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Ultrasound Shear Wave Elastography to Assess Osteopathic Manipulative Treatment on the Iliocostalis Lumborum Muscle: A Feasibility Study

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Abstract

Purpose To investigate the feasibility of ultrasound shear wave elastography (SWE) in assessing iliocostalis lumborum muscle changes after osteopathic manipulative treatment (OMT).

Methods Using a linear array ultrasound transducer (4-9 MHz), we prospectively measured shear wave velocity (SWV) of bilateral iliocostalis lumborum muscles in 20 patients with low back somatic dysfunction (mean age 28y) and in 9 age-matched healthy volunteers. SWV was measured in muscle relaxation and contraction in all subjects and immediately before and after OMT in patients. We developed muscle SWV rate [$SWV_{contraction} – SWV_{relaxation}$) / $SWV_{relaxation}$] and SWV improvement index [($SWV_{pre\text{-}OMT} – SWV_{post\text{-}OMT}$) / $SWV_{pre\text{-}OMT}$] for quantifying muscle contractibility and changes in muscle stiffness following OMT. Statistical analyses included using unpaired t-test to analyze the difference in muscle SWV between muscle relaxation and contraction, between somatic dysfunction and non-somatic dysfunction in patients or health, a paired t-test to examine the difference in SWV and SWV rate before and after OMT, intraclass correlation coefficient (ICC) to test intra- and inter-observer reliability, and Spearman's rank correlation to analyze the correlation of changes in SWV to manual osteopathic assessments.

Results Muscle SWV significantly differed between somatic dysfunction and non-somatic dysfunction in patients or health, between muscle relaxation and contraction, and before and after OMT ($p < 0.001$). SWV improvement index moderately correlated with manual osteopathic assessments ($r=0.68$). The inter- and intra-observer reliability for performing SWE was good (ICC >0.8).

Conclusions Our results suggest that ultrasound SWE is feasible to quantify the change in muscle stiffness and contractibility following OMT.

Key words: Osteopathic manipulative treatment; musculoskeletal disorder; shear wave elastography; somatic dysfunction; ultrasound.

Abbreviations: ICC, intraclass correlation coefficient; MSK, musculoskeletal; OMT, osteopathic manipulative treatment; SWV, shear wave velocity; SWE, shear wave elastography; TART, tissue texture abnormality, asymmetry, altered restriction of motion, and tenderness.

Introduction

Acute and chronic musculoskeletal (MSK) conditions with palpatory findings of somatic dysfunctions are often manually evaluated by osteopathic physicians. In osteopathic medicine, somatic dysfunction is defined as "impaired or altered function of related components of the somatic (body framework) system: skeletal, arthrodial, and myofascial structures, and related vascular, lymphatic, and neural elements". [1] Somatic dysfunction associate with disorders of muscles, tendon, and skeletal with common clinical manifestation of pain (low back or other locations), reduced muscle movement, and decreased limb/spine mobility in patients with MSK condition. Common causes for the development of muscle somatic dysfunction include, but are not limited to, acute trauma, chronic injury, degeneration, and inflammation. [1-3] The criteria for diagnosing a somatic dysfunction in osteopathic medicine are described as TART, the acronym that stands for tissue texture abnormality (T), asymmetry (A), altered restriction of motion (R), and tenderness (T). [2] Patients with somatic dysfunctions and MSK problems are often negatively impacted with physical limitations to their normal activities that may in time lead to short- or long-term disabilities. Published reports approximate that nearly half of all Americans (126.6 million people) suffer from an MSK condition. [3, 4] The societal and economic costs of MSK problems are estimated to be approximately $874 billion per year, and this amount is rising. [5]

Somatic dysfunctions can be treated by a manual therapeutic approach known as osteopathic manipulative treatment (OMT) by which the physician's hands are used to correct the dysfunction in the targeted tissue. Osteopathic physicians who perform OMT commonly observe that tissues with somatic dysfunctions are associated with palpable stiffness of the musculature in the region of concern and that such muscle stiffness changes after OMT. [6-8] Osteopathic manipulative medicine has the advantage of treating the whole patient (body, mind, spirit). OMT is considered more cost-effectively than pharmaceutical or invasive interventions. [9] Osteopathic physicians are more likely to provide care utilizing OMT for low back pain associated with MSK conditions than their allopathic medical counterparts. [10] One of the challenges that plagues the osteopathic profession has been the limited number of objective research studies to evaluate the efficacy of OMT in the clinical setting. [2] Many of the published studies comparing methodologies for assessing the efficacy of OMT were of insufficient quality and quantity to gain wide acceptance from the scientific community. [11, 12]

Non-invasive assessment methods include conventional x-ray, computed tomography, and magnetic resonance imaging. While MRI can provide good resolution and anatomic information of muscles and joints, [13-15] its routine application is limited due to poor patient tolerance, lack of portability, contraindications, and high cost. [16, 17] Surface electromyography (EMG) is another non-invasive method that the electrical activity of muscles can be measured on the skin surface, but this often has limited correlation to deep tissue properties. [18] Therefore, the aforementioned techniques are not ideal methods for quantifying muscle response to OMT in clinical setting.

Ultrasound SWE has been successfully used to assess muscle mechanical properties (stiffness) in physiologic [19, 20] and pathologic conditions such as Parkinson's disease and post-stroke spasticity. [21-23] These developments suggest that ultrasound analysis of muscle properties may be useful in the evaluation of muscle alterations following OMT. To overcome unmet clinical needs of quantitative measurements in osteopathic manipulative medicine, we aim to assess the feasibility of SWE for evaluating the efficacy of OMT.

Materials and Methods

The Institutional Review Board at the university approved the study (IRB# 2017-0023) and all subjects provided written informed consent prior to the outset. We randomly recruited subjects who underwent OMT for low back pain. Inclusion criteria of the study were as follows:

1. Age of 20y and older

2. Consentable status

3. Ability to tolerate osteopathic palpatory examination, ultrasound scan, and OMT

4. Free of cardiovascular or respiratory disease

5. No lumbar spine surgery within a year prior to the ultrasound examination

6. Ability to extend back muscles (Iliocostalis lumbotum)

We also recruited age-matched healthy volunteers who had no history of pain, injury, surgery or identified somatic dysfunction in low back as the control group. Free of low back somatic dysfunction was determined by a licensed osteopathic physician (JC) using manual osteopathic TART assessments.

Ultrasound Shear Wave Elastography (SWE)

Ultrasound SWE was performed on the low back of the subjects as they were in the prone position (Fig. 1). A licensed osteopathic physician targeted the iliocostalis lumborum muscles at the level between lumbar vertebrae 1 to 5 (L1-L5, Fig. 1) to determine somatic dysfunction in the localized area. The Acuson S3000 ultrasound system (Siemens Medical Solutions, Mountain View, CA) equipped with a 9L4 linear array transducer (bandwidth of 4–9 MHz) was used to acquire shear wave velocity (SWV, m/s) measurements of bilateral iliocostalis lumborum muscles. Technical considerations in performing muscle SWE included:

1) placing the transducer along longitudinal section of muscle fibers because anisotropic effect on the muscle is less in longitudinal than in transverse sections of the muscle; [24]

2) ensuring light pressure on the skin and underlying muscle since any excessive pressure on the muscle may lead overestimation of muscle stiffness;

3) maintaining good contact of the transducer to ensure the sound beam is constantly perpendicular to the skin to minimize out of plane motion from operator and patient;

4) using shear wave quality map to verify the quality of the shear wave process (Fig. 2a). A homogenous green color on the digital map demonstrates a high quality of shear wave processing; [22]

5) using standardized size (2.65 cm x 1.0 cm) of the region of interest, to estimate muscle SWV (Fig. 2b);

6) using a temporary skin marker to ensure the same site for SWV measurements before and after OMT.

SWV was measured in iliocostalis lumborum muscle relaxation when the subject was in neutral prone position (Fig. 1a). SWV was also measured in the maximum muscle contraction when the subject was performing Superman's spine extension (trunk and leg extension) to produce a lumbar spine posture (15-30° arch) [25] (Fig. 1b). Muscle SWV in bilateral iliocostalis lumborum muscles was measured at the depth between 2 cm to 4 cm from the skin throughout the study. Mean and standard deviation (SD) of muscle SWV in the entire ROI (2.6 cm x 1.0 cm) was measured twice in muscle relaxation (Fig. 2) and twice in maximum muscle contraction (Fig. 3) in patients and healthy controls. Muscle SWV was also measured immediate before and after OMT in patients with somatic dysfunction (Fig. 3). A single observer performed SWE on the same muscle twice in 10 subjects to test intra-observer repeatability. Two observers performed SWE in the same 10 subjects separately to test inter-observer reproducibility.

Shear wave elastography measures the velocity of shear wave propagation in the target tissue and the value of SWV is positively correlated with the stiffness of the target tissue. SWV is high in stiff tissue and low in soft tissue. SWV is high in muscle contraction and low in muscle relaxation.[19] With SWV data being measured and collected, a SWV improvement index was developed to assess the percentage of change in SWV measured after OMT compared to that measured before OMT. The SWV improvement index was defined as ($SWV_{pre\text{-}OMT}$ – $SWV_{post\text{-}OMT}$)/ $SWV_{pre\text{-}OMT}$. A high SWV improvement index indicates a significant change of the identified muscle responding to OMT. In addition, SWV rate was defined as ($SWV_{contraction}$ - $SWV_{relaxation}$) / $SWV_{relaxation}$ to assess the relation of the muscle SWV measurements between muscle relaxation (Fig. 2) and contraction (Fig. 3) representing muscle contractibility during a maximum back extension. Eventually, a high SWV rate indicates a muscle with strong contractibility whereas a low SWV rate indicates a muscle with weak contractibility (Fig. 3c).

Osteopathic Assessments and Osteopathic Manipulative Treatment (OMT)

Osteopathic assessments were performed using manual osteopathic TART assessments that included 12 TART parameters (Table 1). A positive TART parameter scored as 1 and a negative TART parameter scored as 0 before OMT. A partial resolution of each positive TART parameter scored as 0.5 and a completed resolution of each positive TART parameter scored as 0 after OMT. Total TART score is the sum of scores of all 12 TART parameters. Osteopathic improvement index defined as TART improvement index = (total TART score $_{\text{pre-OMT}}$ – total TART score $_{\text{post-OMT}}$) / total TART score $_{\text{pre-OMT}}$ was developed to evaluate OMT effect.

Osteopathic manipulative treatment (OMT) can be described as the therapeutic application of manually guided forces to improve physiologic function including the muscular, boney and fascial structures which impact neural, vascular and lymphatic elements to support homeostasis that has been altered by somatic dysfunction. [6, 7] OMT involves an eclectic range of manual techniques, such as soft tissue stretching, joint manipulation, resisted isometric “muscle energy” stretches, fascial relaxation or unwinding, counter strain, visceral techniques. OMT is commonly applied to multiple regions with combinations of several techniques. [10]

OMT in this study was targeted to the iliocostalis lumborum muscle, which is a part of the ilicostalis column of muscles and a common area affected by somatic dysfunctions in MSK conditions. OMT techniques based on the individual somatic dysfunctions assessed by the osteopathic physician employed in this study include: articulatory, balanced ligamentous tension, facilitated positional release, high velocity/low amplitude technique, muscle energy technique, myofascial release, and still technique. The iliocostalis lumborum provides resistance when the body bends forward and provides the force necessary to bring the body back into an upright position. Its bilateral action is responsible for the extension and hyperextension of spine. Along with the small multifidus muscles, iliocostalis lumborum can also act to support and stabilize the lumbar spine. [26, 27]

Statistical analysis

All variables were expressed by the mean and standard deviation (SD). The mean SWV of the iliocostalis lumborum muscles between the sites with and without somatic dysfunction in patients, between somatic dysfunction and healthy control, between the muscle without somatic dysfunction in patients and the muscle in healthy control, between muscle relaxation and contraction was examined using an unpaired t-test. Muscle mean SWV and SWV rate measured before and after OMT were tested using a two-tailed paired t-test. A single observer performed SWE on the same subjects twice with a time interval of one minute for testing intra-observer repeatability. Two observers performed SWE on the same subjects separately for testing inter-observer reproducibility. Inter-observer and intra-observer variation in performing SWE was analyzed using an intraclass correlation coefficient (ICC). The correlation of the SWV improvement index to the osteopathic TART assessments improvement index was analyzed using Spearman's rank correlation to assess the feasibility of SWE for evaluating the efficacy of OMT. A p value less than 0.05 is considered statistically significant. All statistical analyses were conducted with the use of the IBM SPSS statistics software platform (SPSS Version 25.4, SPSS Inc., Chicago, IL).

Results

Ultrasound SWE was performed on 20 patients (10 men and 10 women) with the diagnosis of low back somatic dysfunction and 9 age-matched healthy volunteers (5 men and 4 women) from September 2018 to May 2019. There was no significant difference in mean age (29y vs 27y) or BMI (27.8±3.1 vs 28.2±1.9) between men and women, or between patients with somatic dysfunction and healthy volunteers (mean age: 28y vs 26y; BMI: 28.0±2.5 vs 27.5±1.6, all $p > 0.05$). A significant difference in mean SWV was found between muscles with and without somatic dysfunction in 20 patients (1.83±0.28 m/s vs 1.60±0.3 m/s, $p<0.01$), between somatic dysfunctional muscles and healthy muscles (1.83±0.28 m/s vs 1.63±0.27 m/s, $p< 0.01$) as well as between muscle relaxation and contraction ($p< 0.001$). The difference in mean SWV between the muscle without somatic dysfunction in patients and the muscle in healthy control was not significant ($p> 0.05$, Fig. 1c). The mean SWV and SWV rate before and after OMT differed significantly ($p< 0.05$) (Table 2). Mean SWV in the relaxed muscles significantly decreased after OMT (Fig. 2d). SWV rate significantly increased after OMT (Fig. 3c). ICC for testing inter-observer repeatability was high at 0.80 ($P< 0.001$). ICC for testing intra-observer reproducibility was even higher at 0.97 for observer 1 and 0.96 for observer 2 ($p< 0.001$, Table 3). There was a moderate correlation between SWV improvement index to osteopathic improvement index after OMT (Spearman's rank correlation $r=0.68$, $p < 0.01$).

Discussion

We have observed the capability of ultrasound shear wave elastography (SWE) for determining low back somatic dysfunction by comparing mean SWV measured in the muscle with somatic dysfunction to that measured in the muscles without somatic dysfunction in the patients and in healthy controls. We have also demonstrated the feasibility of ultrasound SWE for quantifying changes in stiffness and contractibility of the dysfunctional iliocostalis lumborum muscle after OMT by measuring muscle mean SWV and calculating the developed SWV improvement index and SWV rate. To date, this is the first report on using ultrasound shear wave elastography to quantify the effects of OMT on muscle mechanical properties (stiffness) and contractibility.

In comparison with muscles without somatic dysfunction in the enrolled patients and in healthy controls, SWV values were remarkably high in muscles with somatic dysfunction as muscle elasticity decreased (stiff) due to muscle spasms, restriction of motion, or intrinsic disease. Muscles that are elastic (not stiff) normally will have a low SWV value. [28, 29] In this study, SWV values in the dysfunctional muscle (Fig. 2b) were significantly lowered after receiving OMT (Fig. 2c). Explanations for this change include, but are not limited to, consequences of resolution of muscle spasm, improvement of local blood and lymphatic circulations, and decrease of motion restriction by osteopathic manipulative techniques. Following a significant decrease of the muscle stiffness at the site of somatic dysfunction, the contractility of the iliocostalis lumborum muscle increased significantly, as the representative of the improvement in active muscle movement. These changes in SWE parameters after OMT indicate OMT treatment effects, not only on muscle tissue mechanical properties (stiffness), but also on muscle function (contractibility). In addition, the change in the iliocostalis lumborum muscle SWV calculated by the SWV improvement index moderately correlated with the improvement in somatic dysfunction assessed by osteopathic palpatory methods (TART) after OMT (Spearman's rank correlation= 0.68). [30] Importantly, we have demonstrated good inter-observer and intra-observer reliability of performing SWE in iliocostalis lumborum muscles with somatic dysfunction (ICC=0.8-0.97, $p < 0.001$).

The effectiveness of OMT is commonly evaluated by conventional TART assessments examined by manual palpation subjectively. In this study, we have demonstrated that palpable muscle stiffness can be quantified by muscle elasticity change in SWV values. Asymmetry can be measured by a significant difference in SWV between the site of somatic dysfunction and the site free of somatic dysfunction if the somatic dysfunction was unilateral. Restriction of motion can be evaluated by the SWV ratio representing muscle contractibility. Nevertheless, the change in SWE parameters which correlate with TART assessments may be used to evaluate the effectiveness of OMT.

Limitations in this study include: the small sample size; the lack of testing the reliability of intra- and inter-observer's osteopathic manipulative examination of low back somatic dysfunction; the lack of evaluating the effectiveness of OMT on low back with varying severities of somatic dysfunction in different age groups. Further, the acuity or chronicity of somatic dysfunctions was not known among the subjects.

In conclusion, the results of this study suggest that ultrasound SWE is feasible to assess the effects of OMT in adults with iliocostalis lumborum muscle somatic dysfunction. Additional research is needed to further investigate the role of SWE in the evaluation of OMT for different anatomic locations and across all age groups.

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Tables

Table 1 Total TART score for assessing muscle somatic dysfunction

number of TART scores	TART Criteria	TART parameters
1	**T**issue changes	Red reflex
2		Skin drag
3		Temperature-Hot
4		Temperature-Cold
5	**A**symmetry	Decreased muscle tone
6		Increased muscle tone
7		Paraspinal fullness
8	**R**estriction of motion	Rotation
9		Flexion
10		Extension

11		Restricted motion
12	**T**enderness	Tenderness
Total		

Note: * Total TART score is the sum of scores in all 12 TART parameters listed in the Table. A positive TART parameter scores 1; a negative TART parameter scores 0; a partial resolution of a positive TART parameter after OMT scores 0.5; a complete resolution of a positive TART parameter after OMT scores 0; TART improvement index = (total TART score $_{\text{pre-OMT}}$ – total TART score $_{\text{post-OMT}}$)/total TART score $_{\text{pre-OMT}}$.

Table 2. Shear wave velocity and osteopathic assessments in somatic dysfunction before and after OMT

Parameters	Pre-OMT	Post-OMT	p	improvement index
Total osteopathic score*	6.55±2.18	2.03±1.68	< 0.001	0.73
SWV (m/s): relaxation	1.83±0.28	1.58±0.3	0.009	0.27
SWV (m/s): contraction	3.27±0.69	4.14±0.88	0.001	0.55
SWV rate	0.82±0.55	1.74±0.79	< 0.001	0.96

Note: * Total osteopathic scores is the sum of scores in all 12 palpatory TART assessment parameters (tissue texture abnormality, asymmetry, restriction of motion, and tenderness) listed in Table 1. OMT, osteopathic manipulative treatment; SWV (m/s), shear wave velocity (meters per second); SWV rate represents the muscle contractibility of the muscle (the change rate in muscle stiffness between muscle relaxation and contraction) and it is defined as $(SWV_{contraction} - SWV_{relaxation})/SWV_{relaxation}$. A large SWV rate indicates strong muscle contractibility in spine extension. SWV improvement index= $(SWV_{pre\text{-}OMT} - SWV_{post\text{-}OMT})/ SWV_{post\text{-}OMT})$ measures the change in muscle SWV after OMT.

Table 3. Intra- and inter-observer reliability tests (intraclass correlation coefficient)

		95% Confidence interval		*F*-test with true value 0	
Average measure	ICC*	Lower bound	Upper bound	Value	Significant

observer 1:observer 1	.974	0.951	0.986	38.507	0.000
observer 2:observer 2	.961	0.926	0.979	25.527	0.000
observer 1:observer 2	.797	0.616	0.892	4.919	0.000

Note: ICC, intraclass correlation coefficient; observer 1: observer 1, correlation between two measurements performed by the observer 1; observer 2: observer 2, correlation between two measurements performed by the observer 2; observer 1: observer 2, correlation between measurements performed by observer 1 and measurements performed by observer 2.

Figure legends

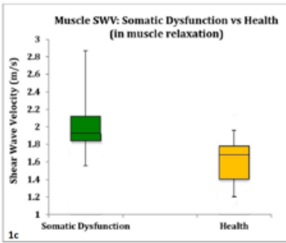
Figure 1a-c. Shear wave velocity (SWV, m/s) of the Iliocostalis lumbotum muscle was measured in the region of lumbar vertebrae 1 to 5 (L1-L5). The ultrasound transducer (white arrow) was placed on the skin in a longitudinal section of the Iliocostalis lumbotum muscle between L1 to L5. Muscle SWV was measured in Iliocostalis lumbotum muscle relaxation when the subject was in a neutral prone position (1a) and measured again in the maximum muscle contraction when the subject was performing Superman's spine extension (1b). Box-and-whisker plots (1c) show a significant difference in mean SWV in muscle relaxation between the muscle with somatic dysfunction (green-colored box) and the muscle in healthy volunteers (yellow-colored box) ($p < 0.01$).

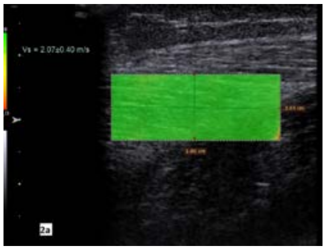
Figure 2a-d. Shear wave elastography was performed on a 30-year-old man with low back pain with the diagnosis of somatic dysfunction in the right lumbar region. Homogeneous green appears in the entire region of interest in shear wave quality map (2a) indicates a high quality of shear wave elastography processing. In his back muscle relaxation, shear wave velocity (SWV) of the right iliocostalis lumbotum muscle measures 2.07±0.40 m/s (2b) and 1.66±0.02 m/s (2c) before and after osteopathic manipulative treatment (OMT), respectively. Color bar in the ultrasound images 2a and 2b indicates the quality of SWV from high (red) to low (blue). Box-and-whisker plots (2d) show a significant difference in mean SWV in muscle relaxation before (green-colored box) and after (orange-colored box) OMT in 20 enrolled subjects with low back somatic dysfunction ($p = 0.009$).

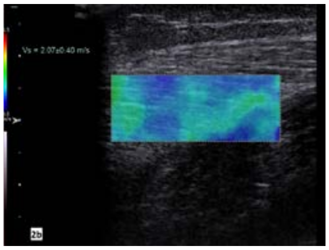
Figure 3a-c. Shear wave elastography was performed on the same subject with low back somatic dysfunction as in Fig. 2. Color bar in the ultrasound images 3a and 3b indicates the quality of shear wave velocity (m/s) from high (red) to low (blue). Shear wave velocity (SWV) of the right iliocostalis lumbotum muscle was measured in the maximum back muscle extension (contraction) before (3a, 3.11±0.88m/s) and after (3b, 4.34±1.68 m/s) osteopathic manipulative treatment (OMT). Using the developed SWV rate ($SWV_{contraction} - SWV_{relaxation}$)/$SWV_{relaxation}$ to assess muscle contractibility, SWV rate of the right iliocostalis lumbotum muscle for this subject was 0.5 and 1.61 before and after OMT, respectively. Box-and-whisker plots (3c) show a significant increase in muscle SWV rate after OMT (orange-colored box) compared with before OMT (green-colored box) in 20 enrolled subjects with low back somatic dysfunction ($p < 0.001$).

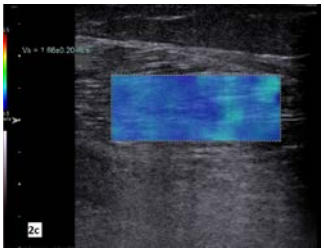

1a

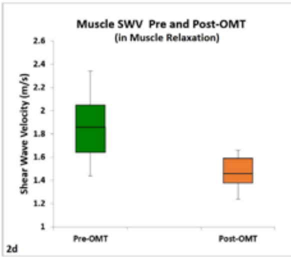

1b

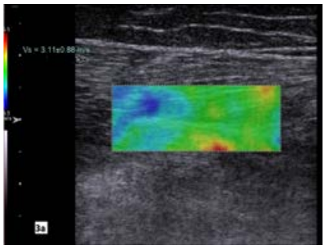

Muscle SWV: Somatic Dysfunction vs Health
(in muscle relaxation)
Shear Wave Velocity (m/s)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Somatic Dysfunction
Health
1c

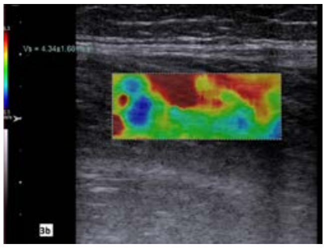


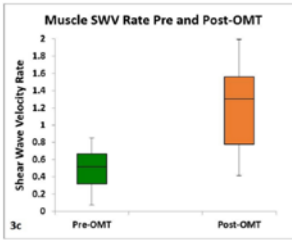

Vs = 2.07±0.40 m/s
2b



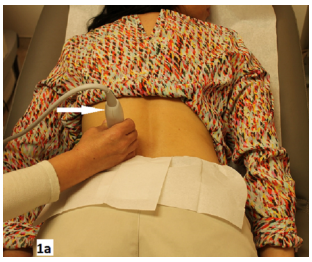

Muscle SWV Pre and Post-OMT
(in Muscle Relaxation)
Shear Wave Velocity (m/s)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Pre-OMT
Post-OMT
2d




3b


Muscle SWV Rate Pre and Post-OMT
Shear Wave Velocity Rate
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre-OMT
Post-OMT

3c



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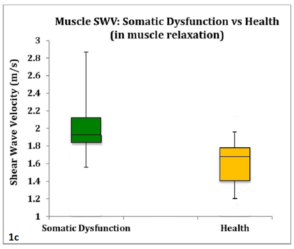
JUM_15092_1b600.tif



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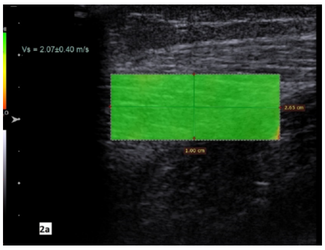

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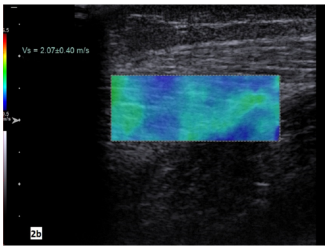

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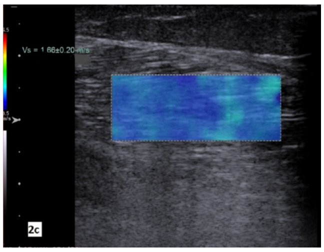

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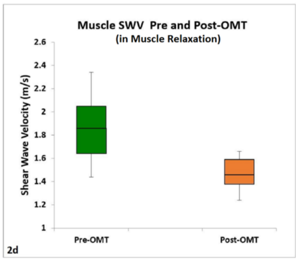

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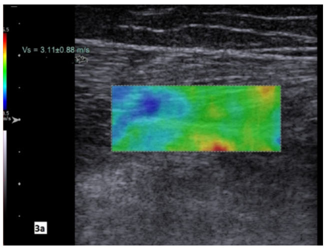

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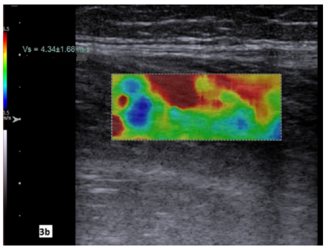
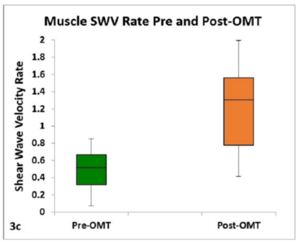


JUM_15092_3b600 (1).tif



JUM_15092_3c600.tif

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