Surgical training using simulators has been shown to be highly effective but is not available for some applications and is too expensive for many programs. The authors piloted a cadaver-based module with the goal of objectively measuring and significantly improving orthopedic residents’ surgical skills in placing thoracic pedicle screws, an advanced procedure. An experienced spine surgeon placed thoracic pedicle screws in 7 cadavers (T1-T12) to establish the skilled accuracy rate. For this pilot study, 3 orthopedic residents unfamiliar with the procedure were given didactic training for safe thoracic pedicle screw insertion. Each resident instrumented alternating sides of 5 consecutive cadavers (T1-T12). Screw positions were graded by computed tomography in a blinded fashion, with accuracy defined as no shank breach of the pedicle or vertebral body. Results were reviewed with the residents, instruction was repeated, and alternating sides of 5 cadavers were instrumented by the residents. The experienced surgeon accurately placed 67 (82%) of 82 pedicle screws. Residents accurately placed 80 (44%) of 180 pedicle screws in the initial set of specimens and 105 (58%) of 180 pedicle screws in the second set of specimens ($P=.01$). Accuracy varied significantly among residents before but not after computed tomography review.

The study’s results show that a cadaver-based training module that resembles the clinical setting can be used to teach complex surgical skills to orthopedic residents.
Education and training in spine surgery are emphasized by national organizations, and residency training requirements are evolving toward a focus on patient care for specific musculoskeletal conditions. The limits on resident work hours put pressure on programs to develop efficient training methods to ensure that surgeons-in-training have the opportunity to master all components of the training program. Virtual training through surgical simulators has been shown to be highly effective in teaching surgical trainees, but simulators are not available for all applications and are not affordable for most programs. A structured surgical skills module for complex surgical procedures may be an effective compromise that would achieve improved skill levels without the expense of simulator systems.

Instrumentation of the thoracic spine is an advanced surgical procedure that is difficult to teach and is important to the future practice of spine surgeons. Pedicle size and orientation make safe pedicle cannulation difficult. Several studies have found that experience correlates with improved accuracy in thoracic pedicle screw placement. Thoracic pedicle screw insertion can be done using fluoroscopy guidance or freehand. The freehand method is preferable because it eliminates the added cost, time, and radiation exposure of fluoroscopy-guided techniques, but this method requires expert knowledge of the topography and 3-dimensional anatomy of the thoracic spine.

Bergeson et al reported significant improvement in resident accuracy rate with freehand placement of thoracic pedicle screws using individual cadaver vertebrae. The current authors investigated the use of an intact cadaver spine for their 2-day cadaver-based education module to teach freehand placement of thoracic pedicle screws, with accuracy assessment based on computed tomography (CT) scan, as in the clinical setting. They compared the accuracy of resident screw placement in the first group of cadaveric specimens vs a second group instrumented after review of the initial CT images and repeated didactic training. The hypothesis was that residents would show a significant improvement in accuracy rate by the end of the module.

**MATERIALS AND METHODS**

**Specimen Preparation**

Twenty-three fresh human upper thoros were used. Anteroposterior (AP) and lateral radiographs were obtained for all specimens to confirm that no spine fracture, deformity, or oncological disease existed. Specimens were placed prone on laboratory operating tables. All soft tissue and paraspinal musculature was retracted to mimic the typical surgical exposure. Ligamentous structures and joint capsules were kept intact. Seven specimens were used by an experienced surgeon (P.J.T.) to assess the accuracy rate of pedicle screw insertion, and the remaining 16 specimens were used by residents participating in the training module. Three orthopedic residents at different training levels participated in the study. All were novices at the procedure.

Based on previous anatomical studies, the junction of the superior articular process-lamina-superior ridge of the transverse process was chosen as a consistent surface landmark to guide the location of the start hole for thoracic pedicle screw placement using the straight-in technique. The senior investigator (P.J.T.), an experienced, fellowship-trained spine surgeon, established the experienced accuracy level using standard procedures.

An entry point was decorticated using a high-speed drill at the surface landmark unilaterally from T1-T12 on 7 specimens. The experienced surgeon then completed pedicle cannulation from T1-T12 in each cadaveric thoracic spine using a curved pedicle probe. Next, each hole was palpated using a ball-tipped probe. This probe was used to provide tactile feedback for assessing the hole for pedicle wall breach. If no breach was felt and a firm endpoint was reached, representing the anterior vertebral body, the probe also served as a guide for pedicle screw trajectory. Each hole was tapped prior to screw insertion and was subsequently reevaluated for breach with the ball-tipped probe. Pedicle screw instrumentation (Revere System; Globus Medical, Inc, Audubon, Pennsylvania) was subsequently placed (screw diameter, 5.0 mm for T1-T4, 4.5 mm for T5-T8, and 5.5 mm T9-T12). Pedicle screw lengths ranged from 35 to 40 mm.

The experienced surgeon administered a self-written multiple-choice test to residents to assess their knowledge of key aspects of pedicle screw placement. The senior investigator included a slide presentation showing the sequence of steps for performing freehand pedicle screw insertion, including (1) creation of a start hole with a 3-mm burr, (2) cannulation of the pedicle with a curved probe, (3) palpation of the pedicle using a ball-tipped probe, (4) tapping of the pilot hole, (5) palpation of the pedicle tract, and (6) final screw placement. Residents used a Sawbones model (Pacific Research Laboratories, Vashon, Washington) to identify the landmark for screw hole placement and then identified the landmark by palpation on a cadaver specimen. The surgeon then demonstrated the screw insertion procedure on a Sawbones specimen. The written test was again administered to residents to assess learning in the didactic session. The residents then each instrumented T1-T12 on alternating sides of 5 consecutive cadaveric spines using the method described above. Residents were timed while instrumenting each of the 5 spines. No feedback was given by the senior investigator during instrumentation to ensure methodological consistency among residents. Axial, sagittal, and coronal reformatted CT images were then obtained for each specimen. A second blinded, experienced,
fellowship-trained spine surgeon (R.M.K.) graded each screw for accuracy and location of a cortical breach, if any. Pedicle screw breach was defined as any breach of the screw shank (inner screw diameter) through the cortical surface of the pedicle or the lateral aspect of the vertebral body (Figure 2). Each resident reviewed the CT images with the senior surgeon.

The second session occurred 1 month after the initial training. The written test was administered again, and the 1-hour didactic session was repeated. The residents then instrumented T1-T12 on alternating sides of 5 consecutive cadaveric spines. Computed tomography images were obtained, and accuracy of pedicle screw insertion was assessed by the second blinded, experienced spine surgeon. The surgeon visually inspected the CT image of each breach to determine whether the error was in the starting point or trajectory.

### Statistical Analysis

Power analysis showed that 60 vertebrae were needed per resident for 80% power to detect a significant difference, assuming a relative accuracy of 85% for the expert and 63% for residents, with an alpha of 0.05. The Fisher exact test and chi-square analyses were used to assess the change in accuracy rate between the first group and the second group of instrumented spines. Analysis of variance was used to compare resident accuracy rates. Pearson correlations were used to determine whether a significant relationship existed between time of instrumentation of each specimen and pedicle screw accuracy. A 2-tailed \( t \) test was used to compare operative time before vs after CT review. Analysis was performed using SPSS version 16 statistical software (SPSS, Inc, Chicago, Illinois).

### RESULTS

The experienced surgeon accurately placed 67 (82%) of 82 pedicle screws from T1 through T12 in 7 cadaveric specimens based on multiplanar CT scans (Table 1). All 15 pedicle breaches by the experienced surgeon were through the lateral cortical pedicle surface.

The residents had an average score of 52% on the pretest, and each scored 100% on the posttest. In the initial set of specimens, 80 (44%) of 180 pedicle screws were inserted accurately (Table 1). Before the second surgical session, residents had an average score of 89% on the repeated written test. In the second set of specimens, 105 (58%) of 180 screws were accurately placed (\( r=6.950; \quad \text{df}=1; \quad P=.01 \)). This success rate was 71% of that achieved by the senior investigator. A significant difference in accuracy rate among residents was observed in the first group of specimens but not in the second group (Table 1). Accuracy varied based on thoracic spine level, with a substantially higher accuracy rate observed in the distal thoracic spine (Table 2).

Of 100 breaches of the pedicle in 180 attempts in the first set of specimens, 13 (13%) were medial breaches. In the second set of specimens, 105 (58%) of 180

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**Figure 1:** Test administered to orthopedic residents. An asterisk identifies the correct answer.
ond set of specimens, 34 (45%) of 75 breaches were medial. Incorrect lateral trajectory was the most common error noted in breaches before and after CT review (Table 3).

Overall mean time to instrument 12 sites on 1 specimen was 29.4 ± 9.2 minutes for the postgraduate year (PGY)-2 resident, 21.9 ± 4.5 minutes for the PGY-3 resident, and 26.7 ± 8.1 minutes for the PGY-4 resident. Mean average instrumentation time for all residents combined was 26.0 ± 7.92 minutes. No significant difference existed in time between the residents (F = 2.512; P = .10). No correlation was found between time and pedicle screw insertion accuracy, and no significant difference existed in time in the first vs the second set of specimens (27.7 ± 8.6 vs 24.3 ± 7.1 minutes; r = 0.101; P = .25).

**DISCUSSION**

A significant increase was observed in accuracy rate among novice orthopedic residents placing thoracic pedicle screws in a pilot didactic/cadaveric laboratory module that closely replicated the clinical setting. Skills were assessed based on an objective measure. These preliminary findings suggest that the basic components of a challenging spine surgery skill can be objectively measured and effectively taught in a relatively short time outside of the operating room. As a potentially more affordable alternative to virtual training via simulators, this training method could be an effective way to build and measure resident surgical skills within the current time and funding constraints.

This pilot study identified potential areas for improvement to raise the level of proficiency developed in the course. Results could be improved if the second training session occurred closer in time to the initial session, thereby building on learning from CT review and initial development of psychomotor skills. Also, it was difficult to clear this training time for residents. Distraction from pagers or awareness of pressure to go to the wards for patient care may have affected performance. In future training sessions, a more concerted effort will be made to obtain truly free educational time to help prevent outside pressures during the session. It is possible that increased awareness of the purpose and value of the session will lead to support from the overall program.

The finding of a significant difference in accuracy rate among residents in the first group of specimens suggests that surgeons inexperienced in the procedure can be expected to show a wide range of skills in their initial effort to place thoracic pedicle screws. The lack of significant difference in accuracy rate among residents in the second group of specimens suggests that a skill threshold exists in the current model. The resident starting at a relatively high initial accuracy did not improve to the same extent as did residents starting with a lower accuracy. A recent study on resident surgical training using a simulator found a similar skill plateau at 12 and 21 training episodes.

The finding of relatively low accuracy rates in the upper thoracic spine (T1-T4) may be related to several factors. The full thoracolumbar specimens were positioned and exposed as in surgery; therefore, the depth of the soft tissue and the amount of

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**Table 1**

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Initial Attempt</th>
<th>Second Attempt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attending</td>
<td>39/46 (85)</td>
<td>28/36 (78)</td>
</tr>
<tr>
<td>All residents</td>
<td>80/180 (44)</td>
<td>105/180 (58)*</td>
</tr>
<tr>
<td>Resident 1: PGY 4</td>
<td>14/60 (23)</td>
<td>32/60 (53)</td>
</tr>
<tr>
<td>Resident 2: PGY 3</td>
<td>25/60 (42)</td>
<td>31/60 (52)</td>
</tr>
<tr>
<td>Resident 3: PGY 2</td>
<td>41/60 (68)</td>
<td>42/60 (70)</td>
</tr>
</tbody>
</table>

**Abbreviations:** CT, computed tomography; PGY, postgraduate year.

*Significant difference (P = .01; r = 6.950).

Analysis of variance.

**Figure 2:** Computed tomography scans showing bilateral accurately placed pedicle screws (A), bilateral wall breaches (B), and a medial pedicle breach (C).
kyphosis were greatest in the upper thoracic levels. It may be more difficult for residents to acquire the skill needed to accurately place thoracic pedicle screws with the higher convergence trajectory needed to cannulate the pedicles at these levels. In contrast, Bergeson et al³ found a higher accuracy rate in the upper thoracic spine, likely reflecting the fact that kyphosis and soft tissues surrounding the spine were eliminated in their study because individual vertebrae were mounted for instrumentation.

In addition, the upper thoracic pedicle diameters are large in adults.²⁰ In the current study, accuracy rates in the midthoracic spine (T4-T9) may have been lower than in the distal spine because pedicle diameters in the midthoracic spine are the smallest of those in the thoracic vertebrae. Bergeson et al³ reported the lowest accuracy rate in T6, which the authors attributed to smaller pedicles at this level. Additional focus on the middle and upper thoracic spine in the current training course may be useful in improving overall accuracy rates.

The majority of breaches were lateral in both the first and second groups of specimens. Excessive lateral trajectory was the most common error found before and after CT review, although the number of occurrences of this error decreased by approximately half after CT review. This finding suggests that residents were initially concerned with avoiding a medial breach after being told about the dangers of this error in the didactic training. The desire to correct for errors of excessively lateral trajectory in the first group of specimens may account for the increase in medial breaches in the second group of specimens. Few errors in location of the starting hole were observed in the first or second group of specimens, suggesting that correct trajectory is the primary challenge of this procedure for novices and that the starting hole location is relatively easy to learn. This is likely explained by the consistency of pedicle start hole location vs the variability of pedicle trajectory depending on spinal level.²⁰

The current laboratory model provided a close approximation of the clinical setting, which may help ensure transferability of skills from the laboratory to the operating room. Full upper torsos were used, and paraspinous soft tissues and rib articulations were left in place. Expert evaluation of CT images was used to determine whether the thoracic pedicle screws were accurately placed. The accuracy rate of 58% in the second set of specimens was lower than that found by Bergeson et al, who used a laboratory model based on immediate feedback with instrumentation of single vertebrae specimens and a definition of accuracy that allowed for breaches of up to 2 mm. As in the current study, those investigators found a significant improvement in accuracy rate after 3 or 4 specimens.⁵

Surgical simulation has been recognized as a valuable educational approach for orthopedic skills training.¹ Sonnadara et al² used a 30-day surgical skills laboratory-based course to train first-year orthopedic residents in essential surgical skills. The authors found significant posttraining improvement in a specific task-related checklist and in a global scale rating general surgical skills. In the current study, the residents’ accuracy rate of approximately 70% of that of the experienced surgeon is substantially lower than the target accuracy rate of 83% adopted

<table>
<thead>
<tr>
<th>Spine Level</th>
<th>Accuracy, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td></td>
</tr>
<tr>
<td>N=30 Spines</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>33.3</td>
</tr>
<tr>
<td>T2</td>
<td>46.7</td>
</tr>
<tr>
<td>T3</td>
<td>40.0</td>
</tr>
<tr>
<td>T4</td>
<td>36.7</td>
</tr>
<tr>
<td>T5</td>
<td>46.7</td>
</tr>
<tr>
<td>T6</td>
<td>46.7</td>
</tr>
<tr>
<td>T7</td>
<td>43.3</td>
</tr>
<tr>
<td>T8</td>
<td>36.7</td>
</tr>
<tr>
<td>T9</td>
<td>50.0</td>
</tr>
<tr>
<td>T10</td>
<td>63.3</td>
</tr>
<tr>
<td>T11</td>
<td>96.7</td>
</tr>
<tr>
<td>T12</td>
<td>76.7</td>
</tr>
<tr>
<td>Second Group</td>
<td></td>
</tr>
<tr>
<td>N=15 Spines</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>33.3</td>
</tr>
<tr>
<td>T2</td>
<td>46.7</td>
</tr>
<tr>
<td>T3</td>
<td>33.3</td>
</tr>
<tr>
<td>T4</td>
<td>33.3</td>
</tr>
<tr>
<td>T5</td>
<td>53.3</td>
</tr>
<tr>
<td>T6</td>
<td>53.3</td>
</tr>
<tr>
<td>T7</td>
<td>53.3</td>
</tr>
<tr>
<td>T8</td>
<td>66.7</td>
</tr>
<tr>
<td>T9</td>
<td>66.7</td>
</tr>
<tr>
<td>T10</td>
<td>73.3</td>
</tr>
<tr>
<td>T11</td>
<td>93.3</td>
</tr>
<tr>
<td>T12</td>
<td>93.3</td>
</tr>
</tbody>
</table>

**Table 2: Accuracy Rate Placing Thoracic Pedicle Screws Based on Thoracic Spine Level**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Medial</th>
<th>Lateral</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-CT</td>
<td>7</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Post-CT</td>
<td>18</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>15</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Medial</th>
<th>Lateral</th>
<th>Inferior</th>
<th>Superior</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-CT</td>
<td>6</td>
<td>67</td>
<td>7</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Post-CT</td>
<td>16</td>
<td>34</td>
<td>4</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>101</td>
<td>11</td>
<td>1</td>
<td>135</td>
</tr>
</tbody>
</table>

**Table 3: Summary of Errors in Breach of Pedicle or Vertebral Body by Residents Before and After CT Review**

*Abbreviation: CT, computed tomography.*
by a multicenter research trial comparing traditional arthroscopic training vs a simulator, or virtual-reality training system. Simulator training is a highly effective and efficient means of developing surgical skills. In a recent study, significantly better results were found in a group of inexperienced trainees using a virtual simulator compared with 2 comparison groups of trainees using conventional surgical preparatory aids. The investigators also noted the training value of experimentation via the simulator and the impracticality of incorporating experimentation into a more traditional training method. According to a recent survey, a majority of program directors and surgical residents believed that surgical simulation should be a required part of training; however, approximately 90% of program directors noted that funding for simulator training was not available. In this setting, it seems possible that didactic/cadaver-based training has the potential for teaching and measuring surgical skills in an affordable way with important advances in resident surgical skills.

The current study has some limitations. The authors purposefully included only 3 residents in this pilot study, and a larger number is needed to assess the strengths and weaknesses of the module. Although a power analysis was performed and statistically significant improvements were found, the results may not generalize to all orthopedic residents. Because scoliotic or pediatric spines were not included in the study, the learning curve reported may not be accurate when applied to those more challenging scenarios. Furthermore, whether the skills acquired during this training module persist or degrade over time cannot be concluded from the data.

**Conclusion**

The accuracy of novice residents placing thoracic pedicle screws improved significantly after participation in this didactic cadaver-based training module. Potential areas for improving the course exist, but the results show that a cadaver-based training module that resembles the clinical setting can be used to objectively measure and teach advanced surgical skills to orthopedic residents.

**REFERENCES**


