 0.80–0.97) and between-day (ICC= 0.81–0.93) reliability. There were higher SEM and MDC values for between-day reliability relative to the within-day reliability. Moreover, we had better reliability at rest compared to the contraction condition. Within- and between-days reliability values of measurements of the LM muscle on both sides are listed in Table 5. Good to high within-day (ICC= 0.80–0.97) and between-day reliability (ICC= 0.81–0.93) were found for the US measurements of the LM muscle. SEM and MDC values were higher during contraction compared to the resting condition; and there were lower ICC, SEM, and MDC values for between-day reliability relative to within-day reliability.

<Tables 4 and 5 about here>

DISCUSSION

To our best of knowledge, this is the first study that comprehensively evaluated intrarater within- and between-day reliability of US measurements of the LM and lateral abdominal muscles in patients with nonspecific CLBP. The new aspects of this study were studying the muscle thicknesses at rest, during automatic contraction, calculating contraction ratio, new site of scanning, vertical alignment of the transducer and including a good number of patients with CLBP.

Reliability of the abdominal muscle thickness

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Our results showed that the mean values of resting thickness of the lateral abdominal muscles were similar in both sides similar to healthy subjects (Rankin et al., 2006; Teyhen et al., 2012). Also, the mean values of contracted and resting thicknesses of these muscles (see Table 2) were consistent with previous studies that have been measured contracted thickness during different tasks and site of scanning (Gibbon et al., 2017; Pulkovski et al., 2012; Rasouli et al., 2011; Teyhen et al., 2009).

Despite the purported use of the ASLR test, to date, there are only a few studies that have investigated the reliability of abdominal muscle thickness during ASLR task (Koppenhaver et al., 2009a; Linek et al., 2014; Teyhen et al., 2011). No study, to our knowledge, has evaluated the reliability of contraction ratio of the abdominal muscles during ASLR task in patients with CLBP. Our results showed that good to high intrarater within- and between-day reliability for the abdominal muscle thickness and contraction ratios in both sides during ASLR task in patients with CLBP like former studies that have investigated the reliability of abdominal thickness during contraction during ADIM (Gibbon et al., 2017; Pulkovski et al., 2012) and dynamic tasks (Arab et al., 2013; Gibbon et al., 2017).

In our study, the *vertical alignment* of the transducer was used in order to show the thickness of layer-shaped muscles in the abdominal region (Urquhart et al., 2005). In line with two other studies using the vertical alignment of transducer but in healthy individuals (Niewiadomy & Szuscik, 2017; Rankin et al., 2006), our findings showed good to high ICCs using this method for measuring thickness and contraction ratio of the lateral abdominal muscles during resting position and ASLR task in patients with CLBP. Previous studies were mostly used the *transverse alignment* of the transducer at different locations for assessing the lateral abdominal muscle thickness (Arab et al., 2013; Gibbon et al., 2017; Teyhen et al., 2011). These observations can be interpreted as good to high intrarater reliability for mentioned US measurements depending on the muscle, transducer orientation, site of scanning, and functional task.

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SEM and MDC can indicate useful information than the ICC, especially for therapists/clinicians (Beaton, 2000). We had a wide range of SEMs (0.5–1.6 mm) and MDCs (0.4–4.4 mm) in our participants**.** Based on the SEM and MDC formula, higher SD causes larger SEM and MDC. There are several possible explanations for these results as the following: In the current study, the relatively large SDs may be related to the variability of muscle recruitment patterns in the patients and high inter-subject variability (Abboud et al., 2014). Moreover, some studies have suggested that parameters like myofascial extensibility, intra-abdominal pressure, and forces from the surrounding muscles might affect the thickness of abdominal muscles. Besides, some confounding factors maybe affect the reliability of US thickness measurement including repositioning of the transducer and reapplying the pressure, repeating the motor task, anatomical landmark detection, and accuracy of marking the fascial bands and measurements. Hence, due to these factors, observation of higher SDs in our study was reasonable so, they had affected SEM and MDC values. Although there is no consensus on an acceptable MDC level, Rankin et al. (2006) reported variations of 1-2 mm and therefore concluded this variation might be due to a measurement error, which is consistent with the results of current study. The study of Rankin also used the vertical alignment of transducer and similar site of scanning to this study.

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Reliability of the LM muscle

The results showed that the mean values of resting thickness of the LM muscle were similar in both sides. Also, the mean values of contracted and resting thicknesses of LM muscle (see Table 3) were consistent with previous studies (Djordjevic et al., 2014; Gibbon et al., 2017). However, former studies have not assessed the thickness of LM in various levels (L3-S1), and these results may not be comparable to other levels. The smallest value of LM contraction ratio was found at the L5-S1 level and the highest values related to the L3-L4 level. Reduced multifidus muscle contraction ratio at L5-S1 level maybe indicates that muscles at this level were influenced by nonspecific CLBP.

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Overall, the results revealed good to high intrarater within-day and between-day reliability of the LM muscle thickness and contraction ratio in both conditions in the patients with CLBP, depending on the level of LM muscle and participant's position. These findings also support previous studies in which acceptable reliability of the US for the LM muscle thickness in patients with LBP (Djordjevic et al., 2014; Gibbon et al., 2017). To our knowledge, this is the first study that evaluated the reliability of contraction ratios of the LM muscle in patients with CLBP. Sarafraz et al. reported the US as a highly reliable method for measuring LM muscle contraction ratio at the L5-S1 level in individuals with and without sciatica (Sarafraz et al., 2018).

In the current study, the SEMs (1.1-2.7 mm) and MDCs (2.9-7.5 mm) of the LM muscle at all levels at rest and during contraction were consistent with prior studies (Gibbon et al., 2017; Koppenhaver et al., 2009b). For example, Sions et al. reported SEMs of 2.3-4.6 mm and MDCs of 6.4-12.6 mm for the LM muscle (Sions et al., 2015).

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Reliability of contraction ratios

Due to the high ICCs and low SEMs and MDCs of the contraction ratios of the lateral abdominal and LM muscles, this value can be considered as a potential outcome measure in order to investigate the neuromotor function in clinical practice and research. The contraction ratio is calculated from both resting and contracted thickness measurements that can clinically be more useful than single thickness measurement. Therefore, it was expected that the reliability of the contraction ratio was consistently lower than those for single thickness measurement. This was likely since the contraction ratios were based on two imperfect measurements rather than one.

The present study had several limitations. We only assessed the intrarater reliability of the US measurement, which may depend on operator experience. Additionally, pain intensity was only evaluated at the initial assessment, not during contractions, which may have adversely affected reliability. However, all participants were able to complete muscle contraction tasks without any problem. Also, the sample size was rather small. Therefore, future studies should investigate the interrater reliability of the US for measuring the LM and abdominal muscles, considering confounding factors with larger sample size.

CONCLUSION

In conclusion, the findings suggest that US imaging has good to high intrarater within- and between-day reliability for assessing absolute thickness and contraction ratio of the TrA, IO, EO, and LM muscles in patients with nonspecific CLBP. The vertical alignment of transducer seems to be an alternative method for measuring the thickness and contraction ratio of the lateral abdominal muscles indicating good to high reliability of measurements. Muscle symmetry was found in all measured muscles at rest, and the reliability of them was comparable on both the right and left sides.

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Figure

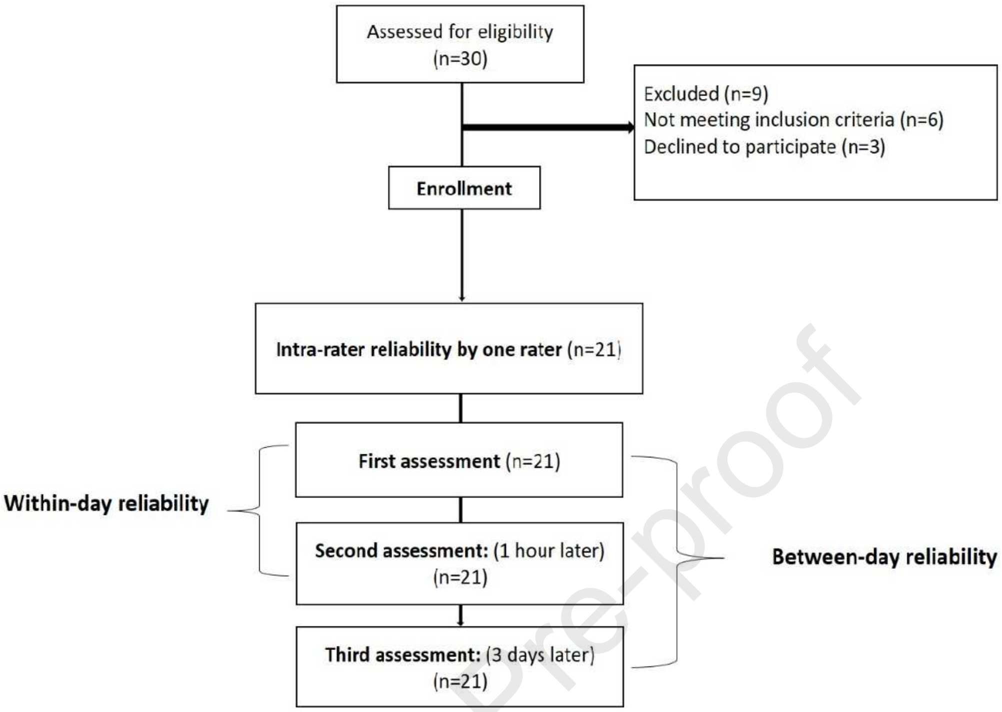

Fig 1. The overview of participants and flow chart of data collection

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TABLES

Table 1.
Demographic and clinical characteristics of the participants (n= 21).

	Mean (SD)
Age (years)	36.4 (9.6)
Female, n (%)	15 (66.6%)
BMI (kg/m^2)	25.8 (4.1)
Pain	5.3 (1.4)
Disability (ODI)	25.6 (13.2)
Activity level (Tegner scale)	3.4 (0.7)
Duration of pain (months)	23.9 (21.1)

SD: Standard deviation; BMI: Body Mass Index; ODI: Oswestry Disability Questionnaire.

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Table 2.
The scores for the ultrasound thicknesses measurements and contraction ratio values of the lateral abdominal muscles.

	First assessment	**Second assessment**	**Third assessment**
EO			
Left			
Rest	6.3 (2.3)	6.1 (2.4)	6.0 (2.5)
Contraction	6.1 (2.3)	6.2 (2.5)	6.3 (2.7)
Contraction Ratio	1.0 (0.2)	1.0 (0.3)	1.1 (0.4)
Right			
Rest	6.6 (2.2)	6.9 (2.5)	7.4 (2.7)
Contraction	6.9 (2.0)	7.1 (2.8)	7.8 (3.2)
Contraction Ratio	1.1 (0.2)	1.0 (0.4)	1.0 (0.3)
IO			
Left			
Rest	7.9 (2.7)	8.4 (2.6)	9.0 (2.9)
Contraction	8.2 (2.8)	8.9 (2.5)	9.6 (2.8)
Contraction Ratio	1.1 (0.2)	1.1 (0.2)	1.1 (0.2)
Right			
Rest	7.7 (2.9)	7.9 (3.0)	8.5 (2.8)
Contraction	7.8 (3.3)	8.1 (2.9)	8.4 (2.9)
Contraction Ratio	1.0 (0.2)	1.0 (0.2)	1.0 (0.2)
TrA			
Left			
Rest	3.9 (1.2)	4.4 (1.4)	4.8 (1.1)
Contraction	4.1 (1.4)	4.5 (1.8)	4.7 (2.1)
Contraction Ratio	1.1 (0.3)	1.0 (0.3)	1.0 (0.4)
Right			
Rest	3.9 (1.3)	4.1 (1.5)	4.6 (2.0)
Contraction	4.2 (1.4)	4.4 (1.5)	4.9 (1.8)
Contraction Ratio	1.1 (0.3)	1.1 (0.3)	1.1 (0.2)

EO: External Oblique; IO: Internal Oblique; TrA: Transversus Abdominis. Values are presented as Mean (SD).
Resting and contracted thicknesses are in millimeters.

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Table 3.
The scores for the ultrasound thicknesses measurements and contraction ratio values of the LM muscle.

	First assessment	**Second assessment**	**Third assessment**
LM (L3-L4)			
Left			
Rest	27.0 (5.9)	27.4 (5.0)	27.8 (5.2)
Contraction	36.2 (6.9)	37.1 (7.3)	37.2 (6.5)
Contraction Ratio	1.3 (0.2)	1.3 (0.2)	1.3 (0.2)
Right			
Rest	28.6 (5.4)	28.8 (5.6)	29.4 (6.2)
Contraction	38.3 (5.2)	39.0 (6.4)	39.6 (7.3)
Contraction Ratio	1.3 (0.2)	1.3 (0.2)	1.3 (0.2)
LM (L4-L5)			
Left			
Rest	28.9 (4.2)	29.6 (4.2)	30.5 (3.9)
Contraction	37.0 (4.8)	37.7 (5.0)	38.5 (5.5)
Contraction Ratio	1.2 (0.1)	1.3 (0.1)	1.2 (0.1)
Right			
Rest	29.3 (5.6)	29.4 (5.9)	30.1 (6.4)
Contraction	38.3 (5.6)	38.7 (6.4)	39.5 (6.9)
Contraction Ratio	1.3 (0.2)	1.3 (0.2)	1.3 (0.2)
LM (L5-S1)			
Left			
Rest	31.5 (4.3)	31.9 (4.6)	32.3 (5.3)
Contraction	38.4 (6.0)	38.6 (6.4)	39.1 (6.8)
Contraction Ratio	1.2 (0.1)	1.2 (0.1)	1.2 (0.1)
Right			
Rest	31.0 (4.7)	31.4 (5.0)	32.1 (5.7)
Contraction	38.1 (5.6)	39.3 (6.6)	39.3 (7.0)
Contraction Ratio	1.2 (0.1)	1.2 (0.1)	1.2 (0.1)

LM: Lumbar multifidus, L3: Third lumbar vertebra, L4: Fourth lumbar vertebra, L5: Fifth lumbar vertebra, S1: First sacral vertebra. Values are presented as Mean (SD).
Resting and contracted thicknesses are in millimeters.

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Table 4.
Within-day and between-day reliability of the ultrasound measurements of the lateral abdominal muscle thicknesses and contraction ratios.

	Reliability values					
	Within-day (First and Second)			**Between-day (First and Third)**		
	ICC	**SEM**	**MDC**	**ICC**	**SEM**	**MDC**
EO						
Left						
Rest	0.96	0.66	1.84	0.92	0.96	2.68
Contraction	0.95	0.76	2.13	0.93	0.94	2.61
Contraction Ratio	0.90	0.13	0.36	0.84	0.20	0.56
Right						
Rest	0.90	1.06	2.94	0.89	1.16	3.23
Contraction	0.91	1.03	2.87	0.83	1.59	4.40
Contraction Ratio	0.84	0.18	0.51	0.81	0.17	0.47
IO						
Left						
Rest	0.95	0.80	2.21	0.9	1.19	3.32
Contraction	0.96	0.74	2.06	0.9	1.23	3.42
Contraction Ratio	0.86	0.10	0.30	0.83	0.13	0.36
Right						
Rest	0.97	0.72	2.00	0.93	1.08	3.00
Contraction	0.97	0.76	2.13	0.92	1.25	3.46
Contraction Ratio	0.8	0.14	0.40	0.80	0.14	0.40
TrA						
Left						
Rest	0.85	0.66	1.84	0.82	0.73	2.04
Contraction	0.9	0.71	1.98	0.81	1.11	3.10
Contraction Ratio	0.87	0.16	0.45	0.81	0.24	0.68
Right						
Rest	0.93	0.57	1.59	0.85	0.98	2.71
Contraction	0.94	0.53	1.49	0.86	0.87	2.42
Contraction Ratio	0.91	0.12	0.35	0.87	0.14	0.41

ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; EO: External Oblique; IO: Internal Oblique; TrA: Transversus Abdominis.

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Table 5.
Within-day and between-day reliability of the ultrasound measurements of the lumbar multifidus muscle thicknesses and contraction ratios.

	Reliability values					
	Within-day (First and Second)			**Between-day (First and Third)**		
	ICC	**SEM**	**MDC**	**ICC**	**SEM**	**MDC**
LM (L3-L4)						
Left						
Rest	0.97	1.30	3.62	0.93	2.03	5.64
Contraction	0.97	1.74	4.82	0.94	2.32	6.44
Contraction Ratio	0.97	0.05	0.16	0.95	0.07	0.21
Right						
Rest	0.98	1.11	3.09	0.94	2.0	5.62
Contraction	0.96	1.64	4.57	0.91	2.70	7.49
Contraction Ratio	0.98	0.04	0.11	0.94	0.06	0.19
LM (L4-L5)						
Left						
Rest	0.97	1.03	2.86	0.9	1.82	5.04
Contraction	0.97	1.20	3.34	0.92	2.08	5.76
Contraction Ratio	0.97	0.03	0.10	0.96	0.04	0.12
Right						
Rest	0.97	1.41	3.90	0.93	2.26	6.27
Contraction	0.98	1.21	3.35	0.94	2.18	6.06
Contraction Ratio	0.96	0.05	0.16	0.94	0.07	0.20
LM (L5-S1)						
Left						
Rest	0.95	1.43	3.96	0.89	2.28	6.34
Contraction	0.97	1.53	4.24	0.92	2.59	7.18
Contraction Ratio	0.97	0.04	0.11	0.97	0.04	0.11
Right						
Rest	0.96	1.40	3.89	0.92	2.11	8.86
Contraction	0.96	1.74	4.83	0.92	2.51	7.10
Contraction Ratio	0.96	0.03	0.10	0.92	0.05	0.14

ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; LM: Lumbar multifidus; L3: Third lumbar vertebra; L4: Fourth lumbar vertebra; L5: Fifth lumbar vertebra; S1: First sacral vertebra.

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HIGHLIGHTS

- The trunk muscle symmetry was found at rest.
- Ultrasound is reliable for measuring abdominal muscle thickness.
- Ultrasound is reliable for measuring lumbar multifidus thickness.
- Vertical alignment of transducer is reliable for measuring the abdominal muscles.
- Contraction ratio is a reliable value for assessing muscles.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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