Impact of surgical approaches on the lumbar multifidus muscle: an experimental study using sheep as models

Laboratory investigation

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Object. In this paper, the authors assessed the effects of different surgical approaches and reconstructive methods on the spinous process after lumbar surgery in sheep.

Methods. A total of 41 healthy, adult sheep weighing 38–40 kg were used in this study. The animals were randomly divided into 4 groups (10 animals per group and 1 control). Animals in Group A underwent a spinous process–splitting procedure to expose the lamina. Animals in Group B had bilateral multifidus muscles stripped and the spinous process excised. All animals in Group C underwent unilateral stripping of the multifidus muscle from the spinous process (Group C1) as well as spinous process splitting at the bottom to expose the contralateral lamina attached to the multifidus muscle (Group C2). To mimic the laminoplasty procedure, the multifidus muscles were stripped bilaterally in Group D. For all groups, the surgical level (L-6), length of incision (4 cm), the retracting distance, and time (40 minutes) remained constant. Ten months after surgery, the atrophy rate of the cross-sectional areas (CSAs) of the multifidus muscle, MR imaging findings, and histological changes of the muscle tissue were evaluated. Normal multifidus muscles taken from a healthy sheep at the L-6 level and the preoperative data of MR imaging in experimental animals provided control data (Group E).

Results. The MR imaging and histological scores of multifidus muscles from sheep in Groups A, B, C1, C2, and D were significantly decreased, and the atrophy rates were significantly higher than those from sheep in Group E (p < 0.05). The postoperative MR imaging and histological scores obtained in Groups A and C2 were highest and the atrophy rates were lowest, while animals from Group B had the highest atrophy rate and lowest MR imaging and histological scores among all experimental groups (p < 0.05). The scores for animals in Groups A and C2, in which the muscles were not stripped from the spinous process, achieved lower atrophy rates and higher MR imaging and histological scores than those for sheep in Groups C1 and D, in which the muscles were stripped (p < 0.05). The groups in which the spinous process was reconstructed after detachment of the muscles (Groups C1 and D) had lower atrophy rates and higher MR imaging and histological scores than Group B (p < 0.05).

Conclusions. The multifidus muscle can be effectively protected by reducing the extent of muscle detachment and reconstructing the posterior bone-ligament complex. A spinous process–splitting procedure is a useful method to reduce postoperative muscle atrophy. (DOI: 10.3171/2009.11.SPINE09174)

Key Words • lumbar spine • multifidus muscle • preservation • approach • experimental study

Abbreviations used in this paper: CSA = cross-sectional area; LSPSL = lumbar spinous process–splitting laminectomy.

* Xinyu Liu and Yanguo Wang contributed equally to this study.

This article contains some figures that are displayed in color online but in black and white in the print edition.
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due to the long duration of muscle retraction, extensive muscle stripping, and damage to the dorsal rami of the posterior branches.4–8,10,12 Many factors, such as retraction pressure, surgical time, and extent of exposure, affect the degree of atrophy after posterior lumbar surgery. In a few other studies, researchers have measured the intramuscular pressure in the muscle that was retracted, and these studies have indicated that the pressure increased, leading to decreased intramuscular blood flow.12 Kotil et al.9 reported that the muscle damage was much greater in patients whose incisions were short and in whom the retractors were never released during the surgery. They found that relaxing the retractor for short intervals decreased creatine phosphokinase levels, muscle necrosis rates, and low-back pain after lumbar discectomy. In a series of patients undergoing operations for lumbar stenosis with muscle retraction (surgical time longer than 80 minutes), reports have indicated that extensor muscle strength is only 50% of the normal strength 6 months after surgery.3

To reduce postoperative low-back pain caused by atrophy of paraspinous muscles, many modified procedures, such as the LSPSL,16 laminotomy or laminoplasty, spinous process osteotomies,7,18,19,22 and unilateral laminotomy for bilateral decompression13 have been reported in the literature. Since patient age and sex, duration of symptoms, preoperative diagnosis, affected segments, and surgical time differ among clinical reports, determining which method is most valuable for protecting paraspinous muscles remains in question. In this study, we performed an experiment in sheep to compare the effects of different approaches and reconstructive methods of the spinous process on the multifidus muscle after lumbar surgery. For this experiment, we chose to use the spines of adult sheep because of the close similarities to those of human spines.20,21

Considering all the indications that affect the degree of atrophy after posterior lumbar surgery, the current study maintained the same size and location of the incision, extent of muscle detachment, and duration of muscle retraction in all experimental animals to minimize the effects of these factors.

Methods

All animal experiments conformed to the regulations of the institutional animal care and use committee of Qilu Hospital of Shandong University, Jinan, China.

Forty-one healthy adult sheep, weighing 38–40 kg (mean 39.2 kg), were used in this study. The L-6 level of adult sheep, similar to the L-5 level in humans, was chosen as the surgical site. A local anesthetic agent (0.25% lidocaine) was administered. A 4-cm posterior midline incision was made based on the length of the L-6 spinous process. The muscles were retracted by the same self-retractors and at the same distance for 40 minutes. The MR imaging and histological changes of the muscle tissue were evaluated 10 months after surgery.

The animals were randomly divided into 4 groups (10 sheep per group and 1 control). The animals in Group A underwent a spinous process-splitting procedure, first described by Watanabe et al.16 to expose the lamina. Briefly, the L-6 spinous process, supraspinous, and interspinous ligaments were split longitudinally along a midline; the structure was then divided at its base from the L-6 lamina, leaving the bilateral paraspinous muscles attached to the lateral aspect of the split spinous process (Fig. 1A). The muscles attached to the L-6 lamina were dissected and retracted for 40 minutes, and subsequently, the spinous process and ligaments were sutured to reconstruct the posterior bone-ligament complex. For the animals in Group B, the multifidus muscles were stripped bilaterally, and the spinous process was excised. After retraction for 40 minutes, the incision was closed (Fig. 1B). The procedure for Group B was similar to the traditional approach used in posterior lumbar surgery.10 Similar to the procedure reported by Kim et al.,8 in all animals in Group C, the unilateral multifidus muscle was stripped (Group C1), and the spinous process was cut at the base to expose the contralateral lamina attached to the multifidus muscle (Fig. 1C). After 40-minute retraction, the incision was closed. In the animals in Group D, the bilateral multifidus muscles were stripped only from the spinous processes (Fig. 1D) to mimic laminoplasty or laminotomy procedures,5,15,19,22 and the incision was closed after 40-minute retraction. Normal multifidus muscles taken from a healthy sheep from L-6 (Fig. 2) and the preoperative MR imaging data obtained in experiment animals were used as the control group (Group E).

Assessment of the Multifidus Muscle Using MR Imaging

Magnetic resonance imaging (Signo EXCITE 3.0T, GE) examination of all animals occurred before and 10 months after surgery. The pre- and postoperative CSAs of the multifidus muscles on axial T1-weighted imaging (Fig. 3) were measured using imaging software (Adobe Photoshop 7.0), and the atrophy rate was calculated according to the following formula: atrophy rate = (preoperative minimal CSA − postoperative minimal CSA)/preoperative minimal CSA × 100%. The fibrosis and the fatty tissue infiltration of the bilateral multifidus on MR imaging (MR imaging scores) were also evaluated by 2 spinal surgeons (Juanaying Li and Long Jia). The grading scale (0–3 points) reported by Kang et al.6 was used in the study (Table 1). The measurements were made blind to the surgical approach used in the given animal, and blind to whether it was a pre- or postoperative image.

Histological Evaluation of the Multifidus Muscle

The sheep were killed 10 months after surgery, and the multifidus muscle from the surgical site was harvested for histological studies. The samples were fixed in 10% formalin, paraffin-embedded, and sectioned at a thickness of 50 μm. The sections were stained with H & E to allow observation of the histological changes of the multifidus. The histological changes were divided into 4 grades (Table 2). Two pathologists (X.W. and B.W.) performed the subjective assessment of pathological evaluation. The assessments were made to the surgical approach used in the given animal, and blind to whether the section had been obtained preoperatively (Group E) or postoperatively (Groups A–D).
Statistical Analysis

Statistical analysis was performed using SPSS 12.0 for windows (SPSS, Inc.). The CSAs and MR imaging and histological scores of bilateral multifidus muscles were measured or evaluated independently. In the event of statistical significance, the F-test was used, while the correlation analysis between parameters was evaluated by Pearson correlation coefficients. A p value < 0.05 was considered statistically significant.

Results

One sheep in Group B was excluded from the experiment because of a deep wound infection. The main pathological changes noted in the multifidus are the atrophy of muscle bundles, increase in interstices, and decrease in size and number of nuclei. Meanwhile, the changes noted on MR images were mainly the decrease in the CSA of the multifidus and infiltration by fibrosis and fatty tissues. The atrophy rate and MR imaging and histological scores are shown in Table 3. Figures 4–7 show the histological and MR imaging changes of the 4 groups.

The MR imaging and histological scores of multifi-
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The postoperative MR imaging and histological scores in animals in Groups A and C2 were highest and the atrophy rates were lowest; animals in Group B had the highest atrophy rate and lowest MR imaging and histological scores among all experimental groups (p < 0.05). The atrophy rate and postoperative MR imaging and histological scores between Groups A and C2 and Groups C1 and D were not statistically different (p > 0.05). The scores for Groups A and C2, in which the muscles were not stripped from the spinous process, achieved lower atrophy rates and higher MR imaging and histological scores than those from Groups C1 and D, which did have muscles stripped (p < 0.05). The groups (Groups C1 and D) in which the spinous process was reconstructed after muscle detachment had a lower atrophy rate and higher MR imaging and histological scores than Group B (p < 0.05). Tables 4 and 5 tabulate the results. The postoperative histological scores were positively correlated with MR imaging scores (p = 0.001), but they had no correlation with the atrophy rate of the multifidus (p = 0.059).

Discussion

The study’s results show significant atrophy of the multifidus muscle in all experimental groups. This result apparently indicates that no method can totally avoid postoperative atrophy of the multifidus. By excluding any possible factors that might affect the experiment’s results, we found that reducing the extent of stripping multifidus muscles from the spinous process and/or reconstructing the spinous process can in part preserve paraspinal muscles and prevent postoperative muscular atrophy.

The LSPSL procedure may be a useful way to protect the paraspinal muscles. In this study, animals in Group A achieved the highest scores based on MR imaging and histological evaluation and the lowest atrophy rate among all the experimental groups. Group A had only mild atrophy

<table>
<thead>
<tr>
<th>Grade</th>
<th>Pathological Changes</th>
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<tbody>
<tr>
<td>3 (normal)</td>
<td>no difference from preop image</td>
</tr>
<tr>
<td>2 (mild atrophy)</td>
<td>area of fibrosis &amp; fatty tissues &lt;10% of multifidus CSA</td>
</tr>
<tr>
<td>1 (medium atrophy)</td>
<td>area of fibrosis &amp; fatty tissues &lt;50% of multifidus CSA</td>
</tr>
<tr>
<td>0 (severe atrophy)</td>
<td>area of fibrosis &amp; fatty tissues &gt;50% of multifidus CSA</td>
</tr>
</tbody>
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**TABLE 2: Histological classification of the multifidus muscle**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>3 (normal)</td>
<td>no atrophy of muscle bundle w/ narrow spatium intermusculare, clear myofibrils, &amp; large nos. of nuclei around muscle fibers (see Fig. 2)</td>
</tr>
<tr>
<td>2 (mild atrophy)</td>
<td>muscle bundles have mild atrophy; no. of nuclei are almost normal, interstices increase slightly (see Fig. 4)</td>
</tr>
<tr>
<td>1 (medium atrophy)</td>
<td>muscle bundles become atrophied &amp; interstices markedly increase; size &amp; no. of nuclei markedly decrease (see Fig. 6)</td>
</tr>
<tr>
<td>0 (severe atrophy)</td>
<td>muscle fibers become thinner w/ waviness, interstices markedly increase w/ fatty infiltration; nuclei become pyknotic (see Fig. 5)</td>
</tr>
</tbody>
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**TABLE 3: Histological and MR imaging scores and atrophy rates of the CSA**

<table>
<thead>
<tr>
<th>Group</th>
<th>Histological Score</th>
<th>MRI Score</th>
<th>Atrophy Rate of CSA (%)</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>1.56 ± 0.23</td>
<td>2.00 ± 0.15</td>
<td>20.40 ± 1.80</td>
</tr>
<tr>
<td>B</td>
<td>0.50 ± 0.08</td>
<td>0.51 ± 0.07</td>
<td>47.71 ± 5.13</td>
</tr>
<tr>
<td>C1</td>
<td>0.80 ± 0.14</td>
<td>1.33 ± 0.37</td>
<td>41.33 ± 9.22</td>
</tr>
<tr>
<td>C2</td>
<td>1.44 ± 0.43</td>
<td>1.67 ± 0.21</td>
<td>28.52 ± 2.81</td>
</tr>
<tr>
<td>D</td>
<td>1.00 ± 0.16</td>
<td>1.50 ± 0.24</td>
<td>37.91 ± 3.66</td>
</tr>
<tr>
<td>E</td>
<td>3.00 ± 0.00</td>
<td>3.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
</tbody>
</table>

* Values are the means ± SDs.

![Fig. 4. Magnetic resonance image (upper) and photomicrograph (lower) showing mild atrophy (arrow) of bilateral multifidus muscle in Group A. The MR imaging and pathological scores are both 2 points.](image-url)
of the multifidus according to the MR imaging and histological evaluations, and the atrophy rate was only 20.4%. The muscle attachments to the spinous process and supra- and interspinous ligaments are preserved during the LSPSL procedure. Additionally, the medial branch of the dorsal ramus may be preserved as well due to decreased paraspinal muscle manipulation. Watanabe et al.\textsuperscript{16} first reported 2-year follow-up rates of LSPSL. In their study, the muscle atrophy rate was significantly lower in the LSPSL group than in the conventional laminectomy group. Kim et al.\textsuperscript{8} compared the effect of 3 approaches on the multifidus. Hemoglobin, C-reactive protein, and creatine phosphokinase levels on the first day after surgery and CT density 1 year later were chosen to evaluate the muscle injury. They found that LSPSL can effectively reduce the damage to paraspinal muscles postoperatively. However, the spinous process–splitting procedure may not provide as good exposure for certain lumbar spinal pathological processes as other techniques; this shortcoming limits the clinical use of this technique.

Studies of spinous process osteotomies, initially described by Yong-Hing and Kirkaldy-Willis\textsuperscript{22} and Weiner et al.\textsuperscript{18} reported prospective and follow-up results of this technique in patients with lumbar spinal stenosis. Apparently, this procedure can avoid the ipsilateral retraction, and interposition of the spinous process and supraspinous/ interspinous ligaments acts as a mechanical buffer to diminish and to broadly distribute retraction pressure felt by musculature.\textsuperscript{19} However, according to the current research, the histological and MR imaging assessments and atrophy rate of the multifidus of Group C1 were only similar to those in Group D, and they were worse than the scores in Groups C2 and A. This demonstrates that spinous process osteotomies can only protect unilateral muscles. Concurrently, the scores of Groups A and C2 were significantly better than those of Groups C1 and D. These findings indicated that the procedures that limit the extent of muscle stripping can be more successful in decreasing postoperative atrophy of multifidus muscles than only preserving spinous processes.

Laminoplasty and laminotomy have been reported to be useful in protecting paraspinal muscles after reconstruction of the lamina, spinous process, and supra- and interspinous ligaments.\textsuperscript{5,15} Although Group D had better results than Group B in the current study, the data indicate that laminoplasty has no advantage in protecting multifidus muscles over Groups A and C2 and, based on our findings, can also cause medium or even severe atrophy. Thus, laminoplasty or laminotomy may be more
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useful in avoiding postoperative epidural fibrosis than in protecting paraspinal muscles. Consistent with the literature, this study found that traditional laminectomy can cause severe postoperative atrophy of multifidus muscles (Fig. 5). Because laminectomy can destroy all posterior bones and ligaments, avoiding the procedure can in part preserve the paraspinal muscle and reduce postoperative low-back pain.

Some reports have assessed lumbar muscles with histology, ultrasonography, electromyography, CT and MR imaging, and creatine phosphokinase analysis of paraspinal muscles after posterior lumbar surgery. Histological observation should be the primary and preferred evaluation standard for muscle atrophy; however, muscle biopsy is an invasive investigation, and most studies of muscle histology have relied on specimens obtained during surgery. Kawaguchi et al. noted that muscle degeneration occurred immediately after surgery and that examination of the muscle tissue obtained in surgically treated patients revealed signs of denervation, severe histological changes, and early aging. The current study found that the most common histological changes of muscle are the atrophy of muscle bundle with different sizes, spatium intermusculare widening, pyknosis of the sarcoplasm, and decreases in the size and number of nuclei. The relationship between paraspinal muscle CSA and a history of low-back pain has been investigated, and it was determined that patients with a history of low-back pain have smaller paraspinal muscles than patients who had never experienced low-back pain. Measurements of the CSA and density of the muscles with CT scans and MR imaging are most commonly used in clinical studies. Since MR imaging can show a decrease in the size of the muscles and an increase in the amount of fat deposits, MR imaging was the preferred method for this research. It is interesting that the postoperative histological scores are positively correlated with MR imaging scores, but in this study, the histological scores had no correlation with the atrophy rate of the multifidus CSA. The reason may be that some animals had significant increases in fibrosis and fatty tissues in the multifidus muscle without obvious change in CSAs of multifidus muscles. Using CSA measurements cannot reflect the degree of muscle bulk due to fat and fibrous tissues. The results of this study are similar to those of Gille et al., which suggest that the assessment of trunk muscles should take into account the density of the muscle as well as its CSA.

**Conclusions**

According to our study, multifidus muscle function can be in part protected by reducing the extent of muscle detachment and reconstructing the posterior bone-ligament complex. The spinous process–splitting procedure is a useful method to decrease postoperative muscle atrophy. However, this issue warrants further study to be confirmed in humans.

**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.
References