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Intra-rater reliability of shear wave elastography for the quantification of lateral abdominal muscle elasticity in idiopathic scoliosis patients

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<th>Linek Pawel</th>
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Ethics approval: Local Ethics Committee, The Jerzy Kukuczka Academy of Physical Education in Katowice Ethics Committee approved this study. Participants gave written informed consent before data collection began.

Source(s) of support: The study was financed by the Polish National Science Centre (decision no. 2016/23/D/NZ7/02003).

Competing interests: Nil

Short Title: Reliability of shear wave elastography
Abstract

Objective: To date, studies evaluating the reliability of shear wave elastography (SWE) measures of the lateral abdominal muscles (LAM) in adolescent idiopathic scoliosis (AIS) patients have never been performed. The aim of the study was to assess the intra-rater reliability of SWE and thickness of the LAM at rest and during isometric contraction (10% of maximal voluntary contraction).

Methods: It was a single-group, repeated-measures intra-rater reliability study. Twenty-four AIS patients between the ages of 10 and 17 years took part in the study. Two and three repeated SWE measurements were recorded in the supine resting position and during isometric contraction, respectively. Two sessions were performed with a seven day interval.

Results: By using the mean of two measures in the supine, resting position, intra-examiner reliability point estimates (ICC3,2) ranged from 0.75 to 0.84 for external oblique, internal oblique and transversus abdominis muscles. During the isometric contraction, the ICC3,3 results ranged from 0.70 to 0.83. The ICC results for muscle thicknesses in both conditions ranged from 0.89–0.96.

Conclusion: Measurements of LAM elasticity are reliable in AIS patients. The superficial fat layer didn’t influence the measurement error between two sets of measurements in the examined adolescent population. The images extracted from SWE can successfully be used to assess LAM thicknesses with high reliability.

Key words: Scoliosis, adolescent, shear wave elastography, abdominal muscle
Adolescent idiopathic scoliosis (AIS) is diagnosed in 0.47–5.20% of the underage population,\(^1\) though the cause has not yet been established. Lam and Mehdian\(^2\) claim that spine deformity may be correlated with weakening or inappropriate functioning of the abdominal muscles. Of all the abdominal muscles, the transversus abdominis (TrA) is responsible for maintaining the neutral curvature and stiffness of the lumbar spine, whereas the more superficial external oblique (EO) and internal (IO) muscles function depends on the external forces created and generates torque to preserve the stability of the trunk.\(^3\) Function of these lateral abdominal muscles (mainly the TrA) may be a cause of scoliosis, as was presented in a recently published paper where some possible theories were given.\(^4\) Other studies have shown that there are some changes in the morphology of lateral abdominal muscles in AIS compared to healthy subjects.\(^5-7\) To date, lateral abdominis muscles have been examined in the AIS population by B-mode ultrasound imaging (USI), because USI gives the easiest way to assess muscle thickness in scientific research.\(^4-8\) In some studies, the reliability of lateral abdominal muscle thickness measurements by B-mode USI in AIS population were confirmed.\(^5,6\)

Recently, a non-invasive and a real-time ultrasound shear wave elastography method has been used to measure muscle elasticity. This method is called supersonic shear imaging or shear wave elastography (SWE). SWE assess muscle elasticity by estimating an apparent shear modulus. Shear modulus measured by SWE is linearly related to active and passive muscle force.\(^9,10\) Thus, muscle shear modulus measured with ultrasound SWE may be useful for inferring muscle stiffness (or tension).\(^9,11\) To our knowledge, there have been no studies on lateral abdominis muscle elasticity (stiffness) in the AIS population. It seems that studies assessing the stiffness of the lateral abdominal muscle in AIS may give new insight into the scoliosis condition and potentially into diagnosis and rehabilitation protocols. However,
before SWE is used in clinical practice and research on AIS population, it is necessary to quantify the reliability of SWE in lateral abdominis muscles.

Available data from MacDonald et al. has shown that for SWE measurements of the lateral abdominal muscle in adults: a) fair to excellent intra-session and inter-rater reliability was observed with a moderate to high intra-class coefficient; b) reliability was greater for superficial than for deep muscles; c) for around 30% of participants some artifacts were detected; and d) the superficial fat layer was thicker in participants for whom artifacts were observed. Thus, the location of the muscles determines the reliability level. Compared to the adult population, in adolescence the lateral abdominal muscles are thinner by 15% (≈ 3 mm) on average. This observation is to be expected as the processes of maturation and physical growth are associated with the growth of the skeleton and muscle mass. Additionally, in adolescence the thickness of the superficial fat layer of the abdomen should be lower compared to the adults, as body mass is correlated with muscle thickness. Hence, we can hypothesize that the reliability of the elasticity measurements of the lateral abdominal muscle should be higher for deeper muscles (TrA, IO) in adolescents than for adults.

The aim of the study was to assess the intra-rater reliability (seven day span between sessions) of shear modulus measured in the lateral abdominal muscles at rest and during isometric contraction. As the thickness of the lateral abdominal muscles have never been assessed in SWE Mode, the reliability of the muscle thickness was also taken into account.

Methods

Setting and study design

This was a single-group repeated-measures design study performed in the ‘Stokrotka’ health resort for pediatric population (under 18) in southern part of Poland. The study was authorised by the Bioethics Committee for Scientific Studies at the Academy of Physical
Education in Katowice on 05 December 2017 (Decision No. 4/2017). All participants and their parents gave their signed informed consent to participate.

**Participants**

A sample of 24 participants (mean age, 12.50 ± 2.23 years; sex, 84% girls; mean body height, 152.1 ± 12.1 cm; mean body mass, 47.5 ± 14.8 kg; mean BMI, 20.10 ± 4.02 kg/m²) with AIS were included in the study. Inclusion criteria were as follows: 1) actual X-ray imaging (not older than three months prior to the study); 2) scoliosis of unknown etiology (AIS) confirmed by medical diagnosis; 3) primary curvature angle of ≥ 10 degrees on Cobb's scale (Table 1). Out of 24 participants, only 16 were able to perform proper isometric contraction by obtaining the dictated electromyographic (EMG) activity level.

**X-ray imaging analysis**

Prior to the study, all X-ray images were analyzed by a medical doctor regarding the number of curvatures, direction of curvatures and Cobb’s angle. Patients who fulfilled the inclusion criteria were then sent for SWE measurements.

**Examiner**

All USI procedures were performed by one physiotherapist, who prior the study had six years of experience in assessing muscle thickness on different populations. The examiner had not previously used SWE. Before testing, the examiner underwent four hours of theoretical and 20 hours of practical training with an instructor who has extensive experience with SWE in the medical field. Additionally, before the study the examiner examined 40 adolescents under control of the instructor. In the opinion of Macdonald et al.,12 20 hours of practical training is enough to achieve good reliability of SWE.
**Instrumentation**

Surface EMG activity was recorded by an eMotion EMG system (Mega Electronics LTD, Kuopio, Finland) with electrodes placed over the right and left rectus abdominis muscle (RA). Two pairs of self-adhesive Ag/AgCl electrodes (Bio-Lead-Lok B, Jozefow, Poland) with a diameter of 36 mm were used. Before the placement procedure, the position of tendinous intersections were checked by B-mode ultrasound imaging to place electrodes on one belly muscle as close as possible to the navel position (the reason to position the electrodes on RA rather than EO or IO muscles was technical, because in some cases when we placed the electrodes on EO muscle it was difficult to obtain proper ultrasound imaging, which in our study should include the musculofascial junction of the TrA). Reference electrodes were placed between and laterally to the active electrodes (Fig. 1A). EMG signals were bandpass filtered (20–500 Hz), notch filtered (50 Hz) and sampled at 1 kHz. To diminish impedance between the skin and the electrodes, the surface of the skin was properly cleaned. The EMG signal was used 1) to assess participant’s maximal voluntary contraction (MVC); 2) to control the level of abdominal muscle activation during isometric contraction; 3) to get similar level of abdominal muscle activity across different participants.

A PBU (Stabilizer Pressure Biofeedback-Chattanooga Group, USA) was used as biofeedback and to help gauge 10% of MVC of the rectus abdominis muscle. The PBU was positioned under the lumbar spine so that the inferior border of the device was aligned with the posterior superior iliac spine marks.

An Aixplorer ultrasound scanner (Product Version 12.2.0., Software Version 12.2.0.808, Supersonic Imagine, Aix-en-Provence, France), coupled with a linear transducer array (2–10 MHz; SuperLinear 10-2, Vermon, Tours, France) was used in the shear wave elastography mode to measure shear modulus of the lateral abdominal muscles (EO, IO and...
TrA) on both body sides. The ultrasound transducer was placed laterally to the navel and transversely to the long axis direction of the body (along the line of muscle fibers of TrA) – black rectangles on figure 1A. We decided to not position the transducer within the direction of the muscle fibers for each muscle, as probe orientation had no influence on local stiffness of the lateral abdominal muscle. Thus, the probe was positioned perpendicular to the longitudinal axis of the body between the iliac crest and the costal margin on the anterolateral wall of the abdomen. In this position the transducer was adjusted to ensure that, at rest and during isometric contraction, the fascial borders of the lateral abdominal muscles (OE, OI and TrA) occurred parallel on the screen. A hypoallergenic transduction gel was also used to limit the applied load to the skin.

**Protocol**

Measurements of EO, IO and TrA shear modulus were taken in semi-supine position at rest and during isometric contraction. In the rest stage, the knees were in 90° flexion and the upper limbs placed along the sides of the trunk. The subjects were asked to breathe comfortably and the SWE image was taken at the end of habitual expiration (the TrA muscle was in the lowest position on the B-Mode screen). In this stage, two separate SWE images were collected from both body sides. Each image was at once inspected for artifacts or/and missing values (unfilled regions within the elastic map). If any were present, the measurement was repeated.

In the isometric contraction stage, the MVCs were first calculated in a semi-supine posture with arms crossed and hands on the shoulders, knees in 90° flexion and feet flat on the therapeutic couch. During the MVC, one examiner (T.W.) put his hands on the patient’s elbow joints and resisted the flexion force applied by the patient (Fig. 1B). Each patient was encouraged to push as much as possible for five seconds. There were four repetitions with 30 seconds intervals. The maximum root-mean-square (RMS) EMG of RA over the four MVCs
was considered the maximal activation of RA. This procedure was used to establish 10% of maximal activation of the RA for each participant and to control the task intensity of the abdominal muscle during isometric contraction on two different sessions. After that, PBU was putted under the lumbar spine and inflated to 40 mmHg pressure and the participants were asked to slowly press a PBU inflated bag without motions of the lower legs and head. Two examiners simultaneously controlled the pressure value of the PBU and EMG activity to ensure the participant achieved 10% maximal activation. The consistency between PBU and EMG values were checked five times.

During the SWE measurements in the isometric contraction stage, participants were asked to: 1) breathe comfortably; 2) slowly press the PBU inflated bag using your lumbar spine until you reach the previously established PBU value (patients continuously control the pressure value on the PBU); 3) try to hold the proper PBU value; and 4) hold your breathing and keep the PBU value. During point four, the SWE examiner stored the SWE image. Here, three SWE images were collected separately from both body sides. Each image was at once inspected for artifacts or/and missing values (unfilled regions within the elastic map). If any were present, the measurement was repeated.

In the current study, the two sessions of SWE measurements were taken within a seven day interval (PBU and EMG values were only assessed on the first occasion). During the whole protocol, patients were blinded to the examiners regarding their personal data and characteristics of the scoliosis.

Data analysis

EO, IO and TrA elasticity was calculated from the images stored in the ultrasound scanner after collecting data from all participants. In each image, the Q-Box™ quantitative tool was used to quantitate muscle stiffness. Inside each muscle, three separate circles were
placed and the muscle elasticity within the circle was automatically calculated. The dimension of the circle was manually adjusted to the internal fascia borders of each muscle (Fig. 2). The mean elasticity value of each muscle was derived as a mean value from the three separate circles on a given image. In cases when there was not enough space to put three circles, only two were taken into account during calculation.

Additionally, lateral abdominal muscle thickness and the thickness of the superficial fat layer were measured on the SWE images (Fig. 3). For this purpose, the images were saved on an external drive in JPEG format and transferred to a computer where they were further processed using Photoshop software (Adobe Systems, Inc., San Jose, CA, USA), which has been used previously for the evaluation of the thickness of the lateral abdominal muscles in adolescents. A detailed protocol for editing the images was presented in a previous study.  

Statistical analyses

To assess a relationship between body fat thickness and elasticity values and thickness measurements (difference between mean values from the first and the second occasions), non-parametric Spearman’s correlation was used. The non-parametric test was used as in most cases normal distribution assumption was not met in Shapiro-Wilk test. Statistical significance was set at p < .05. An intra-class correlation coefficient (ICC) was calculated to assess intra-rater reliability (ICC_{3,k}) of muscle thickness and elasticity. The ICC value was interpreted as follow: < 0.4 poor reliability, between 0.40–0.59 fair reliability, between 0.60–0.74 good reliability and > 0.75 excellent reliability. The standard error of measurement was calculated for each measurement. The reliability was estimated based on the mean values for both sides. Data were analyzed using STATISTICA and SPSS softwares.
Results

With regard to rest state, the reliability for the mean values of the lateral abdominal muscle elasticity from two measurements (ICC$_{3,2}$) was excellent (0.75–0.84). The corresponding SEM values for muscle elasticity ranged from 2.29 to 2.92 kPA. The ICC for muscle elasticity was slightly lower than for muscle thickness (0.89–0.92). The corresponding SEM values for muscle thickness ranged from 0.18 to 0.24 mm (Table 2).

In isometric contraction state, the reliability of the mean values of the lateral abdominal muscle elasticity and thickness from three measurements (ICC$_{3,3}$) were moderate and excellent (0.70–0.96). The corresponding SEM values for muscle elasticity ranged from 7.83 to 10.7 kPA. The corresponding SEM values for muscle thickness ranged from 0.16 to 0.30 mm (Table 3).

The possibility that body fat influences the reliability of the elasticity and thickness measurements was considered. In the examined population, (the mean body fat thickness was 4.62 ± 3.19 mm) there was no correlation (in all cases $P \geq .05$) between body fat thickness and the difference in muscle thickness and elasticity results achieved on the two occasions (R values: a) for muscle thickness at rest: 0.07, 0.10, 0.24 for EO, IO and TrA, respectively; b) for muscle thickness during isometric contraction: -0.26, 0.06, 0.23 for EO, IO and TrA, respectively; c) for muscle elasticity at rest: 0.17, -0.25, -0.05 for EO, IO and TrA, respectively; and d) for muscle elasticity during isometric contraction: -0.54, -0.38, -0.23 for EO, IO and TrA, respectively.

Discussion

The main aim of this study was to assess the intra-rater reliability of elasticity measurements in EO, IO and TrA muscles at rest and during isometric contraction (10% RMS of EMG$_{max}$) among AIS patients. Our results have shown that at rest the mean values of shear modulus
from two separate measurements of lateral abdominal muscles between the two occasions
(seven days interval) were reliable (ICC$_{3,2}$ 0.75–0.84). A recent research study on adults
showed that for lateral abdominal muscles, elasticity measurements were more reliable for
superficial (EO-ICC = 0.89) than for deeper muscles (IO-ICC = 0.61 and TrA-ICC = 0.45).$^{12}$
These results were not confirmed in other studies on adults, where ICC for TrA was 0.86 and
0.97.$^{24,25}$ Results of this study differ compared to the results of MacDonald et al.$^{12}$ indicating
our optimistic ICC results for deeper abdominal muscles are the result of the examined
population. For sure our participants have thinner muscle thicknesses and superficial fat layers
and probably thinner Scarpa’s fascia, external oblique fascia and internal oblique fascia, too.
This means that compared to adults, in adolescence IO and TrA muscles are more superficial
and propagation velocity of the sound waves within fat tissue is not reduced as much. In our
study, there was no correlation between lateral abdominal muscle measurement error and
superficial fat thickness, whereas in the MacDonald et al. study$^{12}$ participants for whom
artifacts from SWE measurements were observed had a thicker fat layer. The ability to
penetration into tissues seems to be important here, as in the studies of Hirayama et al.$^{24,25}$ a
convex probe was used and higher ICC results were gained compared to a study where a
linear transducer was implemented.$^{12}$

In opposition to ICC results, our SEM values for rest conditions were higher (by $\approx 2$
kPa) than in the MacDonald et al. study.$^{12}$ It was a consequences of the disproportion in the
SD values between our studies. The reason for this is that our study examined adolescents in a
high sensitivity period connected with physical and mental maturation. Thus, the elasticity
values of the lateral abdominal muscle in younger ages (10–12) maybe vary more than in
older ones (15–16). Additionally, unlike in adults the examine procedure may be more
stressful for adolescents (mainly younger) and result in greater variability in muscle elasticity.
Some authors suggested that muscles may function differently in psychosocially stressful environments.\textsuperscript{26}

Our results also show that during isometric contraction (10\% RMS of \textit{EMG}_{\text{max}}), the mean values of shear modulus from three separate measurements of lateral abdominal muscles between the two occasions (seven days interval) are reliable (ICC\textsubscript{3,3} 0.70–0.83). This is consistent with other studies assessing some form of isometric contraction.\textsuperscript{12,25} Again, our SEM values were higher than in the MacDonald et al. study.\textsuperscript{12} Much higher mean values show that in our study a completely different methodology and protocol was used and AIS patients used a different strategy to contract the abdominal muscles.

With regard to lateral abdominal muscle thickness measurements from SWE images, (rest and isometric contraction) high reliability was achieved in both conditions. This is consistent with results on healthy adolescents examined by classical B-mode protocol.\textsuperscript{27,28}

In the present study, some limitations have to be considered. First, the examined population was AIS patients and the results shouldn’t be assimilated to healthy adolescents, adolescent athletes or adolescents with other conditions. Second, participants between the first and second measurements took part in normal rehabilitation procedures (planned on admission to the hospital). The rehabilitation protocol included some asymmetrical exercises to reverse the scoliotic pattern. Thus, this fact may partially have influenced the study results. Third, the protocol used surface EMG values from RA muscle to control contraction intensity of EO, IO and TrA. Fourth, the isometric contraction protocol was too difficult for most of the younger patients. Fifth, due to time constraints during the second session of measurements, the RMS protocol was not performed.

\textbf{Conclusion}
The intra-rater measurements of lateral abdominal muscle elasticity measured by SWE are reliable in AIS patients. The superficial fat layer didn’t influence the measurement error between two sets of measurements in the examined adolescent population. The images extracted from SWE can successfully be used to assess lateral abdominal muscle thicknesses with high reliability.

Acknowledgments

We would like to thanks to all the patients and their parents for participating in the study. We also thanks to Tomasz Niesyto and Krzysztof Lehnort for enabling us to conduct research in Stokrotka Health Resort. This study was financed by the Polish National Science Centre (decision no. 2016/23/D/NZ7/02003).

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Table 1. Classification and Incidence and the mean degree of spinal curvatures in patients with adolescent idiopathic scoliosis.

<table>
<thead>
<tr>
<th>Curve Type</th>
<th>No. of subjects (%)</th>
<th>Degree (Cobb)°</th>
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<tr>
<td>Right thoracic</td>
<td>1 (4.18)</td>
<td>12</td>
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<tr>
<td>Right thoracic / left lumbar double curve</td>
<td>4 (16.8)</td>
<td>21/21</td>
</tr>
<tr>
<td>Right thoracolumbar</td>
<td>5 (20.7)</td>
<td>16</td>
</tr>
<tr>
<td>Right lumbar</td>
<td>1 (4.18)</td>
<td>30</td>
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<tr>
<td>Left thoracic / right lumbar double curve</td>
<td>3 (12.5)</td>
<td>11/12</td>
</tr>
<tr>
<td>Left thoracolumbar</td>
<td>8 (33.3)</td>
<td>14</td>
</tr>
<tr>
<td>Left thoracolumbar / right thoracic double curve</td>
<td>1 (4.18)</td>
<td>36/19</td>
</tr>
<tr>
<td>Left lumbar</td>
<td>1 (4.18)</td>
<td>12</td>
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Table 2. Intraexaminer reliability using a mean of 2 measures in two different occasions.

<table>
<thead>
<tr>
<th>Muscle State</th>
<th>Elastography measurements (kPA)</th>
<th>ICC\textsubscript{3.2} (95% CI)</th>
<th>SEM</th>
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<tbody>
<tr>
<td>OE Rest</td>
<td>0.84 (0.66 – 0.93)</td>
<td>2.92</td>
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<tr>
<td>OI Rest</td>
<td>0.75 (0.50 – 0.88)</td>
<td>2.53</td>
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<tr>
<td>TrA Rest</td>
<td>0.77 (0.53 – 0.89)</td>
<td>2.29</td>
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<tr>
<td>Muscle thickness (mm)</td>
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<tr>
<td>OE Rest</td>
<td>0.92 (0.92 – 0.98)</td>
<td>0.24</td>
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</tr>
<tr>
<td>OI Rest</td>
<td>0.90 (0.79 – 0.96)</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>TrA Rest</td>
<td>0.89 (0.78 – 0.95)</td>
<td>0.18</td>
<td></td>
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</table>

EO – external obliques abdominis; IO – internal obliques abdominis; TrA – tranversus abdominis; ICC – intraclass correlation coefficient; SEM – standard error of measurement; SDD – the smallest detectable differences;
Table 3. Intraexaminer reliability using a mean of 3 measures in two different occasions.

<table>
<thead>
<tr>
<th>Muscle state</th>
<th>Elastography measurements (kPA)</th>
<th>ICC\textsubscript{3.3} (95% CI)</th>
<th>SEM*</th>
</tr>
</thead>
<tbody>
<tr>
<td>OE</td>
<td>Contracted</td>
<td>0.83 (0.59 – 0.94)</td>
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<tr>
<td>OI</td>
<td>Contracted</td>
<td>0.70 (0.52 – 0.87)</td>
<td>9.15</td>
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<tr>
<td>TrA</td>
<td>Contracted</td>
<td>0.77 (0.50 – 0.92)</td>
<td>10.7</td>
</tr>
<tr>
<td>OE</td>
<td>Contracted</td>
<td>0.92 (0.79 – 0.97)</td>
<td>0.30</td>
</tr>
<tr>
<td>OI</td>
<td>Contracted</td>
<td>0.95 (0.87 – 0.98)</td>
<td>0.34</td>
</tr>
<tr>
<td>TrA</td>
<td>Contracted</td>
<td>0.96 (0.90 – 0.99)</td>
<td>0.16</td>
</tr>
</tbody>
</table>

EO – external obliques abdominis; IO – internal obliques abdominis; TrA – tranversus abdominis; ICC – intraclass correlation coefficient; SEM – standard error of measurement; SDD – the smallest detectable differences; * - Values in millimetres
Figure 1. The EMG electrodes placement (A) and position to maximal voluntary contraction assessment (B). Black rectangles on figure A show transducer position during shear wave elastography measurement.
Figure 2. Shear wave elastography of lateral abdominal muscles.
Figure 3. Lateral abdominal muscles and fat tissue measurements