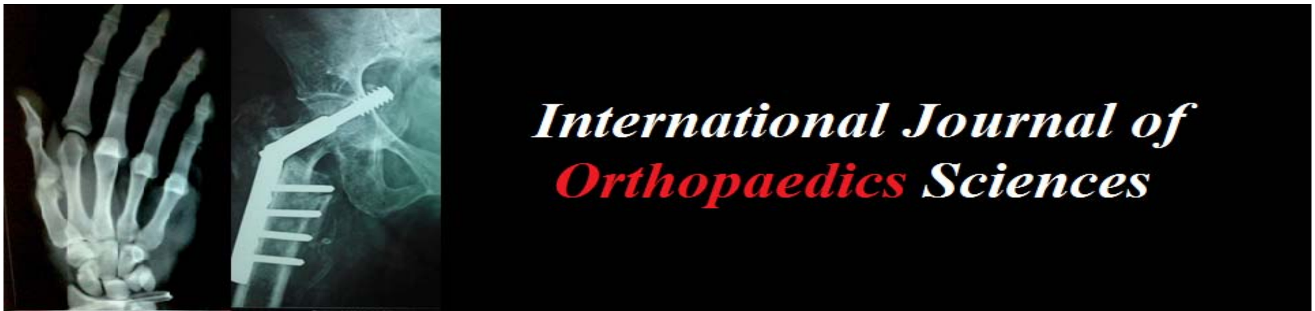

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Accuracy of free hand technique of transpedicular screw fixation in correction of spinal deformities

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Abstract
Introduction: Pedicular screw fixation is now the novel technique to correct spinal deformities. Navigation or CT guided systems are not easily available in Indian scenario. Free hand technique of pedicle screw insertion is commonly practiced for degenerative spine and traumatic spine with fluoroscopic guidance, but for deformed spine fluoroscopy may not be always helpful.
AIM: we intend to evaluate accuracy and safety free hand technique in kyphoscoliotic spine.
Material and Methods: Twenty consecutive patients suffering from kyphoscoliosis underwent posterior stabilization using a total of 260 titanium/stainless steel transpedicular screws. The position of the screws inserted into the deformed spine was evaluated by postoperative computed axial tomography (CAT) scans. All patients underwent 3-mm thin-section postoperative CT. Pedicle perforations were classified as either medial or lateral breech and distance was measured of breach.
Results: Of the 260 screws inserted into the deformed scoliotic spine 27 screws showed moderate lateral cortical perforation whereas 11 screws showed moderate medial cortical breech. These screws showed cortical perforation in the range of 2.1-4.0mm.One screw each showed cortical breech in the range of 4.1-6.0mm on medial and lateral side.
Conclusion: This study concludes that with good knowledge of anatomy of spine, 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.

Keywords: Scoiliosis, Free Hand Technique, Pedicular Screw, Spine Deformity

Introduction
Pedicle screws have dramatically improved the outcomes of spinal reconstruction requiring spinal fusion. Pedicle-screw fixation can be effectively and safely used wherever a vertebral pedicle can accommodate a pedicle screw — that is, in the cervical, thoracic, or lumbar spine.
Transpedicular screw fixation of spinal segments has been described for a variety of surgical indications to include adolescent idiopathic scoliosis, kyphotic deformities, fracture, and tumor. When used in scoliosis surgery, transpedicular screws have been reported to enhance operative correction while permitting a shorter fusion length with less loss of correction. Pedicle screws have been utilized in the lumbar spine for superior three-column fixation for several decades. Recently, thoracic pedicle screws have become an alternative to hook and wire fixation in the thoracic spine. 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. Thus, techniques to optimize placement and confirm intraosseous screw position must be promoted to create as safe an environment as possible for transpedicular screw placement.

Aims and objectives
The present study was designed to investigate the *in vivo* accuracy and safety of pedicle screws using postoperative CT. Specific attention was focused on the incidence and degree of cortical breakthrough within the various spinal regions and to evaluate the clinical implications of misplaced screws in the pedicles and whether the free hand technique which is followed for pedicular screw insertion is safe and effective when used specifically in deformed spine.

Materials and Methods

Twenty consecutive patients suffering from kyphoscoliosis, who underwent posterior stabilization using a total of 260 from titanium/stainless steel transpedicular screws were evaluated retrospectively.

To objectively evaluate the position of the screws inserted into the deformed spine, postoperative computed axial tomography (CAT) scans were performed. All patients underwent 3-mm thin-section postoperative CT. Pedicle perforations were classified as either medial or lateral breech and distance was measured of breach.

Preoperative Assessment

It is important for the surgeon to gain an appreciation of the size of the 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* found the size of thoracic concave pedicles to vary between 4.0 and 8.2 mm in 30 patients with operative adolescent idiopathic scoliosis (14).

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 (13).

Incision and Exposure

The first important component of successful screw placement is meticulous exposure of the posterior elements. The spine is exposed to the tips of the transverse processes bilaterally, staying strictly sub periosteal 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.

Identification and Cortical Burring of Starting Point

We use three techniques for localization of the pedicle: (1) the intersection technique, (2) the pars interarticularis technique, and (3) the mammillary process technique.

The intersection technique is perhaps the most commonly used method of localizing the pedicle. It involves dropping a line from the lateral aspect of the facet joint, which intersects a line that bisects the transverse process at a spot overlying the pedicle.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. 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.

Probing of the pedicle

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 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 2mmtip 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. 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.

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.

Tapping, Repalpation, and Screw Placement

The pedicle tract is under tapped with a 1 cm 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 5.0 mm, and lengths ranging from 25 mm for the smaller diameter screws up to 55 mm for the larger diameter screws. 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.

Confirmation of Intraosseous Screw by Imaging

On the lateral radiograph, the screws should be parallel to the superior endplates and not extending past the anterior border of the vertebral body.

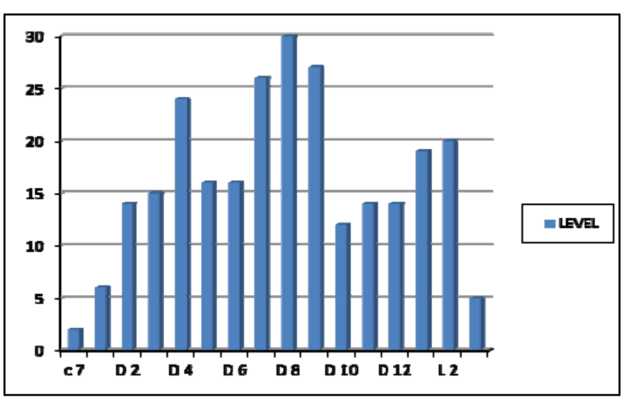
Deformity correction

The pedicular screws are connected with rods which are contoured appropriately and derformity is corrected by derotation manoeuvre.

Results

Demographic Data

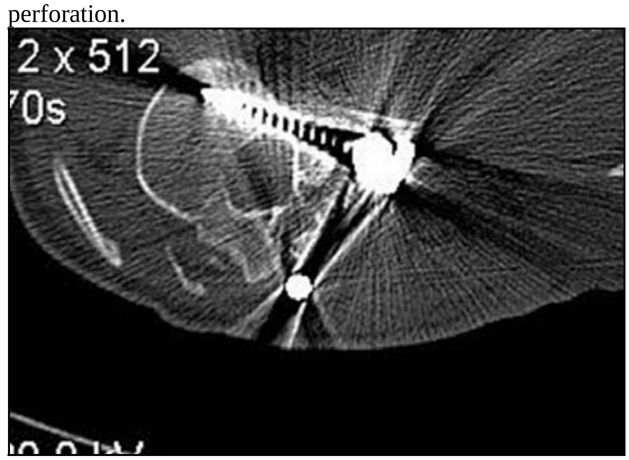
There were 20 patients with a mean age of 20+/-5 years at the time of the surgical treatment. A total of 260 thoracic pedicle screws were inserted. The diameter of the screws used in the thoracic spine ranged from 4.0 to 6.0mm. The number of the screws inserted at each level were as follows:



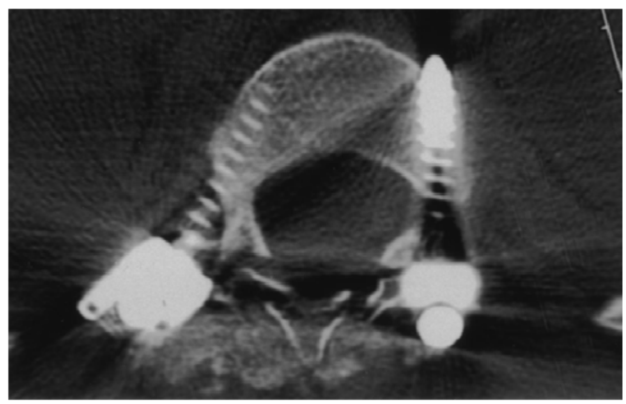
Total n=260: C 7, n=2; D 1, n=6; D 2, n=14; D 3, n=15; D 4, n=24; D 5, n=16;
D 6, n=16; D 7, n=26; D 8, n=30; D 9, n=27; D 10, n=12; D 11, n=14; D 12, n=14;
L 1, n=19; L 2, n=20; L 3, n=5

Accuracy Using CAT Scan Evaluation

All patients underwent 3-mm thin-section postoperative CT (Siemens Somatome). Pedicle perforations were classified as either medial or lateral and categorized into one of four groups: 2.1-4.0 mm, 4.1-6.0 mm for medial or lateral perforation.



An example of a fully contained screw

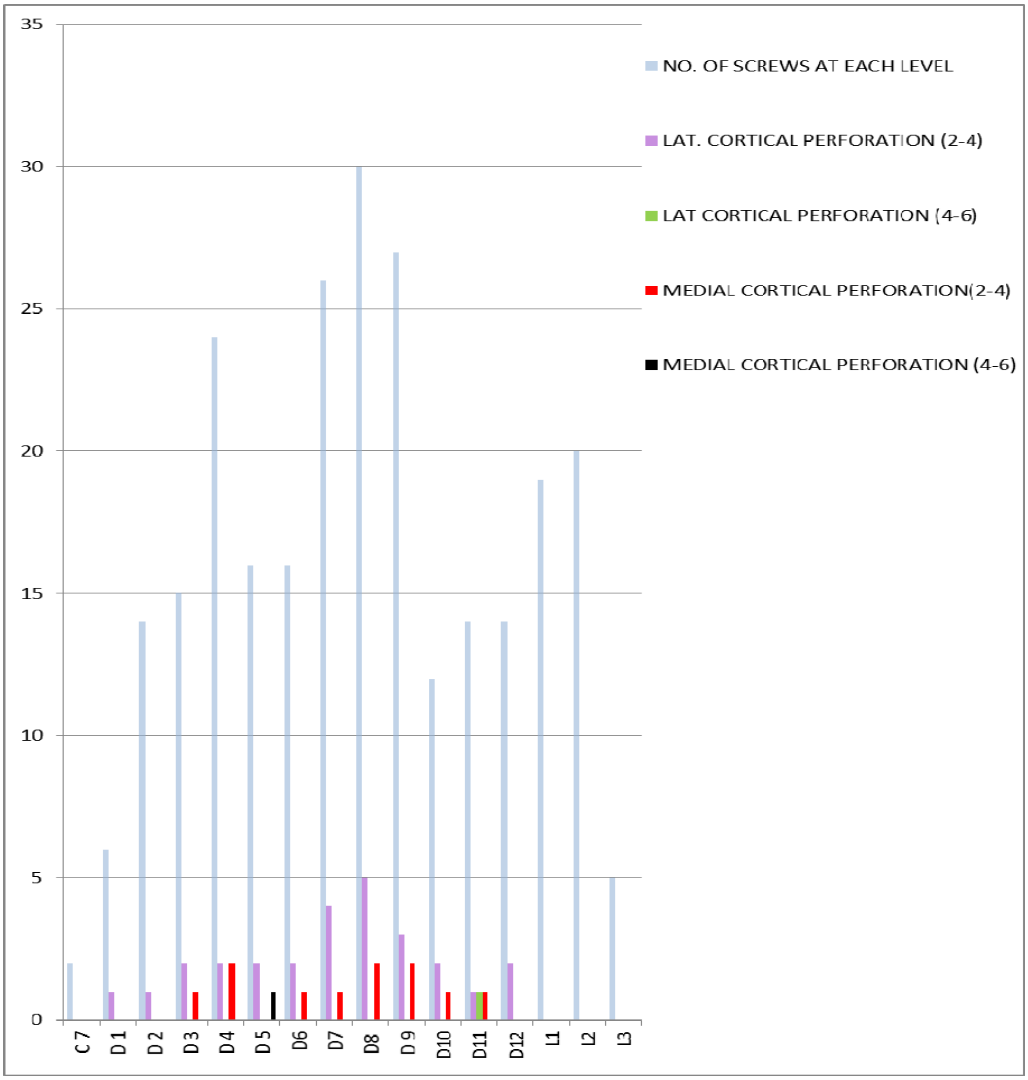


Postoperative computed tomography image shows right lateral pedicle perforation between 4 and 6 mm and a fully contained intrapedicular screw on the left side and anterior vertebral cortex penetration of 2 mm.

The severity of the deformity as judged by cobb's method among the patients included in the present study varied from 45 degrees to 110 degrees.

Of the 260 screws inserted into the deformed scoliotic spine 27 screws showed moderate lateral cortical perforation whereas 11 screws showed moderate medial cortical breech. These screws showed cortical perforation in the range of 2.1-4.0mm.

One screw each showed cortical breech in the range of 4.1-6.0mm on medial and lateral side.



On analysis of the data the following facts are evident

1. Maximum number of screws were inserted in vertebral level of D 7 to D 9 (n=83).
2. Number of screws showing moderate perforation of the Lateral cortical wall (n=27).
3. Number of screws showing moderate perforation of the medial cortical wall (n=11)
4. One screw at the level of D 11 showed lateral cortical perforation of 4-6mm.
5. One screw at the level of D 5 showed a medial cortical perforation of 4-6 mm.
6. Also there were 3 screws that showed penetration of the anterior vertebral body > 2mm.

Complications

1. Neurological

There was one instance on post operative paraplegia in a case of congenital scoliosis which recovered completely over a period of 6wks.The post operative CT of this patient did not show significant medial cortical breech by the pedicular screw.

2. Vascular

Even as 3 screws showed a breech of the anterior wall of the vertebral body there were no instances of vascular complications at the time or surgery or in the post operative period. These screws were not revised.

3. Mortality

One patient died on post operative day 5 due to severe restrictive airway disease. There were no instances of death that could be attributed to the pedicular screws.

Discussion

Thoracic pedicle screw fixation is potentially dangerous because of the maximum permissible translational error of less than 1 mm at the normal midthoracic spine using a geometric model due to small pedicle diameter and little space between the spinal cord and medial pedicle.

There are several methods of pedicle screw insertion to enhance the safety, such as guide pins into the pedicles, intraoperative C-arm image intensifier, direct visualization of the medial wall after laminotomy, and image-guided systems based on CAT scan or fluoroscopy. 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. To detect the cortical wall defect of the pedicle, triggered EMG and intraosseous endoscopy have been used.

For the 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 the0%to 0.9% range. A few reports have described complications caused by over penetration related to the placement of thoracic pedicle screws with major visceral injury. Although many studies reported medial wall violation of the thoracic pedicle between 1.4% and 14% from 1mmto 8.0 mm, there were no permanent neurologic, cardiovascular, or pulmonary complications associated medial wall violation in any cases.

In the present study out of the 260 screws that were inserted in 20 patients having deformed spine 10.7% of the screws showed lateral cortical breech and 4.6 % showed a medial cortical perforation.

The higher percentage of pedicular breech evident in the present study may be attributed to the complexity of the deformities that have been dealth with in this study the average cobb's angle being 65 degrees among the 20 studied cases.

On studying each deformity it was evident that errors in screw placement were least at the ends of the deformity and were maximum at the apex. Out of 40 screws which were out 8 screws were at the ends of the construct and the remaining were at the apex of the deformity.

One screw showed a lateral cortical breech of the pedicular wall in the range of 4-6mm. This occurred in a patient having cobb's angle of 80 degrees and rigid thoracic curve.

One screw which showed perforation of the medial wall of the pedicle of greater than 4mm occurred in a patient having congenital rigid thoracic scoliosis with cobb's angle of 110 degrees. Even after the cortical violation of >4mm the patient did not develop neurological deficit in the post operative period. This could be explained by the fact that in the deformed spine the spinal cord tends to lie along the concave side of the deformity leaving extra space and hence extra margin of safety along the convex side even if the medial wall of the pedicle is violated.

Because of the gross vertebral rotation and relative inaccessibility due to surrounding ribs gaining appropriate trajectory for screw placement particularly along the concave side of the deformity becomes difficult.

In the serial follow-up of the patients none of the patients who had misplaced screws had complications in the form of implant back-out or the loss of correction.

It has to be admitted however that the actifacts caused by the metallic implants especially stainless steel implants do interefere with assessment of the screw position. The artifacts are less with titanium implants. Literature suggests 76% accuracy of post operative CT scans. But among the other methods such as X rays and open laminotomy in assessing the pedicle screws CT scanning is a feasible option.

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%, pedicle screw fixation of scoliotic and non-deformed thoracic spines may be performed in a safe manner.

Obviously, there are many other methods available to aid surgeons to place 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 into the spinal canal. 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.

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.

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