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Thoracic Pedicle Screw Fixation in Spinal Deformities

Are They Really Safe?

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Study Design. A retrospective study.

Objective. To determine the safety of pedicle screw fixation in thoracic deformity correction.

Summary of Background Data. Pedicle screw fixation enables enhanced correction of spinal deformities. However, the technique is still not widely applied for thoracic deformities for fear of neurologic complications.

Materials and Methods. A total of 462 patients subjected to thoracic pedicle screw fixation for spinal deformities were analyzed after a minimum follow-up of 2 years. Etiologic diagnoses were idiopathic scoliosis in 330, congenital kyphoscoliosis in 68, kyphosis in 50, and others in 14. They were reviewed using the medical records and preoperative, intraoperative, and postoperative roentgenograms. Computed tomography was performed when screw position was questionable.

Results. A total of 4604 thoracic pedicle screws were inserted (10.1 screws/patient). There were 67 screw malpositions (1.5%) in 48 patients (10.4%). The malpositions were inferior in 33, lateral in 18, superior in 12, and medial in 4. Screw-related neurologic complications occurred in four patients (0.8%); these comprised a transient paraparesis and three dural tears. Other complications comprised 11 intraoperative pedicle fractures, 35 screw loosenings, 9 postoperative infections, and 1 pneumothorax. There were no significant screw-related neurologic or visceral complications that adversely affected the long-term result. The deformity correction was 69.9% for idiopathic scoliosis and 60.7% for congenital scoliosis. The sagittal plane deformity correction was 47° for kyphosis.

Conclusions. Thoracic pedicle screw fixation is a reliable method of treating spinal deformities, with an excellent deformity correction and a high margin of safety. [Key words: pedicle screw fixation, thoracic, spine deformity] **Spine 2001;26:2049–2057**

In the surgical correction of spinal deformities, addition of internal fixation serves the dual function of improving solid arthrodesis by rigid immobilization of the instrumented segments and correcting preexisting deformities by facilitated application of the corrective forces. Since the introduction of first effective internal fixation of the spine (the Harrington instrument[11]) in early 1960s, the surgery of spinal deformity became a race between the deformity and the instrument systems that offered enhanced control of the vertebral column.

Biomechanically, a spinal internal fixation device consists of anchoring members that form the bone–implant interface, longitudinal members that connect the anchoring members, transfixators that crosslink the longitudinal members to form a quadrilateral construct, and a locking mechanism that forms the interface between the implant members. Of these, the anchoring member plays the principal role in determining the biomechanical characteristics and the rigidity of the fixation offered by the instrumentation system.[15] Spinal pedicle screws, first introduced by Boucher[4] in the 1950s and popularized by Roy-Camille et al[22,23] in the 1960s, are a penetrating type of anchor with resistance and offer secure vertebral grip that enables improved control of the instrumented segments and rigid internal immobilization.[15] Because of these advantages, they offer improved correction and maintenance of spinal deformities.[2] However, compared with its usage in the lumbar spine, it is still not widely applied for the management of spinal deformities because of the fear of irreversible neurologic complications.[20]

Authors have been using the pedicle screws for the management of thoracic deformities since the early 1990s and have observed no serious neurologic or visceral complications.[30,31] With growing interest in thoracic pedicle screw fixation in North America, this retrospective study was carried out to determine the safety of thoracic pedicle screw fixation for the management of spinal deformities.

Materials and Methods

A total of 462 patients with spinal deformity subjected to correction by posterior instrumentation using thoracic pedicle screw fixation and followed up for more than 2 years were retrospectively analyzed for complications of the pedicle screw fixation and the deformity correction. The authors reviewed the medical records and preoperative, intraoperative, and postoperative posteroanterior (PA) and lateral radiographs.

Deformity correction was determined on preoperative and postoperative radiographs taken in standing position using a 14×35-inch-long cassette. The deformity was measured on all the radiographs by the Cobb's method using the end vertebrae determined on the preoperative standing radiographs.

The positions of the screws were evaluated using intraoperative and postoperative radiographs and thin-slice computed tomography (CT) scans taken in the first postoperative week that were available in 20 patients. Because of the high radiation dosage and the cost of the thin-slice CT, it was not performed routinely but had been performed only on those patients with suspicious mechanical complications (*e.g.*, pedicle fracture) or serious medial and inferior malposition of the pedicle screw on the immediate postoperative plane radiographs.

All radiographic evaluations were carried out in a double-blind fashion (by W.-J.K. and J.-H.K.), and the mean values of the measurement were used for analysis. When there was dis-

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agreement about the containment of the screws in the pedicle, it was counted as misplaced to increase the sensitivity.

Surgical Techniques. All the surgeries were carried out by the first author (S.-I.S.). Three surgical methods were used for the correction of the subject deformities: posterior instrumentation with segmental pedicle screw fixation, anterior release/fusion with posterior pedicle screw fixation, and posterior vertebral column resection. The posterior vertebral column resection was carried out mainly for rigid scoliosis and angular kyphosis.[27,29] All the pedicle screws were inserted using the following technique.

Incision and Exposure. A standard posterior midline incision is made from the upper end of the spinous process two levels above the uppermost pedicle instrumented to the lower end of the lamina of the lowest instrumented vertebra. The proximal incision should be long enough to allow convergence of the pedicle screws in the uppermost vertebra. The spine is exposed to the tip of the transverse processes bilaterally, staying strictly subperiosteal to reduce bleeding.

Facetectomy. The facets included in the fusion are destroyed by inferior facetectomy and removal of the articular cartilage to promote intra-articular arthrodesis. Care should be taken not to disturb the adjacent facets to prevent instability and precocious degenerative change.

Determination of Pedicle Entry Sites. Presumed pedicle entry points were decorticated with a rongeur to facilitate the insertion of the guide pins. In the thoracic spine the presumed pedicle entry point is at the junction of the superior margin of the transverse process and the lamina. Then guide pins are inserted shallowly through the exposed cancellous bone at the presumed pedicle entry point. To facilitate radiograph interpretation, the guide pins are directed along the axis of the pedicle in the frontal and sagittal planes. With the guide pins placed at planned pedicle screw sites, intraoperative PA and lateral roentgenograms are taken to determine the association between the presumed entry point and the ideal entry point identifiable on the radiograph and to determine the direction of the screws. Taking the transverse angle of the pedicles into consideration, the ideal pedicle entry point (IPEP) in a neutrally rotated vertebra is at the junction of the line parallel to the vertebral end plates bisecting the pedicle and the lateral margin of the pedicle ring shadow on a PA film. In rotated vertebrae IPEP of the pedicles on the side of the rotation (convex side of scoliosis) moves more medially, whereas IPEP on the opposite side (concave side) moves more laterally with increment of vertebral rotation. On the lateral view, the IPEP is situated at the junction of the line passing through the axis of the pedicle and the posterior border of the facet joints.

Pedicle Entry. After determining the position of the ideal pedicle entry points and the direction of the ideal pedicle paths relative to the guide pin, the pedicle is entered through the point with a small-diameter drill or a small curette. It is important to keep in mind the normal transverse angle of the pedicles for the particular level to prevent inadvertent pedicle perforation. Then the hole is checked with a blunt-ended probe. A safe entry into the pedicle is confirmed when the probe meets bony resistance in all directions and cancellous bone at the tip, meaning that the hole is globally surrounded by bone.

Hole Preparation. Deep drilling is performed following the probe path using a drill bit with the diameter the same as the minor diameter of the screw used. The pedicle screw offers best holding strength when the pilot hole is about 60% of the outer pedicle diameter.[28]

Screw Insertion. The pedicle screw is inserted after reconfirming the bony containment of the pilot hole. When starting to insert the screw, the screw is turned with very gentle force so that the screw follows the predrilled path. Undue force at the beginning may misdirect the screws into a wrong direction. The ideal screw diameter is about 80% of the pedicle diameter.[28] However, in pediatric patients oversized screws up to 115% of the pedicle diameter may be inserted without causing a significant decrease in the screw holding power because of plasticity of the pedicular cortex.[19,28] The ideal screw length is about 70% apparent penetration of the vertebral body on a lateral radiograph to avoid complications of screw overpenetration. The screw dimensions are best determined before surgery using the radiograph measurements, calculating the magnification as 110%.

Screws are inserted on every segment on the correction sides (thoracic concave) and every second or third on the support sides (thoracic convex) in idiopathic scoliosis or curves of similar shape treated by the rod derotation maneuver. In kyphosis and congenital scoliosis, bilateral segmental insertion was performed to increase the rigidity of the fixation and shorten the fusion extent.

Deformity Correction. After the insertion of the pedicle screws in the planned position, deformity correction was carried out using a rod derotation maneuver,[5,30] vertebra-to-rod method, or an osteotomy procedure,[27,29] depending on the pathology of the patient using rods contoured to conform the normal sagittal profile of the instrumented segments (Figure 1).

With locking of the screws in the final corrected position, arthrodesis was carried out using autogenous iliac cancellous bone graft. For those with vertebral column resection, anterior column restoration was carried out using bone-filled titanium mesh cage along with posterior fusions.

Aftertreatment. The patients without vertebral column resection were allowed to ambulate 24 hours after the operation. They were protected using a custom-made thoracolumbosacral orthosis for 3 months. For the patients with vertebral column resection, the patients were kept in bed for a week after the operation and allowed to ambulate in a plaster of Paris body jacket, which is kept for 4 months.

Bleeding. The mean estimated blood loss was 786.5 mL (range, 550–1000 mL) for a posterior procedure (primary posterior segmental pedicle screw fixation and posterior stage of the anterior posterior surgery). The mean estimated blood loss was 3950.6 mL for posterior vertebral column resection (range, 3200–4500 mL).

Operation Time. The mean operation time was 159 ± 34 minutes (range, 120–210 minutes) for a posterior procedure (primary posterior segmental pedicle screw fixation and posterior stage of the anterior posterior surgery), with a mean 15.7 minutes per level. The operating time was 252 ± 81 minutes for posterior vertebral column resection (range, 110–555 minutes).

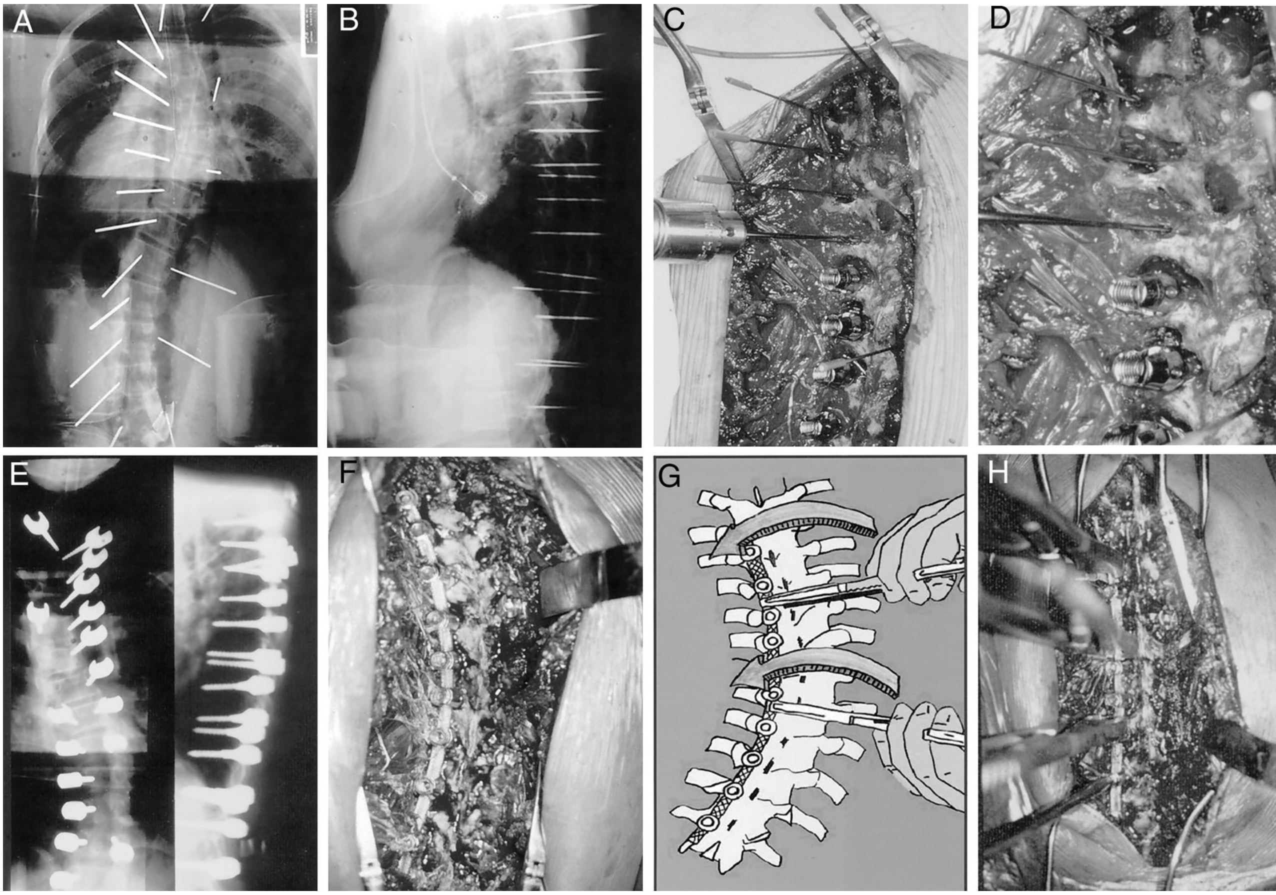

Figure 1. Surgical techniques. **(A** and **B)**. Guide pins were inserted at the presumed pedicle entry points. Determine the association between the presumed entry point and the ideal pedicle entry point on the radiograph. **(C)** Pedicle entry by drilling. **(D)** Confirm a safe entry with a blunt-ended probe. A safe entry is confirmed when the probe meets bony resistance in all directions and cancellous bone at the tip. **(E)** Screw insertion. Screws are inserted on every segment on the correction sides (thoracic concave) and every second or third on the support side. **(F)** Rod insertion. **(G)** Deformity correction by derotation without compression–distraction. **(H)** After derotation.

Results

There were 116 male patients and 346 female patients with a mean age of 18.5 years (range, 2.7–70 years) at the time of the surgical treatment. The etiologic diagnoses were idiopathic scoliosis in 330, congenital kyphoscoliosis in 68, and other in 14. Fifty patients were operated mainly for the kyphotic deformities. The etiologies of kyphosis were postinfectious in 24, ankylosing spondylitis in 13, post-traumatic in 7, and other in 6 (Table 1). A total of 4604 thoracic pedicle screws were inserted in the thoracic level (T1–T12), with an average of 10.1 screws per patient. The diameter of the screws used in the thoracic spine ranged from 4 to 6.5 mm.

The patients with idiopathic deformities had a mean age of 15.9 years (range, 9.1–61 years) at the time of the surgery. They were diagnosed juvenile in 8, adolescent in 311, and adult type in 11. The curve subjected to thoracic pedicle screw fixation was 52.9 ± 18.1° (range, 40–143°) in the coronal plane with a preoperative coronal imbalance of 1.1 ± 1.0 cm (range, 0–4.0 cm). The treatment comprised posterior fusion with segmental pedicle screw fixation in 312, vertebral column resection combined with segmental pedicle screw fixation in 8, and combined anterior and posterior correction in 10. An average of 8.9 thoracic levels (range, 3–14 levels) were fused, with a mean 11.4 thoracic screws per patient (range, 2–18 screws). The patients with congenital deformities had a mean age of 13.9 years (range, 2.7–64 years) at the time of the surgery. The pathology of congenital spinal deformities was single hemivertebra in 48, double hemivertebrae in 9, butterfly vertebra in 4, hemivertebra with unsegmented bar in 1, and other in 6. Preoperative deformity was 51 ± 19° (range, 21–133°) in the coronal plane, with a preoperative coronal imbalance of 2.0 ± 1.5 cm (range, 0–5 cm) and −37 ± 21° (range, −95 to −7°) in the sagittal plane, with sagittal imbalance of 20 ± 13 mm (range, −5 to 55 mm). The treatment comprised posterior fusion with segmental pedicle screw fixation in 31, vertebral column resection combined with segmental pedicle screw fixation in 37, and an average of 4.8 thoracic levels (range, 1–16 levels) were fused with mean 6.5 thoracic pedicle screws per patient (range, 2–17 screws).

The patients with kyphotic deformities had a mean age of 41.3 years (range, 15–70 years) at the time of surgery. Preoperative deformity was −57 ± 32° (range,

Table 1. Etiologic Diagnosis and Method of Treatment

Etiology	Patients [n (screws)]	PF [n (screws)]	VCR [n (screws)]	AP [n (screws)]
Idiopathic scoliosis	330 (3751)	312 (3536)	8 (93)	10 (122)
Juvenile	8 (111)	4 (56)		4 (55)
Adolescent	311 (3513)	308 (3480)		3 (33)
Adult	11 (127)		8 (93)	3 (34)
Congenital kyphoscoliosis	68 (444)	31 (242)	37 (202)	
Single HV	48 (307)	20 (158)	28 (149)	
Double HV	9 (66)	7 (54)	2 (12)	
Butterfly	4 (24)	1 (8)	3 (16)	
HV with unseg. bar	1 (8)		1 (8)	
Other	6 (39)	3 (22)	3 (17)	
Kyphosis	50 (280)		50 (280)	
Postinfectious	24 (154)		24 (154)	
Ankylosing spondylitis	13 (50)		13 (50)	
Post-traumatic	7 (40)		7 (40)	
Other	6 (36)		6 (36)	
Other (*e.g.*, postsurgical, paralytic, Marfan syndrome, tumor)	14 (129)	7 (79)	4 (22)	3 (28)
Total	**462 (4604)**	**350 (3857)**	**99 (597)**	**13 (150)**

PF = posterior fusion with segmental pedicle screw fixation, VCR = vertebral column resection combined with segmental pedicle screw fixation, AP = combined anterior and posterior correction.

10–147°), with a preoperative sagittal imbalance of 2.5 ± 1.7 cm (range, −1 to 8 cm). All were treated by vertebral column resection combined with segmental pedicle screw fixation, and an average of 4.4 thoracic levels (range, 3–7 levels) were fused, with a mean of 5.6 thoracic pedicle screws per patient (range, 2–12 screws).

Deformity Correction

In idiopathic scoliosis the deformity was corrected to 16 ± 15° (range, 3–76°) in the coronal plane showing a correction of 69.9%. At the final follow-up the deformity in the coronal plane was 18 ± 12° (range, 3–90°) showing a loss of correction of 3.6%. The spine was balanced in all the patients. In the congenital scoliosis cases, the deformity was corrected to 20 ± 12° (range, 2–78°) in the coronal plane showing a correction of 60.7%. In the sagittal plane the kyphosis was −11 ± 8.6° (range, −40 to 4°) showing a correction of 26° after the surgery. At the final follow-up the deformity in the coronal plane was 23 ± 13° (range, 3–81°) showing a loss of correction of 6.2%. In the patient with kyphotic deformities, preoperative deformity of −57° was corrected to −10° showing correction of 47°. At the final follow-up the curve was −12° with 2° loss of correction (Figure 2) (Table 2).

Complications

The complications are given in Tables 3, 4, and 5.

Screw Misplacement. Screw containment and the rate of screw misplacement were determined by review of the postoperative radiographs. As pedicle screws were placed segmentally along the scoliotic–kyphotic curvature, any offset of the screws from the gentle arc of the deformity, rotation, or sagittal angulation strikingly dif-

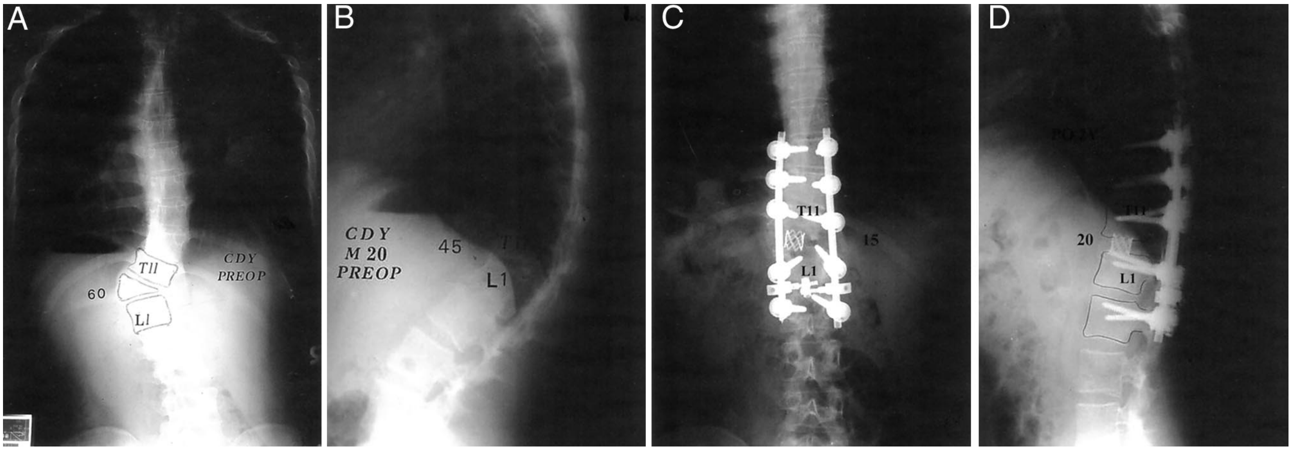

Figure 2. **(A** and **B)** A 20-year-old man with a congenital hemivertebra T12. The magnitude of coronal and sagittal angle was 60° and 45°, respectively. Trunk was 2.5 cm shifted to the left. Lateral roentgenogram show marked hyperkyphosis at thoracolumbar area. **(C** and **D)** Postoperative 2-year follow-up standing radiographs. The coronal and sagittal angle was corrected to 15° and 22°, respectively. He was balanced with same shoulder heights. Preoperative thoracolumbar hyperkyphosis was satisfactorily improved.

Table 2. Deformity Correction

Deformity	Preoperative [° (range)]	IMPO [° (range)]	Correction	Final [° (range)]	LOC
Idiopathic	53 ± 18 (40–143)	16 ± 15 (3–76)	69.9%	18 ± 12 (3–90)	3.6%
Congenital	51 ± 19 (21–133)	20 ± 12 (2–78)	60.7%	23 ± 13 (3–81)	6.2%
Kyphosis	57 ± 32	10 ± 25	47°	12 ± 23	2°

IMPO = immediate postoperative (2 weeks postoperation); LOC = loss of correction.

ferent from the neighboring screws strongly suggested misplacement. CT scans were taken only to confirm the suspicious screws. Of a total of 4604 thoracic pedicle screws inserted, 67 screw malpositions (1.5%) occurred in 48 patients (10.4%). The malpositions were lateral in 18 (18 of 67, 27%), medial in 4 (6%), superior in 12 (18%), and inferior in 33 (49%) (Figure 3). It was most common at the convex side of the uppermost instrumented vertebra (22 of 67, 33%). The screw malpositions were more common in the kyphosis than deformities of other types (idiopathic, 45 of 3751, 1.19%; congenital, 9 of 444, 2.02%; kyphosis, 10 of 280, 3.57%; others, 3 of 129, 2.33%). There was a significant difference between the coronal and sagittal deformities ($P = 0.001$, Kruskal–Wallis test). Misplaced screws were accepted and were left in position as they were if there were no serious complications. Reoperation for removal of a misplaced screw was performed in only one patient with transient paraparesis.

Neurologic Injury. There was a transient paraparesis in one patient with neurofibromatosis. The neurologic injury was because of medial perforation of the pedicle by the screws causing delayed epidural hematoma. The patient was treated by removal of the offending screw and evacuation of the hematoma by a decompressive laminectomy. The neurologic symptoms resolved 3 weeks after the neural decompression. There were three dural tears as evidenced by gushing out of cerebrospinal fluid during the preparation of the screw holes. When this happened the pilot paths were sealed with bone wax, and a new hole was prepared lateral to the initial holes. There were no complications related to the dural tears.

Pedicle Fracture. Intraoperative fractures of the pedicle occurred in 11 pedicles (0.24%). All but two were detected intraoperatively. Those detected fractures occurred during the final stage of insertion of the pedicle screws, but none caused gross intraoperative loosening that necessitated removal of the screws. Those intraoperatively undetected fractures occurred during the course of applying compression over the screws and were recognized on a postoperative CT scan in one patient subjected to osteotomy for correction of a congenital kyphoscoliosis. Fixation failure with loosening of the screws occurred in the other patient with undetected fracture of the pedicle, and revision with proximal extension of the fusion was necessary.

Screw Loosening. Intraoperative loosening of the screw was detected in 35 pedicles (0.76%). They were mostly at the apex of the deformity and occurred during the correction maneuver using a vertebra-to-rod method. There was no screw loosening during the rod derotation maneuvers. This difference may be attributed to the concentration of stress on the apical screw during the vertebra-to-rod method, which is effectively dispersed to several anchors in the rod derotation method.

Infection. There were a total of nine infections (1.9%). Eight of them were superficial and treated by incision and drainage. One deep infection was treated by radical debridement and delayed closure. All the infections healed uneventfully without removal of the implants.

Table 3. Complications

Complication	Patients [n (%)]	Screws [n (%)]
Screw malposition*	48 (10.4)	67 (1.5)
Inferior		33 (0.72)
Lateral		18 (0.39)
Superior		12 (0.16)
Medial		4 (0.09)
Transient paraparesis	1 (0.2)	
Dural tear	3 (0.6)	
Intraoperative pedicle fracture		11 (0.24)
Screw loosening†		35 (0.76)
Infection	9 (1.9)	
Pneumothorax	1 (0.2)	

* Most common at convex side of upper most instrumented vertebra; more common in kyphotic deformity.
† Most common at the apex of the deformity.

Table 4. Screw Complications Related to Type of Deformity

Complication	Screws	Idiopathic	Congenital	Kyphosis	Other
Screw malposition	67	45	9	10	3
Inferior	33	23	4	5	1
Lateral	18	12	3	3	
Superior	12	8	1	2	1
Medial	4	2	1		1
Transient paraparesis	1				1
Dural tear	3	2	1		
Intraoperative pedicle fracture	11	3	7	1	
Screw loosening	35	30	2	3	
Pneumothorax	1	1			

Table 5. Screw Complications Related to Method of Treatment

Complication	Screws	PF	VCR	AP
Screw malposition	67	47	18	2
Inferior	33	25	7	1
Lateral	18	11	7	
Superior	12	9	3	
Medial	4	2	1	1
Transient paraparesis	1			1
Dural tear	3	2	1	
Intraoperative pedicle fracture	11	7	4	
Screw loosening	35	30	4	1
Pneumothorax	1	1		

PF = posterior fusion with segmental pedicle screw fixation, VCR = vertebral column resection combined with segmental pedicle screw fixation, AP = combined anterior and posterior correction.

Others. There was a spontaneous pneumothorax in one patient with idiopathic scoliosis. She was treated by insertion of the chest tube, which was removed 1 week after the thoracotomy. There was one recurrence of deformity in a patient with congenital kyphoscoliosis treated by posterior fusion because of an inappropriately short fusion. It was revised by proximal and distal extension of the fusion.

■ Discussion

Despite the super biomechanical advantages of pedicle screws over other forms of spinal bone–implant interfaces and their widespread use for the treatment of diseases involving the lumbar spine, use of pedicle screws in thoracic spine is yet relatively limited because of the fear of causing permanent neurologic injuries.

In general, complications of pedicle screw instrumentation may be divided into three categories according to the time they occur during the course of the surgery. Phase I categories are complications attributable to the events before the preparation of the pedicle holes and comprise soft tissue injury, adjacent facet joint injuries, and fractures of the transverse process. Phase II categories refer to the complications occurring during the hole preparation and the screw placement. Phase III refers to the complications occurring after the placement of the screws, *e.g.*, those occurring during the rod derotation maneuver or osteotomies.

Although considered and counted as complications of the pedicle screw fixation, those complications in Phase I are not specific to the pedicle screw fixation and bear little association to the pedicle screw fixation *per se*.

Phase II complications of thoracic pedicle screws are caused by overpenetration of the drill and/or screws, malpositioning of the pilot holes, and the resultant misplacement of the screws and intraoperative pedicle fractures. Of these, only the malpositioning of the screws is related to the development of neurologic complications.

The complications caused by overpenetration related to the placement of thoracic pedicle screw with major visceral injury are a rare occurrence with only one report in the literature.[14] It was a fatal cardiac tamponade caused by guide wire-induced prick of the right coronary artery. However, considering the close proximity of the major vessels to the anterior surface of the thoracic vertebra, utmost care should be paid not to penetrate the anterior cortex. In an unreported case an overpenetrated pedicle screw caused irritation of the thoracic aorta resulting in severe chest pain that necessitated removal of the offending screw. The complications from overpenetration may be prevented by careful preservation of the anterior vertebral cortex during the preparation of the pedicle hole and choosing a screw based on the preoperative measurement of the distance between the lamina and the anterior surface of the vertebral body. Because the holding power of the pedicle screw is not significantly affected by the depth of insertion when the screw passes deeper than the posterior one half of the vertebral body, using screws that penetrate 50–70% of the vertebral body seems sufficient.[13,33] Our preference of the screw length are as follows: 40 mm in the lower lumbar spine (L3 down), 35 mm for the thoracolumbar and the upper lumbar spine (T10–T12), 30 mm in the midthoracic

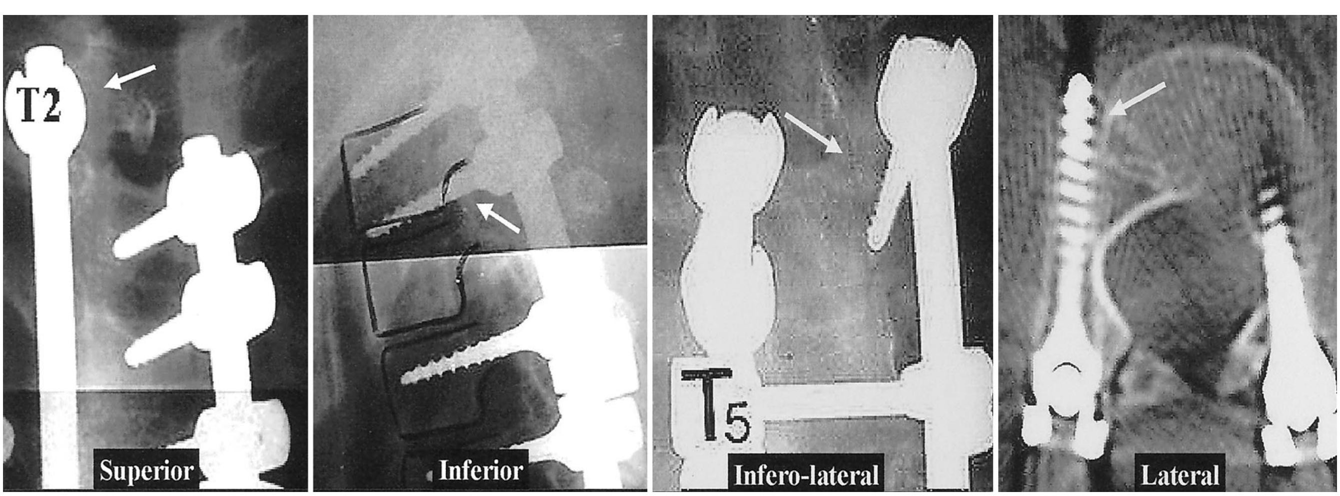

Figure 3. Cases of screw malposition. Lateral malposition was most common.

(T5–T9), and 25 mm for the upper thoracic spine (T1–T4).

As a whole, the reported risk of pedicle screw misplacements ranges from 3% to 40%, with 0–41% neurologic complications attributable to the misplaced screws in surgeries involving pedicle screw instrumentation.[3,7,9,12,18,21,24,30,32] For the thoracic pedicle screws used in the treatment of spinal deformities, the incidence of screw misplacement ranges from 3% to 25%, with screw-related neurologic complications in 0–0.9%.[1,3,16,30] The wide variation in the rate of the screw misplacement may be attributed to the method of evaluating the position of the pedicle screws. Although our present results show only 1.5% misplacement, we admit that the actual rate would be higher as our patients were primarily evaluated by the postoperative radiographs and CT scans were only performed on a small number of patients with suspicious perforations. This was because pedicle screw-related complications were too low to warrant a routine thin slice CT for all the patients subjected to the instrumentation. But even for the misplaced screws, there were few complications.

Compared with the rate of developing a neurologic symptom in the lumbar spine, the rate of the neurologic complications in the thoracic spine is surprisingly low. This low incidence of neurologic complications related to the misplacement of the thoracic pedicle screw may be attributed to anatomic characteristics of the scoliotic spine and the fact that the root injuries in the thoracic level are inconspicuous and may not have been detected even when present.

In the scoliotic–thoracic spine the vertebra is rotated toward the convex side with the cord shifted to the concave side leaving a spacious canal on the convex side. This rotation of the deformed segments toward the convex side increases the angle of convergence of the pedicles on the concave side relative to the sagittal plane, thus making a medial pedicular perforation unlikely should the proper pedicle entry points be chosen. This fact, along with the anatomic characteristic of the thoracic pedicle having a thicker cortical medial wall and thinner lateral wall, reduces the risk of medial perforation, thus preventing a serious neural damage. On the convex side a large free space in the canal to the lateral of the dural tube created by the shift of the neural elements to the concave side prevents the development of neural complications even with medial misplacement of the pedicle screws. With these protective anatomic factors, we believe that the pedicle screw fixation in a scoliotic deformity is relatively safe if one keeps the change in the angle of convergence in rotated vertebrae in mind.

Nevertheless, it is best to avoid the potential, unexpected complications as was in our patient with delayed epidural hematoma who developed paraparesis a week after the surgery, by exact placement of the screws in the pedicle. This can be accomplished by understanding the anatomy of the pedicles in the thoracic scoliosis, that there is significant diminution in the size of the concave side pedicles when compared with the convex side,[17] and strict adherence to the sound insertion techniques and careful confirmation of the safety of the pilot hole before the insertion of the screws.

Also worth mentioning is the high probability that the surgeons undertaking pedicle screw fixation of the thoracic spine are more experienced than average with the pedicle screw fixation techniques. This may have played an important role in reducing the complications of the thoracic pedicle screws.

We began thoracic pedicle screw fixation for spinal deformities only after an extensive experience of lumbar pedicle screw fixation. Initially, thoracic screws were used in the thoracolumbar spine where the pedicles were large and well visible.[31] With success in the thoracolumbar spine, pedicle screws were gradually used in more proximal levels. Because use of the screws offered better intraoperative control and better postoperative results, we eventually abandoned the use of other methods of fixation, using only pedicle screws since 1992. In the earlier period the screws were placed in the hook pattern (screws instead of hooks) after the standard hook fashion as recommended by the CD group. The result of the hook pattern–screw fixation was superior to using the hooks but did not offer a true segmental control of the deformity and was often complicated with pullout of the screws during the derotation maneuver because of stress concentration on the screws. This problem was solved by adding more screws to the concave side of the deformity, dispersing the stress along increased number of screws.[30] The results of segmental pedicle screw fixation were superior to our previous experience with hook pattern–screw fixation or the hook–rod technique. In our series deformity correction of 72% and 1% loss of correction were obtained with segmental pedicle screw fixation, whereas hook pattern–screw fixation had 66% correction with 2% loss and hook–rod technique had 49% correction with 6% loss. It was a relatively safe procedure while offering a satisfactory correction and maintenance of the deformity.[30] There are several methods of thoracic pedicle screw insertion besides our method, including the newly developed computer-guided navigation system and the laminotomy method in which the medial wall of the pedicle is visualized to safeguard a proper entrance of the pilot hole into the pedicles.[8,10,26] Although none has been tried extensively in the treatment of thoracic spinal deformities as our method, the newly developed methods also look promising and may be applied safely by an experienced surgeon familiar with the method. Whatever the method to enter the pedicle, the most important step in the prevention of complications because of screw malpositions is the confirmation of the pedicle hole being safely contained within the pedicle before the insertion of the screws. In addition to the conventional sounding technique, intraosseous endoscopy, pedicle impedance testing, and saline challenge test may be used to increase the sensitivity of detecting a perforation of the pedicular cortex.[6,25]

Intraoperative fracture of the pedicle occurred as a Phase II complication caused mainly by the gross discrepancy between the diameters of the pedicle and the screws inserted. Although screws with a diameter up to 115% of the pedicle diameter may be inserted without causing a fracture of the pedicle in the immature spine, fractures may occur even with the smallest diameter screw we used (4.0 mm) because of the small size of the immature pedicles. However, because of the plasticity of the immature cortical bone in young patients that allows significant deformation, comminuted fracture of the pedicle that renders the screw grossly unstable and puts the neural elements at increased risk of injury is very rare in this age group, and pedicle screws offer significant pullout strength even with the split fracture of the pedicle by a purchase in the vertebral body. These fractures occur mostly during the insertion process of the pedicle screws, especially during the final drive into the pedicles and may be prevented by generous decortication of the entry points and enlarging the proximal portion of the pedicle path using a drill slightly larger than the minor diameter of the screw used. Because they are quite stable, it is not necessary to remove the screws unless there is gross instability. Nevertheless, fractures of the pedicles render the screws unstable to longitudinally directed forces (*e.g.*, compression, distraction) and may necessitate extension of the fusion level should the fractures occur bilaterally at the end of the pedicle screw construct.

Phase III complications that occur after the placement of pedicle screws occur as screw pullout or pedicle breakage during the deformity correction procedure because of concentration of the stress on the specific screw. In our series intraoperative screw loosening occurred only during the vertebra-to-rod correction where a screw was pulled posterior to the rods. Because the displacements were always to the posterior direction, there was no intrusion of the spinal canal that could increase the risk of the neural elements. The results of reviewing the Phase II and III complications in our study show that condemning the use of the pedicle screw for correction of the thoracic deformity because of fear of serious neurologic damage is baseless when using a sound surgical technique. Although the retrospective nature of this study and the heterogeneity of the operations to which the patients were subjected did not allow determination of the exact time consumed for the pedicle screw instrumentation, comparing the total operating time with those of the similar surgeries done by other surgeons showed that pedicle screw instrumentation is not unduly time-consuming (mean operation time, 159 minutes [15.7 minutes per level]). It is our conclusion that using thoracic pedicle screws for the treatment of spinal deformities involving the thoracic spine is a relatively safe procedure while offering a satisfactory correction and maintenance of the deformity.

■ Key Points

- Thoracic pedicle screw fixation is a reliable method of treating spinal deformities.
- Thoracic pedicle screw fixation has excellent deformity correction and a high margin of safety.

References

1. Akbarnia BA, Asher MA, Hess WF, et al. Safety of pedicle screw in pediatric patients with scoliosis and kyphosis. Presented at the annual meeting of the Scoliosis Research Society, Ottawa, Ontario, Canada, 1996.
2. Boos N, Webb JK. Pedicle screw fixation in spinal disorders: a European view. Eur Spine J 1997;6:2–18.
3. Brown CA, Lenke LG, Bridwell KH, et al. Complications of pedicle thoracolumbar and lumbar pedicle screws. Spine 1998;23:1566–71.
4. Boucher HH. A method of spinal fusion. J Bone Joint Surg Br 1959;41:248–59.
5. Cotrel Y, Dubousset J, Guillaumat M. New universal instrumentation in spinal surgery. Clin Orthop 1988;227:10–23.
6. Darden BV 2nd, Owen JH, Hatley MK, et al. A comparison of impedance and electromyogram measurements in detecting the presence of pedicle wall breakthrough. Spine 1998;23:256–62.
7. 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.
8. Frank EH. The use of small malleable endoscopes to assess pedicle screw placement: technical note. Minim Invasive Neurosurg 1998;41:10–2.
9. Garfin SR. Spinal fusion: the use of bone screws in the vertebral pedicles: summation. Spine 1994;19(suppl):2300–5.
10. Girardi FR, Cammisa FP Jr, Sandhu HS, et al. The placement of lumbar pedicle screws using computerized stereotactic guidance. J Bone Joint Surg Br 1999;81:825–9.
11. Harrington PR. Treatment of scoliosis: correction and internal fixation by spine instrumentation. J Bone Joint Surg Am 1962;44:591.
12. Hirabayashi S, Kumano K, Kuroki T. Cotrel-Dubousset pedicle screw system for various spinal disorders: merits and problems. Spine 1991;16:1298–304.
13. Hirano T, Hasegawa K, Takahashi HE, et al. Structural characteristics of the pedicle and its role in screw stability. Spine 1997;22:2504–9.
14. Heini P, Scholl E, Wyler D, et al. Fatal cardiac tamponade associated with posterior spinal instrumentation: a case report. Spine 1998;23:2226–30.
15. Krag MH, Beynnon BD, Pope MH, et al. An internal fixator for posterior application to short segments of the thoracic, lumbar, or lumbosacral spine: design and testing. Clin Orthop 1986;203:75–98.
16. Liljenqvist UR, Halm HF, Link TM. Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. Spine 1997;22:2239–45.
17. Liljenqvist UR, Link TM, Halm HF. Morphometric analysis of thoracic and lumbar vertebrae in idiopathic scoliosis. Spine 2000;25:1247–53.
18. Lonstein JE, Denis F, Perra JH, et al. Complications associated with pedicle screws. J Bone Joint Surg Am 1999;81:1519–28.
19. 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.
20. 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.
21. Pihlajamaki H, Myllynen P, Bostman O. Complications of transpedicular lumbosacral fixation for non-traumatic disorders. J Bone Joint Surg Br 1997;79:183–9.
22. Roy-Camille R, Saillant G, Mazel C. Internal fixation of the lumbar spine with pedicle screw plating. Clin Orthop 1986;203:7–17.
23. Roy-Camille R, Saillant G, Mazel C. Plating of thoracic, thoracolumbar, and lumbar injuries with pedicle screw plates. Orthop Clin North Am 1986;17:147–59.
24. Sjostrom L, Joconsson O, Karlstrom G, et al. CT analysis of pedicles and screw tracts after implant removal in thoracolumbar fractures. J Spinal Disord 1993;6:225–31.
25. Stauber MH, Bassett GS. Pedicle screw placement with intraosseous endoscopy. Spine 1994;19:57–61.
26. Steinmann JC, Herkowitz HN, el-Kommos H, et al. Spinal pedicle fixation:

confirmation of an image-based technique for screw placement. Spine 1993;18:1856–61.
27. Suk SI. A new method of correction in severe adult scoliosis-vertebral column resection (PVCR) through posterior approach. Presented at the 7th IMAST meeting, Barcelona, Spain, 2000.
28. Suk SI, Cha SI, Lee CK, et al. A study on the pullout strength of pedicle screws in relation to the size of the drill holes and inserted screws. Presented at the 30th Annual Meeting of the Scoliosis Research Society, Asheville, North Carolina, 1995.
29. Suk SI, Kim WJ. Treatment of fixed lumbosacral kyphosis by all posterior vertebral column resection. Presented at the 5th IMAST meeting, Sorrento, Italy, 1998.
30. Suk SI, Lee CK, Kim WJ, et al. Segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis. Spine 1995;20:1399–405.
31. Suk SI, Lee CK, Chung SS. Comparison of Zielke ventral derotation system and Cotrel-Dubousset instrumentation in the treatment of idiopathic lumbar and thoracolumbar scoliosis. Spine 1994;19:419–29.
32. West JL, Ogilvie JW, Bradford DS. Complications of variable screw plate pedicle screw fixation. Spine 1991;16:577–9.
33. Zindrick MR, Wiltse LL, Widell EH, et al. A biomechanical study of intrapeduncular screw fixation in the lumbosacral spine. Clin Orthop 1986;203:99–112.

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