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The Effect of Bilateral Laminotomy *Versus* Laminectomy on the Motion and Stiffness of the Human Lumbar Spine

A Biomechanical Comparison

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Study Design. A cadaveric simulation model of the lumbar spine was used to study the intervertebral motion characteristics of the lumbar spine after bilateral laminotomy and facet-sparing laminectomy.

Objective. To assess differences in motion patterns and lumbar spine stiffness after bilateral laminotomy *versus* laminectomy.

Summary of Background Data. Spondylolisthesis after facet-sparing laminectomy has been reported with a frequency of 8% to 31%. Bilateral laminotomies have been shown to be effective in decompressing the spine, without resection of the posterior osteo-ligamentous complex. We hypothesize that bilateral laminotomies induce significantly less iatrogenic hypermobility and less stiffness reduction than a traditional facet-sparing laminectomy in the lumbar spine.

Methods. Six fresh frozen human cadaveric lumbar spines (L1–L5) were mounted into a spine motion simulator for testing. With physiologic follower preload, flexion/extension, lateral bending, and axial rotation moments were applied to the lumbar spine in 3 trials: (1) Intact lumbar spine—no surgery, (2) Lumbar spine after bilateral lumbar laminotomies at L2–L5, (3) Lumbar spine after full laminectomies at L2–L5. The lumbar spine kinematics were measured using a Vicon motion tracking system. Total and segmental range of motion and spine stiffness were recorded.

Results. In flexion/extension, bilateral laminotomies resulted in an average increase in L2–L5 range of flexion/extension motion of 14.3%, whereas a full laminectomy resulted in an increase of 32.0% ($P < 0.05$). Analysis per level demonstrated roughly twofold increase in motion with laminectomy compared with bilateral laminotomies ($P < 0.05$, at every treated level). Stiffness was decreased by an average of 11.8% after the 3-level-laminotomies and by 27.2% ($P < 0.05$) after the 3-level-laminectomy.

Conclusion. These data demonstrate that bilateral laminotomies induce significantly less hypermobility and less stiffness reduction compared with a full laminectomy. The preservation of the central posterior osteoligamentous structures may provide a stabilizing effect in preventing postdecompression spondylolisthesis.

Key words: laminotomy, laminectomy, hypermobility. **Spine 2010;35:1789–1793**

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Lumbar stenosis and neurogenic claudication are common conditions encountered by spine physicians and were described by Verbiest in 1954.[1] Currently, there are a myriad of surgical strategies used by spine surgeons to treat stenosis. However, in the latter half of the 20th century, a commonly performed surgical procedure for the treatment of lumbar stenosis was the radical laminectomy, or the so-called Christmas Tree laminectomy. The radical laminectomy entailed resection of not only the laminae, but the pars and facets as well. Although this procedure proved to be effective in treating neurocompressive symptoms, at least in the short-term, postoperative instability was noted frequently afterward.[2–4] In 1990, Abumi *et al* evaluated the stability of cadaveric lumbar spines after facet sparing and radical laminectomies.[5] They concluded that the facet-sparing laminectomy yielded a stable spine and complete facetectomy, whether unilateral or bilateral, but was not recommended as it predisposed the spine to instability. When performing a facet-sparing laminectomy, it has been recommended to retain at least 50% of the facet bilaterally and sufficient pars to prevent instability. Despite these measures, the incidence of post–facet-sparing laminectomy spondylolisthesis has been reported to range from 8% to 31%.[6,7]

The spinous process, interspinous and supraspinous ligaments are removed in both the radical and facet-sparing laminectomy. The laminotomy procedure, which decompresses the spine while preserving these midline structures, has been shown to be clinically effective in the treatment of lumbar stenosis.[7–15] Studies in calf[16] and porcine[8] models have suggested that laminectomy causes more destabilization of a spinal motion segment than laminotomy and that a lumbar spine with posterior complex integrity is less likely to develop segment instability than a lumbar spine with a compromised anchoring point for supraspinous ligament. To our knowledge, there is no biomechanical human study examining stability of the decompressed spine with the posterior midline ligamentous structures intact. Previous human biomechanical studies examined stability only after resection of these structures. We hypothesized that in a human cadaveric model, facet-sparing laminectomy results in significantly increased hyper-mobility and significantly decreased stiffness as compared with bilateral laminotomy.

Materials and Methods

Six fresh frozen (unembalmed) human cadaveric lumbar spines (L1–L5) were obtained from an authorized biospecimen provider and radiographed in the lateral view to verify no previous trauma or significant pathology. All specimens were >65 years of age. The specimens were double-bagged and stored at −20°C when not being: (1) prepared for testing, or (2) undergoing testing. To prepare each specimen for testing, the specimens were thawed and dissected to remove the soft tissues (musculature) while preserving the osteoligamentous structures (vertebrae, ligaments, and intervertebral discs). Metal screws (approximately 76 mm long) were placed into the terminal ends of lumbar vertebrae (L1 and L5), and each end (including the screws) was potted (embedded) in poly-methyl methacrylate with the screws providing increased fixation within the potting compound. Potting of the ends of the specimen facilitated mounting into a spine motion simulator (see available at: http://depts.washington.edu/uwabl/research.php) for biomechanical testing.

Simulator testing (flexion/extension, lateral bending [LB], and axial rotation [AR]) was performed using a custom six-degree-of-freedom spine motion simulator (Figure 1) in tandem with a Vicon 3-dimensional motion analysis 4-camera system (Model MX13, Vicon Motion Systems, Lake Forest, CA) to track segmental spinal motions. Pure bending moments were applied to each specimen through 3 independently controlled rotary actuators (Model FHA-17C, HD Systems, Hauppauge, NY) that were digitally controlled to induce sagittal-, coronal-, or transverse-plane rotational moments while allowing the spine to freely displace (in X, Y, and Z) through air bearings. The loading rate of the spine simulator was controlled at 2°/s.

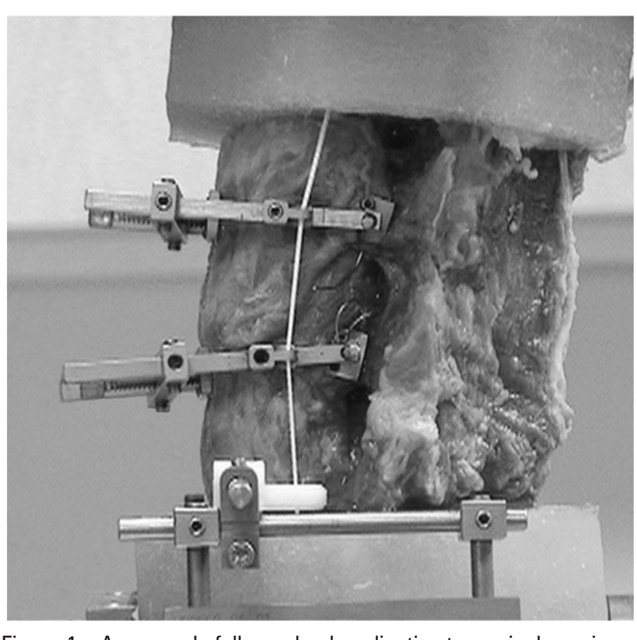

Figure 1. An example follower load application to a spinal specimen.

The applied loads to the specimen were recorded with a 6-axis load cell (Omega 160, ATI Industrial Automation, Apex, NC) connected to a data acquisition board (Model PCI 6034E, National Instruments, Austin, TX) sampling at a rate of 100 Hz. Localized segmental kinematics was captured by the Vicon system using reflective infrared targets mounted at each vertebral level which enabled the markers to be tracked at 60 Hz.

The experimental protocol involved running simulator tests in flexion/extension, LB, and AR in each of the following 3 conditions (trials):

1. Trial 1: Intact lumbar spine—no surgery (Figure 2).
2. Trial 2: Lumbar spine after bilateral lumbar laminotomy at L2–L3, L3–L4, and L4–L5. Laminotomy entailed removal of ligamentum flavum and partial facetectomy to visualize the medial aspect of the pedicle to ensure adequate lateral recess decompression. The cephalad extent of the laminotomy was the superior-most aspect of the facet. The caudal extent of the laminotomy was the inferior-most portion of the facet. The lateral extent of the laminotomy was to the medial margin of the pedicle. No more than approximately 30% of the facet was resected. The spinous process, and inter- and supraspinous ligaments were preserved (Figure 3).
3. Trial 3: Lumbar spine after full laminectomies at L2–L3, L3–L4, and L4–L5. This entailed full removal of the lamina, supra and inter spinous ligaments, and spinous processes. The laminectomy included the full resection of the L3 and L4 lamina. Only the inferior portion of the L2 lamina was resected with preservation of the L1–L2 midline structures. No additional lateral recess or facet resection was done during this trial (Figure 4).

While applying the physiologic flexion/extension, LB, and AR moments, the lumbar spine kinematics (full spine and segmental) were measured using the Vicon motion tracking system. Specimens were tested in flexion (8 Nm), extension (6 Nm), LB (±6 Nm), and (±5 Nm). A 400 N compressive follower preload was applied during the flexion/extension (F-E) tests. This loading scheme is similar to that discussed by Serhan *et al.*[17] The total range of motion (ROM) from L1–L5, as well as the segmental ROM between L1–L2, L2–L3, L3–L4, and L4–L5, was assessed. Additionally, the overall and segmental stiffnesses were computed from the moment-angle plots.

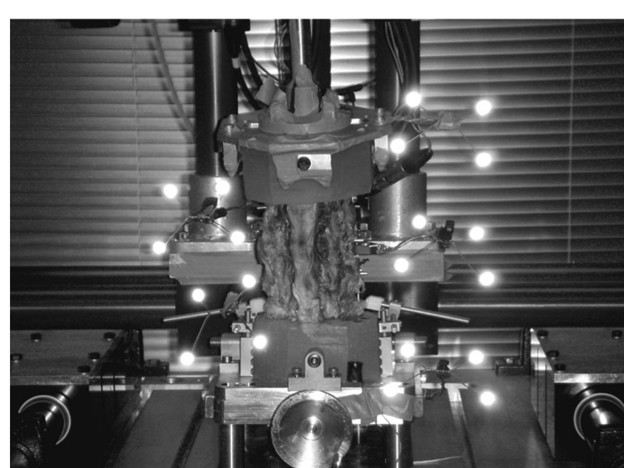

Figure 2. The intact lumbar spine specimen mounted on the motion simulator. Reflective spheres attached at each level allow for accurate tracking of motion.

Figure 3. An oblique photograph of the lumbar spine after laminotomies from L2–L5. The extent of the laminotomy and partial facetectomy ranges from the cephalad-most aspect to the caudal-most aspect of the facet. Laterally, facet is removed to the margin of the pedicle.

A paired two-sample *t* test was used to evaluate differences in stiffness and ROM after (1) bilateral laminotomy and (2) laminectomy. Statistical significance was established at $P < 0.05$.

■ Results

In flexion and extension, bilateral laminotomy resulted in an average increase in total L2–L5 ROM of 14.3%,

Figure 4. The lumbar specimen after facet-sparing laminectomy.

Table 1. Average Motion for All Treated Levels

	Degrees in Flexion/Extension		
	Mean	STD	SEM
Intact (trial 1)	6.07	2.51	0.632
Laminotomies (trial 2)	6.94	2.68	0.594
Laminectomy (trial 3)	8.00	2.93	0.691

STD indicates standard deviations; SEM, standard error of mean.

whereas a full laminectomy resulted in an increase of 32.0% (Table 1). Using the paired two-sample *t* test, the mean flexion/extension ROM was significantly increased with laminotomies, and then subsequently laminectomy. However, confidence intervals were valid only for the laminectomy *versus* intact comparison (Table 2). Segmental kinematic analysis demonstrated approximately a twofold increase in range of motion with laminectomy compared with bilateral laminotomy (Figure 5).

Analysis of range of motion in AR or LB did not yield statistically significant changes between bilateral laminotomy or laminectomy.

The average reduction in stiffness of all specimens after laminotomy was 11.8% (SD = 7.2%), whereas after laminectomies it was 27.2% (SD = 11.1%). This difference was statistically significant ($P < 0.05$).

■ Discussion

Laminectomy with bilateral partial facetectomy is commonly used in the surgical treatment of lumbar stenosis. Although effective in treating the symptoms of neurogenic claudication, the incidence of new onset spondylolisthesis is reported to be as high as 31%.[6]

Laminotomy has been reported to successfully treat symptomatic stenosis.[9–15] There are advantages and disadvantages of bilateral laminotomy over laminectomy. With laminotomy, the posterior ligamentous complex is spared and can continue to act as a tension band and stabilizer to lumbar motion. However, less resection of the posterior elements allows for a smaller operative window and may prolong a case because of increased technical difficulty. In addition, in the event of a spinal fluid egress, a full laminectomy may be required to adequately visualize and repair the rent in the dura.

In 1993, Postacchini *et al* compared bilateral laminotomy with laminectomy and concluded that laminotomy is effective for mild-to-moderate stenosis, but laminectomy is preferred when treating severe stenosis or spondylolisthesis. They noted that with severe stenosis,

Table 2. Paired Differences

	95% Confidence Interval of the Difference		
	Lower	Upper	
Intact *vs.* laminotomies	0.6829864	1.0580258	$P < 0.001$
Intact *vs.* laminectomy	1.6046746	2.2648143	$P < 0.001$

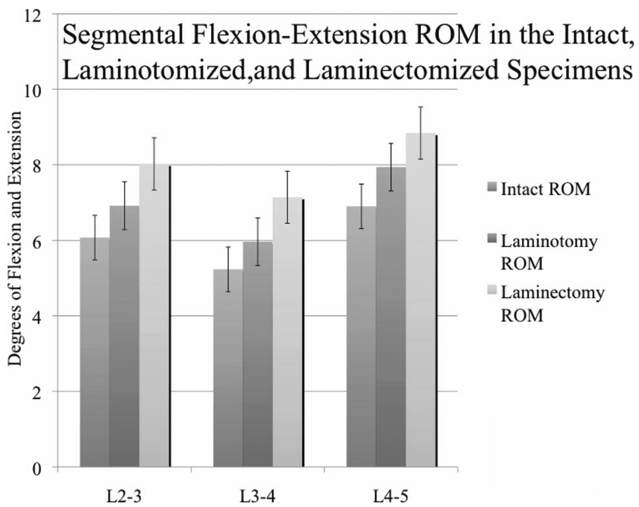

Figure 5. Segmental motion in flexion and extension after laminotomy and laminectomy.

an adequate decompression could not be attained with laminotomy alone and converted these attempted laminotomy cases to laminectomy intraoperatively.

More recently, Fu *et al* compared the clinical results of bilateral laminotomy and laminectomy in the treatment of lumbar stenosis without instability.[7] They report that bilateral laminotomy yielded a significantly superior score in Oswestry Disability Index, Visual Analogue Scale leg pain, and Visual Analogue Scale back pain. An 8% incidence of instability was noted in the laminectomy group at the final follow-up (average, 40 months). No instability was observed in the bilateral laminotomy group. They suggested that the integrity of the posterior osteo-ligamentous structures may be contributory in maintaining stability.

The purpose of the present study was to examine the effect of bilateral laminotomy and laminectomy on lumbar spine motion and stiffness. This study observed a 32.0% increased range of motion ($P < 0.001$) in flexion/extension after laminectomy as compared with 14.3% after bilateral laminotomy. In addition, laminectomy resulted in a significantly larger reduction in stiffness than the laminotomy. These effects were observed in sagittal plane (flexion/extension bending) motion, but not for AR or LB. Although similar data have been previously reported using porcine and calf models, to our knowledge, no other study has demonstrated this using a human cadaveric model,[8,16] which is the standard for biomechanical evaluation. These results suggest that laminectomy may more likely predispose the lumbar spine to increased hypermobility and potential instability over a laminotomy procedure. These data also suggest a role for less invasive decompression. Although not specifically tested in this study, it stands to reason that a minimally invasive approach, whether done unilaterally or bilaterally for bilateral stenosis, is likely to induce less hypermobility than the traditional laminectomy.[18]

Although this study demonstrated greater lumbar spine stability after bilateral laminotomy as compared with laminectomy, we do not recommend that bilateral laminotomy be routinely done in lieu of laminectomy. There are numerous factors that contribute to surgical decision-making. These include: (1) severity of stenosis, (2) preoperative segmental mobility, (3) medical comorbidity, (4) facet tropism, and (5) fluid within the facets. In cases of severe stenosis, a facet-sparing laminectomy may be required to ensure adequate decompression. For degenerative spines with minimal segmental motion, an increase of 32.0%, although statistically significant, may have little clinical relevance. In elderly patients with multiple comorbidities, it may be advisable to perform a technically easier procedure with less operative time and anesthetic exposure. Sagittal orientation of facets has been felt to be predisposing to spondylolisthesis and may affect the surgeon's decision of the procedure to perform. In addition, the presence fluid within the facets has been associated with spondylolisthesis[19] and may alter the surgeon's decision-making.

■ Conclusion

Bilateral laminotomy in the lumbar spine appears to cause less hypermobility and less reduction in stiffness than a laminectomy for sagittal plane motion. Although there are numerous factors that contribute to surgical decision-making, the choice of procedure may also have some effect on the development of postdecompression spondylolisthesis.

■ Key Points

- Bilateral laminotomy results in significantly less iatrogenic flexion and extension than facet-sparing laminectomy.
- Laminectomy results in significantly more reduction in stiffness than bilateral laminotomy.
- These results suggest that laminectomy may be more prone to the development of postdecompression instability than bilateral laminotomy.

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