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TECHNIQUE

Retrospective Computed Tomography Scan Analysis of Percutaneously Inserted Pedicle Screws for Posterior Transpedicular Stabilization of the Thoracic and Lumbar Spine

Accuracy and Complication Rates

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Study Design. Retrospective clinical data analysis.

Objective. To investigate the misplacement rate and related clinical complications of percutaneous pedicle screw insertion in the thoracic and lumbar spine.

Summary of Background Data. Percutaneous insertion of cannulated pedicle screws has been developed as a minimally invasive alternative to the open technique during instrumented fusion procedures of the thoraco-lumbar spine. The reported rate of screw misplacement using open techniques is well described, however data is lacking on the exact failure rate of the percutaneous technique.

Methods. A total of 424 percutaneously inserted pedicle screws from 2007 to 2010 were analyzed in 88 patients, from a single surgeon series (RJM). Axial reformatted computer tomographic images were examined by 2 independent observers and individual and consensus interpretation was obtained for each screw position. A simple grading system was used for assessment of screw accuracy—Grade 0: screw within cortex of pedicle; Grade 1: screw thread breach of wall of pedicle <2 mm; Grade 2: significant breach >2 mm with no neurological compromise; Grade 3: complication including pedicle fracture, anterior breach with neuro-vascular compromise, and lateral or medial breach with neurological sequelae.

Results. The indications for percutaneous pedicle screw insertion include: degenerative (78%), trauma (13%), tumour (8%), and infection (1%). Pedicle screws were inserted into level T4 to S1. The most common levels performed include L4 and L5 with the most common indication for surgery being an L4/5 spondylolisthesis. 383 out of 424 screws (90.3%) were placed in the cortical shell of the pedicle (Grade 0). Forty-one screws (9.7%) were misplaced from T4 to S1. Of these, the majority were Grade 1 pedicle violations (24 screws; 5.7%), with 15 Grade 2 violations (3.5%) and 2 Grade 3 violations (0.5%). Of the 2 Grade 3 pedicle violations, both were pedicle fractures but only 1 had associated neurological deficit (L4 radiculopathy postoperatively).

Conclusion. Percutaneous insertion of cannulated pedicle screws in the thoracic and lumbar spine is an acceptable technique with a low complication rate in experienced hands. The overall rate of perforation is below the higher rates reported in the literature for the open technique. Complication rates including pedicle fracture were low.

Key words: pedicle screw fixation, posterior stabilization, computer tomography, minimally invasive surgery, lumbar spine. **Spine 2012;37:1092–1100**

Spinal fusion using pedicle screws is a widely accepted method for the management of a variety of spinal conditions requiring stabilization. Traditional open techniques for insertion of screws are associated with extensive blood loss, lengthy hospital stays, and significant costs.[1] Minimally invasive techniques use small incisions and small muscle splitting approaches, and are associated with less blood loss, less soft tissue trauma, and less postoperative pain than traditional open techniques.[2–6] Many studies have investigated the accuracy of screw placement by a conventional open approach using simple radiograph, computed tomographic (CT) scan, or magnetic resonance imaging,[7–12] with reported rates of screw misplacement up to 40%.[7] However, there is a paucity of data on the exact failure rate of the percutaneous technique. In this article, we focus on the accuracy by 1 surgeon of purcutaneous pedicle screw placement and introduce a simple grading system for CT evaluation of pedicle screw placement. The purpose of our study was to

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define the incidence of pedicle misplacement and compare it with published data on open and percutaneous pedicle placement techniques.

MATERIALS AND METHODS

Between 2007 and mid-2010, 88 consecutive patients (47 men and 41 women) were analyzed after external transpedicular screw fixation of the thoracic, lumbar and sacral spine (from T4 to S1). All patients had a CT performed within 24 hours of surgery and films entered into a database for review. The age range of the patients was 9 to 85 years (mean, 63 yr). The operations were performed at The Prince of Wales Public and Private Hospitals, Sydney, Australia.

Surgical Procedure

All surgical procedures were performed by a single spine surgeon (RJM). A total of 424 screws were implanted in 88 patients undergoing percutaneous thoracolumbar or lumbosacral stabilization using the Serengeti spinal system (K2M, Leesburg, VA, USA). Percutaneous pedicle screws ranged in diameter from 4.5 to 7.5 mm and were inserted in accordance with the technique described by Wiesner *et al.*[13]

A brief description of this technique follows (Figures 1, 2):

1. The image intensifier (II) is placed in the AP position. The spinous process should be midline between the pedicles to ensure a direct AP projection (Figure 2A).
2. The position of the lateral aspect of the pedicle is marked on the skin. Depending upon the depth of the tissue between skin and pedicle, the skin incision should be made lateral (Figure 1A) so that appropriate angulation of the Jamshidi needle can be made when inserting into the pedicle.
3. The Jamshidi needle is placed through the skin incision and "docked" onto the lateral aspect of the pedicle (Figures 1A, 2). This is called the "3 o-clock" position.
4. The Jamshidi needle is advanced 20 to 25 mm into the pedicle through the cortical bone, making sure the needle remains lateral to the medial pedicle wall (Figures 1A, 2). A second Jamshidi needle can then be placed on the contralateral side in a similar fashion.
5. The II is then positioned in the lateral plane. The Jamshidi needle should now be in the vertebral body, and therefore "safe" with no risk of medial pedicle breach (Figures 1A, 2).
6. The stylet is then removed and a Kirschner (K)-wire is

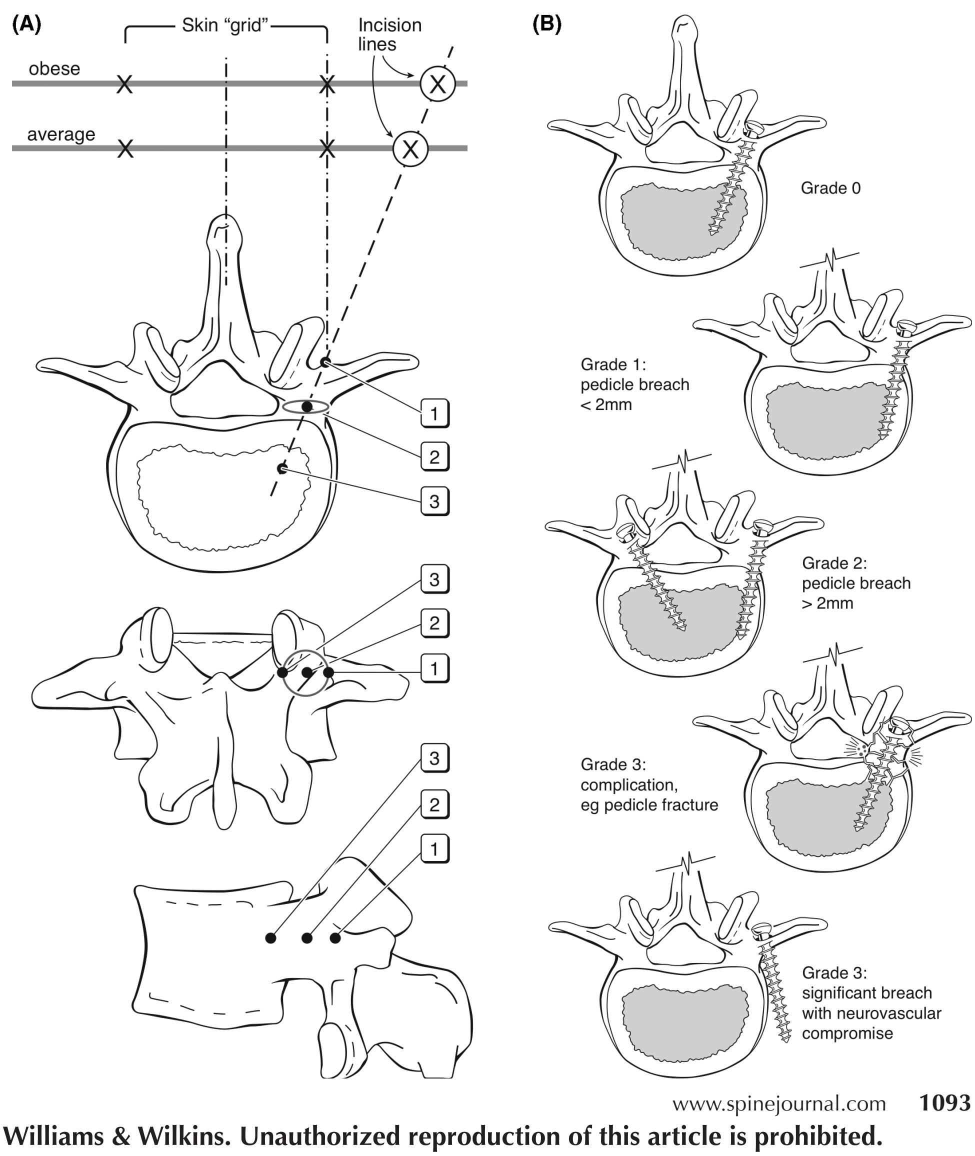

Figure 1. (A) Diagrams illustrating the anatomical principles of percutaneous pedicle screw insertion: views from top to bottom: superior, posterior, lateral, superior. First the initial skin incision is made with the patients' body habitus in mind. Second, the Jamshidi needle is first "docked" onto the lateral aspect of the pedicle — "position 1" — on the anterior/posterior image intensifier (II) radiograph projection. Third, the Jamshidi needle is advanced 20 to 25 mm so that the needle is beyond the medial border of the pedicle and into the vertebral body – to "position 3." Finally, the position is confirmed by lateral II radiograph projection before insertion of the K-wire. **(B)** Grading system for evaluation of screw position.

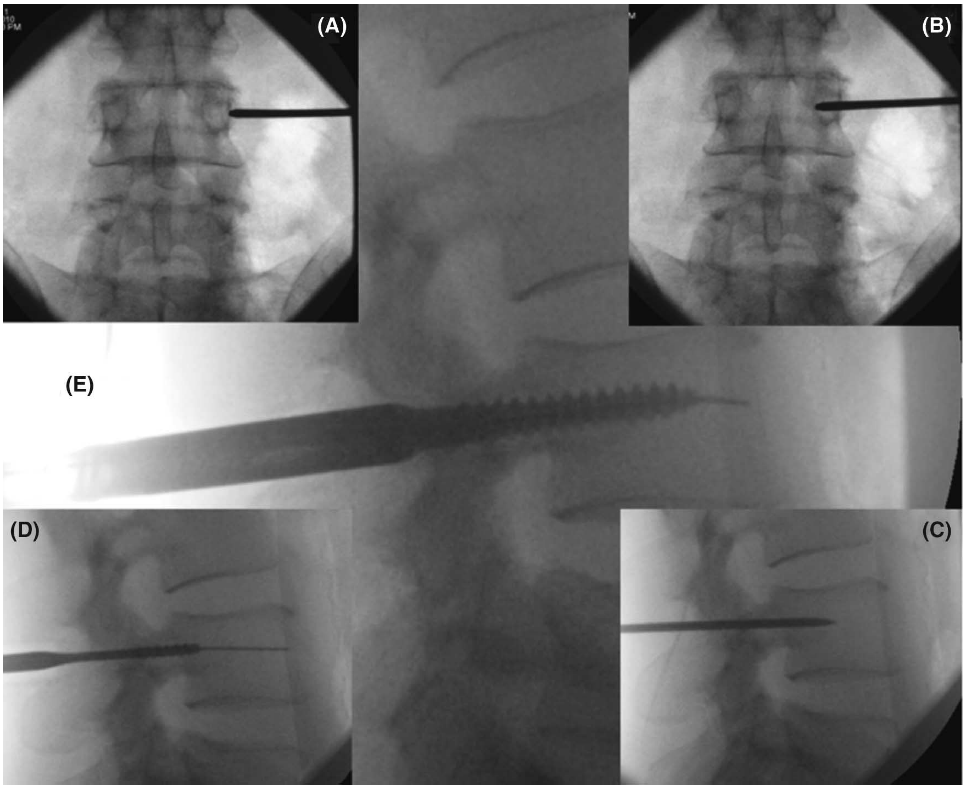

Figure 2. Percutaneous Technique (L4 Pedicle). **(A)** Using AP x-ray, the Jamshidi needle is 'docked' onto the facet/TP junction. **(B)** The needle is advanced 20 to 25 mm making sure that the tip of the Jamshidi is not beyond the medial pedicle border. **(C)** Lateral x-ray confirms that the Jamshidi is within the vertebral body. **(D)** Tapping the pedicle. **(E)** Insertion of pedicle screw.

placed down the barrel of the Jamshidi needle. Once a satisfactory penetration of the pedicle with the K-wire is completed, the Jamshidi needle is removed, taking care to maintain the position of the K-wire. A cannulated scalpel is then passed over the K-wires to provide accurate incisions that are long enough for the tissue guard.

7. Tissue guards are then placed over the K-wires to perform soft tissue dissection down to the level of the bone. A pedicle screw tap is then placed down the trajectory of the K-wire, through the pedicle into the trabecular bone of the vertebral body, taking care the K-wire is not moved during introduction (Figure 2).
8. The tap is then removed and the appropriate pedicle screws (measurements based on preoperative CT scans) are placed down the K-wire (Figure 2), making sure not to advance the K-wire beyond the anterior aspect of the vertebral body. Confirmation of pedicle screw placement is achieved with II.
9. The rods are then inserted via the pedicle screw incision sites and join the pedicle screw heads. A dedicated reduction device can be used with the retractor sleeves for correction of a spondylolisthesis.
10. The retractor sleeves are then removed
11. All wounds are then closed via a standard method.

Postoperative CT was obtained for all patients to assess implant position, using a GE 16 slice Brightspeed unit with 0.625 mm slices acquired in helical mode in a craniocaudal direction.

Evaluation of Screw Position

Two independent observers analyzed digital axial CT slices of all instrumented pedicles, with individual and consensus interpretation for each screw. A simple grading system (Mobbs Raley) was devised for evaluation of screw position (Figures 1B, 6).

The grading system was devised to indicate accuracy of placement (Grade 0, 1, 2) and a significant complication with the technique (Grade 3) that was likely to require revision surgery (Table 1).

The direction of the pedicle violations was noted, and the degree of the screw malalignment in the axial plane was measured. The transverse screw angle was determined by measuring the angle between a line parallel to the vertebral midline and a line through the center of the screw tract, and was measured for all pedicles that showed a screw displacement.

TABLE 1. Grading System for Evaluation of Screw Position

Grade 0	Screw within cortex of pedicle
Grade 1	Screw thread breach of wall of pedicle: ≤2 mm
Grade 2	Significant breach: >2 mm. No neurological compromise
Grade 3	Complication: pedicle fracture, anterior breach with neuro-vascular compromise, lateral/medial breach with neurological sequelae

K-wire Complication

A serious potential complication can arise from insertion of the K-wire beyond the anterior aspect of the vertebral body (Figure 7). This can either occur from aggressive advancement of the K-wire down the barrel of the Jamshidi, osteoporotic bone with poor tactile feedback when inserting the K-wire, or with the K-wire inadvertently moving distally with advancement of the pedicle tap.

There are no reports in the literature that discuss complication rates from anterior placement of a K-wire at the time of percutaneous pedicle screw placement. All cases of anterior placement of K-wires were prospectively recorded, and any subsequent complications noted such as blood loss or ileus.

Radiation Exposure

Mean operative time and mean fluoroscopy time was recorded for the first and last 5 patients in the series receiving single-level fusion (4 pedicle screws), to extrapolate surgeon radiation exposure, and to demonstrate the learning curve associated with the technique. In addition, mean radiation exposure (mGy) to the last 5 patients receiving single-level fusion was obtained from a standard measurement of output from the C-arm of the image intensifier. The C-arm was in the source inferior position for all cases. Only single-shot pulsed imaging was performed.

Statistical Analysis

The chi squared method and Fisher exact test (2-tail) was used to determine significant differences in the number of screw malpositions, the direction of screw misplacement, and corresponding angulation. In addition, because only a small number of screws were placed at the thoracic levels, the pedicles of T4 to T12 were combined and analyzed separately as thoracic pedicles. Among the lumbar vertebrae, tests for equal proportions were used to determine if there was a tendency for lateral or medial pedicle violations and, for those with a lateral pedicle violation, if this was due to incorrect angle of insertion. The significant difference level was set at $P < 0.05$. Statistical analysis was performed using R-2.11.1 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

A total of 424 percutaneously inserted pedicle screws were analyzed in 88 patients, and 383 screws (90.3%) were placed in the cortical shell of the pedicle (Grade 0). Only 41 screws (9.7%) were misplaced from T4 to S1. Of these, the majority were Grade 1 pedicle violations (24 screws; 5.7%), with 15 Grade 2 violations (3.5%) and 2 Grade 3 violations (0.5%; Figure 3). There were 30 lateral and 11 medial pedicle cortex violations (Table 3). At the lumbar level there were significantly more lateral (n = 26) than medial (n = 7) cortical violations ($P = 0.00094$), whereas at the thoracic level there was no difference.

The indications for screw insertion were predominantly degenerative (n = 69, 78%), and included trauma (n = 11, 13%), tumor (n = 7, 8%), and infection (n = 1, 1%; Figure 4). The distribution of screw misplacements with respect to the vertebral level is shown in Table 2 and graphically in Figure 5. There were no significant differences within the lumbar vertebrae, with failure rates between 4% (L2) and 16% (L3), $P = 0.6134$. Combining thoracic levels T4 to T12, there were no significant differences compared with lumbar pedicle screw misplacements (9.2% and 9.5%, respectively, $P = 0.8746$). We found no correlation between the operated level and screw malpositioning.

The transverse pedicle angle was measured for all misplaced screws (Table 2). Considering the direction of the screw malalignment and the difference between the screw and pedicle angle, 18 of the 41 pedicle violations (43.9%) could be attributed to wrong angle of insertion. Of the lateral cortical violations at the lumbar level (26 of 33 misplaced screws), 13 (50%) could be attributed to incorrect angle of insertion ($P = 0.8450$).

There were 2 Grade 3 pedicle violations (patient 31 and 49, respectively, Table 2). One was a pedicle fracture without neurovascular compromise; the other was a pedicle fracture with L4 nerve injury (L4 radiculopathy postoperatively). Both Grade 3 pedicle violations were performed early in the series (within the initial 10 patients operated on).

There were 4 anterior K-wire perforations (0.9% of all screws) during the course of the study period. One case was because of advancement of the K-wire at the time of tapping the pedicle, 2 cases were because of osteoporotic bone with poor tactile feedback for the surgeon and 1 case of forceful advancement of the K-wire with anterior puncture of the vertebral body (Figure 7). From the 4 cases identified with K-wire perforation, 1 patient had a small volume retroperitoneal bleed and ileus treated conservatively. The other 3 patients had an uneventful recovery postoperatively.

Mean operative time was 238 minutes for the first 5 patients, and 147 minutes for the last 5 patients receiving single-level fusion (4 pedicle screws). The mean fluoroscopy time was 1.71 minutes for the first 5 single-level cases (0.43 min/screw), and 0.76 minutes for the last 5 single-level cases (0.11 min/screw). Mean maximum patient exposure for these last 5 cases, measured from the output of the C-arm, was 44.9 mGy (range 26.8–58.1 mGy).

DISCUSSION

The accuracy of pedicle screw placement using the traditional open technique has been the subject of several imaging studies. However, the reported misplacement rates have been very different, ranging from 8% to 40%.[7,14] This is partly due to the lack of image guidance and the variation in pedicle placement assessment methods including the definition of misplacement.

Evaluation of percutaneous screw insertion for temporary external fixation (a diagnostic tool) with fluoroscopic guidance has been undertaken using a human cadaver model.[13] The reported overall perforation rate of the dissected specimens was 10% (mainly medial). In a separate study the same authors evaluated screw position of percutaneous external fixation using axial CT images, with 51 patients and 408

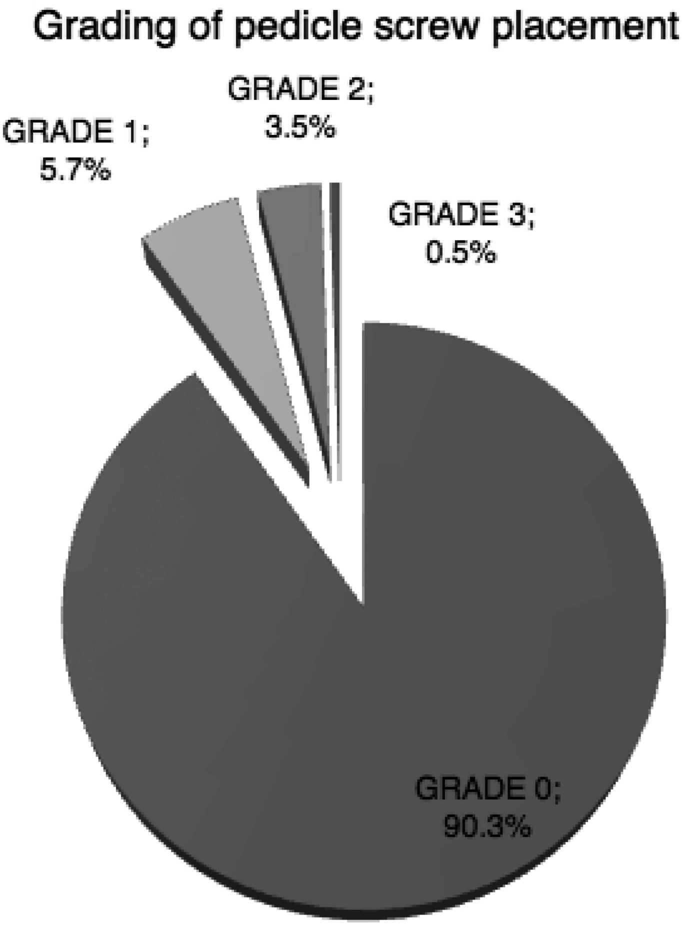

Figure 3. Pie chart showing the number of pedicle screws (%) at each grade.

pedicle screws.[15] They reported a screw perforation rate of 6.6% (mainly medial and more often affecting the S1 pedicles). Despite the screws used being noncannulated, this was the first study to analyze the accuracy of percutaneous transpedicular screws. From recent publications on small series of percutaneously inserted cannulated pedicle screws under flouroscopic guidance,[2,4,16–18] only 2 addressed the accuracy of screw positioning. The smaller group was comprised of only 3 patients with a single perforated screw.[4] A somewhat larger series (15 patients with a total of 60 screws), reported an overall rate of screw perforation of 23% with an incidence of severe frank pedicle penetration of 3.3% as seen on axial images.[18] The larger series to date reporting results of percutaneous fixation does not provide information on screw placement. However, the reoperation rate reported due to screw misplacement was 4% in that study (2 of 49 patients).[17]

In our group of 88 patients with a total of 424 screws the overall rate of screw perforation was 9.7% (41 screws) with an incidence of severe frank pedicle penetration of 0.5% (2 of 424 screws) as seen on axial images. The incidence of screw misplacement in our series falls well within the reported rates for the open technique, ranging from 8% to 40%,[7,14] as well as those reported for the percutanoues technique (6.6% to 10%, and up to 23%[13,15,18]). The neurological injury incidence of 0.5% falls well below reported incidences ranging from 2%[19] to 5%, and even as high as 16.6%.[7] Both Grade 3 pedicle violations occurred early in the series (within the first 30 patients operated on), indicating a steep learning curve for the percutaneous technique.

It should be pointed out that the rates of misplacement vary according to the definition of misplacement and the assessment method used. One study using CT assessment of pedicle screw placement defined misplacement as the position of the central axis of the screw out of the outer cortex of the pedicle wall seen in axial CT images.[20] On our grading scale this would correspond to a Grade 2 or Grade 3 and underestimate the true misplacement rate (interestingly, the authors reported an 8.2% frank misplacement rate which was similar to our overall rate of screw perforation). We included every single cortical encroachment by a screw in the axial plane (Figure 6). It could be argued that such a screw position as that shown in Figure 6(B) should not be regarded as misplacement, and it could be that other studies have not included such examples in their misplacement reporting.

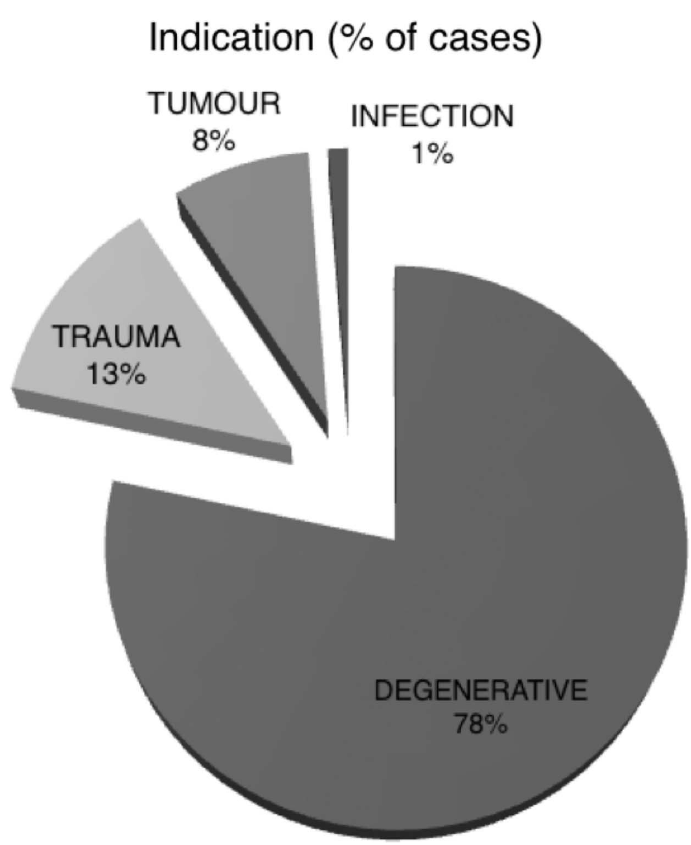

Figure 4. Pie chart showing indications for transpedicular fixation (% of cases).

TABLE 2. Distribution of Pedicle Screws

Level	Number of Screws (%)	Misplaced Screws (%)	Grade 0	Grade 1	Grade 2	Grade 3
T4–T8	18 (4)	3 (7.3)	15	0	1 (T4), 2 (T7)	0
T9–T12	58 (14)	4 (9.8)	54	1 (T11)	2 (T9), 1 (T10)	0
L1	14 (3)	1 (2.4)	13	1	0	0
L2	24 (6)	1 (2.4)	23	1	0	0
L3	63 (15)	10 (24.4)	53	6	3	1
L4	109 (26)	11 (26.8)	98	7	3	1
L5	100 (24)	10 (24.4)	90	7	3	0
S1	38 (9)	1 (2.4)	37	1	0	0
Total	424	41 (9.7)	383	24	15	2

CT examination provides more information than plain films, but has obvious limitations. Wiesner[15] examined CT images of screw tracts for cortical wall defects after screw removal, and reported a low perforation rate of 6.6%. However, in our study, CT assessment of pedicle placement was complicated by image artifacts caused by the *in vivo* screws. Although clearly a limitation of this study, it could be thus argued that screw placement in our study may have greater accuracy than demonstrated by CT examination. A major limitation of this study is that CT images were examined in axial sections only. Schizas *et al*[18] showed a lower incidence of screw perforation in axial images compared with coronal reconstructions. Thus it could be that the true incidence of misplacement is higher when CT images are screened critically including coronal views.

The analysis of the direction of screw misplacements showed that there were significantly more lateral than medial pedicle violations at the lumbar levels and half of these could be attributed to incorrect angle of insertion. This may be explained by an increasing medial inclination of the pedicle in the transverse plane from L1 (17°–25°) to L5 (26°–40°).[21] In 1992, Gunzburg *et al*[22] published the results of a radiographic study in which they found the anatomical pedicle center lies slightly more lateral than the pedicle shadow.

Initially in the series the starting point for the Jamshidi needle would be the center of the pedicle on an AP x-ray. This has the disadvantage that as the Jamshidi needle is introduced further into the pedicle, the risk of medial pedicle breach is higher as the starting point of the Jamshidi is potentially closer to the medial border of the pedicle. The surgeon altered the technique so that the Jamshidi would be docked at the very lateral aspect of the pedicle (Figures 1A, 2), so that with advancement of the Jamshidi, the risk of medial breach is reduced. Thus, the accuracy of pedicle screw placement in this study could potentially be improved by a more lateral cannulation point with an emphasis on medial inclination.

Prospective analysis of K-wire complications revealed 4 anterior breaches (Figure 7). There is minimal data in the literature on the potentially devastating complication of vascular and abdominal injury with this technique. The authors documented all cases and any subsequent complications. There was a single complication of retroperitoneal hemorrhage and ileus that improved with conservative measures. The senior author places all patients with anterior K-wire breach on broad spectrum antibiotics assuming there has been an intestinal puncture. It is paramount that the senior surgeon remind the assistant during the procedure that meticulous care be taken with stabilizing the K-wire when multiple instruments and the pedicle screw are placed over the guide K-wire.

The use of fluoroscopic guidance for screw placement results in potentially significant radiation exposure to both the surgeon and patient. Unfortunately, very little data exists in the literature to help quantify this exposure. Bindal *et al*[23] measured surgeon radiation exposure in minimally invasive transforaminal lumbar interbody fusion (with similar methods for flouroscopic percutaneous pedicle screw placement), using dosimeters placed at various locations. Their mean fluoroscopy time was 1.69 minutes per case, giving a mean exposure of 76 mRem to the surgeon's dominant hand, and 27 mRem to the waist under a lead apron. The mean fluoroscopy time in our series ranged from 1.71 minutes per case for the first 5 single-level cases, to 0.76 minutes per case for the last 5 single-level cases. The maximum allowed annual radiation exposure for radiation workers is 5 Rem to the body and 50 Rem to an extremity.[24] Extrapolating the data from Bindal *et al*[23], on the basis of the mean fluoroscopy time at the end of our series, a surgeon would exceed exposure limits to the torso after 417 single-level cases and to the hand after 1471 single-level cases. Of course, multilevel fusions require correspondingly more fluoroscopy, and a surgeon may also perform other interventional procedures requiring fluoroscopic guidance, such as vertebroplasty. Annual dose limits could potentially be exceeded if a large number of multi-level cases or other fluoroscopically guided procedures are performed.

Patient exposures in this study were low. The mean maximum patient skin exposure for the last 5 cases was 44.9 mGy. The threshold for the lowest dose associated

TABLE 3. Overall View of All Misplaced Pedicles

Patient	Level	Grade	Direction of Misplacement	Screw Angle	Pedicle Angle	Δ Angle	Wrong Angulation
22	T4	2	Medial	27	7	20	x
22	T7	2	Lateral	9	11	–2	
22	T7	2	Medial	24	17	7	
85	T9	2	Medial	14	13	1	
87	T9	2	Lateral	2	15	–13	x
87	T10	2	Lateral	13	14	–2	
29	T11	1	Lateral	1	12	–11	x
37	L1	1	Lateral	3	15	–12	x
32	L2	1	Lateral	2	13	–11	x
2	L3	1	Medial	11	8	3	
11	L3	1	Medial	34	30	4	
61	L3	2	Lateral	8	21	–13	x
31*	L3	3	Lateral	3	18	–15	x
44	L3	1	Lateral	10	11	–1	
46	L3	2	Medial	12	12	0	
46	L3	2	Lateral	10	12	–2	
65	L3	1	Lateral	10	12	–2	
75	L3	1	Medial	1	5	–4	
82	L3	1	Lateral	12	14	–3	
8	L4	1	Lateral	2	14	–12	x
65	L4	2	Lateral	5	16	–11	x
69	L4	1	Lateral	6	14	–8	
72	L4	1	Lateral	12	18	–6	
28	L4	1	Medial	12	12	1	
28	L4	1	Lateral	4	27	–23	x
47	L4	1	Lateral	17	17	0	
49	L4	2	Lateral	7	18	–12	x
54	L4	2	Lateral	8	15	–8	
49†	L4	3	Lateral	3	23	–19	x
80	L4	1	Lateral	15	15	0	
13	L5	1	Lateral	15	22	–6	
13	L5	2	Lateral	–3	29	–32	x
17	L5	1	Medial	10	17	–7	
35	L5	2	Lateral	3	17	–14	x
46	L5	1	Lateral	25	12	13	x
46	L5	1	Medial	23	18	5	
54	L5	1	Lateral	11	25	–13	x
65	L5	1	Lateral	12	32	–20	x
77	L5	1	Lateral	7	21	–14	x
86	L5	1	Lateral	10	10	0	
78	S1	1	Medial	8	13	–5	

Pedicle fracture.

†Pedicle fracture + L4 radiculopathy postoperatively.

Figure 5. Distribution of all screws with respect to vertebral level.

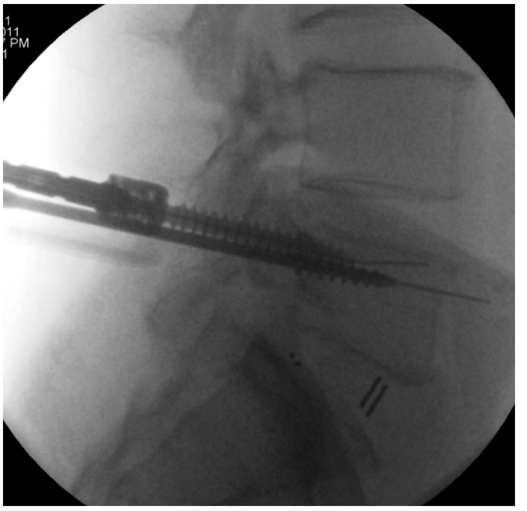

Figure 7. K-Wire complication. Care must be taken with K-wire insertion to ensure that the K-wire is not aggressively advanced into the vertebral body with puncture through the anterior aspect of the vertebra.

with deterministic radiation effects (early transient skin erythema) is 2000 mGy,[25] an order of magnitude higher than our maximum skin dose.

Both radiation exposure and length of procedure are shortened with surgeon experience.[26] With the exception of assisting experienced surgeons or attending surgeon cadaver labs to gain experience, the only alternative is to accept the inherent learning curve with minimally invasive techniques such as percutaneous pedicle screw placement. The senior surgeon's prospective database reveals a significant reduction in operative times from the initial 5 single-level percutaneous cases, at an average of 238 minutes, to 147 minutes with the most recent 5 cases. The senior surgeon also limits exposure by standing 1 meter away from the radiation source whenever an x-ray is taken where the surgeon does not need to directly handle an instrument during fluoroscopy. Although intraoperative CT-guided percutaneous screw insertion is an alternative to reduce surgeon radiation exposure, this has the dual disadvantage of increasing patient exposure with an on-table CT or additional preoperative CT, and reduced accuracy of screw insertion.[27]

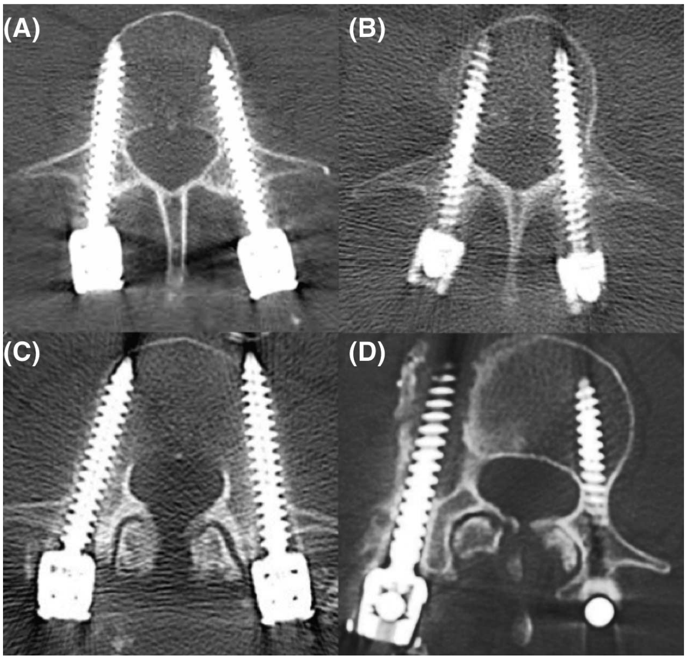

Figure 6. Axial CT images demonstrating grading of screw placement. **(A)** Grade 0. **(B)** Grade 1 (<2 mm cortical encroachment). **(C)** Grade 2: (>2 mm cortical encroachment). **(D)** Grade 3 (complication: pedicle fracture).

This clinical study has shown that percutaneous pedicle screw insertion in the thoracolumbar spine under fluoroscopic guidance is a safe and reliable technique, with a low misplacement rate and an extremely low rate of complications compared with the high rates published in the literature. The drawbacks to this technique include the inherent learning curve, increased exposure to ionizing radiation, and increased operating times compared to an open surgical approach. Once the concepts and techniques of this procedure have been mastered, however, it offers a less traumatic, more aesthetic, and equally effective method for posterolateral fusion.

➢ Key Points

- ❑ Percutaneous insertion of cannulated pedicle screws in the thoracic and lumbar spine is an acceptable technique with a low complication rate in experienced hands.
- ❑ Insertion of percutaneous pedicle screws is a technically demanding technique with a steep learning curve and should be performed with appropriate training and attention to detail.
- ❑ Consistency in the method of screw grading is needed for comparative studies. We introduce a simple grading system (Mobbs Raley) for the CT-guided evaluation of pedicle screw placement.

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