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C7 pedicle vs. lateral mass screws in cervical spondylotic myelopathy: A retrospective analysis of cervical alignment parameters

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Abstract

Cervical spondylotic myelopathy (CSM) frequently requires surgical intervention at C7, with the choice between pedicle and lateral mass screws influencing outcomes. Pedicle screws offer superior biomechanical stability but carry higher neurovascular risks, while lateral mass screws are safer but less stable. Limited data compare these techniques in CSM treatment, particularly without O-arm navigation. To compare the safety, efficacy, and spinal alignment outcomes of C7 pedicle screws versus lateral mass screws in CSM patients, especially in settings lacking advanced imaging technologies. This retrospective cohort study analyzed 23 patients (13 with lateral mass screws, 10 with pedicle screws) who underwent posterior fusion surgery for CSM between 2013 and 2022. Preoperative and postoperative CT scans and a minimum one-year follow-up were required. Radiological parameters, including C2 slope, T1 slope, C2-7 Cobb angle, and sagittal vertical axis (SVA), were assessed, along with complications such as screw loosening, breakage, and revision surgeries. No significant differences were found between the two groups in screw loosening (69.2% vs. 60%), breakage (7% vs. 20%), or distal junctional kyphosis rates (7.7% vs. 0%). Both groups demonstrated similar improvements in spinal alignment parameters at postoperative and one- year follow-ups. One patient in the pedicle group required revision for a major foraminal breach, while three patients in the lateral mass group underwent revision for proximal junctional kyphosis. Both pedicle and lateral mass screws provided comparable safety, efficacy, and alignment outcomes at C7 in CSM patients. The choice of screw type should depend on patient anatomy, surgeon preference, and the availability of imaging technology.

Keywords: cervical vertebrae, bone screws, spinal fusion, tomography

1. Introduction

Cervical spondylotic myelopathy (CSM) is a widespread and disabling degenerative disease of the cervical spine, which usually results in the progressive compression of the spinal cord, thus causing severe neurological deficits and significantly affecting the quality of life.

The C7 vertebra, situated at the cervicothoracic junction, is a special case in surgical planning because spine surgeons have to take into account both the inclusion of C7 in the spinal construct and the choice between pedicle and lateral mass screws. This choice is based on the different biomechanical properties of each screw type and their possible effect on the surgery results. Pedicle screws are more biomechanically stable but have a higher risk of neurovascular complications (1,2). Lateral mass screws, although they may be less stable, have a safer profile (3–5).

This research is intended to contribute to the discussion through the comparison of safety, treatment success, and cervical alignment outcomes of the pedicle versus the lateral mass screw fixation in CSM patients.

2. Materials and Methods

2.1. Study design and patient selection

We conducted a 10-year retrospective analysis of patients with cervical spondylotic myelopathy (CSM) treated surgically at a single tertiary center by a single surgeon between January 2013 and April 2023. The choice to review patients starting in 2013 was driven by a major system change in our patient management: a transition to all-electronic storage, which most likely improved the consistency and reliability of the data from that time on.

Patients included in this study met the following criteria: diagnosis of cervical spondylotic myelopathy (CSM), age over 18 years, surgical intervention at our tertiary center by the designated surgeon, availability of one-year follow-up data, and preoperative and postoperative computed tomography (CT) scans. Also, only patients who had C7 as their final vertebrae incorporated into the fusion construct were included.

Patients were excluded for any of the following reasons: lack of one-year follow-up, incomplete preoperative or postoperative imaging (CT), surgery performed due to trauma

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or malignancy, or had no C7 screw or didn't have C7 as the final construct level.

The study was conducted in accordance with the 1964 Helsinki Declaration and was approved by our university's ethics committee (Decision no: 24-3T/35, Date: 07.03.2024). Consent for publication was obtained using our institutional consent form.

2.2. Clinical variables

The following data was collected from eligible patients' medical records: demographic data (age, sex, comorbidities), survival status, clinical scales (American Society of Anesthesiologists (ASA) score, Modified Rankin Scale (mRS), Nurick scale), radiological parameters (proximal junctional kyphosis (PJK), distal junctional kyphosis (DJK)), and complications (foraminal/spinal canal breach, screw loosening or breakage, revision surgery). Preoperative Goutalier index of paraspinal musculature at the level of C5-6 and Hounsfield units of the C4 vertebra corpus at the midline were also measured. PJK and DJK were defined as 10-degree changes in the relevant vertebrae in the one-year follow-up compared to post- operative CT scans (6).

The patients were also evaluated for their preoperative, postoperative, and one-year follow-up measurements of C2 slope, C2-7 Cobb angle, C2-7 sagittal vertical axis (SVA), T1 slope, neck tilt, and thoracic inlet angle (calculated as the sum of T1 slope and neck tilt) (Fig. 1.).

While all revision surgeries were recorded, only surgery due to DJK was considered relevant to construct failure in the context of C7 instrumentation, as we are comparing the effectiveness and safety of the C7 pedicle and lateral mass screws.

The Goutalier classification system for muscles, previously used for the cervical spine (7–9), was used to assess the posterior muscular support of the construct preoperatively. The multifidus muscle was measured at the C5-6 level.

The Hounsfield units were measured from preoperative CT scans of the C4 vertebra corpus at the midline sagittal view, as this was previously associated with construct failure and may be a predictor of osteoporosis (10,11).

2.3. Statistical Analysis

Descriptive statistics (means, standard deviations, frequencies, etc.) were calculated for demographic data, clinical scores, and radiological parameters. Comparative analyses between patients receiving pedicle screws and those receiving lateral mass screws were conducted using appropriate statistical tests, such as independent samples t-tests for continuous variables and chi-square tests for categorical variables.

The spinal alignment parameters and their change with treatment and time were subject to a repeated ANOVA test. Cox regression analysis and Kaplan Meier survival analysis were performed for the outcome measures.

A p value of <0.05 was considered statistically significant. Data analysis was performed using SPSS version 27 (IBM Corp., Armonk, NY, USA).

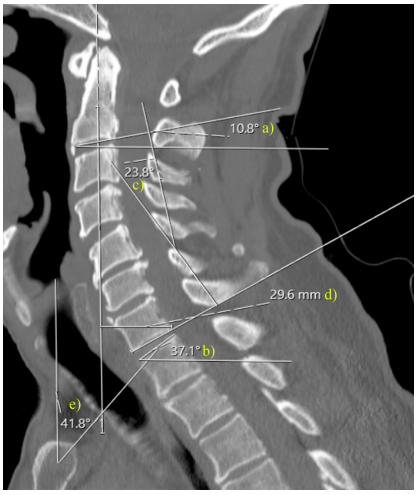

Fig. 1. Figure 1 presents an example of a sagittal cervical spine CT scan, illustrating the key sagittal alignment parameters assessed in this study. These parameters include (a) the C2 slope, defined as the angle between the inferior endplate of C2 and a horizontal line; (b) the T1 slope, the angle between the superior endplate of T1 and a horizontal line; (c) the C2-7 Cobb angle, representing the overall cervical lordosis, measured as the angle between the inferior endplate of C2 and the superior endplate of C7; (d) the C2-7 sagittal vertical axis (SVA), indicating the overall sagittal balance of the cervical spine, measured as the horizontal distance between the posteroinferior corner of C7 and a plumb line dropped from the center of C2; and (e) the neck tilt, the angle between the vertical line (plumb line) and a line connecting the center of C2 to the center of C7.

3. Results

Of 97 patients who underwent posterior fusion surgery, 23 were eligible for analysis, and the exclusion process may be seen in Fig. 2. Both groups were similar in age, sex, ASA score, mRs score, Nurick scale, preoperative Goutalier index at C5-6, and Hounsfield units of C4. These values can be seen in (Table 1).

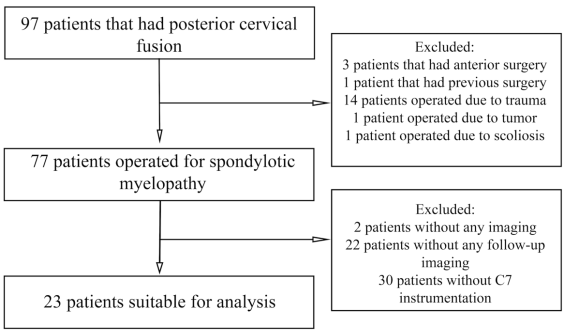

Fig. 2. This flowchart illustrates the step-wise process of identifying the final study cohort (n=23) from the initial pool of 97 patients who underwent posterior cervical fusion. Exclusion criteria were applied sequentially, resulting in the selection of patients with spondylotic myelopathy who had C7 instrumentation and available follow-up imaging.

Table 1. Comparison of baseline patient characteristics between lateral mass and pedicle screw groups

		Lateral mass (n=13)	Pedicle (n=10)	*P*
Age, years	Median (IQR, range)	55 (13.5, 41-60)	59.5 (19, 42-77)	0.089
Sex				0.768
Female	n (%)	6 (46.2%)	4 (40.0%)	
Male	n (%)	7 (53.8%)	6 (60.0%)	
Length of hospital stay (days)	Median (IQR, range)	3 (1.5, 2-53)	3 (1, 2-10)	0.459
Follow-up duration (months)	Median (IQR, range)	31 (57, 12-106)	(27.75, 13-63)	0.252
ASA score	Median (IQR, range)	2 (1, 1-3)	1.5 (1, 1-3)	0.642
Preoperative mRs	Median (IQR, range)	1.5 (1, 1-5)	1 (0.75, 1-3)	0.079
One year follow-up mRs	Median (IQR, range)	1 (1, 0-5)	1 (1, 1-3)	0.118
Preoperative Nurick scale	Median (IQR, range)	1 (1.5, 0-5)	1 (1.25, 0-2)	0.728
Myelopathy in preoperative MRI	n (%)	5 (45.5%)	5 (50%)	0.835
C5-6 Goutalier classification	Median (IQR, range)	1 (1, 1-3)	1.5 (1, 1-3)	0.514
C4 Hounsfield units	Mean (Standard deviation)	348.58 (70.58)	338.20 (96.89)	0.774

Patients were then assessed for outcome parameters, namely, foraminal/spinal canal breach, screw loosening and breakage at the C7 level and other levels, DJK, PJK, and revision surgery (overall and for DJK only). We found out that both groups were similar in terms of outcome variables, suggesting that lateral mass screws might be as effective as pedicle screws in posterior cervical spine surgery for spondylotic myelopathy (Table 2). It should be noted that one of the patients in the pedicle group had early revision due to a major foraminal breach (causing neurological deficit) at the C7 level. At the same time, none did in the lateral mass group. While all three follow-up revisions were in the lateral mass group, only one was due to DJK, and the other two were due to PJK. Due to the low number of revisions, no statistical analysis could be made within the two groups for DJK/PJK surgery.

Cox regression analysis was used to assess the time to failure of DJK, PJK, and revision surgery. None of the investigated factors (i.e., Age, sex, ASA score, preoperative mRs, C5-6 Goutalier grade, C4 Hounsfield units) affected the outcome parameters. In the Cox regression analysis for time to posterior junctional kyphosis (PJK), 69.6% of cases were excluded due to missing values, and the model showed no significant difference in survival distributions between lateral mass and pedicle groups with a hazard ratio of 1.143 (P = 0.872). In the analysis of time to distal junctional kyphosis (DJK), 82.6% of cases were dropped due to missing values, and the model, comparing lateral mass and pedicle, showed no significant difference but with a highly unstable estimated hazard ratio of 434.450 (P = 0.097).

Analysis of the spinal alignment parameters over time suggested that lateral mass screws had a similar effect on C2 slope, T1 slope, C2-7 Cobb angle, C2-7 SVA, neck tilt, and thoracic inlet angle as the pedicle screws, showing that lateral mass screws might be effective as pedicle screws in preserving cervical alignment in spondylotic myelopathy surgery (Table 3).

4. Discussion

The study found no significant differences in the demographics and baseline clinical parameters between the lateral mass and pedicle screw groups. This similarity ensures that the comparison between the two surgical techniques is not biased by age, sex, ASA score, mRs score, Nurick scale, preoperative Goutalier index at C5-6, and Hounsfield units of C4. Both groups had the same frequency of screw loosening (69.2% for the lateral mass screws and 60% for pedicle screws) and breakage (7% vs. 20%). These results indicate that neither technique is better in terms of screw durability. The literature that exists already confirms these findings, which show that both types of screws perform well under physiological loads (1,12), even though pedicle screws are intrinsically more resistant to pull-out forces (13,14).

The need for revision surgery was the same in both groups. One patient in the pedicle screw group had to be revised early because of a major foraminal breach that caused a neurological deficit. In contrast, three patients in the lateral mass screw group were revised during the follow-up, mainly because of the proximal junctional kyphosis (PJK). This indicates that while

pedicle screws may carry a higher risk of acute complications, lateral mass screws might be associated with longer-term alignment issues (15–17).

The spinal alignment parameters, such as C2 slope, T1 slope, C2-7 Cobb angle, C2-7 sagittal vertical axis (SVA), neck tilt, and thoracic inlet angle, were found to be the same in the two groups at the preoperative, postoperative, and one-year follow-up time points. This result means that both techniques are as reliable as the other in keeping the cervical alignment, which is a significant factor for the success of cervical spine surgeries (17–20).

Table 2. Comparison of surgical outcomes between lateral mass and pedicle screw techniques: Chi-Square analysis and Kaplan-Meier Survival estimates for time to PJK and DJK

		Lateral mass (n=13)	Pedicle (n=10)	*P*
Foraminal breach	n (%)	6 (46.2%)	3 (30%)	0.428
C7 screw failure	n (%)	9 (69.2%)	7 (70%)	0.968
Screw breakage	n (%)	1 (7%)	2 (20%)	0.386
Screw loosening	n (%)	9 (69.2%)	6 (60%)	0.645
Other level screw failure	n (%)	8 (61.5%)	6 (60%)	0.940
PJK	n (%)	4 (30.8%)	3 (30%)	0.968
Time to PJK (months)	Mean (SD)	22 (15.56)	26.6 (9.13)	0.872
DJK	n (%)	1 (7.7%)	3 (30%)	0.159
Time to DJK (months)	Mean (SD)	8	23.67 (10.17)	0.083
Early revision surgery	n (%)	0	1 (10%)	-
Revision surgery in follow-up	n (%)	3 (23.1%)	0	0.052

Pedicle screws, although they provide better biomechanical stability, are connected with a higher risk of neurovascular complications. Research has shown that neurovascular injury is more common with pedicle screws because of the closeness of the screw trajectory to the vertebral artery and spinal cord (19). Lateral mass screws, being technically more straightforward to place and associated with fewer complications, offer a safer alternative, especially in anatomically challenging cases (15,16,18).

The rates of both proximal junctional kyphosis (PJK) and distal junctional kyphosis (DJK) were the same in the two groups, which means that the screw type at C7 does not have a significant impact on the occurrence of junctional kyphosis, which is an essential factor for the long-term sagittal balance (13,17,21). Advanced imaging techniques, such as O-arm-based navigation, enhance the accuracy of screw placement, particularly for pedicle screws, reducing the risk of misplacement and related complications (22–26). Considering the safety and strength of the pedicle screws placed using navigation, they may be preferred where a more stable construct is necessary. But lateral mass screws might be safer when no navigation systems are available.

Our study has limitations: Having only 23 patients who met the inclusion criteria out of the 97 we initially assessed, the study may have needed to be more powerful to detect the subtle but possibly significant differences between the two groups. The study's retrospective nature brings inherent limitations, like the possibility of missing data and the inability to control all confounding variables. The absence of random assignment to the treatment groups may result in unknown biases, which can, in turn, affect the allocation of surgical techniques and, hence, the outcomes. The findings might not apply to the entire population because of the one-center, one-surgeon setup, as the surgical outcomes can differ with different surgeons and institutions.

This study supports the use of both C7 pedicle and lateral mass screws in the surgical treatment of cervical spondylotic myelopathy, with no significant differences in complication rates or spinal alignment outcomes. Patient-specific anatomical considerations, surgeon expertise, and the availability of advanced intraoperative imaging technologies should guide the choice between these techniques. Future research with more extensive multicenter studies is needed to refine surgical guidelines further and improve patient care in cervical spondylotic myelopathy.

Table 3. Longitudinal comparison of spinal alignment parameters in patients treated with lateral mass vs. pedicle screws

		Lateral mass (n=13)	Pedicle (n=10)	*P*
C2 Slope				0.365
Preoperative	Mean (SD)	17.278 (10.4049)	14.800 (13.1734)	
Postoperative	Mean (SD)	19.411 (7.2713)	17.111 (7.474)	
One year Follow-up	Mean (SD)	22.767 (7.9398)	17.389 (11.9416)	
T2 Slope				0.962
Preoperative	Mean (SD)	25.400 (12.4199)	25.978 (15.4339)	
Postoperative	Mean (SD)	26.033 (7.2834)	24.890 (10.741)	
One year Follow-up	Mean (SD)	25.467 (9.2145)	23.756 (13.6184)	
C2-7 Cobb Angle				0.841
Preoperative	Mean (SD)	10.356 (6.1746)	12.278 (9.6475)	
Postoperative	Mean (SD)	9.344 (7.4913)	8.220 (8.212)	
One year Follow-up	Mean (SD)	10.856 (5.2515)	11.467 (9.9212)	
C2-7 SVA				0.540
Preoperative	Mean (SD)	25.511 (4.5925)	18.000 (8.689)	
Postoperative	Mean (SD)	27.167 (6.7755)	24.330 (6.819)	
One year Follow-up	Mean (SD)	30.267 (11.8755)	28.560 (11.609)	
Neck Tilt				0.240
Preoperative	Mean (SD)	60.200 (8.0343)	54.971 (7.9554)	
Postoperative	Mean (SD)	59.343 (9.6764)	46.290 (10.719)	
One year Follow-up	Mean (SD)	57.986 (6.8837)	50.100 (11.1692)	
Thoracic Inlet Angle				0.549
Preoperative	Mean (SD)	87.717 (14.0862)	83.233 (10.3241)	
Postoperative	Mean (SD)	83.383 (9.2687)	70.000 (12.946)	
One year Follow-up	Mean (SD)	79.967 (7.6813)	75.067 (11.7294)	

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

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None to declare.

Authors' contributions

Concept: M.S.B., H.B., T.Y., Design: M.S.B., H.B., T.Y., Data Collection or Processing: B.B.A., E.C., Analysis or Interpretation: B.B.A., E.C., Literature Search: B.B.A., M.S.B., Writing: B.B.A., M.S.B, H.B., T.Y.

Ethical statement

The study was approved by Ege University's ethics committee (Decision no: 24-3T/35, Date: 07.03.2024).

References

1. Brara HS, Royse KE, Fennessy J, Harris JE, Guppy KH. Lateral mass screws versus pedicle screws at C7: reoperation rates for operative adjacent segment disease and nonunion in posterior cervical fusion. Spine. 2023 Jul 1;48(13):920–9.
2. Kim S-H, Kim J-H, Kwon J-W, Kim H-S, Moon S-H, Suk K-S, et al. Assessment of Biomechanical Advantages in Combined Anterior-Posterior Cervical Spine Surgery by Radiological Outcomes: Pedicle Screws over Lateral Mass Screws. J Clin Med. 2023 Apr 29;12(9).
3. Inoue D, Shigematsu H, Matsumori H, Ueda Y, Tanaka Y. Accuracy of Lateral Mass Screw Insertion during Cervical Spine Surgery without Fluoroscopic Guidance and Comparison of Postoperative Screw Loosening Rate among Unicortical and Bicortical Screws Using Computed Tomography. Spine Surg Relat Res. 2022 Nov 27;6(6):625– 30.
4. Çelikoğlu E, Demir H. Factors affecting surgical outcomes in cervical spondylotic myelopathy: A retrospective study. Istanbul Med J. 2023 May 31;24(2):172–80.
5. Lenz M, Egenolf P, Weber M, Ott N, Meyer C, Eysel P, et al. Pedicle or lateral mass screws in Goel-Harms construct? A biomechanical analysis. Injury. 2023 Mar 27;
6. Naessig S, Ahmad W, Pierce KE, Passfall L, Kummer N, Krol O, et al. 221. Defining clinically relevant distal failure in the treatment of adult cervical deformity: an improved definition based on functional outcomes and need for reoperation. Spine J. 2021 Sep;21(9):S113–4.
7. Iwamae M, Tamai K, Suzuki A, Terai H, Hoshino M, Kato M, et al. Degeneration of Cervical Multifidus Muscles Negatively Affects Physical Activity-related Quality of Life After Laminoplasty for Degenerative Cervical Myelopathy. Clin Spine Surg. 2024 Feb 16;
8. Mitsutake T, Sakamoto M, Chyuda Y, Oka S, Hirata H, Matsuo T, et al. Greater cervical muscle fat infiltration evaluated by magnetic resonance imaging is associated with poor postural stability in patients with cervical spondylotic radiculopathy. Spine. 2016 Jan;41(1):E8-14.
9. Kim C-Y, Lee S-M, Lim S-A, Choi Y-S. Impact of Fat Infiltration in Cervical Extensor Muscles on Cervical Lordosis and Neck Pain: A Cross-Sectional Study. Clin Orthop Surg. 2018 Jun;10(2):197–203.
10. Lee JS, Son DW, Lee SH, Ki SS, Lee SW, Song GS, et al. The Effect of Hounsfield Unit Value with Conventional Computed Tomography and Intraoperative Distraction on Postoperative Intervertebral Height Reduction in Patients Following Stand-Alone Anterior Cervical Discectomy and Fusion. J Korean Neurosurg Soc. 2022 Jan;65(1):96– 106.
11. Wang M, Mummaneni PV, Xi Z, Chang C-C, Rivera J, Guinn J, et al. Lower Hounsfield units on CT are associated with cage subsidence after anterior cervical discectomy and fusion. J Neurosurg Spine. 2020 Jun 5;1–8.
12. Viswanathan VK, Subramanian S, Viswanathan S. Comparison of Three Different Options for C7 Posterior Vertebral Anchor in the Indian Population-Lateral Mass, Pedicle, and Lamina: A Computed Tomography-Based Morphometric Analysis. Asian Spine J. 2018 Aug;12(4):726–33.
13. Johnston TL, Karaikovic EE, Lautenschlager EP, Marcu D. Cervical pedicle screws vs. lateral mass screws: uniplanar fatigue analysis and residual pullout strengths. Spine J. 2006 Dec;6(6):667–72.
14. Jones EL, Heller JG, Silcox DH, Hutton WC. Cervical pedicle screws versus lateral mass screws. Anatomic feasibility and biomechanical comparison. Spine. 1997 May 1;22(9):977–82.
15. Kothe R, Rüther W, Schneider E, Linke B. Biomechanical analysis of transpedicular screw fixation in the subaxial cervical spine. Spine. 2004 Sep 1;29(17):1869–75.
16. Katonis P, Papadakis SA, Galanakos S, Paskou D, Bano A, Sapkas G, et al. Lateral mass screw complications: analysis of 1662 screws. J Spinal Disord Tech. 2011 Oct;24(7):415–20.
17. Ames CP, Blondel B, Scheer JK, Schwab FJ, Le Huec J-C, Massicotte EM, et al. Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. Spine. 2013 Oct 15;38(22 Suppl 1):S149-60.
18. Abumi K, Ito M, Sudo H. Reconstruction of the subaxial cervical spine using pedicle screw instrumentation. Spine. 2012 Mar 1;37(5):E349-56.
19. Yoshihara H, Passias PG, Errico TJ. Screw-related complications in the subaxial cervical spine with the use of lateral mass versus cervical pedicle screws: a systematic review. J Neurosurg Spine. 2013 Nov;19(5):614–23.
20. Karaikovic EE, Daubs MD, Madsen RW, Gaines RW. Morphologic characteristics of human cervical pedicles. Spine. 1997 Mar 1;22(5):493–500.
21. Oda I, Abumi K, Sell LC, Haggerty CJ, Cunningham BW, McAfee PC. Biomechanical evaluation of five different occipito-atlanto-axial fixation techniques. Spine. 1999 Nov 15;24(22):2377–82.
22. Karaikovic EE, Yingsakmongkol W, Gaines RW. Accuracy of cervical pedicle screw placement using the funnel technique. Spine. 2001 Nov 15;26(22):2456–62.
23. Hur J-W, Kim J-S, Ryu K-S, Shin M-H. Accuracy and Safety in Screw Placement in the High Cervical Spine: Retrospective Analysis of O-arm-based Navigation-assisted C1 Lateral Mass and C2 Pedicle Screws. Clin Spine Surg. 2019 May;32(4):E193–9.
24. Zhang K, Chen H, Chen K, Yang P, Yang H, Mao H. O-Arm Navigated Cervical Pedicle Screw Fixation in the Treatment of Lower Cervical Fracture-Dislocation. Orthop Surg. 2022 Jun;14(6):1135–42.
25. Wada K, Tamaki R, Inoue T, Hagiwara K, Okazaki K. Cervical Pedicle Screw Insertion Using O-Arm-Based 3D Navigation: Technical Advancement to Improve Accuracy of Screws. World Neurosurg. 2020 Jul;139:e182–8.
26. Gan G, Kaliya-Perumal A-K, Yu CS, Nolan CP, Oh JY-L. Spinal navigation for cervical pedicle screws: surgical pearls and pitfalls. Global Spine J. 2021 Mar;11(2):196-202.