Research Square

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Fully percutaneous, navigation-assisted cervical pedicle screw instrumentation: Technical note and a report of Safety and accuracy

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Abstract

Introduction:

Cervical pedicle screws provide superior biomechanical stability compared with lateral mass screws, resulting in stronger and more durable constructs. Although the feasibility of percutaneous placement has been explored, evidence for this technique remains limited. We present a technical note on fully percutaneous cervical pedicle screw instrumentation and report its safety and accuracy in our initial case series.

Material and Methods

Data from thirteen consecutive patients and forty-two cervical pedicle screws were prospectively collected between October 2024 and September 2025. The primary outcomes were screw placement accuracy, radiologically assessed using the Bredow classification and clinically defined by the absence of revision and safety, evaluated through complication rates, intraoperative blood loss, surgical time, and length of stay.

Results

Traumatic fracture was the most common underlying pathology. 36 screws (85.7%) were classified as being in a good radiological position according to the Bredow classification. One screw required revision, resulting in a clinically acceptable accuracy rate of 97.6%. One patient experienced bar dislocation, and another developed occipital neuralgia. No cerebrospinal fluid (CSF) leak, postoperative infection, or vertebral artery injury was observed.

Conclusions

Fully percutaneous, navigation-assisted cervical pedicle screw fixation appears to be a safe and accurate technique, providing high radiological precision and significant early pain improvement.

Introduction

Posterior instrumentation of the subaxial cervical spine using pedicle screws provides superior biomechanical stability when compared with lateral mass fixation, including higher pullout strength, greater resistance to lateral bending, and the possibility of shorter constructs (1–3). These biomechanical advantages are particularly relevant in traumatic, deformity-related, and revision scenarios, where rigid fixation is required to ensure construct durability (4).

Despite these advantages, cervical pedicle screw (CPS) placement has traditionally been considered technically demanding due to the small diameter of cervical pedicles, their anatomical variability, and the close proximity of critical neurovascular structures such as the spinal cord and vertebral artery (5, 6). Reported CPS breach rates vary widely in the literature, and the potential for severe neurovascular complications has limited the widespread adoption of this technique, especially in minimally invasive settings.

Early CPS techniques were performed using open posterior approaches guided by anatomical landmarks, often requiring extensive paraspinal muscle dissection to achieve the necessary medial and cranial screw trajectories (7–9). Such approaches may be associated with increased blood loss, postoperative pain, and longer recovery times. In contrast, minimally invasive spine surgery (MIS) techniques aim to reduce iatrogenic muscular trauma and have

demonstrated clinical benefits such as reduced blood loss, shorter hospital stays, faster functional recovery and even lower (10–14). However, the translation of these benefits to the cervical spine remains challenging due to anatomical constraints and the narrow margin for error.

Recent advances in intraoperative imaging and navigation technologies have significantly improved the accuracy and safety of CPS placement. Navigation-assisted techniques have consistently demonstrated higher accuracy rates compared with conventional fluoroscopy-guided methods, with reported accuracy reaching 91–93% in both open and minimally invasive approaches (15–17). Nevertheless, the current evidence supporting percutaneous CPS placement remains limited, consisting mainly of small case series, cadaveric studies, or feasibility analyses, which restricts the generalizability of these findings to routine clinical practice (18–21).

Moreover, most minimally invasive cervical fixation techniques described to date rely on paramedian incisions, multi-screw constructs, or rigid cranial fixation devices such as the Mayfield clamp. Whether high accuracy and safety can be achieved using fully percutaneous techniques with simplified positioning strategies and shorter constructs remains insufficiently explored.

The aim of the present study is to describe a fully percutaneous, navigation-assisted cervical pedicle screw fixation technique using single incisions per screw, percutaneous rod placement, and a carbon horseshoe headrest. In addition, we report the safety and accuracy of this technique in an initial prospective case series, with particular emphasis on radiological accuracy, clinical safety, and early postoperative outcomes.

Material and Methods

Patient Data

Data from 13 consecutive patients were prospectively collected between October 2024 and September 2025 at a single tertiary neurosurgical center. The study protocol was approved by the local ethics committee, and all participants provided written informed consent prior to inclusion. Clinical and radiological variables were prospectively recorded using standardized forms and anonymized before analysis.

Inclusion criteria comprised adult patients presenting with unstable cervical pathologies requiring posterior cervical or cervicothoracic stabilization. Patients requiring decompressive procedures were excluded, as such cases involved surgical exposures that deviated from the minimally invasive philosophy of this study. All patients were followed for a minimum of 30 days postoperatively. For the purposes of this analysis, thoracic screw data were excluded to ensure a homogeneous evaluation focused exclusively on cervical pedicle screw placement.

Outcomes Measures

The primary outcomes of this study were the accuracy and safety of cervical pedicle screw placement. Accuracy was evaluated both radiologically and clinically, the latter being defined as the absence of any need for screw revision, which was considered clinically acceptable. Radiological accuracy of the cervical pedicle screws was assessed using the novel Bredow classification, recently introduced to provide a more precise evaluation within the cervical region (22, 23). According to this classification, accuracy grades were defined as follows: grade 1, screw completely within the pedicle or with a cortical breach of less than 1 mm; grade 2, breach of less than 2 mm; grade 3, breach of less than 3 mm; grade 4, breach of less than 4 mm; and grade 5, breach greater than 4 mm or foraminal encroachment by half of the screw diameter. All radiological assessments were independently performed by two

authors (G.M.-D. and F.R.), and in cases of disagreement, the images were re-evaluated by a third author (E.S.) to reach consensus. Safety was assessed through the documentation of intraoperative and postoperative complications, length of stay, surgical time, and estimated blood loss. Secondary outcomes included postoperative pain reduction, evaluated using the Visual Analog Scale (VAS). We also calculated the correlation between pedicle dimensions (height and width measured on preoperative CT scans) and radiological screw accuracy.

Technical note

All patients were positioned prone with the head resting on a carbon horseshoe head support (Fig. 1A). The procedures were performed using the NextAR™ Spine augmented reality surgical navigation system (Medacta International SA, Castel San Pietro, Switzerland). The reference frame was fixed with two pins inserted into the C6 and C7 spinous processes through two small stab incisions, preserving the paravertebral musculature (Fig. 1B). Subsequently, a three-dimensional image was acquired using a 3D C-arm system (Ziehm Vision RFD 3D, Ziehm Imaging, Nuremberg, Germany), and the data were transferred via USB 3.0 to the NextAR™ central workstation for navigation setup.

After calibration and referencing of the navigation system, the optimal skin incision sites were planned to ensure a sufficiently lateral screw trajectory. For each screw, a stab incision was made, and the musculature was gently dilated using blunt dissection to minimize movement during screw placement. A navigated drill guide was used to drill the canals (Fig. 1C), followed by insertion of a Kirschner wire along the planned trajectory. All K-wires were placed before screw insertion. All procedures were performed using the M.U.S.T. Mini® Spine System (Medacta International SA, Castel San Pietro, Switzerland). Screw dimensions were selected based on both preoperative imaging and intraoperative navigation measurements. All screws were then inserted simultaneously (Fig. 1D). Post-insertion, the screw positions were verified with an intraoperative 3D reconstruction. Once correct placement was confirmed, rods were inserted percutaneously (Fig. 1E), extending the caudal incisions, and performing the connection in a subfascial fashion. Screw caps were then used to fix de screws to the rods and were well tightened. The wounds were closed in layers in standard manner (Fig. 1F). All patients were stabilized with four pedicle screws, two placed above and two below the lesion.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics, version 29.0.2.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as absolute numbers and percentages. The Shapiro–Wilk test was used to assess data normality. Radiological screw accuracy, interrater reliability, and correlations between pedicle dimensions (width and height) were analyzed using Spearman's rank correlation coefficient (ρ). Comparisons between preoperative and postoperative Visual Analog Scale (VAS) scores were performed using the Wilcoxon signed-rank test for paired nonparametric data. A p-value of < 0.05 was considered statistically significant for all tests.

Results

11 patients were male (84.6%) and 2 were female (15.4%). The mean age of the cohort was 72.6 ± 9.1 years (range, 56–84 years). The main indication for instrumentation was traumatic fracture, observed in 8 cases (61.5%). Degenerative spinal stenosis accounted for 3 cases (23.1%), and metastatic or neoplastic lesions for 2 cases (15.4%). The mean surgical time was 109.3 ± 19.5 minutes (range, 71–142 min), with a median of 112 minutes. The mean estimated intraoperative blood loss was 357.7 ± 168.1 mL (range, 200–700 mL). The mean length of hospital

stay was 14.5 ± 10.8 days (range, 5–45 days), with a median of 13 days. The demographic and clinical characteristics of the patient cohort are presented in Table 1.

Table 1
Baseline demographic and clinical characteristics of the patient cohort. Anterior cervical discectomy and fusion (ACDF); anterior cervical corpectomy and fusion (ACCF); AO spine classification system (AO); diffuse idiopathic skeletal hyperostosis (DISH); spinal instability neoplastic scale (SINS).

	Age	Gender	Previous surgery	Indication	Segment	Surgical time (Min)	Bloodloss (ml)	Complication/Revision
1	75	m	no	Fracture C4 B3 AO spine	C3-6	98	200	no
2	74	m	no	Tumor C2 und C 5 SINS 9	C2-6	139	300	no
3	70	m	ACDF C4-7	Degenerative Myelopathy C4-C7	C4-T1	106	250	no
4	58	f	no	Tumor C3 SINS Score 9	C6-T3	120	700	Bar dislocation
5	56	m	ACDF C6/7	Fracture C6 B3 AO spine	C5-T1	85	300	no
6	72	m	no	Fracture C6 B3 AO spine	C5-7	112	500	no
7	80	f	no	Degenerative Myelopathy C4-6	C2-7	142	600	Occipital neuralgia
8	81	m	no	Fracture C6 B3 AO spine	C6-T1	71	200	no
9	61	m	no	Fracture C4-5	C4-6	114	400	no
10	84	m	no	Fracture C6-7	C5-T1	120	500	Screw revision
11	80	m	no	Fracture C6 B3 AO spine	C5-C7	99	300	no
12	75	m	ACCF C5	Degenerative Myelopathy C4-6	C3-C7	103	200	no
13	78	m	no	Fracture C5-6 B3 AO spine	C5-C6	112	600	no

Postoperative computed tomography (CT) evaluation according to the Bredow classification demonstrated a high degree of radiological precision for screw placement. A total of 36 screws (85.7%) were classified as radiologically acceptable (Grades 1–2), including 27 Grade 1 (64.3%), 9 Grade 2 (21.4%), 3 Grade 3 (7.1%), 2 Grade 4 (4.8%) and 1 Grade 5 (2.4%) placements (Fig. 2A-E). The interrater reliability was $\rho = 0.86$ ($p < 0.001$), demonstrating a high degree of agreement between the examiners. Clinically, 41 of 42 screws (97.6%) were considered acceptable, as only one

screw required revision. Table 2 summarizes all inserted cervical screws, including their Bredow classification, laterality of pedicle breach, and preoperative pedicle.

Table 2
Overview of all inserted screws, including Bredow classification, side of pedicle breach, and pedicle dimensions measured on preoperative CT imaging.

Screw	Level	Bredow classification	Breech	Pedicle WIDTH (mm)	Pedicle height (mm)
1	C3	1	no breech	4.5	5.5
2	C3	1	no breech	4.5	5.5
3	C6	1	no breech	5.5	5.5
4	C6	1	no breech	6	6
5	C2	1	no breech	4.5	5.5
6	C2	3	medial	3.5	5.5
7	C6	1	no breech	6	6
8	C6	2	medial	5	5
9	C4	2	lateral	5	7.5
10	C4	1	no breech	5	7.5
11	C6	1	no breech	5	6
12	C6	1	no breech	5.5	5.5
13	C5	1	no breech	4.5	5.5
14	C5	1	no breech	4	6
15	C5	4	medial	5	6
16	C5	1	no breech	5	5.5
17	C7	1	no breech	6	6.5
18	C7	1	no breech	6.5	6.5
19	C3	1	no breech	4.5	4
20	C3	1	no breech	4.5	4
21	C7	3	medial	5.5	4
22	C7	2	medial	6	4
23	C5	1	no breech	6	7
24	C5	2	medial	5	7
25	C4	3	lateral	5	5.5
26	C4	5	medial	6	5.5
27	C6	2	lateral	5.5	4.5
28	C6	2	lateral	5.5	5
29	C5	2	lateral	3	5
30	C5	1	no breech	3.3	6

Screw	Level	Bredow classification	Breech	Pedicle WIDTH (mm)	Pedicle height (mm)
31	C5	1	no breech	5.2	5
32	C5	1	no breech	4.7	5
33	C7	1	no breech	5	6.5
34	C7	1	no breech	6	6.7
35	C3	1	no breech	4.5	5
36	C3	1	no breech	4.5	5.5
37	C7	1	no breech	5.2	6.6
38	C7	2	lateral	6.2	6.5
39	C5	2	medial	4.5	5.5
40	C5	1	no breech	5	5.5
41	C6	1	no breech	6	6
42	C6	3	medial	5	6

Regarding clinical safety, one patient experienced a bar dislocation and one patient transient occipital neuralgia. No cerebrospinal fluid leak, wound infection, or vertebral artery injury was observed.

Postoperative pain significantly decreased compared with preoperative levels, as assessed by the Visual Analog Scale (VAS). The Wilcoxon signed-rank test showed a statistically significant reduction in neck pain ($Z = -2.944$, $p = 0.003$), with 11 patients (84.6%) reporting lower postoperative VAS scores and 2 patients (15.4%) showing no change.

No significant correlations were observed between pedicle dimensions and postoperative screw accuracy according to the Bredow classification. Spearman's correlation analysis revealed a weak and non-significant association between pedicle width ($\rho = 0.061$, $p = 0.699$), as well as between pedicle height with the Bredow grades ($\rho = -0.168$, $p = 0.288$).

Discussion

Our case series presents a fully percutaneous technique demonstrating safety and accuracy comparable to those reported in the literature. Scholz et al. evaluated the accuracy and safety of a completely percutaneous technique in a series of six patients, reporting an 84.4% rate of accurate screw placement, which is similar to our findings (21). Coric et al. described a case series of 27 patients using a two–paramedian-incision technique with transmuscular screw insertion, reporting complication rates comparable to those observed in our study (19).

We strongly recommend the use of navigation for cervical pedicle screw placement, whether in percutaneous or open techniques. The adoption of this technology has been shown to increase placement accuracy up to 91–93% (24–26). In a study of 167 screws conducted by Richter et al., nearly 9% of breaches were observed in the conventional fluoroscopy group compared to 3% in the navigation group (15).

More recently, Weber et al. published a comparison between 10 patients treated with an open approach and 10 with a MIS technique. They reported a significant reduction in the number of screws used in the MIS group (mean, 4.7) and

in surgical time (mean, 132 minutes) (27). These findings are consistent with our concept of using four screws and achieving a relatively short surgical time.

Another important observation from our results is that, despite several cases showing pedicle wall breaches, the clinical relevance remained low, supporting the safety of the technique. This observation is consistent with the findings of Lee et al., who reported 45 screws with an 11.1% breach rate, none of which were symptomatic (28). Similar findings were also described by Scholz et al. and Kast et al., who reported that 93% of pedicle breaches were asymptomatic in their series with a 32% breach rate (21, 29).

An additional point of interest is that our technique utilized a carbon horseshoe headrest, indicating that high levels of accuracy can be achieved even without the use of a carbon Mayfield clamp. Our study also demonstrated a significant reduction in postoperative pain, which we believe is associated with decreased muscular trauma consistent with the MIS technique.

Ito et al. reported in their navigation-assisted open approach that, in cases of very small pedicles, lateral mass screws were preferred (30). In our study, however, we did not find a statistically significant correlation between pedicle dimensions and screw placement accuracy. These findings indicate that neither pedicle width nor height had a measurable influence on the radiological accuracy of screw placement. Further research is required to support these observations.

The application of new technologies for pedicle screw placement remains an active area of investigation. Ryu et al. presented a cadaveric study of robot-assisted instrumentation showing a high accuracy rate of 97.5% (31). Similarly, Zhou et al. conducted a clinical study in humans reporting an accuracy of 88%, which is comparable to conventional navigation techniques (32). An interesting concept was proposed by Ruiz-Cardozo et al., who performed a cadaveric study implementing augmented reality for instrumentation (33). Additional studies are needed to evaluate the potential advantages and disadvantages of incorporating these technologies into routine clinical practice.

Limitations

The number of patients and screws included in our study was small, resulting in limited statistical power. Additional studies with larger patient cohorts are necessary to validate these findings. Furthermore, the follow-up period in our series was short; long-term follow-up studies may help to address current gaps in the scientific evidence.

Conclusion

Fully percutaneous cervical pedicle screw fixation assisted by navigation demonstrated high radiological accuracy and clinical safety in this prospective series. Among 42 screws placed in 13 consecutive patients, 85.7% were classified as Grade 1–2 according to the Bredow classification. Only one screw required revision, and no major neurovascular complications were observed.

The technique was associated with acceptable operative times, moderate blood loss, and significant postoperative pain reduction, with 84.6% of patients demonstrating improvement in VAS scores. Notably, high placement accuracy was achieved using a carbon horseshoe headrest without rigid cranial fixation, supporting the feasibility of the horseshoe in the minimally invasive workflow.

By providing prospective data focused exclusively on cervical pedicle screws and applying a detailed radiological grading system, this study adds homogeneous evidence to a field largely dominated by mixed or retrospective series.

Although limited by sample size and follow-up duration, these findings suggest that navigation-assisted percutaneous cervical pedicle screw instrumentation is a safe and accurate option for posterior cervical stabilization in selected patients.

Declarations

Author Contribution

Author contributions:• G.M-D., E.S. and B.H. contributed to the conceptualization and design of the study.• G.M-D., F.R. and E.S. was responsible for reviewing and interpreting the CT images.• G.M-D, F.R., A.M-D and B.H. organized and structured the manuscript text.• G.M-D, B.H., F.R., P.E., M.K., H.C., I.K., T.M, A.M-D and E.S., critically reviewed and revised the manuscript for important intellectual content.

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Figures

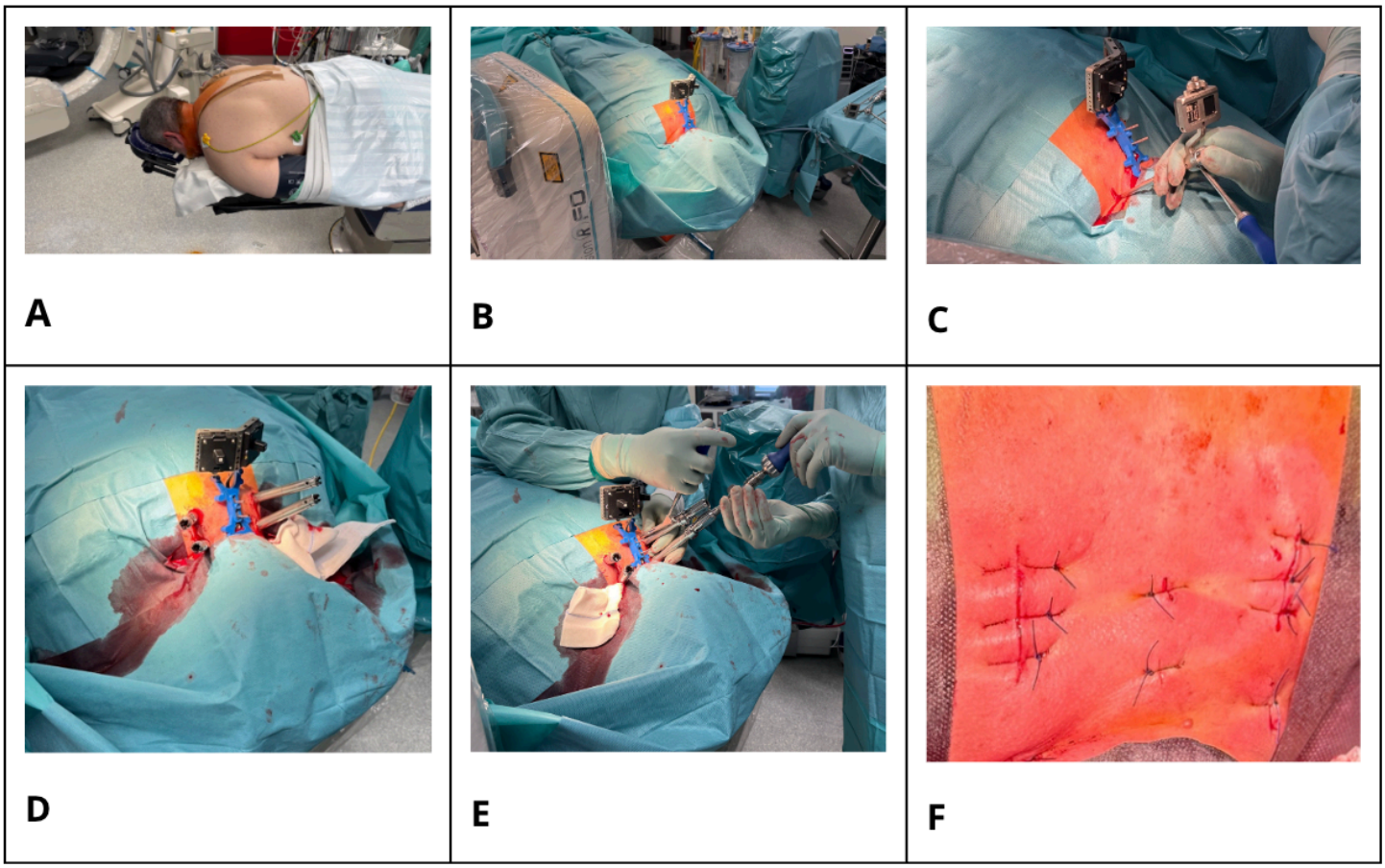


Figure 1

Intraoperative images of the surgical technique (A) Patient positioned prone with the head supported on a carbon horseshoe. (B) Reference frame fixed to the C6–C7 spinous processes through small stab incisions preserving the

paravertebral musculature. (C) Navigated drilling performed using the NextAR™ Spine augmented reality surgical navigation system. (D) Simultaneous insertion of screws from the M.U.S.T. Mini® Spine System after trajectory verification with intraoperative 3D imaging. (E) Rod insertion technique. (F) Standard wound closure.

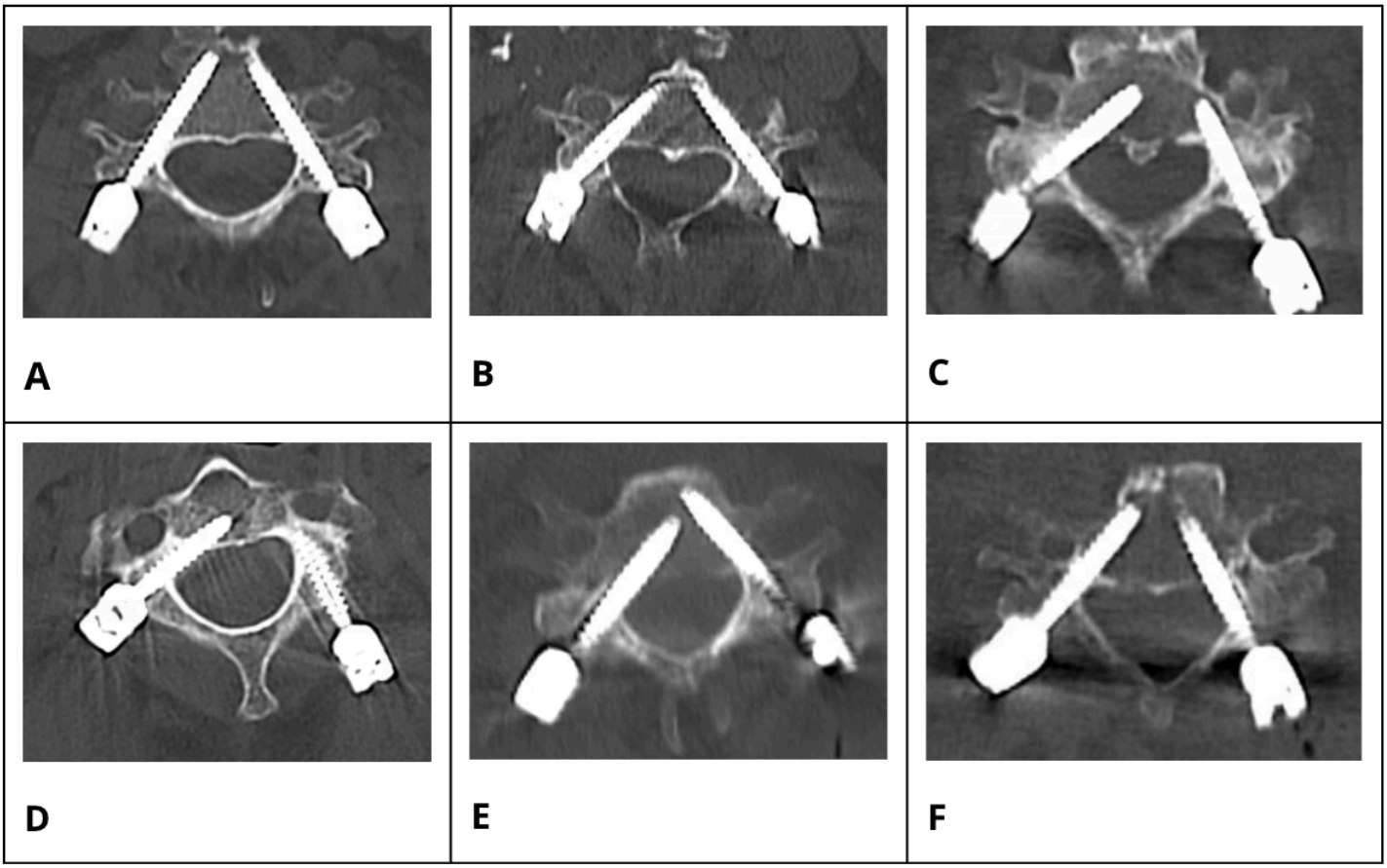


Figure 2

(A–F) Representative examples of the Bredow classification in postoperative CT scans from our cohort. (A) C5 pedicle screws, both Grade 1. (B) C4 pedicle screws, both Grade 1. (C) Right C6 pedicle screw classified as Grade 2. (D) Right C2 pedicle screw classified as Grade 3. (E) Right C4 pedicle screw with Grade 4 perforation. (F) Left C4 pedicle screw classified as Grade 5; this screw was subsequently revised.