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Original Article

"Critical pedicle wall" breaches analysis in complex spinal deformity using O-arm navigation

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ABSTRACT

Background: Free-hand and fluoroscopic-guided pedicle screw placement has been associated with higher rates of pedicle breaches (frequency range 15–40% especially in deformed pedicles). Neurological complications are more "critical" (i.e., frequent and significant) with medial and inferior pedicle-wall breaches due to the proximity of the neural elements. Here, we analyzed the effectiveness of O-arm navigation in minimizing "critical" pedicle wall breaches and their complications in 21 complex spinal deformity cases.

Methods: Twenty-one complex spinal deformity cases were prospectively managed with O-arm-navigated posterior-instrumented fusions. Preoperative assessment included; evaluation of the type of scoliosis, the magnitude of the deformity, and the anatomy of the pedicles – (i.e., classified using Watanabe *et al.*). The O-arm was used to confirm and grade both the intraoperative and postoperative location of screws. Other variables analyzed included; duration of surgery, estimated blood loss, complications, and radiation exposure.

Results: In 21 patients, 259 (63.45%) of 384 pedicles were instrumented; we observed 22 of 259 pedicle screw breaches. Significant (>2 mm) breaches were observed in two medial and one inferior wall cases that required revision; the overall biomechanically significant screw breach rate was (3/259) 1.2% with an accuracy rate of 98.8%. Pedicle screw placement resulted in another 14 nonsignificant (<2 mm) breaches; ten were medial and four involved the inferior wall. As anterior, lateral, and "in-out-in" trajectory pedicle screws beaches were nonsignificant, they were not included in our analysis.

Conclusion: O-arm navigation decreased the incidence of medial and inferior (i.e., >2 mm "critical") pedicle screw breaches applied in 21 patients with deformed pedicles due to scoliosis. Further, the O-arm minimized the operating time, decreased the estimated blood loss, and reduced the incidence of complications.

Keywords: Complex spinal deformity, Critical pedicle wall, Minimal complications, O-arm navigation, Pedicle breach

INTRODUCTION

Free-hand and fluoroscopic-guided pedicle screw placement has been associated with higher rates of pedicle breaches ranging from 15 to 40%, especially in patients with scoliosis and deformed pedicles. Neurological complications closely correlate critical medial and inferior wall breaches due to the proximity of the neural elements. Here, we evaluated whether O-arm navigation would increase the accuracy and safety of pedicle screw insertion in patients with complex scoliotic deformities.[1,3]

MATERIALS AND METHODS

In this Institutional Review Board-approved study, we evaluated 384 pedicles in 21 patients presenting with complex kyphoscoliosis (i.e., congenital scoliosis, neuromuscular scoliosis, syndromic scoliosis, and idiopathic scoliosis of Cobbs >60°) deformities (2021–2023). In this series, 259 pedicles were instrumented (63.45%) in 21 cases; seven had adolescent idiopathic scoliosis, five had congenital scoliosis, five had neuromuscular scoliosis, and four had syndromic scoliosis. The mean preoperative Cobb's angle of major curve was 72.5° (Range: 65–103°).

Pedicle screw analysis

Intraoperatively after primary O-arm spin, computed tomography (CT) scan-based pedicle analysis was done and they were divided into type A–D (i.e., classified using Watanabe *et al.*)[9] [Figure 1]. This analysis was performed by a single spine surgeon and assistant spine fellow. It showed 182 of type A, 111 of type B, 58 of type C, and 33 of type D pedicles of which 126 of type A, 92 of type B, 41 of type C, and none of type D pedicles were instrumented [Table 1].

Devices

Third-generation intraoperative three-dimensional CT scan device, that is, O-arm, along with optical camera-based navigation, that is, S8 stealth station was used in this study for analysis and data storage. A dynamic reference array was attached to the spinous process based on levels of instrumentation [Figure 2].

Pedicle screw insertion

A standard posterior midline approach with standard techniques (i.e., intersection method) along with O-arm navigation aid was used to insert screws into the pedicles. The virtual dimensions (length and width) of the pedicles were displayed on O-arm navigation, and pedicular screws were inserted. In thinned, deformed, and sclerosed type C and D pedicles, where transpedicular screw fixation was not possible, an in-out-in technique [Figures 3 and 4] with planned lateral pedicle wall breaches was performed under navigation guidance. Following the instrumentation, all screws were reevaluated using a second iCT for pedicle breaches. Pedicle wall breaches were graded as significant (>2 mm) and insignificant (<2 mm); their location was also tracked --medially, laterally, inferiorly, and superiorly [Figures 3 and 4]. The total number and grade of breaches for each Watanabe-type pedicle were analyzed [Table 2]. The medial and inferior wall breaches of >2 mm were considered "critical" and required surgical revision. Other variables studied included; screw insertion time, radiation exposure, blood loss, complications (intraoperative and

Table 1: Total Watanabe types of pedicles and instrumented Watanabe types of pedicles in our study.

Intraoperative pedicle analysis as per Watanabe classification	Total number of pedicles	Total number of instrumented pedicles
A	182	126
B	111	92
C	58	41
D	33	0
Total	384	259

A: Large cancellous channel, B: Small cancellous channel, C: Cortical channel, D: Slit/absent pedicle

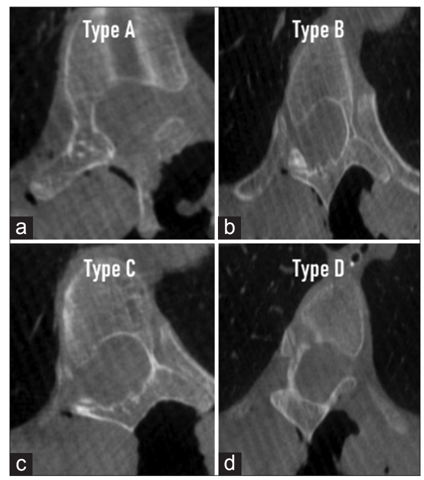

Figure 1: Watanabe *et al.* computed tomography-based pedicle channel classification, (a) Type A: a "large cancellous channel," (b) Type B: a "small cancellous channel," (c) Type C: a "cortical channel," and (d) Type D: a "slit/absent pedicle channel."

Figure 2: (a) Dynamic reference array frame attached in the middle of the surgical field for >6-level exposure, (b) demonstration of O-arm (at the foot end, not seen in the image) and stealth station (at the head end) setup in OR to ease triangulation between navigated instruments, dynamic reference array, and optical tracker.

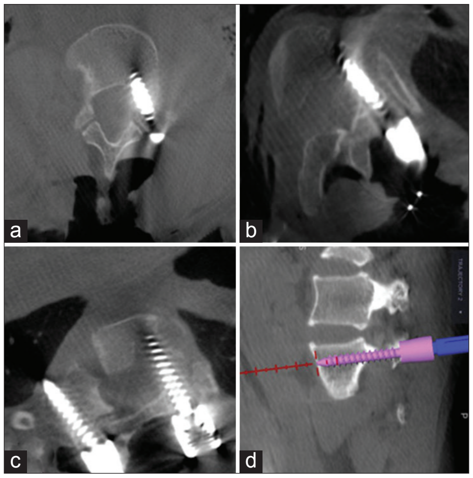

Figure 3: (a and b) Post pedicle screw insertional O-arm spin axial images showing nonsignificant (<2 mm) medial wall pedicle breach, (c) showing significant (>2 mm) medial pedicle wall breach, and (d) showing significant (>2 mm) inferior pedicle wall breach.

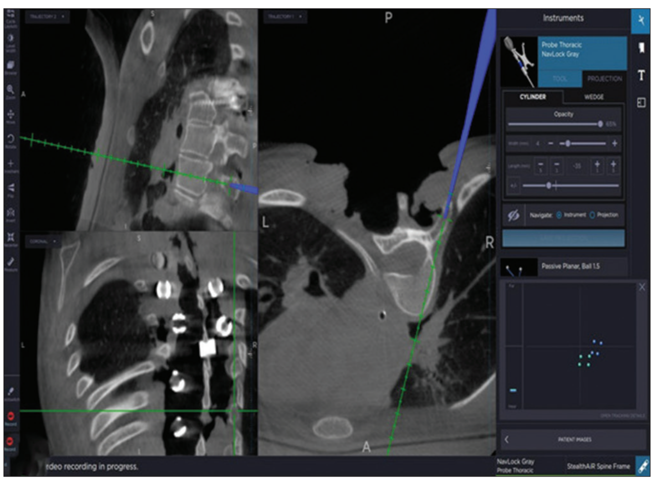

Figure 4: Stealth station real-time navigation image showing thoracic type D pedicle where planned lateral pedicle wall breach by in-out-in trajectory technique is performed.

immediate postoperative), and utility of O-arm navigation for intraoperative assessment of special situations [Figure 5].

RESULTS

Of the 259 instrumented pedicles, 38 pedicular screws were planned in-out-in trajectories screws (majority type C and D pedicles), and excluding in-out-in screws 22 pedicular screw breaches were noted. They occurred; medially in 12 cases, inferiorly in five cases, laterally in three cases, and anteriorly in two cases. There were ten medial and four inferior wall nonsignificant breaches versus significant breaches two medial and one inferior breach that needed revision [Table 2]. The biomechanical nonsignificant (<2 mm) screw breach rate was (19/259) 7.3%, whereas the significant screw breach rate was (3/259) 1.2% with an accuracy rate of 98.8%. Anterior and lateral breaches were nonsignificant and were not considered for analysis. Other variables revealed; an average blood loss of 622 mL, a mean radiation exposure of 13.5 mSv, a mean time to insertion of pedicle screws of 2.1 min/pedicle, a mean correction of Cobb's angle of 40.55°, and no neurological or vascular complications attributable to the screw breaches.

Table 2: Number and grades of critical pedicle wall (medial and inferior) breaches classified based on Watanabe types of pedicles.

Grades of breach	Type A (*n*=82)	Type B (*n*=60)	Type C (*n*=38)	Type D (*n*=20)
Medial wall				
0	76	52	36	18
1	06	07	02	02
2	-	01	-	-
3	-	-	-	-
4	-	-	-	-
Inferior wall				
0	80	57	36	17
1	02	03	02	03
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-

n: Number of pedicles

DISCUSSION

Several studies documented pedicle screw breach rates ranging from 10% to 15% using free-hand or fluoroscopic techniques [Table 3].[2,4,6,7] Literature also shows significant pedicle breach with navigation aid; i.e., Schwarzenbach *et al.*[8] and Rajan *et al.*[5] showed 11% pedicular breach rates. Rampersaud *et al.*[7] showed a 15% pedicular breach rate, while Merloz *et al.*[4] showed a 10% of pedicular breach rate. Schwarzenbach *et al.* and Merloz *et al.* studies both documented neurological complications consisting of nerve root irritation, root, and dural injuries. Further, significant medial and inferior wall breaches are the most likely to result in neural/dural injury, and spinal cord damage, while anterior breaches likely cause great vessel injuries [Table 4].

Complications

Complications are typically seen with navigation-guided pedicular screw placement mainly in complex deformity/dysplastic pedicle cases, for example, severe rigid idiopathic scoliosis, congenital scoliosis, neuromuscular scoliosis, and dystrophic scoliosis. If inferior and medial pedicular

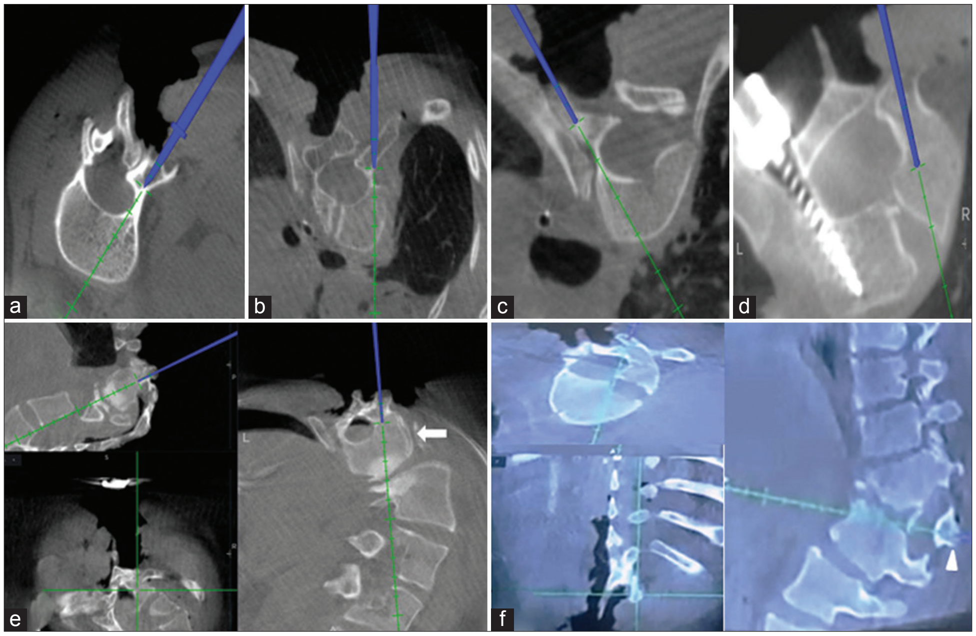

Figure 5: Utility of O-arm navigation in intraoperative assessment of special situations which preoperative and other intraoperative modalities fail to address. (a-c) Intraoperative assessment of Watanabe *et al*. pedicle type B, C, and D pedicle, respectively, enabling safe placement or avoidance of pedicle screw, (d) limiting pedicle screw length in atypical vertebrae, that is, hemivertebrae, (e) demonstration of apical vertebrae in omega deformity which shows complete vertically oriented vertebrae(white arrow), and (f) identification of hemivertebrae and planning pedicle screw dimension avoid an anterior breach, assisting in planning hemivertebrae excision, predicting dimensions of hemivertebrae wedge resection (white arrowhead), and deformity correction.

Table 3: Comparative studies mentioning pedicular screw placement accuracy rate in spinal deformity cases using navigated and nonnavigated surgical techniques.

Study	Non-navigated modality	Accuracy (%)	Navigation modality	Accuracy (%)
Rampersaud *et al.*[7]	-	-	Fluoroscopy based navigation	85
Merloz *et al.*[4]	Free-hand technique	57.6	CT navigation	90
Rajasekaran *et al.*[6]	3D Fluoroscopy	61	CT navigation	97
Laine *et al.*[2]	Free-hand technique	85.7	CT navigation	95.6

CT: Computed tomography

Table 4: Demonstrating pedicle breach rate and associated complications with navigation-guided pedicle screw fixation in spinal deformity in four studies.

Study	Pedicle screw breach rates	Complication
Schwarzenbach *et al*., Spine, 1997[8]		
162 Pedicle Screws	11% Groups A/B	No significant breach-related complications
Rampersaud *et al*., Spine, 2005[7]		
360 pedicle screws with CT fluoroscopy navigation	15%	72% Breaches lateral 49% Breaches-screw diameter > Pedicle diameter
Rajan *et al*., IJO, 2010[5]		
98 cervical 242 thoracic deformed pedicles used Iso-C3D navigation	10–11%	5 Lateral pedicle breaches-vertebral artery injury 3 medial breaches penetrated the canal No neurovascular complications
Merloz *et al*., CORR, 1998[4]		
132 thoracolumbar pedicle screws 28 screws in scoliosis cases used 3D navigation	14%	Medial and lateral breaches No neurovascular deficits

Group A: With pre-operative CT scan, Group B: Without CT scan breaches ("critical") are avoided, neurological complications will not occur. In select cases, we deliberately performed lateral wall breaches (i.e., an in-out-in technique in thoracic dysplastic pedicles), especially for type C and D pedicles [Figure 4].

CONCLUSION

Utilization of O-arm navigation with thorough knowledge of critical pedicle wall majorly in cases of complex spinal deformity helps in avoiding complications yielding favorable outcomes by decreasing surgical time, blood loss, patient radiation exposure, and early recovery. Further, the safety and efficacy are superior to the 10–15% incidence of pedicle screw breaches using free hand and other navigational techniques (i.e., 11–15%).[4-6]

Declaration of patient consent

The Institutional Review Board (IRB) permission obtained for the study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The author(s) confirms that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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