Repair of pars interarticularis defect utilizing a pedicle and laminar screw construct: a new technique based on anatomical and biomechanical analysis

Laboratory investigation

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Object. The theoretical advantage of pars interarticularis repair over spinal fusion to correct pars defects is that the treatment is a direct osteosynthesis that preserves motion at the involved functional spinal unit. Several techniques and constructs have been used to achieve greater rigidity, but these techniques may risk entry into the spinal canal, and adverse events are common. A pedicle and laminar screw construct placed entirely outside the spinal canal may offer greater stiffness and achieve higher pars defect healing rates. The purpose of this study was to biomechanically assess an intralaminar screw construct in cadaveric lumbar spines in comparison with other types of constructs typically used in pars repair and to quantify the sizes of screws that can be placed safely in both normal and spondylolytic vertebrae.

Methods. The L-4 and L-5 laminae in patients with spondylolysis and in controls who underwent CT (n = 41, each group) were measured by analysis of conventional axial CT images and multiplanar reformations constructed on a Vitrea workstation to determine the feasibility of translaminar fixation with a 4.5-mm-diameter screw. Biomechanical tests for torsion and flexion-extension were performed on 8 fresh human cadaveric lumbar spines before and after modeling for bilateral spondylolytic defects. Three pars repair techniques were tested at each level and in the following sequence: pedicle screw-cable, pedicle screw-rod-hook, and pedicle screw-intralaminar screw.

Results. The majority of laminae can accept 4.5 × 25-mm screws. The cable construct allowed the greatest motion and least stability across the defect in all biomechanical tests. The hook and laminar screw constructs performed similarly in all tests and exhibited no significant difference in stiffness.

Conclusions. A surgically placed intralaminar screw construct may be a safe and effective alternative to current pars repair methods.

KEY WORDS • pars repair • pars defect • spondylolysis • lumbar spine • computed tomography • biomechanics

UNILATERAL and bilateral pars interarticularis defects in the lumbar spine are common, occurring in 6%-11% of the population. 12 Although the majority of these patients are asymptomatic, some have incapacitating back pain presumably secondary to the pars defect, associated instability, and less commonly L-5 nerve root compression. The initial treatment is nonoperative management, consisting of activity restrictions, orthosis, trunk exercises, and antiinflammatory medi-

Abbreviations used in this paper: AP = anteroposterior; HIPAA = Health Insurance Portability and Accountability Act.
Nicol and Scott developed a wire technique with loops around the lamina and transverse processes. These were modified with pedicle screw–wire constructs. Lastly, screw–hook–rod systems have been devised to provide compression and rigid fixation across the pars defect. These more rigid systems offer the theoretical benefit of not requiring a postoperative brace. However, adverse events occur in 6%–44% of patients, including neurological injury associated with instrumentation, pseudarthrosis, and failure of hardware.

Recently, the C-2 intralaminar screw has been described to gain fixation when other techniques may be risky due to anomalies of the vertebral artery. We believed that a similarly placed lumbar translaminar screw could be used to achieve fixation of a pars defect. In this construct, pedicle screws are inserted in the standard fashion and linked to an intralaminar screw with a rod. Our study hypothesis is that the lumbar lamina will be able to accommodate a 4.5-mm-diameter screw and that this construct will be biomechanically favorable compared with other constructs. Our laboratory has previously published an in vitro cadaveric model to test pars interarticularis defects were located at the L-2, L-3, L-4, L-5, and L-6 levels in 2, 1, 10, 27, and 1 cases, respectively. Controls (n = 41) were selected from a list of trauma patients who underwent CT for possible lumbar spine injury between 2005 and 2008. Measurements were performed only at L-4 and L-5. A helical 64-channel CT scanner was used for all patients (LS VCT 64, General Electric). The CT parameters included 1.25-mm slice thickness, 0.625-mm interval, 120 kV, 300 mA (Smart mA/Auto mA range of 150–750), and a bone reconstruction algorithm (window width/window level of 3000/300).

Inherent differences in the coronal and sagittal alignment of the lumbar spine, patient position within the CT scanner, and angle of the lamina could theoretically lead to overestimation of the AP diameter and length of the lamina. Therefore, measurements were performed on both conventional axial CT images, as well as multiplanar reformations constructed on a Vitrea workstation (Vital Images) and compared.

For the multiplanar reconstructions, the raw data files from lumbar spine CT were transferred to the Vitrea workstation. The two most caudal vertebral bodies were identified on the sagittal images. A double oblique technique was used to generate a true axial view. Initially, a coronal reformation was constructed from the sagittal images by bisecting the superior and inferior endplates of the vertebral body parallel to the anterior cortex (Fig. 1). An axial image was subsequently created by dividing the vertebral body along the horizontal axis paralleling the pedicles and lateral cortex. This technique ensured a true standardized axial image of every patient regardless of the inherent coronal or sagittal alignment or positioning (Fig. 2). The maximum translaminar screw length was measured on the axial view from the base of the spinous process coursing along the long axis of the lamina to the lateral edge of the lamina at the junction with the facet joint (Fig. 3). Imaging evaluation demonstrated that the narrowest AP diameter was typically in the central aspect of the middle third of the lamina (Fig. 4). Given the obliquity of the laminae, to obtain an accurate AP diameter at this level, a multiplanar reformation was produced by transecting the lamina perpendicular to the long axis, generating a true sagittal image of the lamina. Two AP diameters were measured from this image, one between the inner cortices and one between the outer cortices (Fig. 5).

**Methods**

**Imaging Analysis**

Prior to beginning the study, we obtained approval and a study exemption from the University of Wisconsin institutional review board. The study was also performed in compliance with HIPAA regulations. Computed tomography examinations of the lumbar spine were used to evaluate the size and morphology of the laminae in patients with pars interarticularis defects to determine the feasibility of translaminar fixation with a 4.5-mm screw.

Using a database of CT examinations performed at our institution, we identified 41 patients with spondylolysis. Exclusion criteria included prior instrumentation placement or lower lumbar spine injury. The spondylolytic defects were located at the L-2, L-3, L-4, L-5, and L-6 levels in 2, 1, 10, 27, and 1 cases, respectively. Controls (n = 41) were selected from a list of trauma patients who underwent CT for possible lumbar spine injury between 2005 and 2008. Measurements were performed only at L-4 and L-5. A helical 64-channel CT scanner was used for all patients (LS VCT 64, General Electric). The CT parameters included 1.25-mm slice thickness, 0.625-mm interval, 120 kV, 300 mA (Smart mA/Auto mA range of 150–750), and a bone reconstruction algorithm (window width/window level of 3000/300).

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**Biomechanical Investigation**

**Specimen Preparation.** Eight fresh lumbar spines from human cadavers were thawed and stripped of all muscle tissues while maintaining ligaments and joint capsules. The spines were mounted into frames at T-12 and S-1 with a polyester resin (Lite Weight 3 fiberglass, Evercoat). Testing was performed at L2–3 and L4–5.
Biomechanical Protocol. The biomechanical tests were performed on a modified MTS Bionix 858 servo-hydraulic material tester (MTS Corporation) capable of applying axial compressive and torsional loads about the longitudinal axis of the spine and containing a calibrated load cell. The modification of the materials-testing apparatus consisted of mounting grips to allow sagittal rotation about the center of the 2 end vertebral bodies. These mounting grips were driven by electric motors, and rotation angle was monitored by a potentiometer. This system allowed for a constant bending moment to be applied uniformly over the length of the spine, resulting in a pure sagittal flexion and extension load while maintaining axial load and axial torsion at zero or other preset loads.

Separate tests were performed for torsion and flexion-extension. Coupled motion in rotation or sagittal bending was allowed. Torsion was cycled at ±5 N×m, with a 5-N tensile preload. Flexion-extension bending torques of ±5 N×m, with a 5-N compressive preload. Flexion-extension bending torques of ±5 N×m, with a 5-N compressive preload, were applied. Each test consisted of 5 sinusoidal load cycles at 0.1 Hz. Specimens were preconditioned over the first 4 cycles, with data from the fifth cycle used for analysis. Flexion-extension was measured using extensometers applied across the repaired spinal motion segment. Torsional displacement was measured using a custom-built rotational extensometer mounted above and below each of the spinal motion segments. Angulations were determined using geometry and the distance between the points of contact of the extensometers. Additionally, displacements across the defects on each side were measured by linear extensometers and averaged from right and left sides.

Testing Sequence. Testing was performed on the intact spine and after bilateral spondylolytic defects were created with an oscillating saw (injury model). The testing was then repeated after pars repair. Three pars repair...
methods were tested: pedicle screw–cable (cable), pedicle screw–rod–hook (hook), and pedicle screw–intralaminar screw (screw) techniques. The techniques were tested in that sequence at each level separately. Data analysis consisted of range of motion and stiffness across each disc space in flexion-extension and torsion and strain across the defect in flexion-extension.

Surgical Techniques. All of the techniques required insertion of pedicle screws. The starting point for the pedicle screw was at the junction of the pars, transverse process, and facet. After a pilot hole was made, a curved awl was used to cannulate the pedicle to a depth of 40 mm. A pedicle probe was used to confirm that there was no breach of the pedicle walls. The pedicle was subsequently tapped with a 4.0-mm tap followed by screw insertion. All of the pedicle screws used were 4.5 mm in diameter and 40 mm in length. The same steps were repeated for the left and right sides.

The pedicle screw–cable technique was a modification of the Scott wiring. An Atlas titanium cable (Medtronic) was passed under the head of the pedicle screw and looped around the corresponding spinous process. A second cable was passed in a similar manner on the opposite side. The cables were tensioned carefully to avoid cutting through the bone and to ensure equal tension on both sides. Compression across the pars defect was directly visualized. The cables were crimped and excess cable was removed. Following testing, the cables were removed, although the pedicle screws remained intact.

Using a curette, the ligamentum flavum was elevated from the inferior aspect of the lamina, and a cranially directed sublaminar hook (Legacy, Medtronic) was placed. A 5.5-mm rod was placed between the screw and hook, and rod compression was applied followed by final tightening of the set screws. During rod insertion compression across the pars defect was visualized. This was repeated on the contralateral side. Following testing, the hook was removed while keeping the pedicle screw intact.

The starting point for the intralaminar screws is at the junction of the spinous processes and the lamina. To accommodate the starting points of both left and right intralaminar screws, one screw was placed in a slightly more dorsal and cephalad position than the other. The pilot hole was made with a drill, followed by cannulation of the lamina via a straight awl. A probe was used to ensure that the awl remained within the confines of the lamina. The lamina was then tapped with a 4.0-mm tap, followed by the insertion of a 4.5-mm-diameter, 25-mm-long screw. The screw length is short of the facet joint and is not intended to cross the pars defect. The same steps were repeated for the contralateral side. The intralaminar and pedicle screws were connected with a 4.5-mm-diameter rod, which was compressed and locked into place with set screws. Compression across the defect was visualized. The pedicle screw–intralaminar screw technique is illustrated in CT images and radiographs from one patient in Fig. 6.

Statistical Analysis. Comparison between groups was performed using ANOVA and the Tukey method for multiple groups when appropriate. An α of 0.05 was selected as significant.

Results

Imaging Analysis

Demographics. There was no statistically significant difference in demographic characteristics. The mean age of the control group was 31.4 ± 17.4 (SD) years (range 12–83 years), and the mean age of the spondylolytic group was 27.9 ± 17.8 years (range 9–89 years). The age difference between the control and spondylolytic groups was not significant (p = 0.37). In the spondylolytic group, 10 patients were women and 31 were men. The control group consisted of 13 women and 28 men. We found no statistically significant difference in laminar length or diameter based on age or sex.

Conventional CT Versus Multiplanar Reconstructions. An overestimation of the outer laminar diameter averaged 17% for measurements performed on conventional transaxial CT images versus multiplanar reconstructions generated on the Vitrea workstation (Table 1). This result was statistically significant (p < 0.05) and supports our original hypothesis that the orientation of the laminae superimposed on the natural variations in sagittal and coronal alignment of the lumbar spine would result in elongation of the laminae on images obtained perpendicular to the long axis of the body.

Laminar Diameters. The inner diameters of both L-4 and L-5 had a wide range and in many cases the cortex accounted for the majority of the distance measured, with minimal contribution from the central cancellous bone. The inner diameters ranged between 0.7 and 5.5 mm, with the median values between 2 and 3 mm.

The outer diameters ranged from 3.3 to 9.8 mm, with the median values ranging between 5.7 and 6.2 mm (Fig. 7). There was no statistically significant difference between median values for the outer diameters at L-4 and L-5 in either of the populations.

Laminar Length. The maximum translaminar screw length values for the spondylolytic group (Fig. 8) ranged from 21.4 to 37.7 mm. Comparing L-4 versus L-5 in the controls, the mean L-5 length was longer (p < 0.05) by an average of 2.1 mm. No statistically significant difference between L-4 and L-5 laminar lengths was noted in the spondylolytic group. Comparison of controls and spondylolytic patients revealed no statistically significant difference in laminar lengths at L-4; however, the median length of the L-5 laminae of spondylolytic patients was 1.5 mm shorter than that of the control group (p < 0.05).

Biomechanical Investigation

Motion Segment Stiffness. The stiffness of the functional spinal unit along each axis was normalized to the intact spine (Table 2). The angular motion was significantly greater between vertebral segments in all modes of testing with the pedicle screw–cable construct. There was no statistically different difference in stiffness between the pedicle screw–hook and pedicle screw–intralaminar screw constructs in flexion/extension, lateral bending, or torsion (Figs. 9–11).
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Displacement Across Pars Defect. The displacement across the defect in all testing modes (flexion/extension, lateral bending, torsion) was normalized to the injured state (Table 3). The displacement was significantly reduced by all constructs. However, a 2.5- to 7-fold greater strain occurred after cable fixation, depending on axis of rotation, compared with hook or intralaminar screw constructs (Fig. 12). These differences were statistically significant, although no statistical differences were present between hook and laminar screw constructs.

Discussion

In many patients who are high-level athletes, spondylosis defects in the lumbar spine often become symptomatic due to repetitive hyperextension during adolescence. Most patients respond well to nonoperative treatment involving a brief period of rest, core strengthening exercise, and bracing. Occasionally, patients do not improve with nonoperative treatment and surgery is considered.9 It is believed that their pain originates from motion of the pars defect site. Traditional surgical techniques

![Image](image.png)

**Fig. 6.** Pedicle screw–intralaminar screw technique. A and B: Preoperative axial (A) and sagittal (B) CT images obtained in a patient with failed wiring. C and D: Postoperative AP (C) and lateral (D) radiographs. E: Postoperative sagittal CT image.

**Fig. 7.** Outer laminar diameters for L-4 and L-5 control and spondylosis defect (Spondy) groups. Boxplots showing median values, interquartile range (shaded area), and maximum and minimum values (whiskers).

### Table 1: Comparison of the inner and outer diameters and lengths of L-4 and L-5 laminae measured with conventional CT images and following multiplanar reconstruction

<table>
<thead>
<tr>
<th>Dimension (mm)</th>
<th>Standard CT</th>
<th>Reformatted Image</th>
<th>Difference</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner diameter</td>
<td>3.4</td>
<td>2.7</td>
<td>-25.9%</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>outer diameter</td>
<td>6.8</td>
<td>5.8</td>
<td>-17.2%</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>length</td>
<td>28.7</td>
<td>28.7</td>
<td>0%</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

* Mean values for all study participants (spondylosis group and control group).
address this with an intervertebral fusion that removes motion between 2 vertebral segments. Unfortunately, this may lead to postoperative activity restrictions and, in the long term, adjacent segment degeneration that may require additional surgery. Additionally, return to a high level of sport is not likely after a posterior lumbar fusion. An alternative to fusion, which was investigated in this study, is pars repair.

Pars repair is a direct osteosynthesis with the advantage of preserving intervertebral motion. Multiple techniques have been developed with a variety of outcomes. Bone grafting without instrumentation has had poor union rates due to motion across the fracture site, and it requires prolonged external immobilization. Wiring techniques across the transverse process and spinous process have been attempted but fail to provide enough long-term stiffness for reliable healing of the spondylolytic defect. Recently, with the advent of pedicle screws, a pedicle screw–lamina hook system has been shown to provide biomechanically the stiffest fixation. Even with this technique, pseudarthrosis may still occur. Additionally, this technique involves entering the spinal canal with a hook, and hardware prominence may occur.

In an attempt to provide a stiffer construct, with the goal of achieving higher defect-healing rates, we devised a pedicle screw–intralaminar screw construct. This construct also has the advantage of being entirely outside of the spinal canal, decreasing the chance of a neurological injury, and it is easy to use. This technique is similar the C-2 laminar screw described by Wright.

The imaging analysis demonstrated that the majority of laminae are large enough to accept a 4.5-mm-diameter, 25-mm-long screw. In many cases it will not be possible to place the screw into cancellous bone between laminar cortices, but the entire lamina is thick enough for screws of these diameters. The L-5 laminae of spondylolytic patients were on average 1.5 mm shorter than those of controls, a difference that was statistically significant but clinically unimportant. No difference was found at L-4, but this may be due to the smaller sample size. Rarely, the diameter and length of the lamina will preclude use of a translaminar screw. Prior to any such surgery we recommend a careful review of preoperative imaging studies to ensure that both the pedicle and lamina are capable of accepting instrumentation.

Our biomechanical study showed that the cable construct was the least stable pars repair technique, allowing the most motion across the pars defect in all modes of testing. This finding is consistent with previous studies showing that cable or wire constructs were inferior to the pedicle screw–hook construct. Flexion/extension, lateral bending, and torsion testing did not demonstrate a significant difference in displacement across the pars defect between the hook and laminar screw techniques. Similarly, intervertebral motion was the greatest with the cable construct in all testing modes compared with the hook construct.

### Table 2: Average stiffness (N×m/Rad)-normalized to the intact spine

<table>
<thead>
<tr>
<th>Motion</th>
<th>Pars Defect</th>
<th>Cable</th>
<th>Hook</th>
<th>Laminar Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>axial rotation</td>
<td>0.794</td>
<td>1.192</td>
<td>2.575</td>
<td>2.505</td>
</tr>
<tr>
<td>flexion-extension</td>
<td>0.774</td>
<td>1.100</td>
<td>6.726</td>
<td>6.846</td>
</tr>
<tr>
<td>lat bending</td>
<td>0.828</td>
<td>1.111</td>
<td>7.870</td>
<td>8.206</td>
</tr>
</tbody>
</table>

![Fig. 8. Maximum translaminar screw lengths for L-4 and L-5 control and spondylolytic defect groups. Boxplots showing median values, interquartile range (shaded area), and maximum and minimum values (whiskers).](image)

![Fig. 9. Stiffness in flexion-extension: mean values with standard deviations (error bars).](image)

![Fig. 10. Stiffness in torsion.](image)
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and laminar screw techniques. There was not a significant difference in stiffness between the pedicle screw–hook and pedicle screw–intralaminar screw techniques in any of the testing modes. Biomechanical tests did not include fatigue testing with a load cell within the pars defect. As demonstrated in Fig. 6, the laminar screws are caudal to the pedicle screws. Thus, the force vector is appropriate—superior lateral to inferior medial.

Clinically, this study confirms that L-4 and L-5 spondylolytic laminae can accept laminar screws of practical size. Further, the intralaminar method is biomechanically as strong as other rigid methods to achieve stabilization of a spondylolytic defect. We found that insertion was easy and had a low risk of violating the spinal canal or a facet joint. The CT analysis found no significant age-related variation in laminar size, so the technique would be applicable to both adolescents and adults.

The major limitations of this study are that it provides only biomechanical evidence and it does not demonstrate that bony healing will take place. The intralaminar screw implants are slightly prominent and may require removal after healing, although they are less prominent than pedicle screw–hook implants.

Conclusions

A new surgical technique of pars repair, the pedicle screw–intralaminar screw construct, has been shown to provide excellent fixation across the pars defect. Our technique is biomechanically similar to the pedicle screw–hook technique in flexion-extension, lateral bending, and torsion. Additionally, the pedicle screw–intralaminar screw construct has the benefits of not violating the spinal canal and is of lower profile. Our anatomical study has shown that this technique can be safely performed in the majority of patients using 4.5-mm-diameter screws. We feel that this technique is an excellent alternative to the currently accepted technique of pars repair.

Disclosure

Dr. Steinmetz is a consultant for Biomet Spine. Dr. Anderson owns stock in Pioneer Surgical, holds patents with Stryker and Pioneer Surgical, and is a consultant for Medtronic, Expanding Orthopedics, and Titan Surgical.

Author contributions to the study and manuscript preparation include the following. Conception and design: Patel, Anderson. Acquisition of data: Rosas, Steinmetz. Analysis and interpretation of data: Patel, Rosas, Anderson. Drafting the article: Patel, Rosas, Anderson. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Patel. Statistical analysis: Patel. Administrative/technical/material support: Rosas, Steinmetz. Study supervision: Patel.

References


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