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Case Series

Can Postoperative Radiographs Accurately Identify Screw Misplacements?

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Abstract

Study Design: Retrospective case series.
Objective: The objective of this study was to determine the safety of postoperative radiographs to assess screw placement.
Summary of Background Data: Previously defined criteria are frequently employed to determine pedicle screw placement on intraoperative supine radiographs. Postoperatively, radiographs are typically used as a precursor to identify screws of concern, and a computed tomographic (CT) is typically ordered to confirm screw safety.
Methods: First, available postoperative PA and lateral radiographs were reviewed by 6 independently blinded observers. Screw misplacement was assessed using previously defined criteria. A musculoskeletal radiologist assessed all CT scans for screw placement. Pedicle screw position was classified either as acceptable or misplaced. Misplacements were subclassified as medial, lateral, or anterior.
Results: One hundred four patients with scoliosis or kyphosis underwent posterior spinal fusion and had postoperative CT scan available were included. In total, 2,034 thoracic and lumbar screws were evaluated. On CT scan, 1,772 screws were found to be acceptable, 142 were laterally misplaced, 30 medially, and 90 anteriorly. Of the 30 medially placed screws, 80% to 87% screws were believed to be in positions other than medial, with a median of 73% (63% to 92%) of these screws presumed to be in normal position. Similarly, of the 142 screws placed laterally, 49% to 81% screws were identified in positions other than lateral, with a median of 77% (59% to 96%) of these screws felt to be in normal position. Of the 90 anteriorly misplaced screws, 16% to 87% screws were identified in positions other than anterior, with 72% (20% to 98%) identified as normal. The criteria produced a median 52% sensitivity, 70% specificity, and 68% accuracy across the 6 observers.
Conclusion: Radiograph is a poor diagnostic modality for observing screw position.
Level of Evidence: Level IV.

Keywords: Spinal deformity; Pedicle screw accuracy; Radiograph; CT scan; Pedicle screw misplacements; Posterior spinal fusion

Introduction

Pedicle screw misplacement rates have ranged from 20% to 30%, even among more experienced spine surgeons [1-5]. Plain radiographs, fluoroscopy, and CT scans are used to determine screw accuracy. Although CT is considered the gold standard, radiographs and fluoroscopy are readily available and carry a lower radiation burden. However, radiographs and fluoroscopy have been shown to be inferior to CT scan because of their biplanar nature of image acquisition. To overcome this limitation, a variety of radiograph-based criteria have been delineated. These

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criteria can help identify misplacements in the axial (medial or lateral) and sagittal planes (anterior). In 2005, Kim et al. [6] described three criteria to determine screw position on radiographs: (1) violation of the harmonious segmental change of the tips of the inserted screws with reference to vertebral rotation using the posterior upper spinolaminar junction; (2) no crossing of the medial pedicle wall by the tip of the pedicle screw inserted; and (3) violation of the imaginary midline of the vertebral body by the tip of the screw. They reported a sensitivity of 0.87, specificity of 0.97, and accuracy of 0.98 in determining medial misplacements and sensitivity of 0.94, specificity of 0.90, and accuracy of 0.96 for lateral misplacements. These criteria were developed retrospectively from post-op CT scans and have been frequently used by surgeons for intra- and post-operative assessment of pedicle screw placements. Anterior screw misplacements are usually assessed on lateral radiographs by the 80:20 rule (if the screw length in the vertebral body is ⩾80% of the width of the vertebral body, the screw is likely anteriorly misplaced) [7,8].

Vallespir et al. [9] used Kim et al. [6] criteria in 11 patients and found poor sensitivity in detecting medial and lateral violations but moderately accurate for both. Validity of these criteria, aside from their study, has not been carried out and its interobserver and intraobserver reliabilities have not been determined. Previous studies have shown poor reliability of radiographs in assessing pedicle screw misplacement [5,10-14]. This is due to the rotational component of the deformity and limitation of radiographs due to its two-dimensional nature. Because screw misplacements occur in the axial plane, value of radiographs even with defined criteria need to be evaluated further. The objective of this study was to evaluate the ability of post-operative radiographs to safely identify misplacements using these criteria in a large number of patients with spinal deformity.

Materials and Methods

This was an IRB approved study. Inclusion criteria were patients who had (1) scoliosis or kyphosis; (2) primary posterior spinal fusion using all pedicle screw constructs; (3) posteroanterior (PA) and lateral radiographs; and (4) postoperative CT scan on file. The exclusion criteria were patients who underwent anterior or combined anterior and posterior fusions. One hundred four spinal deformity patients operated between January 2004 and December 2010 met the inclusion criteria. All pedicle screws were placed using the free hand technique, as described by Kim et al. [7].

Radiograph and computed tomography examination

The first available postoperative standard PA and lateral radiographs were used to visualize all instrumented levels. Our use of postoperative CT scan has changed over the time period of data collected for this study. In the early years, the fusion levels were routinely scanned to confirm proper screw placement. In later years, postoperative CT of the entire instrumented spine was obtained only on suspicion of misplacement on radiograph. Multidetector computed tomography (MDCT) was performed on a 16-slice (Mx8000, Philips Medical Imaging, Netherlands) or 64-slice (Lightspeed, General Electric Medical Systems, Milwaukee, WI) scanner. Scans were obtained in the axial plane followed by sagittal and coronal reformatting. Parameters used for both scanners included an amperage of 70−275 mA, peak kilovoltage of 120−140 kVp, 512 × 512 matrix, field of view to fit, helical mode with pitch of 0.5, standard algorithm and windowing appropriate for visualization of hardware. Slice thickness on the 64-slice scanner was 3.75 mm with reformatting in three planes to 0.625 mm thickness; slice thickness on the 16-slice scanner was 2 mm with 1−2 mm spacing.

A fellowship-trained musculoskeletal radiologist assessed all CT scans for screw placement. Pedicle screw position was classified as acceptable or misplaced. Misplaced screw was a screw whose central axis was perforating the outer or inner cortical bone, as described by Kim et al. [6]. These misplacements were further sub-classified as medial (OM), lateral (OL), or anterior (OA), depending on the cortical wall violated by the screw.

Postoperative PA and lateral full-length radiographs obtained at the end of surgery or immediately postoperation were reviewed blindly by six independent observers and evaluated for accuracy of screw placement. These consisted of two trained medical students who were part of the spine deformity research team (Observers 1 and 2), two fellowship-trained musculoskeletal radiologists (Observers 3 and 4), two orthopaedic surgeons; one pediatric orthopaedic fellowship-trained (Observer 5), and one spine fellowship−trained (Observer 6). The radiographs were reviewed on PACS (Picture Archiving and Communication System, GE Healthcare, UK), which allows for adjusting magnification, contrast, brightness, and digital measurements. Screw misplacements on postoperative PA radiographs were assessed using Kim et al.'s [6] criteria. Though described for intraoperative supine radiographs, these criteria are commonly used to identify misplacements on postoperative radiographs. A CT scan is usually done if misplacement is suspected. We adapted Kim et al.'s criteria to postoperative radiographs, as these criteria should be independent of patient position and screw placement does not change with position [6]. Although screw relationship with the vertebra can change during manipulation, these criteria should still be applicable and help identify misplacements after manipulation. On lateral radiographs, screw misplacement was assesed using the following criteria: (1) Extension of the pedicle screw tip past the anterior border of the vertebral body (unacceptable−anterior) [6] and (2) ventral screw penetration ⩾80% of the width of the vertebral body (unacceptable−anterior)

[8]. Screws where the rod overlapped the tip were excluded because of difficulty in assessing placement.

Statistical methods

Sensitivity, specificity, and accuracy of radiography relative to computed tomography (CT) scan was computed for each of six observers. We defined sensitivity as the proportion of misplaced screws on CT scan correctly identified on radiographs and specificity as the proportion of properly placed screws on CT scan correctly identified on radiographs. The concordance and discordance rate of radiographs in relation to CT scan reading was also calculated for each observer. Concordance was present when screw placement was acceptable on both radiograph and CT scan. There was discordance when the assessment of screw placement was different on radiograph and CT scan. Kappa statistic was used to assess overall agreement amongst all observers. Statistical analyses were performed by an independent biostatistician with SAS for Windows, version 9.3 (SAS Institute, Cary NC).

Results

Patient demographics

Of the 104 patients, 74 (71.1%) were females and 30 (29.9%) were males. The mean (±standard deviation) age was 15.6 ± 5.8 years. Mean height and weight were 61.7 ± 5.6 inches and 125.2 ± 46.0 lb.

Deformity characteristics

Scoliosis patients had a mean Cobb angle of 61.8° ± 20.71° and a mean T5–T12 kyphosis of 25.9° ± 15.5°. Kyphosis patients had a mean T5–T12 kyphosis of 75.1° ± 4.6°. There were 68 patients with adolescent idiopathic scoliosis, 17 patients with neuromuscular scoliosis, 10 patients with Scheuermann kyphosis, 4 patients with congenital scoliosis, 3 patients with adult idiopathic scoliosis, and 2 patients with syndromic deformities. Mean fusion length was 11.8 ± 2.4 vertebral levels (range, 4–17 levels). There were 20.8 ± 4.3 fixation points (range, 8–34 fixation points) per patient.

Table 1
Sensitivity, specificity, and accuracy of pedicle screw placement on plain radiograph.

Observer	Sensitivity	Specificity	Accuracy
1	0.45	0.66	0.64
2	0.72	0.45	0.48
3	0.58	0.73	0.71
4	0.55	0.81	0.78
5	0.44	0.66	0.63
6	0.36	0.84	0.78
Overall median and range	0.52 (0.36–0.72)	0.70 (0.45–0.84)	0.68 (0.48–0.78)

Table 2
Sensitivity, specificity, accuracy of pedicle screw placement for AIS and Non-AIS patients.

Sensitivity	AIS N = 1367	Non-AIS N = 670
Observer		
1	0.48	0.40
2	0.67	0.79
3	0.56	0.62
4	0.53	0.58
5	0.45	0.40
6	0.33	0.42
Specificity		
1	0.65	0.70
2	0.42	0.51
3	0.71	0.77
4	0.80	0.83
5	0.63	0.71
6	0.84	0.84
Accuracy		
1	0.63	0.65
2	0.45	0.55
3	0.69	0.75
4	0.77	0.79
5	0.61	0.66
6	0.79	0.77

Screw imaging

A total of 2,034 screws were evaluated. Specifically, 2 screws were placed in T1, 16 in T2, 80 in T3, 130 in T4, 137 in T5, 141 in T6, 145 in T7, 159 in T8, 170 in T9, 172

Table 3
Sensitivity, specificity, and accuracy for the six observers by location of pedicle screws within spine.

Observer	Sensitivity				
	Lumbar (n = 354)	Main thoracic (n = 816)	Sacral (n = 12)	Thoracolumbar (n = 346)	Upper thoracic (n = 506)
1	0.50	0.49	1.00	0.46	0.40
2	0.50	0.71	1.0	0.65	0.75
3	0.50	0.58	0.00	0.54	0.61
4	0.50	0.57	0	0.50	0.56
5	0.08	0.53	0	0.35	0.42
6	0.08	0.35	0	0.38	0.40
	Specificity				
1	0.73	0.61	0.73	0.67	0.69
2	0.56	0.44	0.55	0.48	0.35
3	0.88	0.68	0.92	0.82	0.60
4	0.94	0.77	0.92	0.90	0.68
5	0.80	0.56	1	0.65	0.72
6	0.96	0.79	0.91	0.86	0.81
	Accuracy				
1	0.73	0.60	0.75	0.66	0.62
2	0.55	0.47	0.58	0.49	0.45
3	0.86	0.67	0.92	0.79	0.60
4	0.92	0.75	0.92	0.87	0.65
5	0.77	0.56	0.92	0.63	0.64
6	0.93	0.74	0.83	0.82	0.71

Table 4
Concordant evaluation of imaging modality of radiographic and computed tomographic scan.

Observer	Anterior (n = 90), n (%)	Lateral (n = 142), n (%)	Medial (n = 30), n (%)	Normal (n = 1,772), n (%)
1	12 (13)	72 (51)	4 (13)	1,175 (66)
2	50 (56)	55 (39)	6 (20)	798 (45)
3	76 (84)	30 (21)	4 (21)	1,291 (73)
4	73 (81)	30 (21)	4 (13)	1,291 (73)
5	18 (20)	41 (29)	5 (17)	1,165 (66)
6	45 (50)	29 (19)	4 (13)	1,491 (84)
Median value	47.5 (53)	42.88 (25)	4.5 (13)	1,225.6 (69.5)

in T10, 170 in T11, 176 in T12, 170 in L1, 152 in L2, 124 in L3, 57 in L4, 21 in L5, and 12 in S1. On CT scan, 1,772 screws were found to be acceptable, 142 were OL, 30 OM, and 90 OA misplaced.

Radiograph assessment by the 6 observers blinded to CT findings resulted in a median sensitivity of 0.52 (0.36–0.72), median specificity of 0.70 (0.45–0.84), and a median accuracy of 0.68 (0.48–0.78) (Table 1). This indicates that radiographs correctly identified 36% to 72% of unacceptably positioned screws and 45% to 84% of acceptably positioned screws. Sensitivity, specificity, and accuracy of radiographs relative to CT scan were further assessed by diagnosis (AIS vs. non-AIS) and by thoracic and lumbar spine subgroups for each observer (Tables 2 and 3).

The concordance rate of radiographs relative to CT scan reading was calculated separately for OA, OL, OM and normal screw positions for each observer (Table 4). A median of only 53% (13% to 84%) of 90 OA screws seen on CT scan were identified correctly by all six observers on radiographs. A median of 25% (21% to 51%) of 142 OL screws seen on CT scan were correctly identified, whereas a median of 13% (13% to 20%) of 30 OM screws were correctly identified by the six blinded observers on radiographs. In contrast, a median of 69.5% (45% to 84%) of 1,772 normal-placed screws on CT scan were identified on the radiographs by the observers.

The discordance rate was also calculated separately for OA, OL, OM, and normal screw positions (Table 5). Of the 30 OM screws seen on CT scan, 24 (80%) to 26 (87%) screws were believed to be in positions other than medial, with a median of 73% (63% to 92%) of these screws presumed to be in normal position (Fig. 1 and 2). Similarly, of the 142 OL screws on CT scan, 70 (49%) to 115 (81%) screws were identified in positions other than lateral by the observers, with a median of 77% (59% to 96%) of these screws felt to be in normal position (Figs. 3 and 4). Of the 90 OA screws on CT scan, 14 (16%) to 78 (87%) screws were identified in positions other than anterior by the six observers, most commonly as normal placements with a median of 72% (20% to 98%) of such screws (Fig. 5).

Out of the 1,772 screws found to be normal on CT, 281 (16%) to 974 (55%) screws were identified as unacceptable

Table 5
Discordant evaluation of imaging modality for all six radiograph observers and CT.

Observer discordance	CT-based evaluation results			
	Anterior (n = 90), n (%)	Lateral (n = 142), n (%)	Medial (n = 30), n (%)	Normal (n = 1,772), n (%)
Observer 1 discordance	78 (87)	70 (49)	26 (87)	597 (34)
	L 13 (17)	A 3 (4)	A 1 (4)	A 79 (13)
	M 5 (6)	M 0	L 7 (27)	L 443 (74)
	N 60 (77)	N 67 (96)	N 18 (69)	M 75 (13)
Observer 2 discordance	40 (44)	87 (61)	24 (80)	974 (55)
	L 15 (38)	A 33 (38)	A 7 (29)	A 539 (55)
	M 17 (43)	M 3 (3)	L 2 (8)	L 223 (23)
	N 8 (20)	N 51 (59)	N 15 (63)	M 212 (22)
Observer 3 discordance	14 (16)	112 (79)	26 (87)	481 (27)
	L 2 (14)	A 31 (28)	A 7 (27)	A 410 (85)
	M 3 (21)	M 0	L 0	L 37 (7)
	N 9 (64)	N 81 (72)	N 19 (73)	M 37 (8)
Observer 4 discordance	17 (19)	112 (79)	26 (87)	338 (19)
	L 2 (12)	A 26 (23)	A 7 (27)	A 267 (79)
	M 3 (18)	M 0	L 0	L 34 (10)
	N 12 (71)	N 86 (77)	N 19 (73)	M 37 (11)
Observer 5 discordance	72 (80)	101 (71)	25 (83)	607 (34)
	L 9 (13)	A 21 (21)	A 3 (12)	A 196 (32)
	M 11 (15)	M 3 (3)	L 2 (8)	L 305 (50)
	N 52 (72)	N 77 (76)	N 20 (80)	M 106 (17)
Observer 6 discordance	45 (50)	115 (81)	26 (87)	281 (16)
	L 1 (2)	A 16 (14)	A 1 (4)	A 202 (72)
	M 0	M 1 (1)	L 1 (4)	L 72 (26)
	N 44 (98)	N 98 (85)	N 24 (92)	M 7 (2)

A, anterior; CT, computed tomography; L, lateral; M, medial; N, normal.
Descriptions of the observer's discordance can be seen below each respective column.

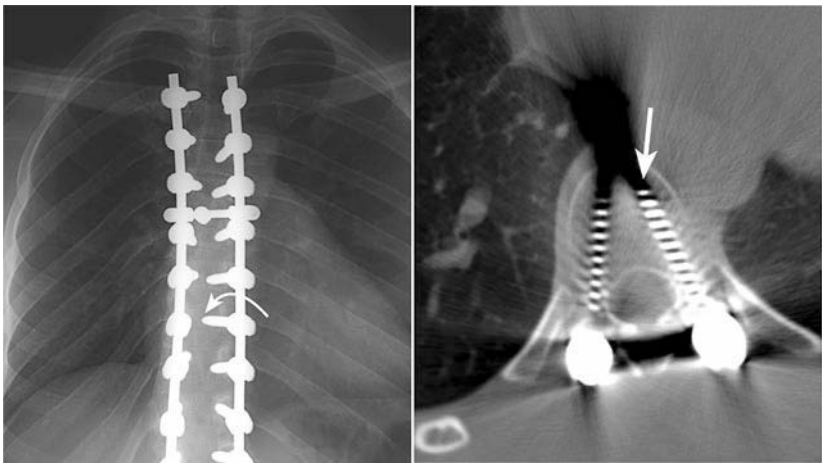

Fig. 1. Radiographic film (left) showing a medical misplacement denoted by the arrow, with the computed tomographic scan (right) showing a normal screw placement, denoted by the arrow.

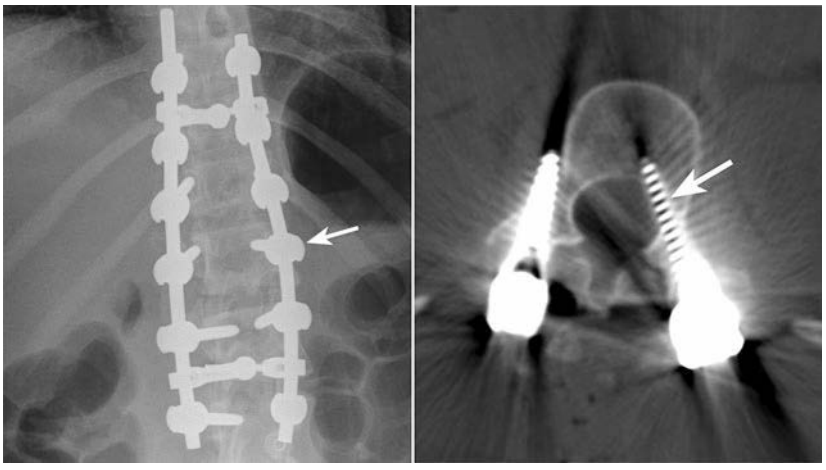

Fig. 2. Radiographic film (left) showing a normal screw placement denoted by the arrow, with the computed tomographic scan (right) showing a medial misplacement, denoted by the arrow.

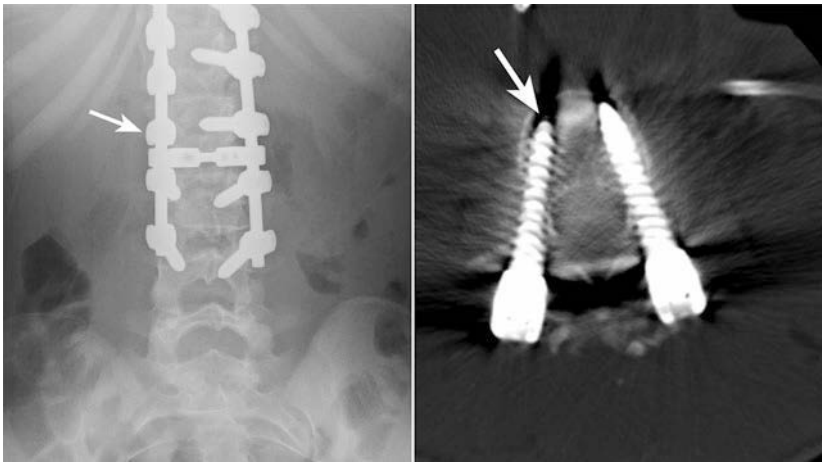

Fig. 3. Radiographic film (left) showing a lateral misplacement denoted by the arrow, with the computed tomographic scan (right) showing a normal screw placement, denoted by the arrow.

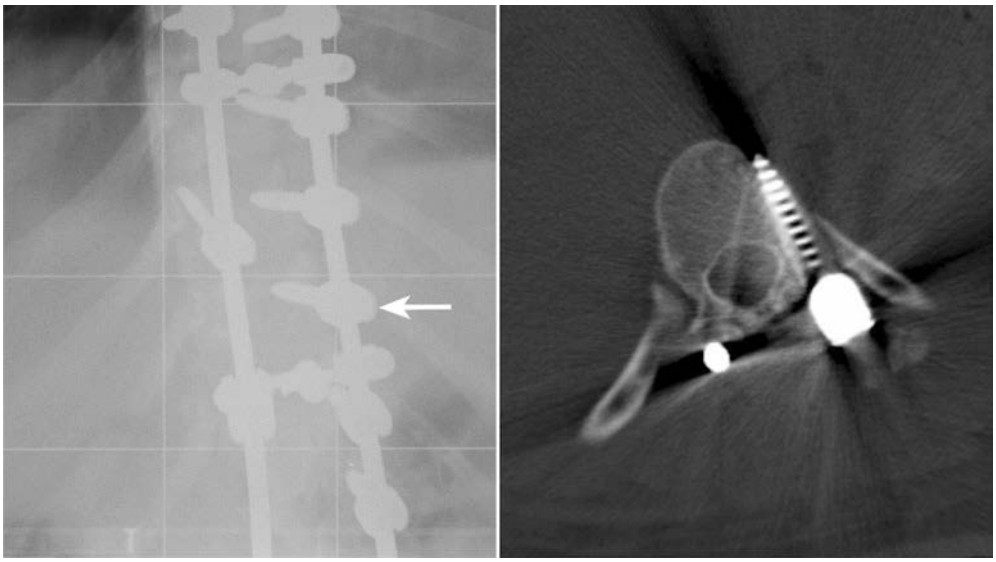

Fig. 4. Radiographic film (left) showing a normal screw placement, with the computed tomographic scan (right) showing a lateral misplacement, denoted by the arrow.

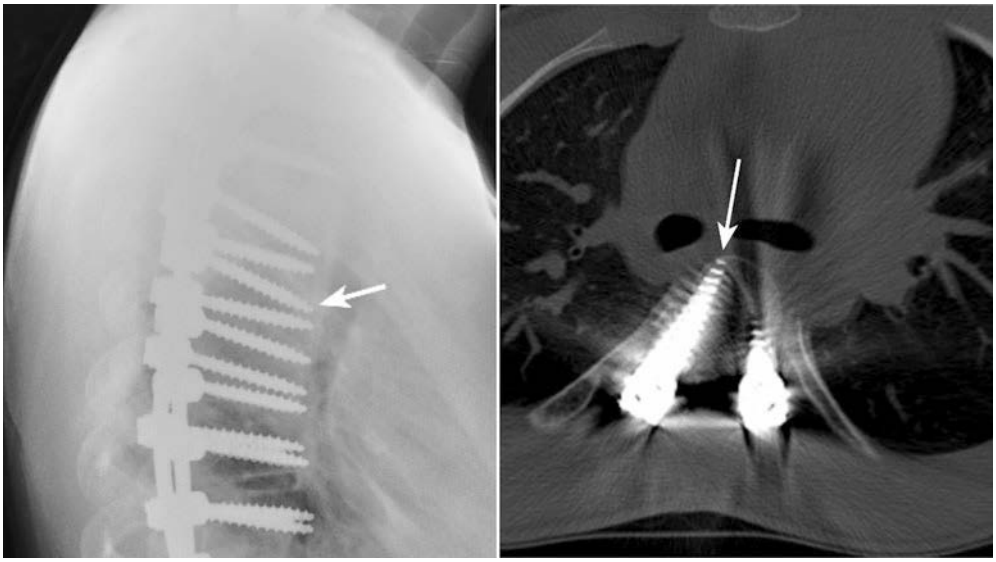

Fig. 5. Radiographic film (left) showing an anterior misplacement denoted by the arrow, with the computed tomographic scan (right) showing a normal screw placement, denoted by the arrow.

on radiographs by the six observers. Out of these, 79 (13%) to 410 (85%) screws were felt to be OA, 37 (7%) to 443 (74%) screws were felt to be OL, and 7 (2%) to 212 (22%) screws were felt to be OM. Overall agreement among six observers was poor, with a kappa value 0.23 (95% CI 0.23−0.24). Further analysis was carried out excluding the less experienced observers; the kappa value was 0.32 (0.31−0.33).

Discussion

The anatomy surrounding the thoracolumbar spinal column presents a significant risk in the case of pedicle screw misplacement. Complications can be neurological or vascular. Multiple reports describe injury to the aorta, perforations of the lung and gut, and migration of a broken screw in the retroperitoneum [5,15-18]. Silvestre et al. [19] have stressed the risk proximal thoracic pedicle screws pose to the esophagus, trachea, and bronchi. A recent study of 2,724 screws in 127 patients reported an accuracy rate of 87.96% [20]. However, per-patient analysis showed that only 23 (18.11%) patients had all screws placed accurately, whereas 18 (14.17%) had screws at risk [20]. The low overall rate of screw misplacement reported in the literature does not necessarily reflect the potential impact on patient morbidity. In dysplastic pedicles the likelihood for this

misplacement significantly increases [21]. We, therefore, strongly feel that it is critical to confirm screw position and it is essential that the most appropriate imaging technique be considered.

Previous studies have defined CT scan as the ''gold standard'' for identifying pedicle screw position [12-14,22]. The decision to subject a young child to ionizing radiation is not one that should be taken lightly. The prevalence of breast cancer among women with scoliosis exposed to multiple radiographs is higher than expected [23]. At the same time, this potential risk must be placed in perspective vis-à-vis the very real risk of a misplaced pedicle screw causing catastrophic neurovascular injury. Radiographs, on the other hand, have been shown to have poor reliability. In a cadaver study, Ferrick et al. [10] reported varying sensitivity for radiographs to detect screw malposition, from 58% to 83%, depending on the experience of the reviewer. Kim et al. [7] showed intraoperative radiographs to have poor sensitivity (0.58) and positive predictive value (0.35) for the assessment of pedicle screws. The anatomic variations and rotation pose difficulties in interpretation of screw position [6,7]. Kim et al. [6] developed a set of radiographic criteria to detect pedicle screw violations. Using these criteria, they showed radiographs to have 98% accuracy and 87% sensitivity to detect medial wall violations, and 96% accuracy and 94% sensitivity to detect lateral wall violation. Vallespir et al. [9] tested their criteria and found radiographs to be poorly sensitive to detect medial or lateral wall pedicle screw violations (0.25 and 0.23, respectively), although highly specific and accurate.

Our results indicate that radiograph is a poor diagnostic modality with poor sensitivity (0.52 [0.36–0.72]) and moderate specificity (0.70 [0.45–0.81]). These results translate to a 52% rate of correctly detecting unacceptable screws on radiographs, and 70% rate of correctly identifying acceptable screws on radiographs. Our study showed a strong tendency for radiographs to overestimate the number of screw misplacements. Out of the 1,772 screws found to be in normal position on CT, a median of 539 (281–974) screws were indicated to be in position other than normal. Out of these a median of 235 (79–539) screws were indicated to be anterior. This high false-positive rate for anterior screws was a major contributor to overall false-positive screw assessment, although many acceptable screws were also incorrectly identified as lateral (148 [74–443]) or medial (37 [7–106]). One criterion for anterior screw misplacement was ventral screw penetration $\geqslant$80% of the width of the vertebral body as imaged on the lateral radiograph. This criterion has a strong basis in previous literature [8]. However, it appears to overestimate anterior screw misplacements. Also, the discordance seen between radiographs and CT scan solely in terms of the lateral and medial false positives is considerable. Furthermore, of the 30 medial screws seen on CT scan, a mean of 4.5 screws (15%) were correctly identified on radiographs. Nineteen screws (63.3%) were incorrectly assessed as acceptable, and 6.5 (21.66%) incorrectly assessed as other misplacements. The inability of radiographs to accurately find medial misplacements is important. The poor accuracy and concordance rates, we observed, suggest the limitations of radiographs to correctly assess pedicle screw misplacement. The study finds that even with defined criteria, radiograph is inferior to CT scan for assessing screw position. The strengths of this study lie in the large sample size investigated and the blinded review of radiographs.

The limitation of this study could be the postoperative nature of radiographic evaluation. Ideal time to detect misplacement is intraoperative. Most surgeons use intraoperative radiographs or fluoroscopy to assess misplacement, whereas others use navigation aids. The findings of our study hold significance for those using radiographs and fluoroscopy to assess adequacy of placement. The criteria that we have used are not sufficient, which is not surprising as a two-dimensional modality cannot accurately assess the changes in the third dimension. Also, unlike Kim et al. we used postoperative radiographs to evaluate screw placement. It can be argued that postoperatively (1) the rod may overlap the screw tip and (2) the correction maneuvers can change the screw vertebra relationship [6]. In reviewing the 104 patients in this study, we did not find the rod to overlap the screw to preclude assessment of screw tip. Although screw-vertebra relationship can change (eg, ploughing of screw or pullout), the criteria for screw misplacement will still stay the same and if accurate should allow detection of such a change. Thus, a ploughing or screw pullout should appear as a violation of the harmonious segmental change of screw tips. In fact, in our own practice we have not infrequently used these criteria on intraoperative and postoperative radiographs to determine any such changes in fixation. Intraoperative assessment through navigational aids may facilitate more accurate screw placement. Issues with costs, efficiency, and radiation exposure must be improved before these technologies are more widely incorporated by deformity surgeons.

Key Points

- Radiograph is a poor diagnostic modality for identifying proper pedicle screw position.
- Our results indicate that previously defined screw placement criteria yield a median sensitivity value of 52%, specificity of 70%, and accuracy of 68%.
- A median 73% of medially misplaced screws on computed tomographic (CT) scan were considered to be in normal positions on radiograph.
- A median 77% of laterally misplaced screws on CT scan were considered to be in normal positions on radiograph.
- A median 72% of anteriorly misplaced screws on CT scan were considered to be in normal positions on radiograph.

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