Pedicle screws are a mainstay in the treatment of spinal disorders requiring instrumented arthrodesis. Their ability to stabilize the spinal column via a posterior fixation entry point has rendered them the standard to which many other fixation techniques are compared. However, pedicle screw placement may be challenging, particularly in the cervical and thoracic spine because of the smaller pedicle size and complex morphology. As a result, conventional methods based on anatomical landmarks and intraoperative fluoroscopy still result in pedicle breach rates of up to 39.8% in the literature. In light of the potential complications, a number of techniques such as virtual fluoroscopy and CT-based computer guidance systems have been introduced to minimize the risk of pedicle screw placement. Although image-guided surgical techniques have resulted in lower perforation rates (ranging from 9.3% to 14.3%), these technologies have their limitations. Virtual fluoroscopy is dependent on the resolution of the acquired fluoroscopic projections. On the other hand, CT-based computer guidance systems require preoperative imaging; thus, variations in patient positioning before and during the operation may alter intervertebral relationships, leading to potential navigational inaccuracies.

To bridge the gap between preoperative and intraoperative position-dependent changes, intraoperative CT scanning has recently been introduced. Here, we summarize our experience using intraoperative CT scanning during pedicle screw placement for spinal pathologies.
Spinal instrumentation using intraoperative CT

requiring instrumented fusion. We document and catego-
rise our misplaced screws and note the number of patients
who required a postoperative revision surgery for pedicle
screw revision. To compare the efficacy of intraoperative
CT scanning, we also compare our results with a previous
cohort of 964 patients at our institution who received 6816
pedicle screws in the thoracolumbar spine via the free-
hand technique coupled with postoperative CT imaging.30

Methods

Data Collection

We retrospectively reviewed the records of all pa-
tients undergoing pedicle screw placement in the cervi-
cal, thoracic, or lumbar spine from December 2009—the
month that the intraoperative CT scanner was inaugu-
rated at our institution—through July 2012. In this study,
all pedicle screws, including C-2 and C-7 pedicle screws,
were inserted using a free-hand technique in which anato-
mical landmarks are used to guide screw placement.
Fluoroscopy or navigation was not used. The screws were
placed by a total of 8 neurosurgeons. Patient demograph-
ics, clinical presentation, indications for hardware place-
ment, radiological studies, operative variables, and length
of follow-up were reviewed for each case.

For all patients included in this study, the location
and accuracy of the pedicle screws or, in many cases, the
pedicle markers, were objectively evaluated using CT
imaging performed intraoperatively. The presence and
extent of cortical breach by any misplaced pedicle
screw or marker was determined by review of axial, sag-
ital, and coronal reconstructed images obtained from
the intraoperative CT scan. The location and direction
of cortical breach—medial, lateral, superior, inferior, or
anterior—were noted in each instance. The numbers and
locations of screws that were removed and replaced, or
markers that then required a trajectory modification, were
noted. If the marker or screw was placed properly within
the pedicle but the surgeon felt it necessary to make an
adjustment (such as changing the trajectory or the screw
length), the screw was counted as requiring modification.
In some instances, a second CT scan was obtained when
the surgeon wanted to confirm placement of the newly
revised instrumentation. In other instances, if the surgeon
felt confident of the revision, he or she did not obtain a
second scan given concerns for radiation exposure to the
patient. Patients who required revision surgery due to
misplacement of screws were documented.

Surgical Technique

Free-hand pedicle screw placement was performed
using anatomical landmarks as previously described.30
Pilot holes were made using the high-speed air drill. A
pedicle probe was used to cannulate the pedicle. Using
a pedicle feeler, evaluation for a breach was performed.
Upon determining that no breach had occurred, pedicle
markers were placed. If a breach was noted, the traject-
ory was revised using a pedicle probe. Once the traject-
ory was noted to be satisfactory, a pedicle marker was
placed. In some instances a plain lateral radiograph was
obtained intraoperatively to confirm marker position;
then the holes were subsequently tapped and the screws
were placed prior to CT imaging.

An intraoperative CT scanning study with sagittal
and coronal reconstructions was obtained either after
placement of the pedicle markers or, if the surgeon was
confident of the trajectory, after placement of the pedicle
screws. In some instances, a CT scan was obtained after
marker placement, followed by a second scan obtained
after pedicle screw placement. However, as described
above, a second scan was not uniformly obtained. In cas-
es that required intraoperative revision of a pedicle screw,
multiple CT scans may have been obtained based on the
number of revisions needed.

Radiation Exposure

The intraoperative scanner is a 40-slice scanner (as
opposed to a 64-slice scanner). While both scanners emit
similar radiation doses, we tend to scan for a shorter
amount of time with the intraoperative CT because we
focus on the area of instrumentation. For example, a typical
lumbar spine CT would require 10 seconds of scanning
time at 300 mA for a total radiation dose of 8–10 mSv.
With the intraoperative CT, we can focus just on the area
of instrumentation and cut down the scanning time to 4
seconds at 300 mA for a total radiation dose of 3–4 mSv.
The radiation exposure to the surgeon is nonexistent as all
surgeons completely leave the operating room while the
CT scan is taking place.

Operative Time

At our institution, preparation of the anesthetized
patient for the imaging procedure requires 15 minutes
while the patient is positioned but before skin incision.
Each intraoperative CT scan and interpretation of the
subsequent images by the spine surgeon requires an ad-
ditional 10 minutes. Therefore, radiological confirmation
of the pedicle screws after 1 intraoperative CT scan adds
25 minutes to the total operative time.

Results

Patient Population

In December 2009, our institution began using an in-
traoperative CT scanner. Between December 2009 and
July 2012, a total of 203 patients underwent posterior
spinal instrumented fusion using confirmatory intraop-
erative CT imaging. The average patient age was 61.0 ±
11.7 years, and 45.3% were male. Of these 203 patients,
24 (11.8%) underwent surgery for trauma to the spine, 23
(11.3%) had tumors, 148 (72.9%) had degenerative spi-
nal disease, 68 (33.5%) had spondylolisthesis, 4 (2.0%)
had congenital spinal disorders, and 10 (4.9%) had infec-
tious pathology of the spine (Fig. 1). Twenty-nine patients
(11.3%) had diabetes mellitus, 78 (44.3%) had hyperten-
sion, 8 (4.5%) had coronary artery disease, 15 (8.5%) had
osteoporosis, 3 (1.7%) were morbidly obese, 4 (2.3%) had
chronic obstructive pulmonary disease, and 43 (24.4%)
had a history of previous spinal surgery. Forty-nine pa-
tients underwent cervical pedicle screw placement at ei-
ther C-2 or C-7; 184 patients had pedicle screws placed in the thoracic or lumbar region. Thirty patients had subaxial cervical constructs that extended into the thoracic region.

In total, 56 (4.88%) pedicle screws were placed at C-2, and 20 (1.74%) pedicle screws were placed at C-7 (Fig. 2 upper). In the thoracic spine, 72 (6.27%) pedicle screws were placed at T-1, 78 (6.79%) were inserted at T-2, 18 (1.57%) at T-3, 18 (1.57%) at T-4, 12 (1.05%) at T-5, 9 (0.78%) at T-6, 16 (1.39%) at T-7, 20 (1.74%) at T-8, 16 (1.39%) at T-9, 32 (2.79%) at T-10, 32 (2.79%) at T-11, and 22 (1.92%) at T-12. Forty pedicle screws (3.48%) were placed at L-1, 76 (6.62%) screws were placed at L-2, 128 (11.15%) at L-3, 199 (17.33%) at L-4, 195 (16.99%) at L-5, and 89 (7.75%) at S-1. Of a total of 1148 screws, 76 (6.57%) were placed in the cervical spine, 345 (29.84%) were inserted in the thoracic spine, and 727 (62.89%) were placed in the lumbar spine. Excluding the cervical cases, a total of 1072 screws were placed in the thoracic or lumbar spine. Of thoracic and lumbar screws alone, 6.71% were placed at T-1, 7.28% at T-2, 1.68% at T-3, 1.68% at T-4, 1.12% at T-5, 0.84% at T-6, 1.49% at T-7, 1.87% at T-8, 1.49% at T-9, 2.99% at T-10, 2.99% at T-11, 2.05% at T-12, 3.73% at L-1, 7.09% at L-2, 11.94% at L-3, 18.56% at L-4, 18.19% at L-5, and 8.3% at S-1 (Fig. 2 lower). In total, 32.2% of pedicle screws in this subgroup were placed in the thoracic spine, whereas 67.8% were inserted in the lumbar spine.

**Intraoperative and Perioperative Outcomes**

Within the cervical spine, 7 (12.50%) of the 56 pedicle screws or markers at C-2 were revised intraoperatively, and 7 (35.00%) of the 20 pedicle screws or markers at C-7 were revised (Fig. 3 upper). Four (5.56%) of 72 screws were revised at T-1, 10 (12.82%) of 78 screws at T-2, 2 (11.11%) of 18 screws at T-3, 1 (5.56%) of 18 screws at T-4, 1 (8.33%) of 12 screws at T-5, 1 (11.11%) of 9 screws at T-6, 1 (6.25%) of 16 screws at T-7, 2 (10.00%) of 20 screws at T-8, 1 (6.25%) of 16 screws at T-9, 1 (3.12%) of 32 screws at T-10, 0 (0.00%) of 32 screws at T-11, and 1 (4.55%) of 22 screws at T-12. Within the lumbar spine, 2 (5.00%) of 40 screws or markers were revised at L-1, 5 (6.58%) of 76 screws at L-2, 9 (7.03%) of 128 screws at L-3, 15 (7.54%) of 199 screws at L-4, 25 (12.82%) of 195 screws at L-5, and 8 (8.99%) of 89 screws at S-1. Thus, of 1148 pedicle screws, a total of 103 (8.97%) were revised: 14 (18.42%) of 76 screws were revised in the cervical spine, 25 (7.25%) of 345 screws were revised in the thoracic spine, and 64 (8.80%) of 727 screws were revised in the lumbar spine (Fig. 3 lower). Compared with screws in the thoracic and lumbar regions, pedicle screws placed in the cervical spine were statistically more likely to be revised (p = 0.0061). In contrast, there was no statistical difference between the rates of revised screws between the thoracic and lumbar regions (p = 0.4098).

In total, 103 pedicle screws (8.97%) were revised in 72 patients (35.5%). Of this total, 41 pedicle screws or markers (39.81%) were classified as having a lateral breach based on intraoperative CT scanning. Twenty-nine pedicle screws or markers (28.16%) were medially...
Spinal instrumentation using intraoperative CT

breached, 7 (6.80%) were superiorly breached, and 13 (12.62%) were inferiorly breached. In these cases, the screw was removed and placed again along an improved trajectory. If the marker was found to have breached the pedicle cortex, it was removed and a new trajectory was obtained using the pedicle finder. Twelve pedicle screws or markers (11.65%) violated the anterior vertebral body cortex; they were removed and replaced with shorter screws. On the other hand, 8 screws (7.77%) were deemed too short and were replaced with longer screws (Fig. 4). Four pedicle screws were removed and not replaced. Three screws were replaced with ones with a larger diameter. Only one screw was revised to accommodate a smaller diameter screw.

Of note, in 172 patients (84.73%) the pedicle screws were placed prior to intraoperative imaging, while in the remaining 31 patients (15.27%) markers were used. Of the 103 revised screws or markers, 94 trajectories (91.26%) were changed following scanning with pedicle screws versus 9 revisions (8.74%) following pedicle markers (Fig. 5).

Intraoperatively, 17 patients (3.44%) had incidental durotomies. Perioperatively, 4 patients (1.97%) had surgical site infections, 3 (1.48%) had CSF leaks, 1 (0.49%) experienced deep venous thrombosis, and 1 (0.49%) had a pulmonary embolism. The average length of stay for patients was 6.33 ± 5.17 days.

Two patients required reoperations 3 and 4 days after the index operation because of undetected misplacement of pedicle screws. In the first case, the patient underwent an instrumented L1–3 posterolateral fusion. Intraoperatively, the left L-3 screw had been revised because of a medial breach; however, a postrevision CT scan was not obtained. Postoperatively, the patient experienced unremitting left L-3 radiculopathy. A postoperative CT scan

![Graph showing number of pedicle screws placed in the cervical, thoracic, and lumbar spine as a percentage of total pedicle screws placed. Lower: Percentage of pedicle screws placed in the thoracic and lumbar spine only.](image-url)
was subsequently ordered, and the left L-3 screw was found to have inferiorly breached the pedicle. The patient was taken back to the operating room; the left L-3 screw was removed, and the fusion was extended to L-4. Intraoperative CT scanning revealed proper placement of the pedicle screws. After the revision surgery, the patient’s symptoms improved and the patient was discharged to rehabilitation with no residual neurological deficit. In the second case, the patient underwent an L2–3 instrumented posterolateral fusion. Intraoperative CT imaging revealed proper placement of the pedicle markers. Pedicle screws were subsequently placed; a second intraoperative CT scan was not obtained after screw placement. Postoperatively, the patient complained of significant abdominal pain. A CT scan was obtained and revealed an anteriorly breached right L-2 screw, abutting the aorta. The vascular surgery team was consulted, and removal of the screw was recommended. The patient was taken back to the operating room; the right L-2 screw was removed and replaced with a shorter screw. The patient was subsequently discharged to home with no neurological deficit.

Discussion

Pedicle screws have become the standard by which all other posterior instrumented fixation techniques are compared. Despite being one of the predominant means of fixation in the posterior spine, the intrinsic anatomy inherent to screw placement, coupled with interpatient pedicle variability, translates into the potential for neurological risk to many patients. Rampersaud et al. demonstrated that the mean maximum permissible translational screw placement error in the thoracic spine was 0.6 mm, with a rotational error of 2.6°. In the lumbar spine, the translational screw placement error was 2.0 mm and the rotational error was 6.3°. In light of the small margin for error, a number of assistive techniques such as virtual fluoroscopy and CT-based computer guidance...
systems have been introduced to increase the accuracy of pedicle screw placement. The recent advent of intraoperative CT scanning offers the possibility of monitoring and visualization of pedicle screws immediately after their placement.

In our experience, among the 203 patients who underwent pedicle screw placement with intraoperative CT imaging, 72.9% had degenerative spinal disease. Of 1148 pedicle screws placed, 76 (6.57%) were placed in the cervical spine, 345 (29.84%) were inserted in the thoracic spine, and 727 (62.89%) were placed in the lumbar spine. To compare the efficacy of the intraoperative CT scanner in reducing reoperations for pedicle screw revision, we compared our results with our published institutional series of pedicle screws placed via a free-hand technique confirmed with postoperative CT.

In our previous study, we reported the results of 6816 pedicle screws placed via free-hand technique in 964 patients at our institution. Among these screws, 3443 (50.5%) were placed in the thoracic spine and 3373 (49.5%) were placed in the lumbar spine. Upon postoperative CT scanning, 115 screws (1.7%) were identified as breaching the pedicle or vertebral body cortex. Compared with our breach rate of 103 (9.61%) of 1072 screws placed in the thoracic/lumbar spine, this was a significantly lower rate (p < 0.0001). Among the free-hand cohort, these 115 pedicle screws were misplaced in 87 patients (9.0%); in our cohort who underwent intraoperative CT scanning, screws were revised in 72 patients (35.5%). This increase in this cohort was statistically significant (p < 0.0001).

The increase in breach rate—both in terms of misplaced screws and number of patients affected—is likely due to differing definitions of breached screws. In the publication describing the free-hand technique with postoperative CT scans, we defined breach as pedicle screws with more than 25% of the screw diameter residing outside the pedicle or vertebral body cortex. In contrast, in this study any perceived breach of pedicle screws or pedicle markers visualized on the intraoperative CT scan prompted surgeons to revise the screw. Additionally, screws that were too short or those that the surgeon deemed required an improved trajectory were counted as revised/breached screws. Thus, the intraoperative CT scanner is much more sensitive at detecting unfavorably placed screws than conventional intraoperative fluoroscopy or radiography and dramatically lowers the threshold for screw revision.

This lowered threshold for screw revision likely explains the equivalent rates of revision between thoracic and lumbar pedicle screws in the intraoperative CT scan cohort. Thus, whereas patients who received free-hand pedicle screws had a thoracic spine breach rate of 2.5% versus a 0.9% breach rate within the lumbar spine (p < 0.0001), patients who underwent intraoperative CT imaging had 25 screws (7.25%) revised in the thoracic spine and 64 (8.80%) revised in the lumbar spine (p = 0.4098) (Table 1). In contrast, 14 pedicle screws (18.42%) were revised in the cervical spine, with the highest percentage of revised screws at C-7 (35.0%). The cervical screw revision rate was statistically higher than the thoracic or lumbar screw revision rates in patients undergoing intraoperative CT imaging (p < 0.0001).

In patients undergoing free-hand pedicle screw placement in the previously published series, the direction of breach was lateral in 73 cases (61.3%), medial in 39 (32.8%), and superior in 3 (2.5%). For patients who had pedicle screw placement with the assistance of the intraoperative CT scanner, 41 pedicle screws (39.81%) were classified as lateral breached, 29 pedicle screws (28.16%) were medially breached, and 7 (6.80%) were superiorly breached (Table 1). These trends were consistent regardless of patient cohort, likely due to the fact that screws were placed using the free-hand technique in both the postoperative CT scan and intraoperative CT scan cohorts. Thus, although the detection of screw breaches may be made and corrected intraoperatively, the quality...
of the breach itself is likely to be unaltered by the presence of the intraoperative CT scanner. Nonetheless, intraoperative imaging did allow for replacement of short screws and for adjustments to the trajectory of suboptimal screws that did not have a frank breach. In the previously published postoperative CT scanning cohort, 8 patients (0.8%) underwent revision surgery to correct a malpositioned screw. In contrast, 2 patients (0.99%) in the intraoperative CT cohort required reoperations due to misplaced hardware. Compared with patients experiencing free-hand placement of screws with postoperative CT scans, patients in the intraoperative CT cohort had a similar rate of reoperation (p = 0.6881).

We also compared our results with a similar cohort of patients undergoing postoperative CT scans by the same surgeons during a matched period of time as the intraoperative CT cohort of patients (2009–2012; Tables 2 and 3). In this postoperative cohort, 4440 pedicle screws were placed via free-hand technique in 607 patients at our institution (Table 2). On postoperative CT scanning, 6 misplaced pedicle screws required reoperation for screw revision. The most common indication for revision was anterior displacement of the pedicle that extended beyond the vertebral body (3 of the 6 revisions; Table 3). In these cases, the long screw compressed the adjacent aorta with a risk of a luminal tear (Fig. 5). Of the 607 cases, the reoperation rate in the postoperative CT cohort was 0.99%, comparable to a reoperation rate of 0.99% in the intraoperative CT cohort (p = 0.997).

Our results demonstrate that the presence of intraoperative CT scanning lowers the threshold for pedicle screw revision, resulting in statistically higher rates of pedicle screw revision in the thoracic and lumbar spine compared with postoperative CT scanning. Many of the revisions done in the intraoperative CT cohort were to correct minor breaches that would have been merely observed had intraoperative CT imaging not been available. Thus, we may have unnecessarily revised some screws in the absence of neurovascular impingement by the screw or loss of biomechanical fixation. However, given the presence of the intraoperative CT scanner and the relative ease of revising pedicle screws during the initial surgery, various spinal surgeons consistently decided to make minor adjustments to seemingly render the instrumentation perfect. Unfortunately, our results indicate that the intraoperative CT and the relative ease of revising pedicle screws during the initial surgery, various spinal surgeons consistently decided to make minor adjustments to seemingly render the instrumentation perfect. Unfortunately, our results indicate that the intraoperative CT and postoperative CT groups were very similar. Intraoperative CT imaging allowed for correction of minor breaches that would have been merely observed had intraoperative CT imaging not been available. Thus, we may have unnecessarily revised some screws in the absence of neurovascular impingement by the screw or loss of biomechanical fixation. However, given the presence of the intraoperative CT scanner and the relative ease of revising pedicle screws during the initial surgery, various spinal surgeons consistently decided to make minor adjustments to seemingly render the instrumentation perfect. Unfortunately, our results indicate that the intraoperative CT and postoperative CT groups were very similar.

### TABLE 1: Comparison of revision rates and direction of pedicle screw breaches between the intraoperative CT group and the postoperative CT group (published data set)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rate (%)</th>
<th>Intraop CT</th>
<th>Postop CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>revision rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thoracic</td>
<td>7.25</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>lumbar</td>
<td>8.80</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>direction of pedicle screw breaches‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lateral</td>
<td>39.81</td>
<td>61.3</td>
<td></td>
</tr>
<tr>
<td>medial</td>
<td>28.16</td>
<td>32.8</td>
<td></td>
</tr>
<tr>
<td>superior</td>
<td>6.8</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>inferior</td>
<td>12.62</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>anterior</td>
<td>11.65</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>short screws</td>
<td>7.77</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

* NA = not available.
† A total of 1148 screws were placed in the intraoperative CT group and 6816 were placed in the postoperative CT group.
‡ A total of 103 pedicle screw revisions were performed in the intraoperative CT group and 115 were performed in the postoperative CT group.

### TABLE 2: Comparison of perioperative characteristics in patients undergoing intraoperative versus postoperative CT scanning (matched patient data set)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Intraop CT</th>
<th>Postop CT</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of patients</td>
<td>203</td>
<td>607</td>
<td></td>
</tr>
<tr>
<td>mean age ± SD</td>
<td>61.0 ± 11.7</td>
<td>59.1 ± 15.3</td>
<td>0.076</td>
</tr>
<tr>
<td>diagnosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>congenital</td>
<td>4 (2.0)</td>
<td>23 (3.79)</td>
<td>0.230</td>
</tr>
<tr>
<td>degenerative spinal disease</td>
<td>148 (72.9)</td>
<td>450 (74.14)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>infection</td>
<td>10 (4.9)</td>
<td>18 (2.97)</td>
<td>0.164</td>
</tr>
<tr>
<td>spondylolisthesis</td>
<td>68 (33.5)</td>
<td>98 (16.14)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>trauma</td>
<td>24 (11.8)</td>
<td>38 (6.26)</td>
<td>0.010</td>
</tr>
<tr>
<td>tumor</td>
<td>23 (23.0)</td>
<td>94 (15.49)</td>
<td>0.190</td>
</tr>
<tr>
<td>spinal region</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cervical only</td>
<td>19 (9.4)</td>
<td>154 (25.37)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>cervicothoracic</td>
<td>30 (14.8)</td>
<td>111 (18.29)</td>
<td>0.233</td>
</tr>
<tr>
<td>thoracolumbar</td>
<td>184 (90.6)</td>
<td>342 (56.34)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>blood loss (ml)</td>
<td>547.22</td>
<td>527.5</td>
<td>0.924</td>
</tr>
<tr>
<td>total no. of screws</td>
<td>1148</td>
<td>4440</td>
<td></td>
</tr>
<tr>
<td>mean no. of screws/op ± SD</td>
<td>5.7 ± 2.7</td>
<td>7.3 ± 4.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>reop for misplaced screws</td>
<td>2 (0.99)</td>
<td>6 (0.99)</td>
<td>0.997</td>
</tr>
</tbody>
</table>

* Values are presented as the number of cases (%) unless specified otherwise. Values in boldface are statistically significant.

### TABLE 3: Comparison of direction of pedicle screw breaches and location between the intraoperative CT group and the postoperative CT group (matched patient data set)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Intraop CT Revisions (%)</th>
<th>Postop CT Revisions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of revisions</td>
<td>103</td>
<td>6</td>
</tr>
<tr>
<td>direction of breach</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lateral</td>
<td>41 (39.81)</td>
<td>2 (33.33)</td>
</tr>
<tr>
<td>medial</td>
<td>29 (28.16)</td>
<td>1 (16.67)</td>
</tr>
<tr>
<td>superior</td>
<td>7 (6.80)</td>
<td>NA</td>
</tr>
<tr>
<td>inferior</td>
<td>13 (12.62)</td>
<td>NA</td>
</tr>
<tr>
<td>anterior</td>
<td>12 (11.65)</td>
<td>3 (50.00)</td>
</tr>
<tr>
<td>short</td>
<td>8 (7.77)</td>
<td>1 (16.67)</td>
</tr>
<tr>
<td>location of breach</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cervical</td>
<td>14 (16.42)</td>
<td>NA</td>
</tr>
<tr>
<td>thoracic</td>
<td>25 (7.25)</td>
<td>1 (16.67)</td>
</tr>
<tr>
<td>lumbar</td>
<td>64 (8.80)</td>
<td>5 (83.33)</td>
</tr>
</tbody>
</table>
operative CT scanner is no guarantee of perfection. In our institution’s 2.5-year experience with the intraoperative CT in 203 patients, we did not observe a decrease in rates of reoperation due to pedicle screw misplacement. As with all retrospective clinical studies, certain biases may play a confounding role. Since our university is a teaching institution, although the attending surgeons remained constant over the time course of these studies, the residents and fellows may not have been equally represented throughout. Along these lines, the surgeons in this study use the free-hand insertion technique. This method has certain advantages but it has limitations as well, namely the lack of radiographic guidance during screw placement. The imaging protocol that was used also varied depending on the surgeon’s preference. Some surgeons obtained intraoperative CT images after pedicle marker placement, while others obtained images after pedicle screw placement. Some surgeons obtained 1 intraoperative CT scanning study, while others obtained multiple studies to confirm placement of particularly difficult pedicle screws. Finally, although indications for surgery in both the intraoperative CT as well as postoperative CT cohorts were similar, the exact percentages of underlying pathologies (trauma, tumor, degenerative, spondylolisthesis, congenital, and infection) were not the same. Thus, additional studies with more patients are needed to further confirm whether the presence of an intraoperative CT scanner can effectively reduce the rate of reoperations due to misplaced pedicle screws.

Conclusions

Pedicle screws remain technically demanding to place as a result of the intrinsic anatomy involved and considerable interpatient variability. To date, a number of technologies have aimed to increase the accuracy rate of pedicle screw placement with the ultimate goal of reducing reoperation rates due to misplaced pedicle screws. Here, we present one of the first experiences in a North American population using an intraoperative CT scanner. Our experience suggests that use of intraoperative CT scanning reduces the threshold for revising pedicle screws, increasing the overall incidence of screw revision. Our initial 2.5-year experience did not show a decreased rate of reoperation compared with the free-hand pedicle screw placement technique with postoperative CT imaging. Future studies with larger patient populations will be needed to demonstrate more concretely the effectiveness of intraoperative CT scanning in enhancing patient safety during pedicle screw placement.

Disclosure

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References


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