Accuracy and safety of free-hand pedicle screw fixation in age less than 10 years

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ABSTRACT
Background: Pedicle screws are being used commonly in the treatment of various spinal disorders. However, use of pedicle screws in the pediatric population is not routinely recommended because of the risk of complications. The present study was to evaluate the safety of pedicle screws placed in children aged less than 10 years with spinal deformities and to determine the accuracy and complication (early and late) of pedicle screw placement using the postoperative computed tomography (CT) scans.

Materials and Methods: Thirty one patients (11 males and 20 females) who underwent 261 pedicle screw fixations (177 in thoracic vertebrae and 84 in lumbar vertebrae) for a variety of pediatric spinal deformities at a single institution were included in the study. The average age of patients was 7 years and 10 months. These patients underwent postoperative CT scan which was assessed by two independent observers (spine surgeons) not involved in the treatment.

Results: Breach rate was 5.4% (14/261 screws) for all pedicles. Of the 177 screws placed in the thoracic spine, 13 (7.3%) had breached the pedicle, that is 92.7% of the screws were accurately placed within pedicles. Seven screws (4%) had breached the medial pedicle wall, 4 screws (2.3%) had breached the lateral pedicle wall and 2 screws (1.1%) had breached the superior or inferior pedicle wall respectively. Of the 84 screws placed in the lumbar spine, 83 (98.8%) screws were accurately placed within the pedicle. Only 1 screw (1.2%) was found to be laterally displaced. In addition, the breach rate was found to be 4.2% (11/261 screws) with respect to the vertebral bodies. No neurological, vascular or visceral complications were encountered.

Conclusions: The accuracy of pedicle screw placement in pedicles and vertebral bodies were 94.6% and 95.8% respectively and there was no complication related to screw placement noted until the last followup. These results suggest that free-hand pedicle screw fixation can be safely used in patients younger than 10 years to treat a variety of spinal disorders.

Key words: Computed tomography, pediatric spine, pedicle screws

INTRODUCTION

Spinal instrumentation systems that use pedicle screws have gained popularity for the surgical treatment of various spinal deformities. The use of pedicle screws offers several advantages, which include three-column fixation, improved deformity correction, reduced rate of pseudoarthrosis and reduced rate of implant failure without the routine use of a postoperative orthosis. Furthermore, pedicle screws have been shown to resist significantly greater loads than spinous process wires. Pedicle screws have also been reported to perform as well as or better than sublaminar wires and hooks.

However, use of pedicle screws in the pediatric population is not routinely recommended because of the risk of complications, based on the belief that the smaller pedicle diameters of vertebrae in children (especially thoracic vertebrae) increase the risk of injuries to the spinal cord and segmental vessels during the transpedicular fixation. Furthermore, screw placement might be even more difficult in the presence of a spinal deformity. In addition, it has been reported that a theoretical risk of spinal stenosis exists with pedicle screw fixation in children.

Despite these concerns, owing to its proven biomechanical benefits, the indications for pedicle screw placement in young children are gradually increasing, currently encompassing trauma, posterior hemivertebra resection, congenital kyphosis and scoliosis.
This study was undertaken retrospectively to evaluate the safety of pedicle screw placement in children aged less than 10 years with a scoliotic deformity by documenting the incidence of short and long term complications and by determining the accuracy of pedicle screw placement by computed tomography (CT) scan.

**Materials and Methods**

Patients aged less than 10 years that underwent pedicle screw fixation from 2003 to 2009 at our institution were the subjects of this study. The study was approved by our Institutional Review Board. 31 patients (11 males and 20 females) of average age 7 years and 10 months (range: 2 years 3 months - 9 years 11 months) were included in the study. These patients were followed up for a mean of 45 months (range: 25-84 months). Of the 31 patients, 27 had congenital kyphoscoliosis, 2 had neuromuscular scoliosis and 2 cases of idiopathic juvenile scoliosis [Table 1].

261 pedicular screws (177 in thoracic vertebrae and 84 in lumbar vertebrae) were inserted in the 31 patients from vertebral level T1 to L5 (an average of 8.4 screws per patient). All surgeries were performed by the two senior spine surgeons (J.Y.C. and H.Y.S.). CT scans were taken immediately after surgery. A retrospective chart review and assessment of postoperative CT scans was performed. All the pedicle screws were placed using the free hand technique. The starting point in all the thoracic vertebrae was the junction of the horizontal line along the inferior border, just below the facet joint and the vertical line at the junction of the outer third and inner two-thirds of the facet joint, chosen as an ideal entry point for thoracic pedicles. If there was any difficulty, then the funnel technique of pedicular screw insertion was used.

In the lumbar spine, the junction of the mammillary process, center of the base of transverse process and the pars interarticularis (Roy-Camille technique) was chosen as the entry point.

Entry point was initially delineated using a rongeur to allow visualization of cancellous bone and obtain a good grip of the trocar. Further passage in the pedicle was achieved using a laterally directed short trocar, which was rotated medially for further entry without using the undue force while inserting. A slightly curved ball point tip probe was used to check the entry point and passage in the pedicle again. Transpedicular drilling was then performed and bone was felt through the entire length of the pedicle and body. Drilling should proceed in a smooth and consistent manner with a snug feel because of the small size of the pedicle. Any sudden advancement of the drilling or probing suggests penetration of the pedicle wall or vertebral body violation. Once the drilling was over, the tract was visualized to make sure that only blood was coming out and not cerebrospinal fluid. For confirming the drilling position, drill-bit was inserted into the tracks and checked imaging via fluoroscopy. The coronal and sagittal radiographs confirmed the harmonious position. A ball point tip probe was again used to check pedicle wall integrity. If any breach was found, entry was gained using a different direction. The pedicle was then under tapped and the pedicle tract was once again palpated. Finally, screws of the appropriate length and diameter were inserted [Figure 1].

On postoperative CT scans, pedicle screw breach, that is, perforation of the pedicle wall, vertebral body endplate, or the anterior cortex were evaluated. “No breach” was

![Figure 1: A 9-year-old girl with juvenile scoliosis (double thoracic curve). (a) Preoperative anteroposterior radiograph shows 60° main thoracic curve and 45° proximal thoracic curve. (b) Preoperative lateral radiograph. (c) Anteroposterior radiograph taken 1 month later surgery. The main thoracic curve was corrected to 17° and the proximal thoracic curve was corrected to 25°. (d) Lateral radiograph taken 1 month later surgery. (e and f) Anteroposterior and lateral radiographs taken 2 years later surgery. Coronal and sagittal alignments were well maintained during the followup](image-url)

| Diagnosis                        | No. patients |
|----------------------------------|--------------|
| Congenital kyphoscoliosis         | 27           |
| Neuromuscular scoliosis           | 2            |
| Juvenile idiopathic scoliosis     | 2            |

Table 1: Indications
defined when the axis of the screw was within pedicle cortex [Figure 2] and “breach” when the screw axis lay outside pedicle cortex [Figures 3 and 4]. Postoperative CT scans were obtained using 3-mm bone windows. Scans were examined on a CT viewer to allow precise evaluation. Two independent observers (spine surgeons) not involved in the surgeries assessed each CT scan and collected data. Discrepancies were settled by consensus.

To evaluate postoperative complications, charts and radiographs from the perioperative period to final followup were reviewed. Long term complications were defined as those presenting 2 years after surgery.

**RESULTS**

No neurologic, vascular, or visceral complication was encountered in any of the 31 patients. However one screw required immediate revision due to lateral malposition. Two cases of deep infection occurred postoperatively, but resolved after debridement and irrigation. In addition, two patients had respiratory problems that resolved in the intensive care unit without life-threatening events.

Screw breach was not associated with pedicle fracture and all breached screws were asymptomatic. The accuracy of pedicular screw placement was 94.6% [247/261 screws; Table 2]. Of the 177 screws placed in thoracic spines, 13 (7.3%) had breached, that is 92.7% of screws were accurately placed within thoracic pedicles. 7 screws (4.0%) perforated the medial pedicle wall, 4 screws (2.3%) perforated the lateral pedicle wall and 2 screws (1.1%) perforated either superior or inferior pedicle wall. Of the 84 screws placed in the lumbar spine, one screw (1.2%) breached laterally, that is 98.8% of the screws were accurately placed within pedicles. The number of inserted pedicle screws at each level and screws that breached is summarized in Table 3. In addition, the accuracy of pedicle screw placement in the bodies was 95.8% (250/261 screws) [Table 4]. 3 of 31 patients (9.7%) had breached screws. Median screw diameter in the thoracic area (T1-T12) was 5 mm (range 4.35-6 mm) and in the lumbar region (L1-L5) it was 5.5 mm (range: 5-6 mm). The median screw lengths in the thoracic (T1-T12) and lumbar (L1-L5) areas were 30 mm (range: 30-40 mm) and 40 mm (range: 30-45 mm), respectively.

In terms of long term complications, deformity progression more than 10° of Cobb angle occurred in three patients (9.7%). Two of these underwent revision surgeries of fusion levels extension for the adding-on phenomenon (at 13 months and 18 months later the primary surgery) and one case was applied the spinal orthosis (at 8 months after surgery). However, no revision surgery was conducted for screw-related reasons (there was no screw pull-out and breakage).
In the present study, 14 of 261 pedicle screws had breached in patients aged less than 10 years, but no short term complications specifically, related to the use of pedicle screws were encountered. These results confirm that pedicle screws of appropriate diameter and length can be and safely placed in patients less than 10 years of age with meticulous technique. Three patients in this series had deformity progression and interpediculate spinal canal diameters demonstrate little growth after 3 years of age. Furthermore, in the present study, coronal, sagittal and axial plane CT images were used to evaluate screw positions and thus, assessments of not only superior and inferior breach but foraminal breach were also possible. The identification of a foraminal breach is particularly important in the lower lumbar spine where the breached pedicle screw could impinge a nerve root ganglion or even the nerve root itself.

In the present study, we studied the screw breach rate in patients aged less than 10 years. This age was chosen based on the juvenile categorization of idiopathic scoliosis and the growth features of the pedicle. In the upper thoracolumbar spine (T12-L3), pedicles reach the adult size (1 cm) by 12 years of age, and anteroposterior and interpediculare spinal canal diameters demonstrate little growth after 3 years of age. In addition, growth of the pedicle in relation to the spinal canal showed that the increase in pedicle size takes place lateral to the spinal canal. The findings of the present study suggest that pedicle screw diameters of 5-6 mm lengths of up to 17

### Table 2: Screw breaches in pedicles as assessed by CT

| Level | No. of screws | No. of screw breach |
|-------|---------------|----------------------|
|       |               | Medial | Lateral | Superior | Inferior |
| Thoracic | 177          | 7 | 4 | 1 | 1 |
| Lumbar   | 84           | 0 | 1 | 0 | 0 |
| Total    | 261          | 14 (5.4%) |

CT = Computed tomography

### Table 3: Details of the screws that breached with respect to pedicular level and anatomy

| Level | No. of screws | No. of screw breach |
|-------|---------------|----------------------|
|       |               | Medial | Lateral | Superior | Inferior |
| T1     | 11            | 1 | 0 | 0 | 0 |
| T2     | 9             | 0 | 1 | 1 | 0 |
| T3     | 8             | 0 | 1 | 0 | 0 |
| T4     | 11            | 0 | 0 | 0 | 0 |
| T5     | 15            | 0 | 0 | 0 | 0 |
| T6     | 17            | 1 | 0 | 0 | 0 |
| T7     | 17            | 1 | 0 | 0 | 0 |
| T8     | 18            | 0 | 0 | 0 | 1 |
| T9     | 19            | 0 | 0 | 0 | 0 |
| T10    | 22            | 0 | 1 | 0 | 0 |
| T11    | 19            | 1 | 0 | 0 | 0 |
| T12    | 17            | 3 | 1 | 0 | 0 |
| L1     | 19            | 0 | 1 | 0 | 0 |
| L2     | 24            | 0 | 0 | 0 | 0 |
| L3     | 16            | 0 | 0 | 0 | 0 |
| L4     | 12            | 0 | 0 | 0 | 0 |
| L5     | 7             | 0 | 0 | 0 | 0 |

CT = Computed tomography

### Table 4: Screw breaches in vertebral bodies as assessed by CT

| Level | No. of screws | No. of screw breach |
|-------|---------------|----------------------|
|       |               | Anterior cortex | Superior end plate |
| Thoracic | 177          | 5 | 5 |
| Lumbar   | 84           | 1 | 0 |
| Total    | 261          | 11 (4.2%) |

CT = Computed tomography

**DISCUSSION**

In the present study, 14 of 261 pedicle screws had breached in patients aged less than 10 years, but no short term complications specifically, related to the use of pedicle screws were encountered. These results confirm that pedicle screws of appropriate diameter and length can be and safely placed in patients less than 10 years of age with meticulous technique.

Three patients in this series had deformity progression without loosening or breakage of the pedicle screws and a limited fusion, two levels above the neutral vertebra had to be done for them. Several studies have addressed the results and complications associated with pedicle screw use in patients with a spinal deformity, but the majority of these studies involved adolescent cases. Transpedicular fixation is a relatively safe method provided that appropriate screw dimensions are selected based on considerations of pedicle morphometry in a given population. Though, uncommon studies have been undertaken regarding the use of pedicle screws in preadolescent patients. Ranade et al. described the accuracy of pedicle screw placement in 16 children aged less than 8 years of age as assessed by CT and reported an overall breach rate of 6.8% with no neurologic or vascular injury. Ruf and Harms described the use of transpedicular instrumentation following posterior hemivertebra resection in 25 children aged 1-6 years without any neurologic complications. Furthermore, three patients at 7-year followup showed near normal growth of instrumented vertebrae and achieved excellent correction (72%) in the coronal plane. As demonstrated by the above results, theoretically, pediatric patients had higher dilation potential based on considerations of bone plasticity. Misenheimer et al. concluded that when the endosteal pedicle diameter is exceeded, due to the sequential application of increasingly larger screw diameters, one of the following three outcomes is possible: Pedicle expansion, pedicle cut out by screw threads, or pedicular fracture. In the present study, we were able to use pedicle screws of slightly larger diameter, probably because of the plasticities of the pedicle and the ability to undergo expansion. No pedicle fractures were encountered in this series.

CT scans are commonly used to determine the accuracy of pedicle screw placement based on assessments of the containment of pedicle screw axis within pedicle cortices. The long term implications of asymptomatic thoracic pedicle screw breaches are largely unknown. As shown in previous studies, slight medial (≤2 mm) or lateral (≤6 mm) breaches are of little clinical consequence. In the present study, there were no neurologic, vascular or visceral complications, which concur with previous reports. Furthermore, in the present study, coronal, sagittal and axial plane CT images were used to evaluate screw positions and thus, assessments of not only superior and inferior breach but foraminal breach was also possible. The identification of a foraminal breach is particularly important in the lower lumbar spine where the breached pedicle screw could impinge a nerve root ganglion or even the nerve root itself.
30-40 mm, respectively, can be used safely in the thoracic and lumbar spines of children less than 10 years.

Few limitations of this study need to be acknowledged. CT scans were used and not visual examinations using a cadaveric human spine as a reference. Furthermore, the pedicle screws used were a mixture of stainless steel and titanium. The stainless steel screws caused some scatter artifacts in CT scans, which sometimes made it difficult to determine cortical integrity precisely. Long term effects of pedicle screws on growing pedicles were not studied and it is possible that protruding screw tips in the long term become embedded in vertebral bodies. These facts require additional investigation by long term followup.

To conclude the pedicle screw fixation in juvenile patients is both effective and safe when performed meticulously, though prospective long term studies are required to draw more valid conclusions.

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