Biomechanical evaluation of posterior thoracic transpedicular discectomy

Laboratory investigation

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Object. The authors investigated the biomechanical properties of transpedicular discectomy in the thoracic spine and compared the effects on spinal stability of a partial and total facetectomy.

Methods. Human thoracic specimens were tested while intact, after a transpedicular discectomy with partial facetectomy, and after an additional total facetectomy was incorporated. Nonconstraining pure moments were applied under load control (maximum 7.5 Nm) to induce flexion, extension, lateral bending, and axial rotation while spinal motion was measured at T8–9 optoelectronically. The range of motion (ROM) and lax zone were determined in each specimen and compared among conditions.

Results. Transpedicular discectomy with and without a total facetectomy significantly increased the ROM and lax zone in all directions of loading compared with the intact spine (p < 0.008). The segmental increase in ROM observed with the transpedicular discectomy was 25%. The additional total facetectomy created an insignificant 3% further increase in ROM compared with medial facetectomy (p > 0.2).

Conclusions. Transpedicular discectomy can be performed in the thoracic spine with a modest decrease in stability expected. Because the biomechanical behavior of a total facetectomy is equivalent to that of a medial facetectomy, the additional facet removal may be incorporated without further biomechanical consequences.

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Key Words • biomechanics • transpedicular discectomy • facetectomy • thoracic spine

Thoracic disc herniations requiring operative treatment are rare, constituting between 0.15 and 4% of disc operations.1,5,11,12,16 Nevertheless, various surgical approaches have been devised to access thoracic discs. These approaches are usually divided into anterior (transsternal), anterolateral (thoracotomy and thoracoscopy), posterolateral (lateral extracavitary and costotransversecctomy), and posterior (transpedicular and transfacet pedicle-sparing) approaches. The anterior and anterolateral approaches have the advantage of providing a direct view to the disc space. However, they are associated with chest-related complications, including pulmonary contusion, atelectasias, pleural effusion, hemotherax, chylothorax, and intercostal neuralgia.8,15 In contrast, posterolateral approaches provide an oblique view of the spinal canal and avoid the morbidity associated with opening the chest. Despite these benefits, a variable amount of rib resection and extensive muscle dissection are necessary and lead to significant postoperative pain. If the posterior tension band or the sternal-rib complex that supports the spine is disrupted, fusion is warranted.8,18

As familiarity with the surgical anatomy has improved, posterior approaches, which avoid these complications and decrease length of hospitalization, have become increasingly widespread. Of these approaches, the least invasive is the transpedicular discectomy. Through this route the lateral portion of the lamina, medial facet, and rostral third of the pedicle are removed. The exact extent of access through the facets depends on the need to increase the working area into the anterior disc space. Theoretically, a greater extent of access will induce a greater amount of segmental instability. We therefore

Abbreviations used in this paper: LZ = lax zone; ROM = range of motion.
analyzed the biomechanics of the transpedicular discectomy in the thoracic spine and compared the effects on spinal stability after partial and complete removal of the facet joints.

**Methods**

**Specimen Preparation**

Seven human cadaveric spine specimens (T6–11) with 3 cm of intact proximal ribs, intercostal ligaments, and costovertebral joints were used in this study (Table 1). Specimens were obtained fresh frozen and thawed in a bath of normal saline at 30°C. Residual muscle tissue was carefully cleaned to preserve the ligaments, discs, and joint capsules. The medical history of each donor was reviewed to exclude the presence of trauma, malignancy, or metabolic disease that might compromise the mechanical properties of the thoracic spine. On visual and radiographic inspection, none of the specimens had evidence of spinal pathology. Bone mineral density was determined using dual-energy x-ray absorptiometry to ensure that no specimen had severe osteoporosis. Before testing, the rostral and caudal vertebrae were reinforced with household screws and potted in metal fixtures using polymethyl methacrylate for the application of loads.15

**Biomechanical Testing**

Nonconstraining, nondestructive, pure moment loads were applied through a system of cables and pulleys in conjunction with a standard servohydraulic test system (MTS), as previously described.20 Loads were applied around the appropriate anatomical axes to induce 6 types of motion: flexion, extension, left lateral bending, right lateral bending, left axial rotation, and right axial rotation (Fig. 1). Before data were collected in each loading mode, the specimens were preconditioned 3 times by applying a 7.5-Nm load, with each load held for 60 seconds. After the third preconditioning cycle, no load was applied for 60 seconds to allow the specimen to recoil to a natural resting position before data collection began. During data collection, loads were applied in 1.25-Nm increments to a maximum of 7.5 Nm with each increment held for 45 seconds.

Specimen motion was monitored using the Optotrak 3020 system (Northern Digital). This system stereophotogrammetrically measures the 3D displacement of infrared-emitting markers rigidly attached in a noncollinear arrangement to 3 stainless-steel surgical guide wires inserted in each vertebra. Custom software aligned the local Cartesian coordinate system at T7–8, T8–9, and T9–10 with vertebral anatomy by using a digitalizing probe and converted the marker coordinates on T-7, T-8, T-9, and T-10 to segmental angles around each axis.2,4

Specimens were tested in the following conditions: 1) intact, 2) after transpedicular discectomy, and 3) after ipsilateral total facetectomy. During testing, specimens were kept wrapped in saline-soaked gauze to prevent dehydration. If a second day of testing was required, specimens were refrozen to mitigate degradation from prolonged exposure.

**Statistical Analysis**

The angular ROM and angular LZ were quantified in each condition to quantify stability. The ROM is the angle reached at maximum load (7.5 Nm); the LZ is that portion of the ROM in which there is minimal ligamentous resistance. The LZ is similar to the neutral zone in that both parameters identify the portion of the ROM that occurs under minimal loading; the LZ was used instead of the neutral zone because it is less susceptible to variations in the loading environment and to joint friction.3 The LZ and ROM values are presented as recorded and after normalization to account for the natural degradation of specimens from repeated testing. For normalization, ROM and LZ at the index level (T8–9) were adjusted based on variations in these parameters at the adjacent levels. The mean ROM (or LZ) increase at the adjacent levels. The mean ROM (or LZ) increase at the adjacent levels.

$$F = \frac{(\text{ROM}_{T7-8, \text{intact}} + \text{ROM}_{T9-10, \text{intact}})}{(\text{ROM}_{T7, \text{resected}} + \text{ROM}_{T9-10, \text{resected}})}$$

### TABLE 1: Summary of specimen information

<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>BMD (g/cm²)</th>
<th>Age (yrs)</th>
<th>Cause of Death</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.625</td>
<td>M, 36</td>
<td>trauma</td>
<td>1.78</td>
<td>104</td>
</tr>
<tr>
<td>2</td>
<td>0.845</td>
<td>M, 52</td>
<td>respiratory failure</td>
<td>1.78</td>
<td>104</td>
</tr>
<tr>
<td>3</td>
<td>0.660</td>
<td>M, 40</td>
<td>myocardial infarction</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>4</td>
<td>0.658</td>
<td>F, 38</td>
<td>cardiac arrest</td>
<td>1.55</td>
<td>103</td>
</tr>
<tr>
<td>5</td>
<td>0.460</td>
<td>M, 47</td>
<td>adenocarcinoma</td>
<td>1.73</td>
<td>57</td>
</tr>
<tr>
<td>6</td>
<td>0.605</td>
<td>M, 51</td>
<td>cerebrovascular accident</td>
<td>1.73</td>
<td>82</td>
</tr>
<tr>
<td>7</td>
<td>0.640</td>
<td>M, 39</td>
<td>seizure</td>
<td>1.78</td>
<td>88</td>
</tr>
</tbody>
</table>

* BMD = bone mineral density; NS = not specified.
This scaling factor was multiplied by the corresponding index-level ROM (or LZ). Thus, the increase in motion related to natural degradation was controlled so that the normalized increases in motion at the index level represented only the effect of the resections.

One-way repeated-measures ANOVA, followed by Holm-Sidak tests, was used to determine whether motion parameters differed significantly from normal after transpedicular discectomy and total facetectomy. Probability values < 0.05 were considered significant.

**Results**

Transpedicular discectomy and total facetectomy significantly increased the ROM and LZ in all directions of loading compared with the intact spine (p < 0.008) (Table 2, Figs. 3 and 4). A moderate variability in the amount of change in stability after resection was observed among specimens, as evident from the larger standard deviations at the index level than at adjacent levels (Fig. 3). Compared with transpedicular discectomy, the additional facetectomy created no further significant change in ROM or LZ (p > 0.2) (Tables 2 and 3). The mean increment in T8–9 ROM among loading modes after transpedicular discectomy was 0.72° (24.8%) represented as nonnormalized values or 0.76° (25.6%) represented as normalized values; the mean increment in ROM after total facetectomy was 0.13° (3.3%) represented as nonnormalized values or 0.01° (0.1%) represented as normalized ROM.

**Discussion**

In 1978 Patterson and Arbit first proposed the transpedicular approach as a safe and less invasive alternative for the treatment of thoracic disc disease. They reasoned that the facets and pedicle of the vertebra caudal to the protruded disc should be removed to provide access to the intervertebral disc; they also suggested that removal of part of the articular process might be sufficient for the exposure. Most centrolateral and central thoracic disc herniations can be managed adequately without extensive bone disruption. Only seldom are the facets removed completely. Nevertheless, the cavity created is narrow, and the access to ventrally located lesions is difficult. The current experiment was therefore performed to address the relative stability warranted by the facets in this approach. To the best of the authors’ knowledge, this is the first study to assess the biomechanics of the transpedicular discectomy.

Previous studies have provided data on the relative importance of the pedicle-facet complex. Kothe et al. analyzed the effects of pedicle injuries to the thoracic spine in a cadaveric model. After the pedicles had been removed, Kothe and colleagues observed a significant decrease in stability during axial rotation and lateral bending. Furthermore, this effect was greater in the middle thoracic spine than in the lower spine. Contrary to our study, the spinal segments were constrained using pedicle screw and rod constructs, which ultimately underestimated their contribution.
Our data indicate that transpedicular discectomy significantly decreased the relative stability of the middle thoracic spine segments in all directions. However, a total facetectomy was associated with similar results in terms of flexion, extension, axial rotation, and lateral bending. Compared with the intervertebral disc, the facets contributed little to the overall restriction of ROM. The vertical orientation of the facets in the middle thoracic spine allows the facets to provide resistance against anteroposterior translation.19 Horton and coworkers7 showed that 4 levels of total bilateral facetectomies performed between T4–8 increased ROM by 12% during flexion and extension. Individual radical discectomy of the same levels increased ROM by 44% in the same directions. Feiertag et al.6 reported that total unilateral facet excision did not significantly increase motion in cadaveric thoracic spines when performed individually. In contrast, Oda and colleagues6 reported that the lateral portion of the facet joints plays an important role in providing stability to the thoracic spine and should be preserved to minimize postoperative kyphotic deformity and segmental instability when performing decompressive wide laminectomy. In our study, transpedicular discectomy increased ROM during flexion and extension by about 34% (Fig. 3) and by an additional 4% after total facetectomy. It should also be noted that the drill cuts for facetectomy were a vertical disruption of the superior and inferior facets rather than angled undercuts, likely leading to maximal instability because no buttressing structures remained.

During all loading modes, transpedicular discectomy increased both ROM and LZ relative to the intact condition. Also, the increase observed in normalized LZ (mean 53%) was substantially greater than in normalized ROM (mean 26%). This finding implies that the elastic properties of the ligaments, disc, and articulations changed little once they were stretched. Such behavior is desirable to avoid the increased stress that can occur at remaining ligamentous structures with the introduction of stiffer structures such as metal hardware or bone-on-bone contact.

**Limitations of the Study**

This study has some limitations. As is common in research using cadaveric specimens, which are expensive and difficult to obtain, the number of specimens was limited (7), leading to low statistical power or probability of avoiding false-negative findings. Furthermore, the clinical relevancy of the findings is affected by subtle variations in the procedure studied as performed by different surgeons. Other surgeons may remove more, less, or different regions of disc material, lamina, or facet, potentially leading to different outcomes. Furthermore, the rib cage was not present in our specimens for biomechanical testing. Because the ribs provide additional stability, we would have expected to observe even less total motion and smaller differences than were found here if the ribs had been present.

**Clinical Considerations**

Our data indicate that transpedicular discectomy can be performed without risk of creating excessive instability in the middle thoracic spine. These data agree with clinical experience, which has shown that transpedicular discectomy is not an excessively destabilizing procedure.11 Given that the lateral portion of the facets added little stiffness in this approach, a facetectomy can be incorporated without expecting any alteration to the immediate stability of the spine and likely not requiring fusion. To our knowledge, however, no clinical series corroborating this finding has been reported. These results may help clinicians refine the technique for transpedicular discectomy. Patterson and Arbit14 noted that the outcome in patients with pain alone has not been entirely satisfactory. In clinical experience, which has shown that transpedicular discectomy is not an excessively destabilizing procedure.11 Given that the lateral portion of the facets added little stiffness in this approach, a facetectomy can be incorporated without expecting any alteration to the immediate stability of the spine and likely not requiring fusion. To our knowledge, however, no clinical series corroborating this finding has been reported. These results may help clinicians refine the technique for transpedicular discectomy. Patterson and Arbit14 noted that the outcome in patients with pain alone has not been entirely satisfactory. In clinical experience, which has shown that transpedicular discectomy is not an excessively destabilizing procedure.11 Given that the lateral portion of the facets added little stiffness in this approach, a facetectomy can be incorporated without expecting any alteration to the immediate stability of the spine and likely not requiring fusion. To our knowledge, however, no clinical series corroborating this finding has been reported. These results may help clinicians refine the technique for transpedicular discectomy. Patterson and Arbit14 noted that the outcome in patients with pain alone has not been entirely satisfactory. In clinical experience, which has shown that transpedicular discectomy is not an excessively destabilizing procedure.11 Given that the lateral portion of the facets added little stiffness in this approach, a facetectomy can be incorporated without expecting any alteration to the immediate stability of the spine and likely not requiring fusion. To our knowledge, however, no clinical series corroborating this finding has been reported. These results may help clinicians refine the technique for transpedicular discectomy. Patterson and Arbit14 noted that the outcome in patients with pain alone has not been entirely satisfactory. In clinical experience, which has shown that transpedicular discectomy is not an excessively destabilizing procedure.11

<table>
<thead>
<tr>
<th>Loading Mode</th>
<th>Transpedicular Discectomy</th>
<th>Total Facetectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle increase (°)</td>
<td>% Increase</td>
</tr>
<tr>
<td>flexion</td>
<td>0.66</td>
<td>32</td>
</tr>
<tr>
<td>extension</td>
<td>0.82</td>
<td>35</td>
</tr>
<tr>
<td>lat bending</td>
<td>0.58</td>
<td>18</td>
</tr>
<tr>
<td>axial rotation</td>
<td>0.85</td>
<td>23</td>
</tr>
<tr>
<td>adjusted ROM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>flexion</td>
<td>0.55</td>
<td>27</td>
</tr>
<tr>
<td>extension</td>
<td>0.81</td>
<td>35</td>
</tr>
<tr>
<td>lat bending</td>
<td>0.82</td>
<td>25</td>
</tr>
<tr>
<td>axial rotation</td>
<td>0.76</td>
<td>20</td>
</tr>
</tbody>
</table>
Fig. 3. Mean nonnormalized motion at each level and in each direction of loading. Full columns represent ROM; horizontal lines on each column separate the LZ (closer to 0) from the stiff zone. Error bars show SD of the ROM. TF = total facetectomy; TPD = transpedicular discectomy.
damage during surgery. From an experimental perspective, however, unilateral total facetectomy during a transpedicular discectomy approach does not necessarily cause biomechanical instability. Patients whose only symptom is axial pain are not good candidates for surgery.

**Conclusions**

We investigated the biomechanical properties of transpedicular discectomy in a cadaveric model of the middle thoracic spine. The data demonstrated that transpedicular discectomy could be used safely with an expected 25% increase in ROM. If necessary, a facetectomy can be incorporated without further biomechanical consequences. These data may help refine the surgical technique for transpedicular discectomy.

**Disclosure**

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Crawford, Deniz, Brasilense, Lazaro. Acquisition of data: Crawford, Deniz, Lazaro, Reyes, Sawa. Analysis and interpretation of data: Crawford, Deniz, Reyes. Drafting the article: Crawford, Deniz. Critically revising the article: Crawford, Deniz. Reviewed final version of the manuscript and approved it for submission: Crawford, Deniz, Brasilense, Lazaro, Reyes, Sawa, Sonntag. Statistical analysis: Crawford, Deniz. Study supervision: Crawford, Sonntag.

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**References**


**TABLE 3: Increases in LZ after each procedure**

<table>
<thead>
<tr>
<th>Loading Mode</th>
<th>Transpedicular Discectomy</th>
<th>Total Facetectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Increase (°)</td>
<td>% Increase</td>
</tr>
<tr>
<td>flexion-extension</td>
<td>1.70</td>
<td>88</td>
</tr>
<tr>
<td>lat bending</td>
<td>1.58</td>
<td>44</td>
</tr>
<tr>
<td>axial rotation</td>
<td>1.76</td>
<td>39</td>
</tr>
<tr>
<td>adjusted LZ</td>
<td>flexion-extension</td>
<td>1.59</td>
</tr>
<tr>
<td>lat bending</td>
<td>1.65</td>
<td>46</td>
</tr>
<tr>
<td>axial rotation</td>
<td>1.37</td>
<td>31</td>
</tr>
</tbody>
</table>
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