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Free Hand Pedicle Screw Placement in the Thoracic Spine: Is it Safe?

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Study Design. A retrospective study.

Objective. To evaluate the safety of a free hand technique of pedicle screw placement in the thoracic spine at a single institution over a 10-year experience.

Summary of Background Data. Thoracic pedicle screw fixation techniques are still controversial for thoracic deformities because of possible complications including neurologic.

Materials and Methods. Three hundred ninety-four consecutive patients who underwent posterior stabilization utilizing 3204 transpedicular thoracic screws by 2 surgeons from 1992 to 2002 were analyzed. The mean age was 27 + 10 years (range 5 + 3–87 + 0 years) at the time of surgery. Etiologic diagnoses were: scoliosis in 273, kyphosis in 53, other spinal disease in 68. Pedicle screws were inserted using a free hand technique similar to that used in the lumbar spine in which anatomic landmarks and specific entry sites were used to guide the surgeon. A 2-mm tip pedicle probe was carefully advanced free hand down the pedicle into the body. Careful palpation of all bony borders (floor and four pedicle walls) was performed before and after tapping. Next, the screw was placed, followed by neurophysiologic (screw stimulation with rectus abdominus muscle recording) and radiographic (anteroposterior and lateral) confirmation. An independent spine surgeon using medical records and roentgenograms taken during treatment and follow-up reviewed all the patients.

Results. The number of the screws inserted at each level were as follows (total n = 3204): T1, n = 13; T2, n = 60; T3, n = 192; T4, n = 275; T5, n = 279; T6, n = 240; T7, n = 230; T8, n = 253; T9, n = 259; T10, n = 341; T11, n = 488; T12, n = 572. Five hundred seventy-seven screws inserted into the deformed thoracic spine were randomly evaluated by thoracic computed tomography scan to assess for screw position. Thirty-six screws (6.2%) were inserted with moderate cortical perforation, which meant the central line of the pedicle screw was out of the outer cortex of the pedicle wall and included 10 screws (1.7%) that violated the medial wall. There were **no** screws (out of the entire study group of 3204) with any neurologic, vascular, or visceral complications with up to 10 years follow-up.

Conclusions. The free hand technique of thoracic pedicle screw placement performed in a step-wise, consistent, and compulsive manner is an accurate, reliable, and safe method of insertion to treat a variety of spinal disorders, including spinal deformity. [Key words: thoracic pedicle, pedicle screws, free hand technique, neurophysiologic monitoring] **Spine 2004;29:333–342**

Pedicle screws have been utilized in the lumbar spine for superior three-column fixation for several decades. Abundant literature supports techniques for optimal screw placement and the resultant clinical benefits of lumbar screws.[1–11] Recently, thoracic pedicle screws have become an alternative to hook and wire fixation in the thoracic spine.[6–8,12–18] Because of the unique neurologic and vascular anatomy present in the spinal canal and thoracic cavity, respectively, optimal screw placement is as, if not more, important for thoracic pedicle screws.[19–23] Thus, techniques to optimize placement and confirm intraosseous screw position must be promoted to create as safe an environment as possible for thoracic screw placement.

Methods to aid the surgeon in appropriate screw placement have included the use of intraoperative fluoroscopy and/or radiography as well as image-guided techniques.[13,18,24–29] The goal of the free hand technique is to mimic as close as possible the technique of lumbar screw placement without use of any intraoperative fluoroscopy, radiography, and/or image-guided techniques.[7,13,30] The purpose of this study is to delineate the free hand method of thoracic screw placement and to evaluate the safety of a free hand technique of pedicle screw placement in the thoracic spine at a single institution over a 10 year experience.

Materials and Methods

Three hundred ninety-four consecutive patients who underwent posterior stabilization utilizing 3204 transpedicular thoracic screws by 2 surgeons from 1992 to 2002 were analyzed. The mean age was 27 + 10 years (range 5 + 3–87 + 0 years) at the time of surgery. All pedicle screws were inserted using a free hand technique, similar to that used in the lumbar spine, in which anatomic landmarks and specific entry sites were used to guide the surgeon. An independent spine surgeon (Y.J.K.) using medical records and roentgenograms taken during treatment and follow-up retrospectively reviewed all the patients to find the screw related neurologic, vascular, and visceral complications.

To objectively evaluate the position of the screws inserted into the deformed spine, postoperative computed axial tomography (CAT) scans were performed without any selection criteria in 45 patients (577 thoracic pedicle screws). All left-sided

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Figure 1. Complete exposure and facetectomy: expose the posterior elements of the spine to the edge of the transverse processes bilaterally. Remove the inferior facets with a 0.5-inch straight osteotome (down to T10) or rongeur (below T10). Also remove articular cartilage from the dorsal side of the superior facet of the inferior vertebra using a small curette.

pedicle screws among scanned screws were inserted by one senior spine surgeon (L.G.L.), and all right-sided screws were inserted by one of four spine fellows under direct supervision of the senior spine surgeon (LGL). The position of the scanned thoracic pedicle screw was determined by three independent spine surgeons (Y.J.K., Y.S.C., K.D.R.). When there was disagreement on position of the screws in the pedicle, it was counted according to at least two concordant reads. The authors compared accuracy of the free hand technique and checked the intersurgeon variability using postoperative CAT scans. We checked the sensitivity and specificity of the triggered electromyographic confirmation to detect medial malposition of the screws as compared to the postoperative CAT scans. We also checked the sensitivity and specificity of intraoperative radiograph confirmation to detect the malposition of screws.

Preoperative Assessment. It is important for the surgeon to gain an appreciation of the size of the thoracic pedicles on preoperative radiographs. The size of the convex pedicles does correlate closely with the size of the concave pedicles, and, thus, patients with tiny convex pedicles will have tiny concave pedicles as well. O'Brien *et al*[14] found the size of thoracic concave pedicles to vary between 4.0 and 8.2 mm in 30 patients with operative adolescent idiopathic scoliosis.

Surgical Technique: "Free Hand" Placement. The surgical technique of "free hand" thoracic pedicle screw placement can be broken down into specific steps that are repeated at each level.

1. *Incision and Exposure.* The first important component of successful thoracic screw placement is meticulous exposure of the posterior elements. The spine is exposed to the tips of the transverse processes bilaterally, staying strictly subperiosteal to reduce bleeding. The facet joints must be thoroughly cleaned of soft tissue. With an osteotome, remove the inferior 3–5 mm of the inferior facet and scrape the cartilage on top of the superior facet to enhance the intra-articular arthrodesis (Figure 1).

2. *The Cortical Burring of Starting Point.* Many studies on the morphometry of the thoracic pedicle agree with a high interindividual variability in pedicle dimensions.[14,19,22,31–35] Usually the supine preoperative film is very illustrative to find the ideal starting point because of prone positioning during the operation.[36]

In general, we always start from the neutrally rotated and most distally instrumented vertebra. The starting point of the 12th vertebra is at the junction of the bisected transverse process and lamina at the lateral border of the pars. There is a trend towards a more medial and cephalad starting point on the posterior elements as one proceeds to the apical midthoracic region (T7–T9) level by level. The starting point of the apical midthoracic region (T7–T9) is the most medially located, at the junction of the proximal edge of the transverse process and just lateral to the mid portion of the base of the superior articular process. Above the midthoracic region, the starting point tends to move slightly lateral and caudad as one proceeds more proximal in the thoracic region. The starting point of the fourth thoracic vertebra is at the junction of the proximal one third of the transverse process and lamina just medial to the lateral border of the pars. Lastly, the starting point of the first thoracic vertebra is at the junction of the bisected transverse process and lamina at the lateral border of the pars (Figure 2). It is advantageous to note these trends when placing a screw at each level in succession, working from distal to proximal in the thoracic spine, to make fine adjustments to the trajectory of the next screw base on the previous level screw or contralateral screw. A 3.5 mm acorn tipped burr is utilized to create posterior cortical breach, approximately 5 mm in depth.

3. *Gearshift Probing.* A pedicle "blush" may be visualized suggesting entrance into the cancellous bone at the base of the pedicle. This may not be seen in smaller pedicles because of very limited intrapedicular cancellous bone.

The thoracic gearshift (2 mm blunt-tipped, slightly-curved pedicle finder) is placed in the base of the pedicle searching for a cancellous "soft spot" indicating entrance to the pedicle. The

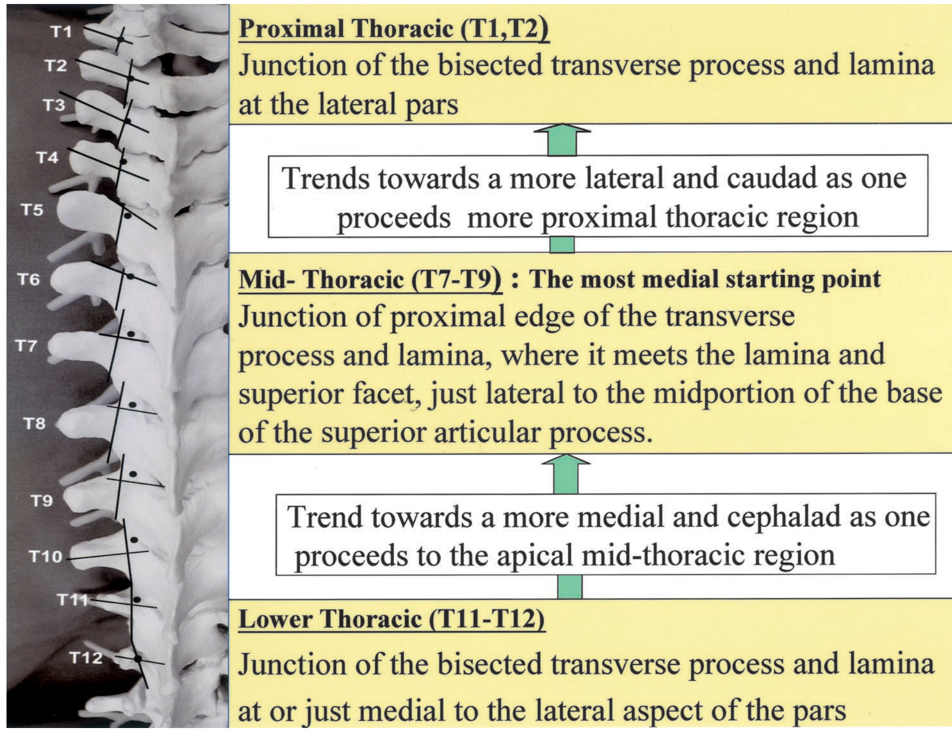

Figure 2. Pedicle screw starting points with 3.5 mm acorn-tipped burr: the posterior elements are burred to create a posterior cortical breach, approximately 5 mm in depth.

appropriate ventral pressure of the thoracic gearshift probe is slightly higher than is needed when inserting the lumbar gearshift probe. The gearshift is initially pointed lateral as a safety measure to avoid medial wall perforation. The 2 mm tip will go down the cancellous portion of the pedicle even if it is quite small. Often, the endosteal diameter of the pedicle is quite small, so one must allow the pedicle finder to "fall" into the pedicle. After inserting the tip approximately 15–20 mm (to beyond the medially based spinal canal), the gearshift is removed and the tip turned to face medial. Before advancing the pedicle finder, place the tip carefully into the base of the hole. The path down the pedicle is then continued medial into the body with an ultimate depth averaging 30–40 mm for the lower thoracic region, 25–30 mm in the mid thoracic region, and 20–25 mm for the proximal thoracic region in adolescents and most adults.[35] Rotate the finder 180° to make room for the screw after advancing the finder to the approximate length of the desired screw. Make sure you feel bone the entire length of the pedicle and body. Probing of the pedicle with the thoracic gearshift should proceed in a smooth and consistent manner with a snug feel because of the small size of the thoracic pedicles. Any sudden advancement of the gearshift suggests penetration into soft tissue and thus a pedicle wall or vertebral body violation. These should be investigated immediately in order to possibly salvage the pedicle and avoid complications. The surgeon must use caution as the anterior and lateral vertebral body cortices are not very strong and may be easily penetrated by the gearshift tip (Figure 3).

4. *Palpation and Pedicle Length Measurement.* Once the pedicle seeker is removed, the tract is visualized to make sure that only blood is coming out and not cerebrospinal fluid (CSF). We notice the amount of blood extruding from the pedicle hole, as excessive and/or pulsatile bleeding may indicate epidural bleeding secondary to a medial wall perforation. Next, a flexible ball-tipped pedicle sounding or palpating device is utilized to palpate five distinct bony borders: a floor and four walls (medial, lateral, superior, and inferior). Pay special attention to the junction of the middle and upper portions of the tract (the first 10–15 mm of the tract), as this is the region of the pedicle where the spinal canal is located and the pedicle isthmus is located. This is an absolutely critical step, whereby inadvertent deep (anterior), medial, lateral, or more rare superior and inferior pedicle breaches can be identified. At this point, if a soft tissue breach is palpated, there may be an opportunity to redirect the screw into an appropriate position into the pedicle so that complete intraosseous borders can be obtained. If any wall including the medial has been breached, the pedicle may be salvageable. Otherwise, place bone wax in the pedicle hole to eliminate the bleeding and reangle the pedicle finder with a more appropriate trajectory.

With the sounder in the base of the anticipated pedicle tract after confirming five intraosseous borders, mark the length of the tract with a hemostat and measure it. If the tract appears too shallow, consider replacing the gearshift and advancing to the appropriate length (Figure 4).

5. *Tapping, Repalpation, and Screw Placement.* The pedicle tract is undertapped with a 0.5 mm less diameter tap than the intended screw. If there is difficulty passing the tap, use the next smaller tap and retap the pedicle. Following this, the pedicle tract is palpated again to make sure that the five osseous borders are intact. This second palpation will often allow palpation of distinct bony ridges confirming intraosseous position, and the tract length is remeasured with a hemostat. Compare this measurement directly adjacent to the screw to be placed to ensure appropriate screw length. Place the screw slowly down the pedicle into the body in the same alignment to confirm it is threaded properly and allow for viscoelastic expansion. Invariably, the smaller pedicle diameters are located at T6 and T7 and in the proximal thoracic concavity (*e.g.*, T3–T4). It is advantageous to have a variety of pedicle diameters and lengths available between 4.0 mm to 7.0 mm in 0.5 mm increments,

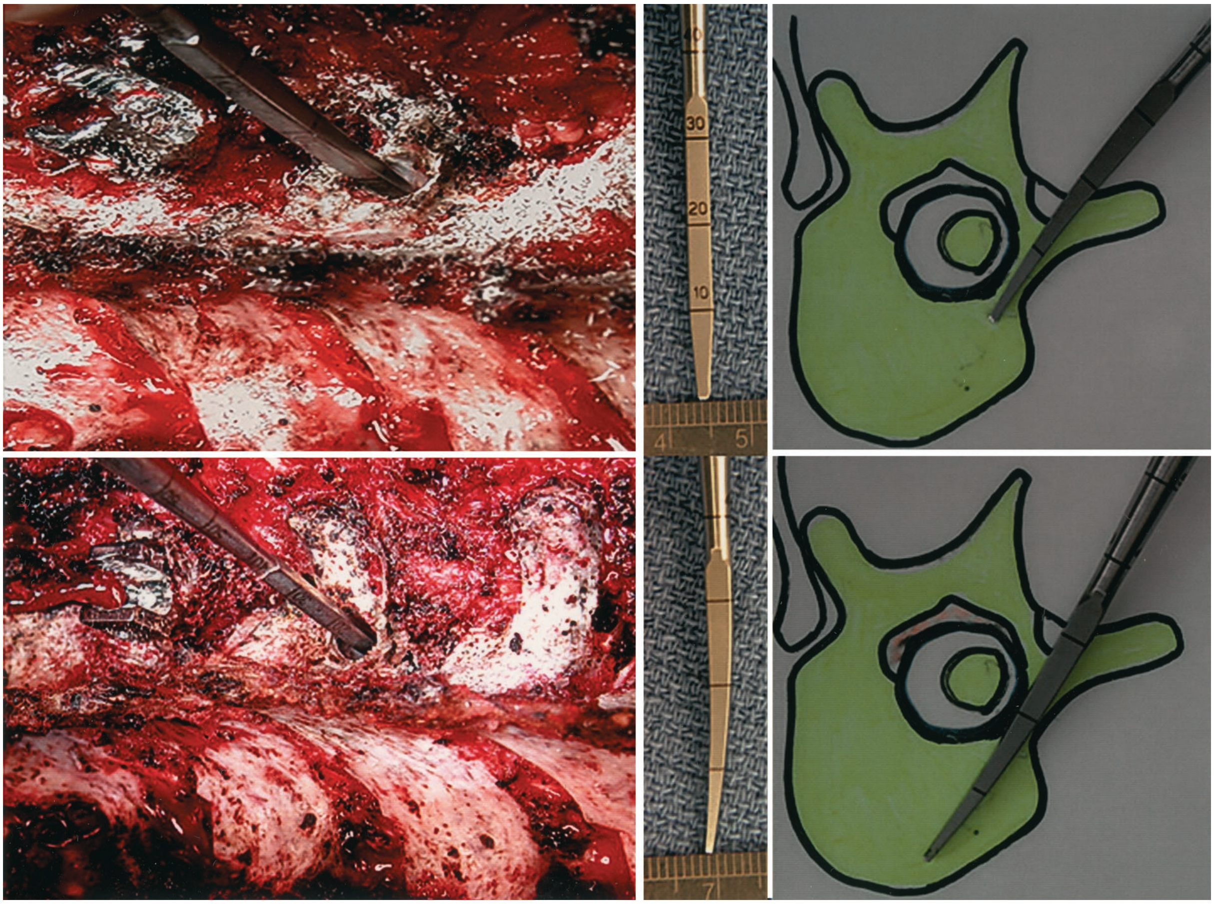

Figure 3. Gearshift probing: initially, direct the gearshift laterally to the depth of 20 mm (the approximate depth of the pedicle) to diminish the likelihood of medial pedicle perforation. Then, remove the gearshift and redirect it medially. Use the nondominant hand to brace the gearshift from sudden advancements.

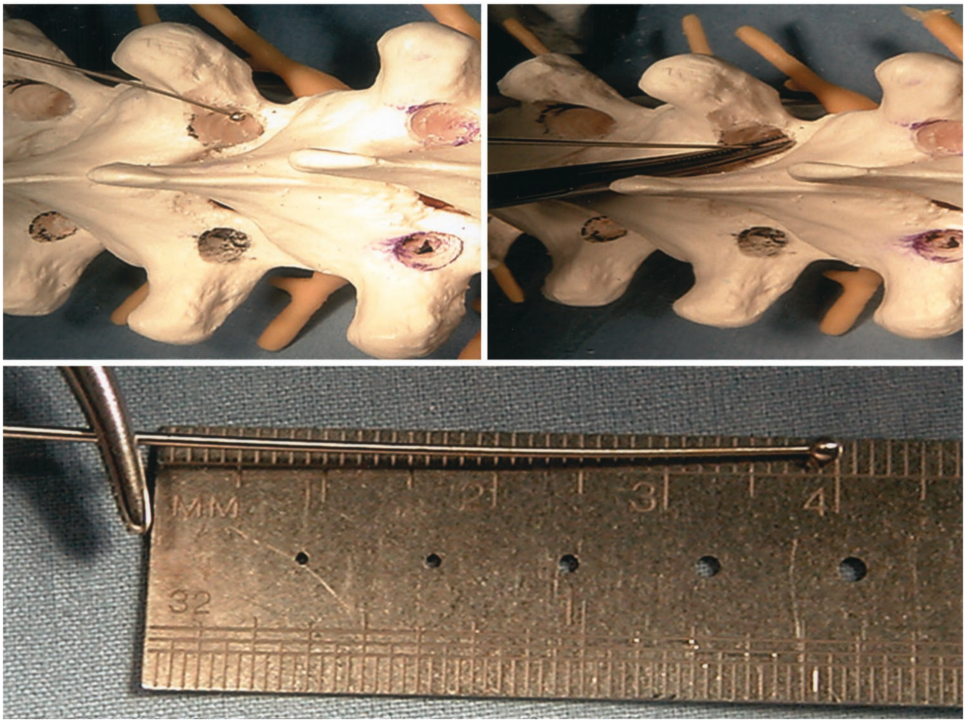

Figure 4. Palpation and pedicle length measurement: palpate all four walls of the pedicle and the pedicle tract floor using the ball-tipped probe to insure intrapedicular placement. With the probe fully inserted, clip the probe with a hemostat at the level of the lamina, and then measure the tract-length to determine pedicle screw length.

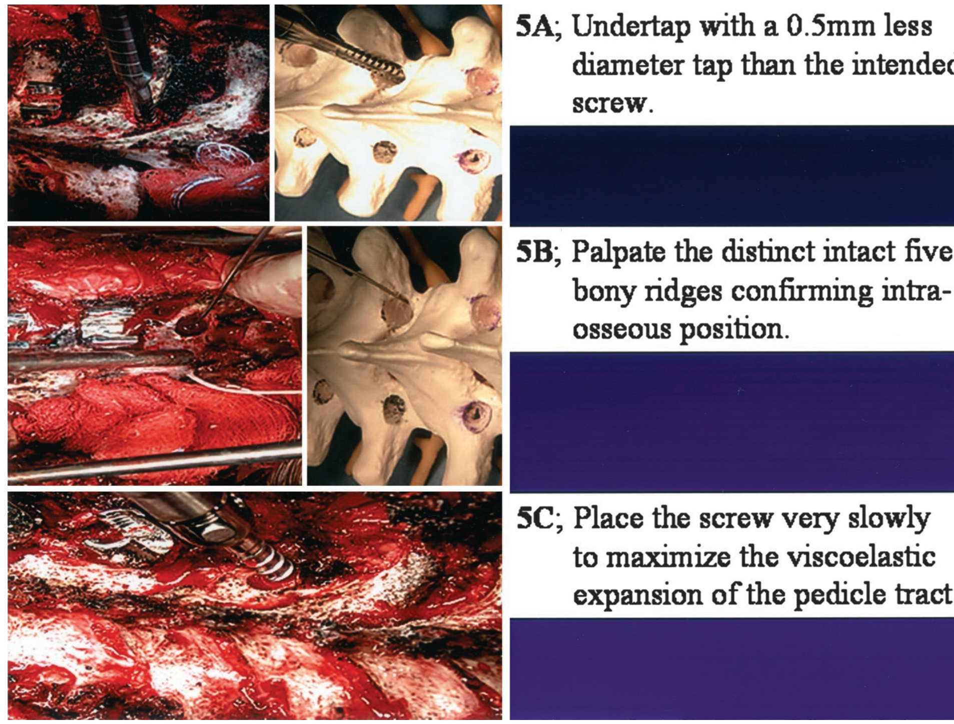

Figure 5. Tapping, repalpation, and slow screw placement. **A**, Undertap the pedicle 0.5 mm smaller than the intended screw diameter. **B**, Repalpate the pedicle tract with the ball-tipped probe once more. **C**, Place the screw very slowly to maximize the viscoelastic expansion of the pedicle tract. It is important to pay attention to screw height to facilitate rod placement later.

and lengths ranging from 25 mm for the smaller diameter screws up to 55 mm for the larger diameter screws (Figure 5).

If the pedicle is quite small or when more than one pass has to be made into a pedicle with the thoracic gearshift, then a K-wire is placed down the pedicle tunnel into the body and tapping can occur over that. It is mandatory that a bony floor exists when using a K-wire so as not to advance the K-wire beyond the anterior or lateral cortex. If there is any question whether the anterior wall is intact, never use a K-wire as cardiac tamponade due to K-wire advancement into a coronary artery has been reported.[37]

Screws are inserted on every segment on the correction side such as the concave side of a hypokyphotic or normal kyphotic idiopathic scoliosis curve and convex side of a hyperkyphotic idiopathic scoliosis. On the contralateral side, we have inserted screws every third or fourth vertebrae after placing two lower most screws. In kyphosis and congenital scoliosis, more screws were utilized to increase the rigidity of the instrumentation

6-1. *Confirmation of Intraosseous Screw by Imaging.* It is imperative that the surgeon document intraosseous placement *via* fluoroscopy and/or radiography. The coronal plane radiograph is evaluated for the harmonious position of all screws especially when any rotational scoliosis deformity exists. In cases of shorter or longer screws compared to adjacent screws, the screw length as viewed on the lateral radiograph is mandatory to check for harmonious position. On the lateral radiograph, the screws should be parallel to the superior endplates and not extending past the anterior border of the vertebral body. These two-plane radiographs should confirm the harmonious position of the screws as noted by the surgeon (Figure 6A).

6-2. *Confirmation of Intraosseous Screw by triggered Electromyography (EMG).* Electromyograph (EMG) stimulations are performed with real time monitoring of thoracic nerve root recording from the rectus abdominus musculature. This will be an appropriate assessment for screws placed from T6 to T12, which innervates the rectus abdominus muscles. A triggered EMG threshold of less than 6.0 mA, coupled with threshold values 65% or more decreased from the "average" of all other T6–T12 screws in that patient thresholds in a given patient, should act as a "red flag" alerting the surgeon to suspect a medial pedicle wall breach by the screw.[15] We removed the screw and repalpated the pedicle walls once again if a screw met these warning criteria. We then decided to replace or discard the screw by the result of the third pedicle wall palpation, screw positioning on radiographs, and overall assessment of how the screw felt during placement throughout the thoracic and lumbar spine (Figure 6B).

7. *Deformity Correction.* After the insertion of the pedicle screws, deformity correction was carried out using a translational technique, rod rotation maneuver,[3] and direct vertebrae rotation and translational techniques using bilateral multiple screw anchors. In addition, various osteotomy procedures such as a single pedicle subtraction or multiple Smith Peterson type, or a vertebral column resection were used depending on the etiology of the deformity. Final locking of the screws was done after final rod contouring using scoliosis and coronal benders. Bone grafting from posterior iliac crest or autogenous ribs was performed (Figure 7).

■ Results

Demographic Data

There were 394 patients with a mean age of 27 + 10 years (range 5 + 3–87 + 0 years) at the time of the surgical treatment. A total of 3204 thoracic pedicle screws were inserted. The diameter of the screws used in the thoracic spine ranged from 4.0 to 6.5 mm. The number of the screws inserted at each level were as follows (total n = 3204): T1, n = 13; T2, n = 60; T3, n = 193;

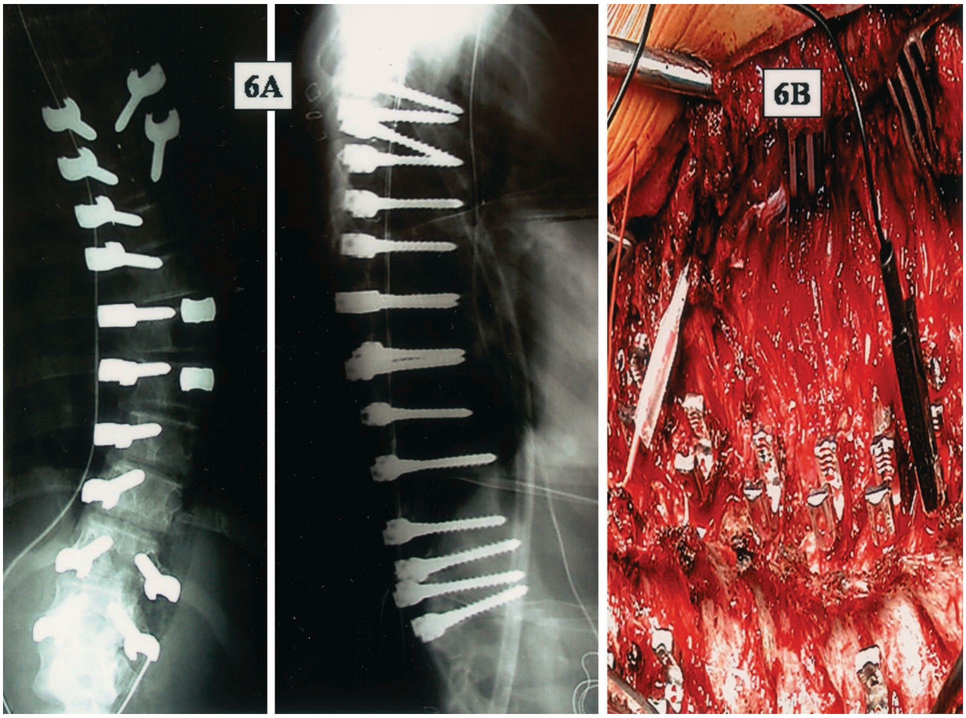

Figure 6. Confirmation of intraosseous screw placement using intraoperative anteroposterior/lateral radiographs and triggered EMG testing. **A**, Anteroposterior and lateral radiographs including all inserted screws are performed after all screws are placed. **B**, Triggered EMG testing of the screws. Thoracic screws from T6 to T12 can be monitored with the rectus abdominus muscles.

T4, n = 275; T5, n = 279; T6, n = 240; T7, n = 230; T8, n = 253; T9, n = 259; T10, n = 341; T11, n = 489; T12, n = 572 (Figure 8).

The etiologic diagnoses were scoliosis (273 patients): adolescent idiopathic scoliosis (n = 150); congenital scoliosis (n = 18); juvenile idiopathic scoliosis (n = 8); adult idiopathic scoliosis (n = 54); neuromuscular scoliosis (n = 33); scoliosis associated with various syndromes (n = 10); kyphosis (53 patients); Scheuermann kyphosis (n = 18); fixed sagittal imbalance syndrome including ankylosing spondylitis (n = 31); congenital scoliosis (n = 3); neuromuscular kyphosis (n = 1); fracture (45 patients); tumor (12 patients); infection (4 patients); and failed back surgery syndrome (7 patients) (Table 1).

Accuracy Using CAT Scan Evaluation

Five hundred seventy-seven screws inserted into the deformed thoracic spine were randomly evaluated by thoracic CAT scan to assess for screw position. According to the diagnoses, the number of screws placed were: 488

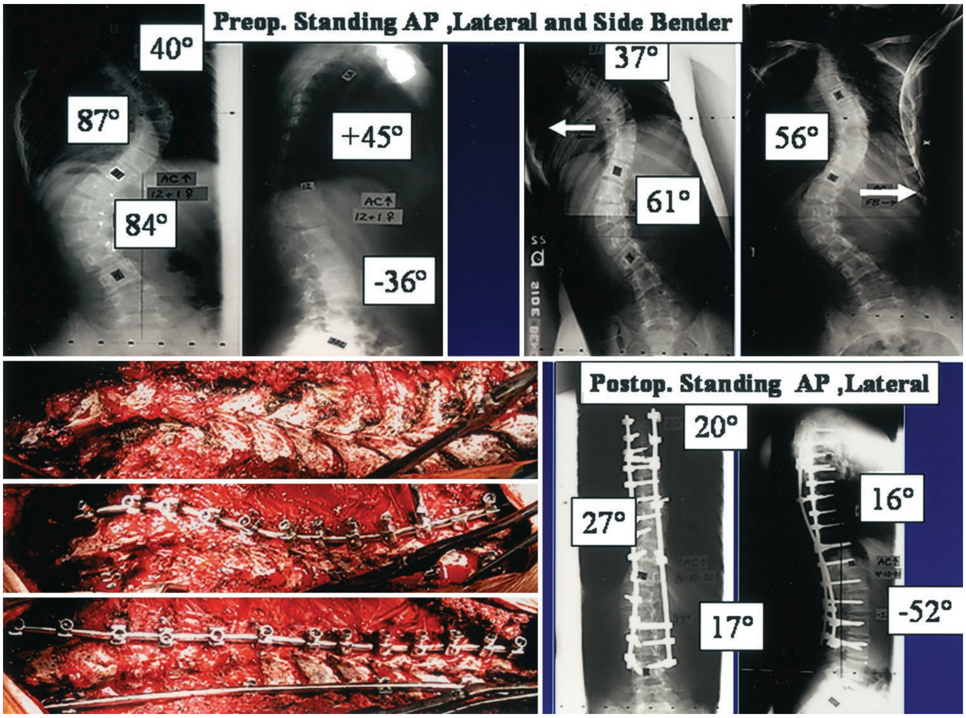

Figure 7. A patient with a triple major curve, Lenke type 4C+: perioperative radiographs and intraoperative pictures.

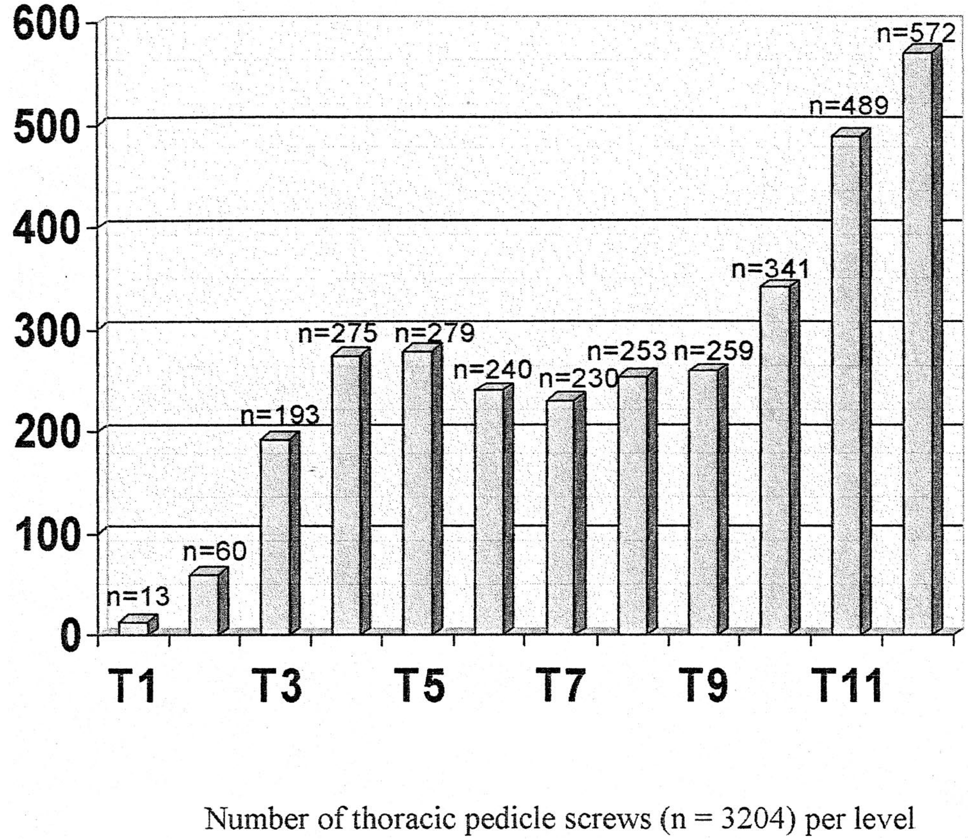

Figure 8. Number of thoracic pedicle screws (n = 3204) per level.

screws for adolescent idiopathic scoliosis (39 patients), 26 for scoliosis associated with various syndromes (2 patients), and 63 for Scheuermann kyphosis (4 patients).

Of the 577 thoracic pedicle screws inserted into deformed spine, 370 screws were placed by one senior spine surgeon (L.G.L.), and 207 were placed by the four spine fellows under supervision of the senior spine surgeon. Thoracic pedicle screws were accurately placed in 93.8% by the 5 surgeons. Thirty-six screws (6.2%) showed moderate cortical perforation, which meant the central line of the pedicle screw was out of the outer cortex of the pedicle wall, and included 10 screws (1.7%) that violated the medial wall. Among the 370 screws were inserted by one senior spine surgeon (L.G.L.), 22 screws (7.0%) showed moderate cortical perforation and included 5 screws (1.4%) that violated the medial wall. Of the 207 screws inserted by the 4 spine fellows, 14 screws (6.8%) showed moderate cortical perforation and included 5 screws (2.4%) that violated the medial wall. There were no significant differences in overall accuracy between the senior surgeon and four spine fellows under supervision (χ^2 test, P = 0.70) including medial cortical wall perforation (Fisher exact test, P = 0.34).

Table 1. Patients' Distribution by Diagnosis

Diagnosis	No. of Patients
Scoliosis	n = 273
Congenital scoliosis	18
Juvenile idiopathic scoliosis	8
Adolescent idiopathic scoliosis	150
Adult idiopathic scoliosis	54
Neuromuscular scoliosis	33
Syndrome related	10
Kyphosis	n = 53
Congenital kyphosis	3
Scheuermann kyphosis	18
Ankylosing spondylitis	4
Neuromuscular kyphosis	1
Fixed sagittal imbalance	27
Others	n = 68
Fracture	45
Tumor	12
Infection	4
Failed back surgery syndrome	7

Out of 514 screws inserted into the scoliotic spine, 33 screws (6.4%) were inserted with moderate cortical perforation and included 9 screws (1.8%) that violated the medial cortical wall. Among 63 screws inserted into the kyphotic spine, 3 screws (4.8%) were inserted with moderate cortical perforation and included 1 screw (1.6%) that violated the medial wall.

Four hundred fifteen thoracic pedicle screws were placed between T6 and T12 in 45 patients. Among them, 339 screws have triggered EMG and postoperative CAT scans. The CAT scan showed 334 well-positioned screws and 5 screws with distinct medial wall violation. Two out of five medially violated screws met the warning criteria by Raynor *et al.*[34] According to the threshold values of triggered EMG, 25 screws met a warning criteria. As a warning criteria for medial wall violation in the thoracic spine, the sensitivity of the triggered EMG was 0.40 and specificity was 0.93. The positive predictive value of the triggered EMG was 0.08 and negative predictive value was 0.99.

The intraoperative radiographs demonstrated 517 well-positioned screws and 60 screws with pedicle wall violation. Among the 60 malpositioned screws, only 21 screws met the moderate pedicle wall violations by postoperative CAT scan. The sensitivity of the intraoperative radiographs was 0.58 and specificity was 0.93 in detecting significant pedicle wall violation. The positive predictive value of the triggered EMG was 0.35 and negative predictive value was 0.97.

Complications

Screw Insertion Related. Ten out of 577 thoracic pedicle screws randomly evaluated by thoracic CAT scan showed medial cortical wall violation between 2.5 to 5.0 mm. There were 26 screws inserted with moderate lateral cortical perforation between 3.0 to 6.0 mm. Misplaced screws were accepted and were left in position because there were no associated complications.

Neurologic Problem. There were **no** screws (out of the entire study group of 3204 thoracic pedicle screws) with any neurologic or vascular complications at up to 10 years follow-up. There were several instances of CSF emanating from the initial pedicle tract during the preparation of the screw holes. The tract was sealed off using bone wax, and the screw site was abandoned. There were no postoperative CSF leaks.

■ Discussion

Thoracic pedicle screw fixation is potentially dangerous because of the maximum permissible translational error of less than 1 mm and rotational error of less than 5° at the normal midthoracic spine using a geometric model due to small pedicle diameter[27] and little space between the spinal cord and medial pedicle.[19,38] There are several methods of thoracic pedicle screw insertion to enhance the safety, such as guide pins into the pedicles[16,17] intraoperative C-arm image intensifier,[8,12,39] direct visualization of the medial wall after laminotomy,[22,40] and image-guided systems based on CAT scan or fluoroscopy.[23–28,42] Although recently developed, image-guided techniques have been associated with increased accuracy. However, this technique needs preoperative CAT scanning with irradiation, high cost, expensive equipment, and prolonged operative time.[18,24–28] To detect the cortical wall defect of the pedicle, triggered EMG[15,30,43,44] and intraosseous endoscopy[29,40] have been used.

For thoracic pedicle screws used in the treatment of spinal deformities, the incidence of screw misplacement ranges from 3% to 44.2%, with screw-related neurologic complications in the 0% to 0.9% range.[1–3,7–9,11–13,16–18,39] A few reports have described complications caused by overpenetration related to the placement of thoracic pedicle screws with major visceral injury.[16,37,45] Although many studies reported medial wall violation of the thoracic pedicle between 1.4% and 14% from 1 mm to 8.0 mm, there were no permanent neurologic, cardiovascular, or pulmonary complications associated medial wall violation in any cases.[6,8,12,13,18,24,30,39]

This current study showed 10 screws with medial cortical wall violation (between 2.5 and 5.0 mm) and 26 screws with lateral wall violation (between 3.0 and 6.0 mm) out of 577 thoracic pedicle screws evaluated by CAT scanning. There have been no perioperative complications and postoperative neurologic complications. Also, there have been no vascular or visceral sequelae. Additionally, there were **no** screws (out of the entire study group of 3204 thoracic pedicle screws) with any neurologic or vascular or visceral complications at up to 10 years follow-up through medical records.

This low incidence of neurologic complications related to the misplacement of the thoracic pedicle screws may be attributed to unique characteristics of the thoracic spine. The anatomic characteristic of the thoracic pedicle demonstrates a thicker medial cortical wall compared to the lateral wall. Compared to the lumbar spine, the pedicle entry point is more ventral. The convex and ventral side of the scoliotic spine usually has spacious room because the dural sac and spinal cord shift toward the concave, dorsal side. Rotation of the concave pedicle toward the convex side increases the angle of convergence relative to the sagittal plane but the paravertebral muscles on concave side make a medial pedicular perforation more difficult. The removal of the 5 mm of dorsal laminar bone around the pedicle entry point by a burr could make the starting point for the gearshift ventral to the dorsal surface of the dura and very near the pedicle isthmus. Because of these unique anatomic characteristics and possible plastic deformation of the pedicle wall when the ratio of the screw-to-pedicle diameter exceeded 65% or 80%,[10,33] pedicle screw fixation of scoliotic and nondeformed thoracic spines may be performed in a safe manner.

We hypothesize a "definite safe zone" (<2 mm), "probable safe zone" (2–4 mm), and "questionable safe zone" (4–8 mm) of medial encroachment if there are no abnormal electrophysiologic findings during and after insertion because of plastic deformation, fluid, or soft tissue-filled potential space and mild pedicle fracture based on many above-mentioned *in vivo* studies. This assumes the encroachment is not occurring at the concave apex of a scoliosis deformity where these tolerances may not be acceptable and no direct contact between screw and the spinal cord.

Although Raynor *et al*[15] showed that triggered EMG responses less than 6 mA or less than 35% from the "average" of all other T6–T12 screws in that patient thresholds in a given patient should act as a "red flag" alerting the surgeon to suspect a medial pedicle wall breach by the screw, this study demonstrated that triggered EMG monitoring with same criteria did not significantly improve the reliability of the safe screw placement in the thoracic spine, based on postoperative CAT scanning, because of poor sensitivity and positive predictive values.

The reliability of pedicle screw assessment utilizing plain radiographs *versus* CT reconstruction or on cadaver study was very poor from 10% to 83%.[5,41,46–48] This study also demonstrated poor sensitivity and positive predictive value. In the case of a scoliotic spine, medial cortical wall violation is much more difficult to determine because of the rotational deformity. Therefore, the accuracy rate of thoracic pedicle screws should be determined by CAT or MRI scans or direct visualization only.

Obviously, there are many other methods available to aid surgeons to place thoracic pedicle screws safely. One of the more common means is to use intraoperative fluoroscopy. In this manner, the circle of the pedicle can be viewed as a "bullseye" in the frontal plane and the sagittal inclination of the vertebra can be accurately assessed with lateral fluoroscopy. Some assessment of the axial plane orientation of the screw can also be obtained, but it is not foolproof. There are also other more advance technologies using CT scan-acquired images to created intraoperative models to help assess local access and screw placement. Surgeons can also make intraoperative laminotomies with direct medial wall palpation of the pedicle to assure that the screws are not penetrating medial[11] into the spinal canal. Thus, we stress that surgeons should use whatever they require to make thoracic pedicle screw placement in their hands. Our results document that we have been able to create a safe method of thoracic pedicle screw placement without use of these other intraoperative methods/devices, but we acknowledge that this method may not be the best for many surgeons. Surgeons must use their best judgment for creating the safest environment as possible when placing thoracic pedicle screws.

■ Conclusion

A free hand thoracic pedicle screw insertion technique for the surgical treatment of normal and deformed thoracic spines without any radiographic guidance and/or intraoperative tracking devices appears to be a safe, and reliable procedure. One must have a thorough knowledge of spine and vertebral anatomy, follow and use diligent and repetitive confirmatory steps to compulsively assure intraosseous placement.

■ Key Points

- The free hand technique of thoracic pedicle screw placement performed in a step-wise, consistent and compulsive manner is an accurate, reliable, and safe method of insertion to treat a variety of spinal disorders, including spinal deformity.

References

1. Boos N, Webb JK. Pedicle screw fixation in spinal disorders: a European view. *Eur Spine J* 1997;6:2–18.
2. Brown CA, Lenke LG, Bridwell KH, et al. Complications of pediatric thoracolumbar and lumbar pedicle screws. *Spine* 1998;23:1566–71.
3. Cotrel Y, Dubousset J, Guillaumat M. New universal instrumentation in spinal surgery. *Clin Orthop* 1988;227:10–23.
4. Esses SI, Sachs BL, Dreyzin V. Complications associated with the technique of pedicle screw fixation: a selected survey of ABS members. *Spine* 1993;18:2231–9.
5. Farber GL, Place HM, Mazur RA, et al. Accuracy of pedicle screw placement in lumbar fusions by plain radiographs and computed tomography. *Spine* 1995;20:1494–9.
6. Halm HF, Niemeyer T, Link TM, et al. Segmental pedicle screw instrumentation in idiopathic thoracolumbar and lumbar scoliosis. *Eur Spine J* 2000;9:192–7.
7. Hamill CL, Lenke LG, Bridwell KH, et al. The use of pedicle screw fixation to improve correction in the lumbar spine of patients with idiopathic scoliosis. Is it warranted? *Spine* 1996;21:1241–9.
8. Liljenqvist UR, Halm HF, Link TM. Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. *Spine* 1997;22:2239–45.
9. Lonstein JE, Denis F, Perra JH, et al. Complications associated with pedicle screws. *J Bone Joint Surg Am* 1999;81:1519–28.
10. Sjöström L, Jacobsson O, Karlström G, et al. CT analysis of pedicles and screw tracts after implant removal in thoracolumbar fractures. *J Spinal Disord* 1993;6:225–31.
11. West JL, Ogilvie JW, Bradford DS. Complications of variable screw plate pedicle screw fixation. *Spine* 1991;16:577–9.
12. Belmont PJ, Klemme WR, Dhawan A, et al. In vivo accuracy of thoracic pedicle screws. *Spine* 2001;26:2340–6.
13. Kim YJ, Lenke LG, Bridwell KH, et al. CT scan accuracy of "free hand" thoracic pedicle screw placement in pediatric spinal deformity. Poster presented at: Scoliosis Research Society Annual Meeting; September 2001; Cleveland, Ohio.
14. O'Brien MF, Lenke LG, Mardjetko S, et al. Pedicle morphology in thoracic adolescent idiopathic scoliosis: is pedicle fixation an anatomically viable technique? *Spine* 2000;25:2285–93.
15. Raynor BA, Lenke LG, Kim YJ, et al. Can triggered EMG thresholds predict safe thoracic pedicle screw placement? Presented at: Scoliosis Research Society Annual Meeting; September 2001; Cleveland, Ohio.
16. Suk SI, Kim WJ, Lee SM, Kim JH, Chung ER. Thoracic pedicle screw fixation in spinal deformities: are they really safe? *Spine* 2001;26:2049–57.
17. Suk SI, Lee CK, Kim WJ, et al. Segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis. *Spine* 1995;20:1399–405.
18. Youkilis AS, Quint DJ, McGillicuddy JE, et al. Stereotactic navigation for placement of pedicle screws in the thoracic spine. *Neurosurgery* 2001;48:771–9.
19. Ebraheim NA, Jabaly G, Xu R, et al. Anatomic relations of the thoracic pedicle to the adjacent neural structures. *Spine* 1997;22:1553–7.
20. Vaccaro AR, Rizzolo SJ, Allardyce TJ, et al. Placement of pedicle screws in the thoracic spine. Part I: Morphometric analysis of the thoracic vertebrae. *J Bone Joint Surg Am* 1995;77:1193–9.
21. Vaccaro AR, Rizzolo SJ, Balderston RA, et al. Placement of pedicle screws in the thoracic spine. Part II: An anatomical and radiographic assessment. *J Bone Joint Surg Am* 1995;77:1200–6.
22. Xu R, Ebraheim NA, Ou Y. Anatomical considerations of pedicle screw placement in the thoracic spine. Roy-Camille technique versus open-lamina technique. *Spine* 1998;23:1065–8.
23. Xu R, Ebraheim NA, Shepherd ME, et al. Thoracic pedicle screw placement guided by computed tomographic measurements. *J Spinal Disorder* 1999;12:222–6.
24. Amoit LP, Lang K, Putzier M, et al. Comparative results between conventional and computer-assisted pedicle screw installation in the thoracic, lumbar, and sacral spine. *Spine* 2000;25:606–14.
25. Assaker R, Reyns N, Vinchon M, et al. Transpedicular screw placement: image-guided versus lateral-view fluoroscopy: in vitro simulation. *Spine* 2001;26:2160–4.
26. Laine T, Lund T, Ylikoski M, et al. Accuracy of pedicle screw insertion with and without computer assistance: a randomized controlled clinical study in 100 consecutive patients. *Eur Spine J* 2000;9:235–41.
27. Rampersaud YR, Simon DA, Foley KT. Accuracy requirements for image-guided spinal pedicle screw placement. *Spine* 2001;26:352–9.
28. Schwarzenbach O, Berlemann U, Jost B, et al. Accuracy of computer-assisted pedicle screw placement: an in vivo computed tomography analysis. *Spine* 1997;22:452–8.

29. Stauber MH, Bassett GS. Pedicle screw placement with intraosseous endoscopy. *Spine* 1994;19:57–61.
30. Reidy DP, Houlden D, Nolan PC, et al. Evaluation of electromyographic monitoring during insertion of thoracic pedicle screws. *J Bone Joint Surg Br* 2001;83:1009–14.
31. Krag M, Weaver DL, Beynnon BD, et al. Morphometry of the thoracic and lumbar spine related to transpedicular screw placement for surgical fixation. *Spine* 1988;13:27–32.
32. Liljenqvist U, Allkemper T, Hackenberg L, et al. Analysis of the vertebral morphology in idiopathic scoliosis with magnetic resonance imaging using multiplanar reconstruction. Presented at: Scoliosis Research Society Annual Meeting; September 2001; Cleveland, Ohio.
33. Misenhimer GR, Peek RD, Wiltse LL, et al. Anatomic analysis of pedicle cortical and cancellous diameter as related to screw size. *Spine* 1989;14:367–72.
34. Panjabi MM, O'Holleran JD, Crisco JJ, et al. Complexity of the thoracic spine pedicle anatomy. *Eur Spine J* 1997;6:19–24.
35. Zindrick MR, Knight GW, Satori MJ, et al. Pedicle morphology of the immature thoracolumbar spine. *Spine* 2000;25:2726–35.
36. Marsicano JG, Lenke LG, Bridwell KH, et al. The lordotic effect of the OSI frame on operative adolescent idiopathic scoliosis patients. *Spine* 1998;23:1341–8.
37. Heini P, Scholl E, Wyler D, et al. Fatal cardiac tamponade associated with posterior spinal instrumentation: a case report. *Spine* 1998;23:2226–30.
38. Liljenqvist UR, Link TM, Halm HF. Morphometric analysis of thoracic and lumbar vertebrae in idiopathic scoliosis. *Spine* 2000;25:1247–53.
39. Gertzbein SD, Bobbins SE. Accuracy of pedicular screw placement in vivo. *Spine* 1990;15:11–4.
40. Frank EH. The use of small malleable endoscopes to assess pedicle screw placement: technical note. *Minim Invasive Neurosurg* 1998;41:10–21.
41. Berlemann U, Heini P, Muller U, et al. Reliability of pedicle screw assessment utilizing plain radiographs versus CT reconstruction. *Eur Spine J* 1997;6:406–11.
42. Steinmann JC, Herkowitz HN, el-Kommos H, et al. Spinal pedicle fixation: Confirmation of an image-based technique for screw placement. *Spine* 1993;18:8560–61.
43. Danesh-Clough T, Taylor P, Hodgson, et al. The use of evoked EMG in detecting misplaced thoracolumbar pedicle screws. *Spine* 2001;26:1313–6.
44. Lenke LG, Padberg AM, Russo MH, et al. Triggered electromyographic threshold for accuracy of pedicle screw placement. An animal model and clinical correlation. *Spine* 1995;20:1585–91.
45. Papin P, Arlet V, Marchesi D, et al. Unusual presentation of spinal cord compression related to misplaced pedicle screws in thoracic scoliosis. *Eur Spine J* 1999;8:156–9.
46. Ferrick MR, Kowalski JM, Simmons ED. Reliability of roentgenogram evaluation of pedicle screw position. *Spine* 1997;22:1249–53.
47. Weinstein JN, Spratt KF, Spengler D, et al. Spinal pedicle fixation: Reliability and validity of roentgenogram-based assessment and surgical factors on successful screw placement. *Spine* 1988;13:1012–8.
48. Whitecloud TS, Skalley TC, Cook SD, et al. Roentgenographic measurement of pedicle screw penetration. *Clin Orthop* 1989;245:57–68.

Point of View

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Our extensive experience (approximately 10 years) with thoracic pedicle screw fixation has yielded similar results as presented by the authors. We have witnessed minimal morbidity and have found it to be a safe and reliable form of fixation. We utilize a mini-laminotomy technique that allows for inspection of the superior, medial, and inferior borders of the pedicle. Furthermore, identification of the pedicle walls provides feedback to the operating physician for both starting location and screw projection. Drilling of the pedicle is completed while the assistant surgeon monitors and protects the medial wall with a probe. Violation of the lateral wall of the pedicle is not typically problematic, as the screw is usually secured within the costovertebral articulation. The leading threads of the screw must always reside within the vertebral body.

A retrospective review of 100 consecutive patients treated at our institution utilizing this application technique yielded nearly comparable results. There were no permanent spinal cord injuries, spinal fluid leaks, visceral injuries, or vascular injuries. One patient was found to have a transient incomplete posterior cord syndrome and one other had a transient thoracic radiculopathy.

Plain radiographs are of limited value in assessing screw location, particularly in deformity cases. Computed tomography is the imaging modality of choice. Triggered electromyographic monitoring may provide the surgeon with a false sense of security and should not be relied on solely for screw location. Screw placement at unrecognized stenotic sites may place the patient at greater risk for iatrogenic neurologic injury. Decompression should be completed before hardware placement.

Although considered generally safe, thoracic screw placement should be completed only by surgeons who command appropriate understanding of spinal anatomy and the technical issues of screw placement.

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