Measurement of lumbar multifidus muscle contraction with rehabilitative ultrasound imaging

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Abstract

Rehabilitative Ultrasound Imaging (RUSI) has been validated as a noninvasive method to measure activation of selected muscles. The purpose of this study was to determine the relationship between muscle thickness change, as measured by ultrasonography, and electromyography (EMG) activity of the lumbar multifidus (LM) muscle in normal subjects.

Bipolar fine wire electrodes were inserted into the LM at the L4 level of five subjects. Simultaneous EMG and RUSI data (muscle thickness) were collected while subjects performed increasingly demanding postural response tasks thought to activate the LM muscle. To determine the relationship between muscle thickness change and EMG activity, the normalized EMG data were correlated to normalized RUSI data. To determine if the tasks increased the demand on the LM, the mean EMG data were compared over each of the four tasks.

Muscle thickness change as measured by RUSI was highly correlated with EMG activity of LM in asymptomatic subjects ($r = .79$, $P < .001$).

Mean EMG data showed increasing levels of activation across tasks (19–34% of maximum voluntary isometric contraction (MVIC)). The results of the repeated measures ANOVA demonstrated these differences were significant ($F_{3,12} = 25.39$, $P < .001$).

Measurement of muscle thickness change utilizing RUSI is a valid and potentially useful method to measure activation of the LM muscle in a narrow range (19–34% of MVIC) in an asymptomatic population.

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1. Introduction

Lumbar paraspinal musculature plays a key role in providing stability during dynamic tasks (Cholewicki and McGill, 1996). Of particular interest in the literature of late has been study of the lumbar multifidus (LM) muscle. Several abnormal characteristics have been identified in the LM in low back pain subjects. Structural abnormalities include histological changes, where fatty infiltrates replace LM muscle tissue (Weber et al., 1997; Zhao et al., 2000; Yoshihara et al., 2003), and atrophy (Kader et al., 2000; Hides et al., 2001). Motor control deficits including altered recruitment patterns (Hodges and Richardson, 1997; Danneels et al., 2002) as well as endurance deficits (Biedermann et al., 1991) have also been reported.

Quantification of multifidus activation in those with low back pain may be helpful in determining effective...
intervention. The gold standard measurement tool used to assess muscle activation is electromyography (EMG). EMG measures the electrical activity in the muscle and can be interpreted to represent muscle activation. To ensure a reliable signal is obtained from the multifidus, an indwelling electrode should be used (Stokes et al., 2003). RUSI offers a noninvasive method to measure muscle activation (Hodges et al., 2003; McMeeken et al., 2004) and has gained popularity in various aspects of low back pain rehabilitation (Hides et al., 1992, 1996, 1998, 2001; Critchley, 2002; Bunce et al., 2004). “RUSI is a procedure used by physical therapists to evaluate muscle and related soft tissue morphology and function during exercise and physical tasks. RUSI is used to assist in the application of therapeutic interventions aimed at improving neuromuscular function. This includes providing feedback to the patient and physical therapist to improve clinical outcomes. Additionally, RUSI is used in basic, applied, and clinical rehabilitative research to inform clinical practice. Currently, the international community is developing education and safety guidelines in accordance with World Federation for Ultrasound in Medicine and Biology (WFUMB)” (Teyhen, 2006).

RUSI utilizing high-frequency sound waves to evaluate tissue properties such as thickness. Ultrasound examination is considered low risk. According to the safety committee of the European Committee for Medical Ultrasound (ECMUS), “Based on scientific evidence of ultrasonically induced biological effects to date, there is no reason to withhold scanning for any clinical application”.

It is known that muscle thickness changes when the muscle is activated (Hodges et al., 2003). The amount of thickness change that occurs with muscle activation can be quantified with the use of RUSI by comparing resting muscle thickness values to those obtained during muscle activation. Measurement of muscle thickness change compared to EMG activity has been performed on the gastrocnemius muscle (Maganaris et al., 1998), on the transverse abdominis (McMeeken et al., 2004) and on other trunk and peripheral muscles (Hodges et al., 2003). To our knowledge this type of study has not been performed on the LM. The purpose of this study is to determine the relationship between muscle thickness change, as measured by RUSI, and EMG activity of the LM muscle in normal subjects.

2. Methods

2.1. Subjects

Five healthy subjects, three of which were female (mean age = 28.0 years SD 5.6, mean height = 170.7 cm, SD 9.4, mean weight = 70.3 kg SD 15.9) volunteered for this study. Subjects were excluded if they had current or recent history (within 6 months) of LBP or hip pain, a history of lumbar/sacral surgery, congenital lumbar/sacral condition such as spondylolisthesis, or spina bifida, or boney pathology such as a fracture. All volunteering subjects signed an institutional-review-board-approved consent form following verbal instructions of the procedure.

2.2. Procedures

Subjects were positioned in prone on a standard plinth. An inclinometer was placed longitudinally over the lumbo/sacral junction and pillows were used to flatten the lumbar curve to less than 10°. Subjects were then oriented to and practiced the maximum voluntary isometric contraction (MVIC) procedure which was performed with the elbows flexed to approximately 90° and shoulders abducted to approximately 120°. Subjects then lifted their head, trunk, and upper extremities and held with maximum effort against a load applied at the elbow by one of the researchers. The contralateral upper extremity lifting movement, used to activate the multifidus, was then practiced. It consisted of the upper extremity lift with four levels of graded resistance as described below.

To study the multifidus muscle, fine wire (California Fine Wire Company, Grover Beach, CA) electrodes were fabricated from pairs of nylon coated 50 μm wires which were inserted into a 27 ga hypodermic needle. Approximately 1–2 mm of coating was removed from the tip of the wire, the tips were bent back at 2–3 and 3–4 mm, respectively, and the needle and wires were sterilized. The L4 spinous process was identified, and the needle was inserted just lateral to the spinous process to the depth of the lamina, then withdrawn, leaving the electrode in the deepest portion of the LM muscle. A surface ground electrode was placed over the subject’s lateral malleolus.

The ultrasound images were generated at 25 Hz utilizing computerized ultrasonography (Sonosite 180plus, Sonosite Inc, Seattle, WA). The primary investigator operated the ultrasound unit and did all the scanning for this study. A 70 mm 5-MHz curvilinear transducer was placed longitudinally along the spine with the mid-point over the L4 spinous process. It was moved laterally and angled slightly medially until the L4/5 zygapophyseal joint could be identified (Richardson et al., 1999) (Fig. 1). This scan point is directly over the LM multifidus and a measurement from this landmark to the plane between the muscle and subcutaneous tissue was used for the linear measurement of the LM (Richardson et al., 1999) at rest (Fig. 2a) and during activation (Fig. 2b). An on-screen caliper was used to obtain the resting measurement (Fig. 2a and b), captured simultaneously with resting EMG data. The reliability of capturing LM images and
measuring them on the screen was established in a pilot study of eight asymptomatic subjects (ICC$_{3,1} = .85$). Subsequent images taken during the arm lifting tasks were saved and printed for off-screen manual measurement. The reliability of the manual measurement was calculated by having a second researcher, blinded to the grade of activation, measure the muscle thickness. This represents reliability of measuring the same image between raters and was found to be excellent (ICC$_{3,1} = .95$). The muscle thickness measurements obtained during each task were normalized to the resting measurement and the percent change from rest was calculated (Activity─Rest/Rest × 100). This percentage change in muscle thickness from rest to activation represented muscle activation as measured by RUSI.

The MVIC data were collected as the subject performed the maximum upper extremity and trunk lift as described above. Two trials of 5 s each were performed and the greatest root mean square (RMS) peak amplitude was used to normalize the EMG activity. Normalization provides a standard reference of electrical activity and all data are reported as a percentage of the MVIC (Bamman et al., 1997).

The contralateral arm lifting tasks were performed in the same plane as the MVIC’s. The subjects were instructed to lift their extremity straight up off of the table approximately 5 cm and hold for approximately 8 s which allowed enough time to capture two images of the contracted LM muscle. Two trials each of the four levels of increasingly demanding upper extremity lifting tasks were performed while EMG data and the images were obtained simultaneously. The first level (no load) had resistance of only the limb; the next three levels (low, medium, and high load) had graded resistance based on the subject’s body weight (Table 1). The average of the two trials for each task was used for

**Table 1**
Graded resistance levels for upper extremity lifting tasks in kilograms

<table>
<thead>
<tr>
<th>Subject mass (kg)</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
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<tbody>
<tr>
<td>&lt;68.2</td>
<td>.45</td>
<td>.68</td>
<td>.90</td>
</tr>
<tr>
<td>68.2–79.5</td>
<td>.45</td>
<td>.68</td>
<td>1.14</td>
</tr>
<tr>
<td>79.5–90.9</td>
<td>.45</td>
<td>.90</td>
<td>1.14</td>
</tr>
<tr>
<td>&gt;90.9</td>
<td>.45</td>
<td>.90</td>
<td>1.36</td>
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<tr>
<th>Table 2</th>
<th>Mean and standard deviation values for the lumbar multifidus muscle during rest and each of the lifting task conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic</td>
<td>Rest</td>
</tr>
<tr>
<td>Mean</td>
<td>2.48</td>
</tr>
<tr>
<td>SD</td>
<td>.19</td>
</tr>
<tr>
<td>EMG Mean</td>
<td>na</td>
</tr>
<tr>
<td>SD</td>
<td>na</td>
</tr>
</tbody>
</table>

Ultrasonic values are thickness measured in centimeters and EMG values are expressed as a percent of MVIC.
analysis. See Table 2 for mean ultrasound and EMG data.

2.3. EMG analysis

The EMG data were sampled at 2000 Hz using the Biopac II Student Lab Pro (Biopac System, Inc. Santa Barbara, CA) amplified 1000 x and filtered at 30–500 Hz. The Biopac has a signal-to-noise ratio of >90 dB and an input impedance of 1.0 MΩ. The data were saved and imported to a PC for analysis with Datapac software (Run Technologies, Mission Viejo, CA). RMS peak amplitudes were calculated for each .5 s period. Data from the middle three seconds of each trial was averaged and expressed as a percent of MVIC. The average of the two trials for each task was used for analysis.

2.4. Statistical analysis

To determine if a correlation exists between the EMG and RUSI data points, a Pearson’s correlation coefficient was calculated.

To determine if the individual tasks adequately increased muscle activation, a repeated measures analysis of variance with a Bonferroni post hoc analysis (α level .05) was performed on the EMG data.

3. Results

The results of the Pearson’s product moment correlation coefficients revealed that LM muscle thickness change as measured by RUSI correlated highly ($r = .79$, $P < .001$) with LM EMG activity (Fig. 3).

The repeated measures ANOVA for the EMG data demonstrated that the tasks studied were significantly different from each other ($F_{3,12} = 25.39$, $P < .001$). Post hoc analysis revealed significant differences between the no-load and medium and high load tasks and between low load and high load tasks.

4. Discussion

Our main finding was that a high correlation exists between EMG activity and thickness change in the LM muscle during typical contractions. This adds to the limited body of knowledge related to the use of RUSI as a measurement tool for muscle activation. We demonstrated a linear relationship between thickness change in the LM muscle and EMG activity during the graded contralateral upper extremity lifting tasks. Previous research assessing the relationship between muscle thickness change and EMG activity in the transverses abdominis muscle utilized volitional activation matched to percent of MVIC (Hodges et al., 2003; McMeeken et al., 2004) through a large range of activation levels. The tasks we chose produced average activation from 19% to 34% of MVIC, a narrow range. Analysis of variance showed a significant difference between tasks, with post hoc testing demonstrating a difference between no-load and medium and high load tasks and between low load and high load. Although not statistically significant, the difference between the no load and low task was 5%, which is consistent with increases between levels of activation in previously cited studies of the transverse abdominis. Isolated volitional activation of the LM is discussed in the literature (Hides et al., 1996), studying subjects trained to perform this activity may be a method for future research to study a broader range of activation levels.

Direct comparison of our EMG results is not possible as we did not locate earlier studies that isolated EMG activity of the multifidus during contralateral limb movement in the prone position. Arokoski et al. in two separate papers (Arokoski et al., 1999, 2001) studied a variety of stabilization exercises and reported an average 41% MVIC for the LM during a standing, alternating shoulder flexion movement with an average load of 1.5 kg. Our average load across each task was .8 kg, which produces an average output of 28% of MVIC. Despite these methodological differences, research to measure multifidus activity during various lumbar stabilization exercises, involving loaded limb movements, has shown somewhat similar activation levels to our study.

Previous studies measuring thickness change and EMG activity of other muscles have reported conflicting results. Hodges et al. (2003) compared EMG activity to architectural change measured by RUSI in several
muscles across a broad range of activation levels. This study measured thickness change and EMG activity of the tibialis anterior, biceps brachii, brachialis, internal oblique and transverse abdominis and reported a curvilinear relationship where RUSI could detect changes at low levels of contraction (up to approximately 20% of MVIC) and higher levels of contraction produce little further thickness change. McMeeken et al. (2004) measured the transverse abdominis during abdominal hollowing from 5% to 80% of MVIC and demonstrated a linear relationship between thickness change and EMG activity across all levels of activation measured.

Our methods differed somewhat from similar research in that we did not match a volitional contraction to a set level of activation; rather we chose tasks thought to activate the LM at progressively greater levels. This resulted in measurement in a narrow range of muscle activation and is a limitation of our study. We cannot assume a linear relationship exists across the entire range of muscle activation as we tested a narrow range. We demonstrated RUSI can detect changes in LM EMG activity from and average of 19% of MVIC (no load) to of 34% of MVIC (high load).

Further research is needed to determine if RUSI is a valid measure of LM activation across a greater range of activation levels, and in those with low back pain. If RUSI can be validated as a noninvasive measurement of LM muscular activity in the low back pain population, this may be useful for clinicians who use therapeutic exercise as an intervention in this population. RUSI could be used to measure potential LM activation impairment and how various interventions effect the impairment.

5. Conclusion

These results provide preliminary data on the potential use of RUSI in the measurement of LM muscle activation. The measurement of muscle thickness change utilizing RUSI is valid noninvasive method to measure activation of the LM muscle as it is highly correlated with EMG in a limited range (19–34% of MVIC) in an asymptomatic population.

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References


