Lumbar Muscle Activity During Common Lifts: A Preliminary Study Using Magnetic Resonance Imaging

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The purpose of this preliminary study was to assess lumbar multifidus, erector spinae, and quadratus lumborum muscle activity during lifts as measured by changes in transverse relaxation time (T2) from magnetic resonance imaging (MRI). Thirteen healthy adults performed dynamic squat, stoop, and asymmetric stoop lifts at a standard load, with each lift followed by MRI. Increase in T2 for the multifidus and erector spinae was greater for the stoop than squat. No difference in T2 increase was noted between the multifidus and erector spinae for the squat or stoop. Increase in T2 for the contralateral multifidus was less for the asymmetric stoop than stoop. Future research using MRI and other biomechanical techniques is needed to fully characterize lumbar muscle activity during lifts for various populations, settings, postures, and loads.

Keywords: biomechanics, exercise, MRI, muscle, spine

The etiology and physical mechanisms of low back pain are not fully characterized, and conflicting evidence exists regarding the relationship between lifting and low back pain. Some researchers have found that activities involving lifting, bending, and twisting are strongly associated with low back injury in occupational settings, whereas others have noted that lifting is not likely an independent cause of occupational low back pain. A variety of lifting strategies are used in materials handling, and many studies have assessed the biomechanical properties of the spinal joints and muscles during lifts. However, the specific activity patterns of the lumbar muscles during lifts remain unclear.

Traditionally, skeletal muscle activity is assessed with electromyography (EMG). Although surface EMG has technical limitations and needle EMG is invasive, preliminary studies with EMG have provided some insight about lumbar muscle activity during lifts. For example, Dolan and colleagues reported that squat lifting increases the lumbar extensor moment and decreases bending torque compared with stoop lifting. Hart and colleagues found that the lumbar extensors are more active during lifts in a lordotic posture than in a flexed posture. Zetterberg and colleagues and Jonsson observed different levels of myoelectric activity between lumbar multifidus and erector spinae muscles during submaximal isometric contractions involving lateral flexion and axial rotation.

Muscle functional magnetic resonance imaging (MRI) is a noninvasive procedure that can be used as an alternative to EMG for studying skeletal muscle activity. Resistance-type exercise is associated with increases in skeletal muscle proton transverse relaxation time (T2), which can be detected on MR images during and immediately after exercise. This exercise-induced T2 increase has demonstrated good reliability, and is strongly and linearly related to the level of muscle activity across a wide range of exercise intensities.

Muscle functional MRI has been used to assess lumbar muscle activity patterns following exercise in healthy individuals, patients with chronic low back pain, and individuals with experimentally induced acute low back pain. Dickx and colleagues established that muscle functional MRI is a valid method to quantify lumbar muscle activity and can be used independently for this purpose. This research demonstrated that surface EMG measurements during exercise and T2 changes noted on muscle functional MRI immediately after...
exercise are highly correlated for the lumbar multifidus ($R^2 = .97$) and erector spinae ($R^2 = .89$).\textsuperscript{17}

Despite its use elsewhere, muscle functional MRI has not been used to assess lumbar muscle activity during common lifts. The purpose of this preliminary study was to assess changes in activity of the lumbar multifidus, erector spinae (longissimus thoracis, iliocostalis lumborum), and quadratus lumborum muscles during squat, stoop, and asymmetric stoop lifts as assessed by T2 changes observed on muscle functional MRI. We tested the hypothesis that lumbar muscle T2 increase is dependent on both the type of lift performed and the specific muscle group observed within each lift. This knowledge will help to inform researchers and clinicians about the specific activity patterns of the lumbar muscles during three lifts, which will provide a framework for future research and broader clinical applications with asymptomatic and clinical populations in other settings.

**Methods**

**Study Design**

An observational study of repeated lumbar spine MRI was conducted at a university-based research laboratory to assess T2 changes of the lumbar multifidus, erector spinae (longissimus thoracis, iliocostalis lumborum), and quadratus lumborum muscles at rest, and following squat, stoop, and the asymmetric stoop lifts with standardized external loads. These muscle groups were selected because of their importance in lifting mechanics, involvement in maintaining structural integrity of the lower trunk, and relationship to low back pain.\textsuperscript{21,22} These lifts were selected because of their perceived common use, to standardize the lifting approaches, for comparison with other studies, and their applicability to the revised lifting equation of the US National Institute for Occupational Safety and Health (NIOSH).\textsuperscript{23}

**Participants**

Thirteen adults in good general health and without low back pain participated in the study (Table 1). Given the low variability of T2,\textsuperscript{24,25} a sample size of 13 was deemed to be adequate to detect a 1.0 ms mean difference in T2 increase among the various lifts and muscles, assuming a standard deviation for T2 increase of 0.6, at a power of 0.80, $\alpha = .05$, and two-tailed test.

Participants were recruited by word of mouth from a university setting and provided written informed consent before participation. The sponsoring universities’ institutional review boards approved the experimental protocol. Based on preenrollment screening conducted by the investigators, candidates were excluded from participation for any of the following reasons: (1) history of low back pain or spinal pathology (for example, neurological disorders, arthritis, neoplasm, or collagen disease involving the lumbosacral area), systemic disease (for example, cardiovascular, renal, hepatic, neurological, endocrine, or psychological disorders), alcohol or drug abuse; (2) cardiovascular or orthopedic contraindications to resistance exercise; (3) resting systolic blood pressure outside of 90–140 mm Hg; (4) resting diastolic blood pressure outside of 60–90 mm Hg; (5) females who were pregnant; and (6) current use of a pacemaker or other implanted metallic devices.

**Determination of Upper Body Mass, Trunk Extension Strength, and Lift Load**

**Upper Body Mass.** Immediately following screening procedures, upper body mass and trunk extension strength were assessed in qualified participants using a bedside digital scale (Acme, San Leandro, California, USA) and a variable angle Roman chair (VARC; BackStrong International LLC, Brea, California, USA). To quantify the load during dynamic trunk extension exercises that rely on upper body mass for all or part of its load, upper body mass must be considered. To measure upper body mass, each participant was positioned prone on the VARC with the upper body resting on the bedside scale in a horizontal position. This procedure was conducted three times and the mean of the three values was used to represent upper body mass.

**Trunk Strength.** To determine trunk extension strength (maximum voluntary isometric contraction—MVIC), the participant was fitted with a nylon torso harness and metal chain, and placed on the VARC. The proper fit of the harness and chain was such that the participant’s torso was parallel to the ground (ie, 0° of lumbar flexion) during the MVIC test. Next, the participant crossed the hands on the opposite shoulders and performed the MVIC for four seconds by using the trunk extensors to pull on the chain while exhaling and keeping the pelvis on the pelvic pad of the VARC. To ensure maximum

| Table 1 | Participant characteristics, total trunk extension strength, and external load for lifts |

<table>
<thead>
<tr>
<th>Sex</th>
<th>n</th>
<th>Age (y) Mean SD</th>
<th>Height (cm) Mean SD</th>
<th>Total Body Mass (kg) Mean SD</th>
<th>Upper Body Mass (kg) Mean SD</th>
<th>Total Trunk Extension Strength (kg) Mean SD</th>
<th>External Load (kg) Mean SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>6</td>
<td>22.0 5.1</td>
<td>167.2 6.6</td>
<td>60.7 6.6</td>
<td>26.3 4.7</td>
<td>693.6 151.9</td>
<td>9.1 3.2</td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>23.6 5.2</td>
<td>176.1 5.2</td>
<td>72.4 7.9</td>
<td>34.4 4.9</td>
<td>983.1 76.8</td>
<td>15.8 2.7</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>22.8 5.0</td>
<td>172.0 7.3</td>
<td>67.0 9.3</td>
<td>30.6 6.2</td>
<td>849.5 187.4</td>
<td>12.7 4.5</td>
</tr>
</tbody>
</table>
effort, the participant performed a minimum of three trials with a three-minute recovery between trials until a plateau in performance was achieved. The trial that generated the highest score was considered MVIC. The protocols used for measuring upper body mass and trunk extension MVIC has been previously described and found to be reliable (intraexaminer test-retest reliability, $R^2 = .98$ upper body mass; $R^2 = .94$ trunk extension MVIC).26

**Lift Load.** During all dynamic lifting exercises for each participant, exercise intensity (lift load) was standardized at 50% total trunk extension strength (Table 1). The following equation was used to determine total trunk extension strength (TTES): $TTES$ (kg) = Upper Body Mass (kg) + Mass of Harness and Chain (0.7 kg) + MVIC (kg).26 The following equation was used to determine the external load (crate and metal plates) for the lifting exercises: External Load (kg) = (TTES (kg) × 0.50) – Upper Body Mass (kg). A submaximal load of 50% TTES was arbitrarily selected, yet ensured that the total weight lifted for all participants did not exceed the recommended weight limit suggested by NIOSH for asymmetric stoop lifts.23

**Lifting Exercises**

On a separate day within seven days after trunk extension strength testing, the participant performed three series of dynamic lifts (squat, stoop, and asymmetric stoop) with a small crate (0.5 m × 0.5 m × 0.5 m; Figure 1). The squat lift involved bending the knees to lift a crate that was placed directly in front of the participant and centered between the feet. The stoop lift involved keeping the knees straight and bending at the waist to lift a crate that was placed directly in front of the participant and centered between the feet. The asymmetric stoop lift was similar to the stoop lift, except that the crate was shifted to the left. In addition, the crate was rotated 90 degrees so that its handles faced anterior and posterior instead of right and left as in the squat and stoop lifts.

To begin each lift, the participant positioned the feet at shoulder width and grasped the handles on the crate (handles were approximately 0.5 m from the floor). Next, the participant lifted the crate in a smooth, controlled fashion using primarily the lower trunk and lower extremity muscles to elicit movement. When the hip/trunk and knees were fully straightened ($0^\circ$ hip/trunk flexion and $0^\circ$ knee flexion) and the crate was lifted to waist level in the midsagittal plane ($0^\circ$ torso rotation and $0^\circ$ lateral flexion), the participant slowly lowered the crate to its original starting position on the floor. For each lift, the participant was instructed to use the arms as little as possible, maintain lumbar lordosis in a neutral position, exhale when lifting the crate, and inhale when lowering the crate. Each repetition was completed in four seconds, two seconds to lift the crate and two seconds to lower the crate. Proper form and lumbar posture was monitored visually by the investigator. Cadence of repetition speed was maintained with a stop watch. The participant performed three sets of ten repetitions for each series of lifts, with a one-minute rest period between each set. We chose multiple sets of exercise (compared with a single set) since we wished to achieve maximum T2 increase for a given lift, which may not have been possible with a single set of exercise. A standardized exercise protocol of three sets of ten repetitions has been previously used to study the activity of the cervical and lumbar muscles with muscle functional MRI and deemed appropriate.18,27

Before completing the lifts, the participant relaxed in a supine position for 30 minutes and then a resting MRI scan was obtained from the lumbar region. Immediately after the third set of the squat lift, MRI scans were obtained from the participant’s lumbar region. The average time span between the end of exercise and

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**Figure 1** — Illustration of the lifts from the left side—squat (left panel); stoop (center panel); asymmetric stoop (right panel).
the beginning of the scanning procedure was approximately one minute, forty-five seconds. Following the scan, the participant rested in a supine position with the lumbar spine in a neutral posture for 50 minutes. After the 50-minute rest, the participant performed a series of stoop lifts, followed by MRI scans, and another 50-minute rest period. Finally, the participant performed a series of asymmetric stoop lifts followed by MRI scans. Approximately 60 minutes elapsed between each series of lifting exercises and, therefore, approximately 60 minutes elapsed between each MRI scan. A minimum of 95% recovery of muscle T2 is expected in 60 minutes. The order of execution for the lifts was the same for all participants—the squat was performed first, followed by the stoop, and finally, the asymmetric stoop.

Magnetic Resonance Imaging Procedures

A 1.5 Tesla superconducting magnet (Siemens Corporation, New York, NY, USA) was used to obtain the muscle functional MRI scans. The participant was placed in the magnet bore in a supine position with the legs fully extended and the lumbar spine in a neutral alignment. First, a sagittal localizing sequence was performed to identify lumbar disc space intervals. The midpoint of the L3-L4 interspace was used as a reference in establishing the orientation of the slices for transaxial imaging. Ten 5 mm thick transaxial slices, with a 0.25 mm space between each slice, were identified with five slices above and five slices below the L3-L4 interspace. Thus, imaging slices spanned from approximately the upper part of the L3 vertebral body to the lower part of the L4 vertebral body. Next, T2-weighted images were obtained using the following imaging sequence as previously described: 2,000 ms repetition time (TR); 30 ms and 65 ms echo times (TE); 256 × 256 matrix; one excitation; 180 cm field of view; six minutes, 27 seconds total scan time. The imaging procedures used for the three postexercise scans were identical to the procedures used for the resting scan.

Image Analysis

After scanning procedures, muscle T2 was calculated from the MR images using Image J, a Java-based, public domain software (US National Institutes of Health, Bethesda, Maryland, USA). Muscle T2 (ms) was calculated for each pixel on the two images obtained from the two echo times by the formula: $T2 = \frac{(t_a - t_b)}{\ln (i_a/i_b)}$, where $t_a$ and $t_b$ are the spin echo times and $i_a$ and $i_b$ are signal intensity levels. The variability associated with the calculation of muscle T2 is low with standard deviations of less than 5% of the mean. A third image (ie, T2 image) was derived from these T2 values and was used for further analyses. Next, regions of interest were identified on the derived T2 images for each of the ten slices that defined the borders of each muscle in question (ie, from medial to lateral: multifidus, longissimus thoracis, iliocostalis lumborum, quadratus lumborum). Nonmuscular tissue, such as fat, fascia, and vessels, was avoided when defining a region of interest. For both large and small muscles, the test-retest reliability for identifying the same region of interest on a given MR image is high ($R^2 = .97$ and .91, respectively). Next, a mean T2 value was calculated for each region of interest (Figure 2). The average T2 value for the ten transaxial slices was calculated and used for further analyses. Scanning and image analysis procedures have been previously described.

Data Analysis

Means and standard deviations were calculated for participant demographic data, peak strength, and exercise loads. Means, standard deviations and 95% confidence intervals were calculated for T2 raw values and T2 increase values (T2 Increase = Lift T2 Raw – Rest T2 Raw) for each muscle (Table 2). To evaluate muscle T2 response to the various lifts, T2 increase data were analyzed using repeated measures analysis of variance (ANOVA). Factors for T2 increase were lift type (squat, stoop, asymmetric stoop), muscle (multifidus, longissimus thoracis, iliocostalis lumborum, quadratus lumborum), and side of body (right, left). If sphericity assumptions were violated

![Figure 2](image-url)
according to the Mauchly’s test, then Huynh-Feldt corrected $P$ values were reported. Statistical significance was accepted at the .05 alpha level. As applicable, post hoc, pairwise comparisons were made using dependent $t$ tests and Bonferroni adjustments to correct for inflation of alpha levels for multiple comparisons. SPSS version 18.0 software (SPSS Inc., Chicago, Illinois, USA) was used for data analysis.

## Results

Lumbar muscle T2 increase varied depending on both the type of lift performed and the specific muscle group observed during each lift (Table 2). From the repeated-measures ANOVA for T2 increase, significant main effects and interactions were noted for lift type ($df = 2.000, F = 23.257, P = .0001$), muscle ($df = 2.293, F = 14.295, P = .0001$), lift type × muscle ($df = 3.902, F = 6.110, P = .001$), lift type × side ($df = 2.000, F = 6.804, P = .0001$), and lift type × muscle × side ($df = 4.109, F = 6.445, P = .0001$). No significant effects were noted for side ($df = 1.000, F = 0.001, P = .972$) and muscle × side ($df = 1.802, F = 1.904, P = .176$). Results of relevant post hoc, pairwise comparisons for T2 increase are highlighted below.

Among the three lifts, the stoop lift generally resulted in the highest level of T2 increase in the lumbar muscles. For all muscles except the right quadratus lumborum, T2 increase was significantly greater for the stoop than the squat. For all muscles except the left and right quadratus lumborum and the left iliocostalis lumborum, T2 increase was significantly greater for the asymmetric stoop than the squat. For the left (contralateral) multifidus, T2 increase was significantly greater for the stoop than the asymmetric stoop. No difference in T2 increase between the stoop and asymmetric stoop was noted for any other muscle.

Among the three muscles groups, the multifidus and erector spinae muscles displayed a similar level of T2 increase during lifts, and these muscles generally displayed a larger T2 increase than the quadratus lumborum. For the squat, T2 increase was significantly greater for the left erector spinae than the left quadratus lumborum, while there were no significant differences among any other muscles for the right and left sides. For the stoop and asymmetric stoop, T2 increase was significantly greater for multifidus and erector spinae than the quadratus lumborum.

### Table 2 Muscle T2 raw values at rest by muscle group and side of body, and muscle T2 increase values by lift type, muscle group, and side of body

<table>
<thead>
<tr>
<th>Muscle</th>
<th>T2 Raw at Rest (ms)</th>
<th>T2 Increase (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Multifidus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>29.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Right</td>
<td>27.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Longissimus Thoracis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>30.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Right</td>
<td>27.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Iliocostalis Lumborum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>30.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Right</td>
<td>28.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Quadratus Lumborum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>32.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Right</td>
<td>29.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*Note. CI = confidence interval; T2 Increase = T2 Raw during lift – T2 Raw at rest.*
lumborum for the right and left sides, while there were no significant differences among the multifidus and erector spinae for the right and left sides.

Discussion

To our knowledge, this is the first study that used muscle functional MRI to study activity of the lumbar multifidus, erector spinae, and quadratus lumborum muscles during common lifts. Previous investigations using MRI confirmed that lumbar muscle activity (as assessed by T2 increase) during prone trunk extension exercises is dependent on exercise intensity. The current study demonstrated that lumbar muscle activity is also affected by the type of lift performed.

The current study discovered that the lumbar multifidus and erector spinae muscles were more active during the stoop lift than the squat lift when performed at a submaximal exercise intensity. Since the squat lift involves knee extension, the quadriceps muscles likely contribute to force production during the lift. However, during the stoop lift, the force contribution of the quadriceps muscles is assumed to be much less because knee extension is not a component of the lift. Consequently, during the stoop lift, additional load was likely placed on the lumbar muscles to complete the lift. Longitudinal experimental studies are needed to compare the safety of these lifts relevant to the loading characteristics on the lumbar muscles and the incidence of back injury.

The current study also found no difference in activity between the lumbar multifidus and erector spinae during any of the three lifts. On the contrary, two previous studies reported greater activity in the multifidus compared with the erector spinae during prone trunk extension exercise performed on a Roman chair. Differences in findings among the studies may be related to different biomechanical strategies required to lift loads while standing without any external pelvic stabilization (eg, stoop lift) compared with the prone position with the pelvis partially stabilized (eg, Roman chair exercise).

Perhaps the most significant finding of the current study is that activity for the contralateral (opposite side of body from which the load is moving toward) lumbar multifidus muscle was lower during the asymmetric stoop than during the stoop. To our knowledge, the relatively lower activity of the contralateral lumbar multifidus during asymmetric movements has not been previously reported. In contrast to the current study’s finding, other investigators have reported increased myoelectric activity of the contralateral lumbar multifidus during isometric and dynamic trunk rotation. The differences in findings among the studies are possibly associated with differences in the mechanics of the exercises performed. In the current study, the asymmetric stoop lift was a complex 3-dimensional exercise involving dynamic hip extension and lumbar lateral flexion, rotation, and extension. In the previous studies, the movements solely consisted of spinal rotation.

The side-to-side imbalance in activity of the lumbar multifidus during the asymmetric stoop lift provides additional evidence from a muscular perspective about the potentially unsafe nature of asymmetric lifts. Nonsagittal and asymmetric lifts have been considered unsafe movements for the lumbar spine and risk factors for low back pain. Since the multifidus provides intersegmental stability of the spine, lower activity on one side of the lumbar multifidus during asymmetric lifts may result in a greater level of instability and increase the torsional forces on the lumbar discs and other spinal structures. This potential instability, combined with evidence that the lumbar bending torque is increased by 30% during asymmetric lifts, may leave the delicate spinal structures, such as intervertebral discs, facets, and intersegmental ligaments, unguarded and prone to injury.

A limitation of the current study is that the findings are only generalizable to those without a history of low back pain, during three standardized lifts, at a single submaximal load. Another possible limitation of the current study is that the lifting exercises were performed in a fixed, sequential order versus a random or balanced order. Previously reported T2 decay rates of at least 95% decay in 60 minutes for other skeletal muscles may not be applicable to the lumbar muscles. Therefore, because of the fixed order design of the current study, residual T2 changes following a given lift may have impacted T2 increases during subsequent lifts. Furthermore, muscle fatigue resulting from previous exercise bouts may have impacted performance on subsequent exercise bouts. Nevertheless, we assumed that a fixed, sequential order progressing from the hypothesized lowest to highest exercise intensities for the assessed lumbar muscles was less likely than a balanced or random order to result in residual T2 increases or muscle fatigue on subsequent exercise bouts.

This preliminary study demonstrated that muscle functional MRI is useful for assessment of lumbar muscle activity during dynamic lifts. Muscle functional MRI can be used for research purposes in conjunction with and to complement other assessment techniques to provide additional information about the biomechanical characteristics of lifting tasks and similar activities. Future studies that collect kinetic and kinematic data, ideally in conjunction with MRI data, may help elucidate why the specific T2 increases are observed in the lumbar muscles during lifts.

Data from this study provide a framework for future research with asymptomatic and clinical populations in other settings. To gain a more complete understanding of lumbar muscle activity during lifts, research is needed to compare individuals with and without low back pain. Moreover, research is needed to assess lumbar muscle activity when lifts are performed with preferred styles in natural environments. Future studies should also be conducted to assess lumbar muscle activity and its relationship to other biomechanical factors during a variety of other lifts, postures, trunk movements, and exercises, across a wide range of intensities.
Practical applications of this study’s findings ultimately depend on the results of confirmatory research. Assuming positive results of confirmatory research, these findings may be useful for clinicians when educating individuals without low back pain on proper lifting strategies. For example, asymmetric lifting tasks with external loads should be avoided. If a goal is to maximize lumbar muscle activity during lifts, then the stoop is preferred over the squat. On the other hand, if a goal is to minimize lumbar muscle activity during lifts, then the squat is preferred over the stoop.

In summary, this preliminary study found that magnetic resonance imaging assessment is useful to characterize lumbar muscle activity during common lifts. For healthy individuals without low back pain performing lifts at a submaximal exercise intensity, activity of the lumbar multifidus and erector spinae muscles is greater during the stoop lift compared with the squat lift. The contralateral lumbar multifidus muscle is de-activated during the asymmetric stoop lift compared with the stoop lift. Additional research is needed with a variety of populations, lift types, loads, and settings to fully characterize lumbar muscle activity during lifts.

References