

Optimizing Postoperative Sagittal Alignment: The Effect of Pedicle Screw Fixation in 540° Combined Surgery for Degenerative Cervical Disease

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Abstract

Study design: Retrospective cohort study.

Objective: To determine whether increased pedicle screw use in the lower subaxial cervical spine (C5-C7) improves sagittal alignment after posterior–anterior–posterior (PAP) surgery.

Method: A total of 108 patients who underwent posterior–anterior–posterior (PAP) surgery for multilevel cervical degenerative disease were retrospectively reviewed. Patients were divided into three groups according to the distal fixation level: Group 1, pedicle screw fixation limited to C7; Group 2, pedicle screw fixation limited to C6-7; and Group 3, pedicle screw fixation extending to C5-6-7. Cervical sagittal alignment and patient-reported outcomes were evaluated preoperatively, immediately postoperatively, at 3 months, and at 1 year.

Results: Baseline sagittal parameters were similar among groups. CL increased in all groups but was significantly greater in Groups 2 and 3 than in Group 1 postoperatively (21.8° and 26.1° vs 14.2°) and at 1 year (22.3° and 26.0° vs 14.8°; $P < 0.05$). T1S–CL decreased significantly in Groups 2 and 3 but not in Group 1 at 3 months (8.5° and 3.4° vs 16.6°; $P < 0.001$) and at 1 year (7.7° and 7.3° vs 17.8°; $P < 0.001$). Group 1 showed greater vertical height loss (3.9 vs 2.3 and 2.2 mm; $P = 0.016$) and higher subsidence rates. C2-7 SVA, C2 SVA, and clinical scores improved in all groups without between-group differences.

Conclusions: Greater use of pedicle screws at C5-C7 enhanced sagittal alignment correction compared with C7-only fixation, while clinical outcomes were similar across groups.

Keywords

cervical sagittal alignment, cervical pedicle screw, cervical posterior-anterior-posterior surgery, lower subaxial cervical spine, cervical lordosis, T1 slope-cervical lordosis

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Introduction

Optimizing sagittal alignment following cervical spine surgery is crucial for achieving favorable clinical outcomes. Improved postoperative cervical lordosis (CL) is associated with reduced neck disability and a lower incidence of adjacent segment disease (ASD), underscoring the importance of sagittal alignment correction for durable surgical outcomes.^{1,2}

In cases of degenerative cervical disease accompanied by cervical kyphosis and severe radiculopathy or myelopathy, combined anterior-posterior (AP) surgical approaches are often required for sufficient decompression, alignment correction, and stable fusion.³⁻⁶ In our practice, a posterior-anterior-posterior (PAP) approach—also referred to as a 540-degree combined surgery—has been routinely performed to maximize safety and efficacy in such complex cases.⁷⁻⁹

Historically, lateral mass screws have been the preferred option for posterior fixation of C3 to C6, while pedicle screws are considered for C7 to avoid instrumentation failure. Previous studies have demonstrated that cervical pedicle screws provide superior biomechanical stability and load-sharing capacity compared to lateral mass screws, resulting in reduced subsidence and improved maintenance of cervical lordosis and vertebral body remodeling.^{8,10-12} As a result, we have extended the use of pedicle screws beyond C7 to other lower subaxial levels. Furthermore, our surgical team has developed a unique posterior fixation technique that utilizes a medial pivot point for pedicle screw insertion, which facilitates the safe placement of pedicle screws in the subaxial cervical spine.¹³

In this study, we aim to investigate whether the use of a greater number of pedicle screws in the lower subaxial cervical spine is associated with better postoperative sagittal alignment. We hypothesize that increased pedicle screw insertion contributes to more effective sagittal balance correction and maintenance, compared to the use of lateral mass screws.

Material and Methods

The study was conducted in accordance with the Declaration of Helsinki and approved by the institutional review board of our institution. The need for informed consent was waived by the IRB committee. (IRB number: 3-2024-0072). We hypothesized that multi-level pedicle screw fixation at C5-C7 would achieve greater correction and maintenance of cervical lordosis and T1S-CL than C7-only fixation.

Study Design

In this retrospective, multi-center, retrospective observational study, a thorough review was conducted on patients who underwent 540° combined posterior-anterior-posterior (PAP) surgery at our institution. All patients underwent surgery between January 2016 and December 2022, and clinical and

radiographic data were collected prospectively during routine follow-up until December 2023.

The inclusion criteria encompassed patients with a minimum 1-year postoperative follow-up, while those who underwent revision or fusion extension surgery, experienced trauma during follow-up, missed scheduled appointments, or received fusion to the T1 level were excluded. Postoperative trauma was defined as any traumatic event during follow-up (eg, fall or traffic accident) that could independently influence the cervical construct, sagittal alignment, or clinical outcome. Patients with fusion extending to T1 were excluded because the indication for crossing the cervicothoracic junction was not standardized. In particular, in authors' country, the reimbursement criteria for T1-level fusion are not clearly defined, and the decision to extend fusion to T1 may be influenced not only by clinical factors such as sagittal malalignment or poor bone quality, but also by healthcare system-related constraints. Therefore, inclusion of these cases could introduce substantial selection bias in distal fixation strategy. Additionally, cases involving hypermobile C7-T1 segments were also excluded from this analysis. Although extension to T1 is occasionally indicated in such cases to prevent junctional failure, these patients were excluded to maintain cohort homogeneity. Revision cases were excluded because prior fusion status, instrumentation, and segmental stiffness could not be uniformly controlled. After applying these criteria, the study cohort comprised a total of 108 subjects. To minimize confounding effects and to isolate the impact of distal fixation level on sagittal alignment, patients with marked distal segment mobility were excluded from the analysis.¹⁴

Following patient selection, the cohort was stratified into three distinct groups based on the surgical approach employed. The first group included patients who received a traditional C7 pedicle screw in addition to lateral mass screw fixation at other levels. This group consisted of 47 patients. The second group comprised patients who underwent C6 and C7 pedicle screw fixation, totaling 29 patients. The third group consisted of patients who received pedicle screw fixation at the C5, C6, and C7 levels, encompassing 32 patients (Figure 1).

Surgical Indication and Technique

Surgeons typically consider cervical surgical interventions for patients who have exhibited radiculopathy or myelopathy refractory to conservative management over a prolonged period, including oral medication or intervention techniques. Notably, previous literature emphasizes the consideration of a combined anterior-posterior approach for patients presenting with cervical degenerative diseases characterized by rigid kyphotic deformity, commonly referred to as K-line (–) patients, and severe myelo-radiculopathy. This consideration is due to the necessity for correcting sagittal alignment, as

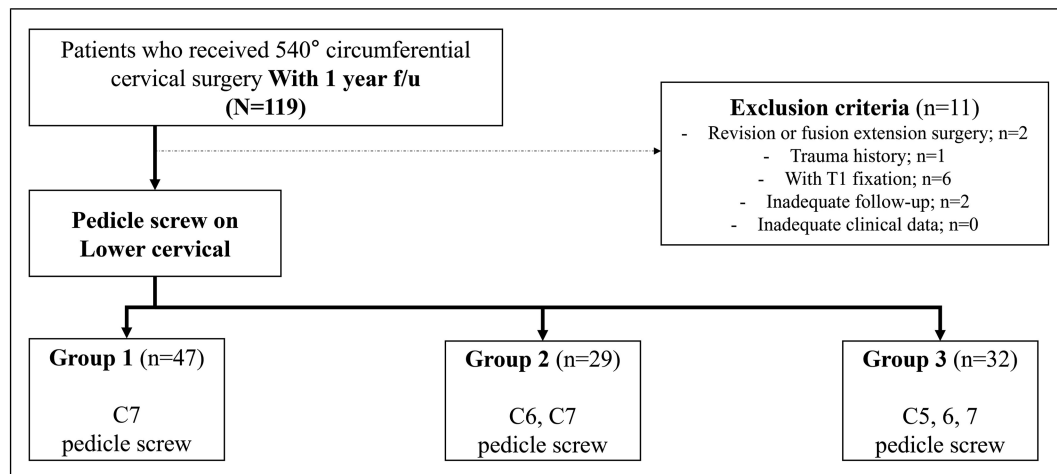


Figure 1. Flow diagram of patient selection and grouping. Among 119 patients who underwent 540° combined posterior–anterior–posterior (PAP) cervical surgery, 11 were excluded according to predefined criteria. The remaining 108 patients were classified into three groups based on the levels of pedicle screw fixation: Group 1 (C7 only, $n = 47$), Group 2 (C6–C7, $n = 29$), and Group 3 (C5–C7, $n = 32$)

well as conducting extensive decompression and fusion procedures.

At our institution, PAP approach was preferentially selected in cases where a single anterior- or posterior-only procedure was considered insufficient to achieve both adequate decompression and sagittal alignment correction. PAP surgery offers distinct advantages, particularly in terms of avoiding the risk of cord injury and ensuring effective decompression. The surgical procedure begins with posterior decompression, alongside screw insertion. Typically, lateral mass screws are inserted from C3 to C6, while pedicle screws are positioned at the C7 level. However, in cases where the pedicle diameter exceeds 3.5 mm without vertebral artery anomalies, pedicle screws are considered at that specific level.¹³

In the second stage, we proceed with anterior cervical discectomy and fusion (ACDF) across multiple levels, including the resection of the uncinate process as necessary. In the anterior stage, a structural allospacer (CORNERSTONE® PSR, Medtronic Sofamor Danek, Inc.; Memphis, TN, USA) was used in all cases. The size of the allospacer was selected based on the original disc height and intraoperative segmental tension, typically ranging from 6 to 7 mm in height and 12 to 14 mm in anterior–posterior diameter, with a standard lordotic angle of 6 degrees. Finally, the patient is repositioned once more, and a rod is applied, followed by posterolateral fusion using autogenous bone graft material. This two-stage approach is designed not only to achieve adequate decompression but also to optimize sagittal alignment, which is a key determinant of postoperative clinical outcomes.

Outcome Measurement

Demographic and perioperative data were extracted from the electronic medical record (EMR) system of our institution. This encompassed information such as age, gender, body

mass index (BMI), and detailed operation records. These variables were considered as potential confounders in the following analysis.

The primary outcome measures focused on cervical sagittal parameters and selected global sagittal parameters. Specifically, cervical sagittal parameters included cervical lordosis (CL, Cobb's angle of C2–7), C2–7 sagittal vertical axis (SVA), and T1 slope (T1S). Global sagittal parameters comprised C2 SVA (the distance from the center of the body of C2 to the postero-superior corner of the sacrum), C7 SVA, and various pelvic parameters. Subsidence was additionally calculated as the change in this vertical height over time, with clinical subsidence defined as a decrease of more than 3 mm from the postoperative measurement.⁸ All radiographic parameters were independently measured twice by two experienced spine surgeons, and the mean of the two measurements was used for analysis to minimize interobserver variability. The interobserver reliability of these measurements was excellent, with an intraclass correlation coefficient (ICC) of 0.93, indicating a high level of measurement consistency.

Clinical outcomes were assessed using the Visual Analog Scale (VAS) for neck and upper extremity pain, along with functional scores including the Neck Disability Index (NDI), Japanese Orthopaedic Association (JOA) score, and EuroQol-5 Dimension (EQ-5D) questionnaire.

Statistical Analysis

All eligible cases that met the inclusion criteria during the study period were included in the analysis, and no priori sample size calculation was conducted. Missing data was minimal (< 5% for all variables) and were handled by case-wise deletion. Patients who were lost to follow-up were

excluded from the final analysis, and the number of such cases was reported.

To compare demographic data and preoperative radiologic parameters among the three groups, we utilized ANOVA analysis. For within-group changes in radiographic and clinical parameters between postoperative and follow-up time points, paired *t*-tests were applied to normally distributed data, whereas the Wilcoxon signed-rank test was used for non-normally distributed variables. Additionally, to compare differences in parameter changes among the groups, we employed a mixed-effects model approach. The results of our analysis were summarized using box-plot graphs representing each parameter across the three groups.

A significance threshold of $P < 0.05$ was applied to determine statistical significance. Statistical analyses were conducted using the R software version 2.2.1 (R Project for Statistical Computing, Vienna, Austria) (R Development Core Team, 2011).

Result

Patient Profile

Patient profile is summarized in Table 1. The mean age of study subjects was 63.4 ± 10.3 , and the total male patients was 48 (44.03%). There was no difference in age and sex ratio between three groups. The mean body mass index (BMI) was $24.7 \pm 3.2 \text{ kg/m}^2$, and the major operated level was 4 levels (54.4%) and 5 levels (34.2%). There was also no difference in BMI and operated levels between three groups. The mean follow-up duration was 18.4 ± 6.2 months (range, 12-36 months). Preoperative bone mineral density (BMD) did not differ significantly among the groups, suggesting that bone quality was comparable and unlikely to confound the observed outcomes. Missing data rates were $<5\%$ for all radiographic and clinical variables and were excluded from analysis on a case-wise basis.

Cervical Lordosis and T1 Slope – Cervical Lordosis

Sagittal parameters in the preoperative and postoperative periods are summarized in Table 2. No significant differences were observed among the groups in any preoperative sagittal

parameter. Figure 2 illustrates the changes in selected sagittal parameters—CL, T1S–CL, C2-7 SVA, and C2 SVA—from the preoperative period to 1 year postoperatively.

CL was increased in all three groups statistically after operation and maintained until 1 year. In Group 1, CL was increased from 9.23 ± 9.59 degree to 14.23 ± 6.26 degree and maintained until POD 1 year with 14.84 ± 12.32 degree. Also, in Group 2 and 3, CL was increased from 8.88 ± 10.67 and 9.36 ± 10.67 degree to 21.76 ± 14.77 and 26.07 ± 8.57 degree after operation. CL was maintained also until POD 1 year in Group 2 and Group 3. (Group 2, 22.28 ± 11.13 ; Group 3, 26.01 ± 11.20 (deg)) The ratio of change after operation was different between three groups based on mixed model approach, (P -value < 0.05) and the exact value of CL was also different between Group 1 and other groups on immediate postoperative period to POD 1 year.

There was no difference in preoperative T1S – CL between three groups after ANOVA test. (Group 1, 17.42 ± 8.96 ; Group 2, 18.96 ± 6.09 ; Group 3, 14.30 ± 10.44 ; P -value = 0.09) However, while T1S – CL decreased on postoperative 3 month in Group 2 and 3, there was no change in Group 1. (Group 1, 16.61 ± 11.18 ; Group 2, 8.46 ± 8.84 ; Group 3, 3.38 ± 9.49 ; P -value < 0.001) This difference was maintained until 1 year follow up. (Group 1, 17.80 ± 11.48 ; Group 2, 7.74 ± 4.91 ; Group 3, 7.26 ± 12.10 ; P -value < 0.001), and the total change of T1S – CL was also statistically larger in Group 2 and 3. (P -value = 0.050).

C2-7 SVA and C2 SVA

There was a trend of mild increase of C2-7 SVA in Group 3 after operation, but it was not statistically different, and the upper quartile range was under 40 mm. Finally, there was no change in C2-7 SVA in all groups and no difference between three groups also. C2 SVA also had similar trend, that no change during follow-up period.

Clinical Subsidence

Although initial vertical height measurements were similar across all three groups, Group 1 exhibited a significantly greater reduction in vertical height compared to the other groups at both 3 months and 1 year postoperatively. The average change in vertical height from immediate

Table 1. Patient Profile

	Group 1 (C7P ^a , N = 47)	Group 2 (C67P ^a , N = 29)	Group 3 (C567P ^a , N = 32)	<i>P</i> -value
Age	61.94 ± 11.47	65.2 ± 9.06	64.36 ± 9.43	0.337
Sex ratio (man %)	50% (n = 24)	66.66% (n = 12)	44.47% (n = 12)	0.091
BMI ^b (kg/m ²)	25.23 ± 2.93	24.7 ± 3.45	24.19 ± 3.3	0.251
Operation level	4.42 ± 0.81	4.07 ± 0.7	4.21 ± 0.63	0.247
BMD ^c (T-score)	-0.83 ± 1.39	-0.88 ± 1.57	-0.91 ± 1.78	0.356

^aC7P, pedicle screw fixation at C7 only; C67P, pedicle screw fixation at C6 and C7; C567P, pedicle screw fixation at C5, C6, and C7.

^bBMI, Body mass index.

^cBMD, Bone mineral density.

Table 2. Preoperative and Postoperative Cervical and Global Sagittal Parameters

		Group 1 (C7P ^a , N = 47)	Group 2 (C67P ^a , N = 29)	Group 3 (C567P ^a , N = 32)	P-value
CL ^b	Preoperative	9.23 ± 9.59	8.88 ± 10.67	9.36 ± 10.67	0.968
	Postoperative	14.23 ± 6.26	21.76 ± 14.77	26.07 ± 8.57	<0.001
	POD 3 months	15.77 ± 10.09	24.18 ± 10.37	27.26 ± 9.75	<0.001
	POD 1 year	14.84 ± 12.32	22.28 ± 11.13	26.01 ± 11.20	<0.001
C2-7 SVA	Preoperative	20.39 ± 14.98	20.62 ± 13.64	23.12 ± 11.67	0.436
	Postoperative	24.00 ± 12.87	24.36 ± 9.94	30.66 ± 13.20	0.135
	POD 3 months	23.46 ± 14.86	20.97 ± 12.58	29.60 ± 14.96	0.120
	POD 1 year	25.55 ± 15.62	24.18 ± 15.65	28.25 ± 13.50	0.694
T1 slope	Preoperative	25.9 ± 10.7	27.93 ± 8.33	23.65 ± 8.33	0.379
	Postoperative	30.32 ± 8.62	30.72 ± 9.83	30.31 ± 8.31	0.989
	POD 3 months	31.97 ± 8.77	33.50 ± 10.01	30.97 ± 9.42	0.711
	POD 1 year	32.47 ± 8.55	33.53 ± 9.00	32.68 ± 9.74	0.958
CBVA	Preoperative	-1.59 ± 7.98	-2.45 ± 8.48	-3.6 ± 8.67	0.43
	Postoperative	-4.20 ± 9.0	-0.72 ± 10.0	-3.62 ± 9.5	0.734
	POD 3 months	-2.97 ± 8.98	2.96 ± 14.11	-3.06 ± 9.72	0.273
	POD 1 year	0.07 ± 9.71	2.89 ± 11.38	0.64 ± 10.36	0.851
C2 SVA	Preoperative	47.36 ± 41.34	42.23 ± 42.92	42.76 ± 44.33	0.728
	Postoperative	49.26 ± 45.0	47.15 ± 50.0	48.31 ± 47.0	0.922
	POD 3 months	50.68 ± 46.49	50.69 ± 65.27	52.58 ± 49.84	0.992
	POD 1 year	68.23 ± 43.37	81.39 ± 71.35	51.33 ± 57.68	0.430
C7 SVA	Preoperative	39.53 ± 43.2	37.23 ± 34.54	33.08 ± 34.93	0.566
	Postoperative	39.99 ± 44.0	36.18 ± 46.0	34.01 ± 42.0	0.847
	POD 3 months	39.78 ± 48.41	35.49 ± 53.29	36.87 ± 43.57	0.965
	POD 1 year	54.95 ± 47.42	64.18 ± 55.80	34.11 ± 52.37	0.319
PI	Preoperative	50.4 ± 9.42	43.54 ± 11.46	50.53 ± 8.15	0.871
	Postoperative	49.21 ± 10.5	44.72 ± 11.0	50.18 ± 9.5	0.730
	POD 3 months	49.36 ± 10.66	44.68 ± 12.00	50.25 ± 11.09	0.387
	POD 1 year	48.74 ± 8.93	45.63 ± 15.75	42.45 ± 17.64	0.460
SS	Preoperative	31.19 ± 7.66	31.52 ± 4.57	33.33 ± 9.15	0.350
	Postoperative	32.20 ± 8.5	28.53 ± 5.5	34.61 ± 9.0	0.620
	POD 3 months	30.11 ± 9.92	29.16 ± 5.48	34.05 ± 8.71	0.218
	POD 1 year	29.15 ± 10.24	30.10 ± 3.30	28.74 ± 10.98	0.958
PT	Preoperative	18.52 ± 11.11	14.34 ± 10.47	17.03 ± 10.34	0.680
	Postoperative	18.99 ± 12.0	15.80 ± 11.0	18.38 ± 13.0	0.548
	POD 3 months	19.29 ± 12.40	15.22 ± 11.10	19.80 ± 17.28	0.668
	POD 1 year	19.54 ± 13.07	14.71 ± 15.71	18.25 ± 9.51	0.700

^aC7P, pedicle screw fixation at C7 only; C67P, pedicle screw fixation at C6 and C7; C567P, pedicle screw fixation at C5, C6, and C7.

^bCL, Cervical lordosis; SL, Segmental lordosis; SVA, Sagittal vertical axis; CBVA, Chin brow vertebral angle; PI, Pelvic incidence; SS, Sacral slope; PT, pelvic tilt.

postoperative to 1 year was 3.9 ± 4.5 mm in Group 1, compared with 2.3 ± 2.4 mm in Group 2 and 2.2 ± 2.3 mm in Group 3 ($P = 0.016$). The proportion of patients with clinical subsidence (> 3 mm) followed a similar trend (36.2% vs 24.1% vs 18.8%, respectively). Notably, subsidence outcomes between Group 2 and Group 3 were comparable, suggesting that extending pedicle screw fixation from C6-C7 to C5-C7 did not further reduce interbody collapse beyond the effect already achieved by multi-level pedicle fixation (Table 3).

Clinical Outcome

All three groups demonstrated improvements in both neck and arm pain over time (Table 4). The average preoperative neck

pain VAS was 7.42 ± 1.38 in Group 1, 7.65 ± 1.29 in Group 2, and 7.51 ± 1.41 in Group 3, which decreased to 3.21 ± 1.16 , 3.18 ± 1.23 , and 3.09 ± 1.19 respectively at 1 year postoperatively. Similarly, arm pain VAS also decreased from approximately 7.7 preoperatively to below 3.5 at the 1-year follow-up in all groups.

The NDI scores improved across all groups. Preoperative scores ranged from 40.89 to 44.03, which reduced to 15.26-17.32 at final follow-up. JOA scores showed gradual improvement, increasing from approximately 10.4 preoperatively to over 14.3 postoperatively in all groups.

No statistically significant differences were observed among the three groups at any time point in any clinical measure (all $P > 0.05$), suggesting that the degree of pedicle screw usage did not lead to a difference in clinical symptom

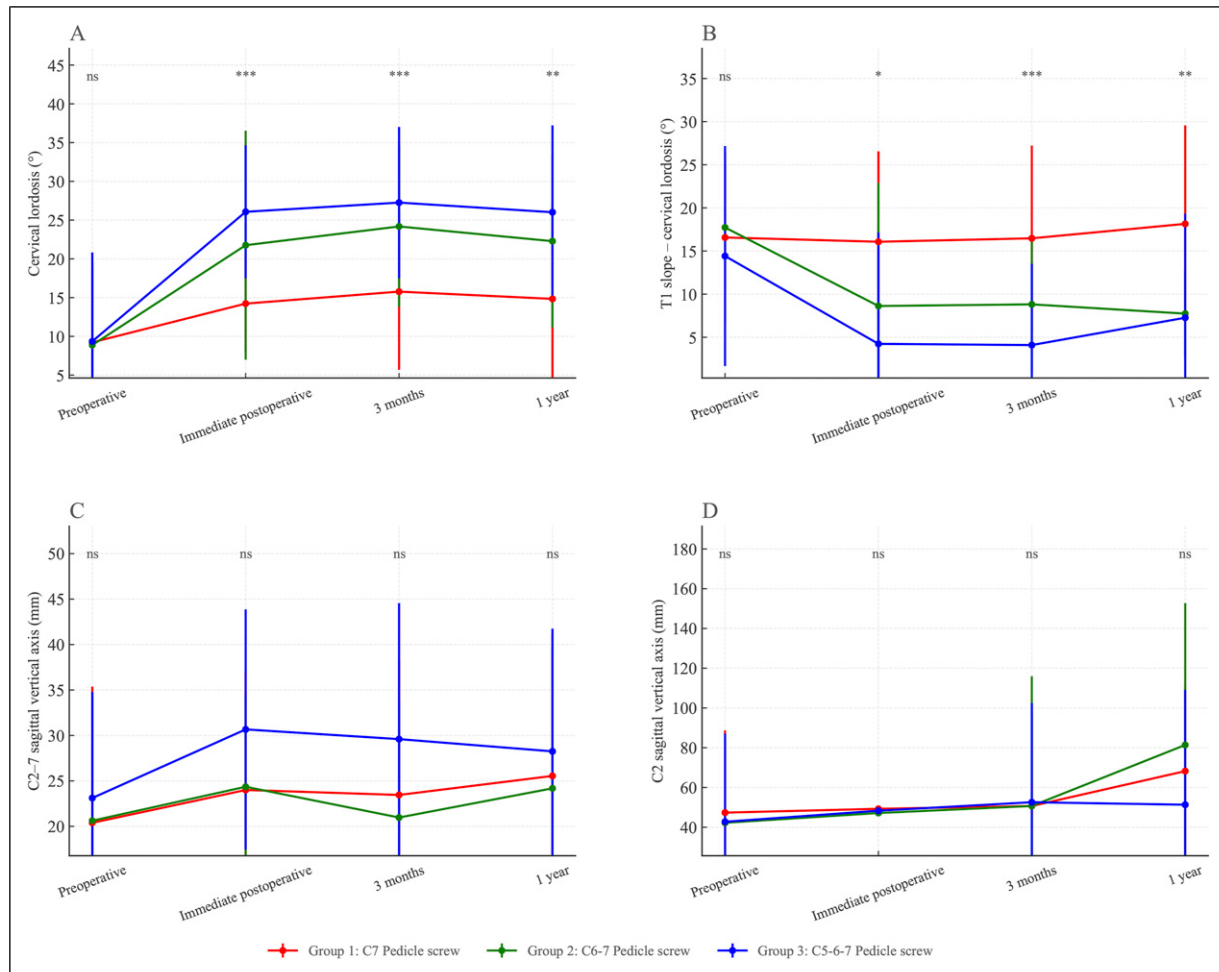


Figure 2. Changes in sagittal alignment parameters after posterior–anterior–posterior cervical reconstruction. (A) Cervical lordosis (°) increased immediately after surgery compared with preoperative values and was maintained during follow-up; improvements were greater in Group 2 (C6-7 pedicle screws) and Group 3 (C5-6-7 pedicle screws) than in Group 1 (C7 pedicle screw). (B) T1 slope – cervical lordosis (°) decreased immediately after surgery and remained improved at follow-up; reductions were greater in Groups 2 and 3 than in Group 1. (C) C2-7 sagittal vertical axis (mm) showed no significant between-group differences at any time point. (D) C2 sagittal vertical axis (mm) showed no significant between-group differences at any time point. Error bars indicate standard deviations; asterisks denote between-group significance at each time point ($P < 0.05$, $*P < 0.01$, $**P < 0.001$; ns = not significant)

relief. Furthermore, There were no significant differences in complication rates and operative time among the groups.

Discussion

Postoperative sagittal alignment of the cervical spine is a critical determinant of long-term surgical success, as demonstrated in multiple clinical investigations. Multiple studies consistently demonstrate that cervical sagittal malalignment—particularly increased C2-7 SVA and mismatch between T1 slope and cervical lordosis—is strongly associated with worse postoperative pain, disability, and health-related quality of life. Failure to restore physiologic cervical alignment after surgery results in inferior functional outcomes, underscoring that optimal sagittal alignment is a critical determinant of clinical success rather than a purely

radiographic goal.¹⁵⁻¹⁸ Collectively, these data support that achieving and maintaining optimal sagittal alignment is not merely radiographic optimization but a fundamental prerequisite for favorable clinical and functional outcomes.

In our study, it was observed that when pedicle screws were more frequently utilized at the C5-6-7 levels, the sagittal alignment was more effectively corrected. The reasons for these results can be inferred in several ways. First, similar to the lumbar spine, the lower levels might also play a crucial role in the sagittal alignment of the cervical spine. Generally, when correcting the lumbar sagittal plane, a major portion of the lordosis angle is created at the L4-L5-S1 levels. In the cervical spine, 77% of the lordotic angle is created between the C0-C2 levels.¹⁹ However, in the context of the C2-7 region, the lordosis of C5-6-7 contributes approximately 50% of the C2-7 lordosis. Additionally, Tinh-Hsien et al reported

Table 3. Comparison of Interbody Subsidence Among the Three Groups

	Group 1 (C7P ^a , N = 47)	Group 2 (C67P ^a , N = 29)	Group 3 (C567P ^a , N = 32)	P-value
Postoperative				
Control vertical height (mm)	82.0 ± 13.5	83.1 ± 13.2	83.8 ± 13.0	0.612
POD 3 months				
Mean vertical height (mm)	78.4 ± 12.7	81.2 ± 13.0	81.6 ± 12.9	0.045
Change (Postoperative → POD 3 months) (mm)	3.6 ± 4.3	1.9 ± 2.2	1.7 ± 2.1	0.012
Clinical subsidence (>3 mm), n (%)	15 (31.9%)	6 (20.7%)	5 (15.6%)	0.058
POD 1 year				
Mean vertical height (mm)	78.1 ± 12.8	80.8 ± 12.9	81.0 ± 12.7	0.041
Change (Postoperative → POD 1 year) (mm)	3.9 ± 4.5	2.3 ± 2.4	2.2 ± 2.3	0.016
Clinical subsidence (>3 mm), n (%)	17 (36.2%)	7 (24.1%)	6 (18.8%)	0.044

^aC7P, pedicle screw fixation at C7 only; C67P, pedicle screw fixation at C6 and C7; C567P, pedicle screw fixation at C5, C6, and C7.

that during anterior cervical fusion, subsidence mainly occurred at the C5-6-7 levels rather than the C2-5 levels.²⁰ This subsidence can be associated with the maintenance of postoperative sagittal alignment. In our study, subsidence analysis also demonstrated that multi-level pedicle screw fixation significantly reduced vertical height loss compared with C7-only fixation, likely due to its superior load-sharing effect.

However, in the present study, no statistically significant differences were observed between Group 2 and Group 3 at the 1-year follow-up, suggesting that extending fixation beyond C6-7 to C5 may provide limited additional benefit in sagittal alignment correction. This may be explained by the relatively greater contribution of the C6-7 segment to cervical lordosis, analogous to the disproportionate role of lower lumbar segments in overall lordosis. Nevertheless, Group 3 demonstrated a trend toward greater cervical lordosis at 1 year and lower T1S-CL mismatch at 3 months, indicating that further proximal fixation may offer incremental benefits that were not statistically evident in the present cohort.

Considering the significance of the lower cervical spine levels, utilizing pedicle screws at these locations may be effective for correcting sagittal alignment. In our institution, analysis of advantage of cervical pedicle screws was conducted. Cases utilizing pedicle screws, as opposed to lateral mass screws, demonstrated a lower subsidence rate and greater anterior body remodeling.⁸ The rate of allo-spacer failure was also lower in cases using pedicle screws compared to those using lateral mass screws or anterior plate-screw constructs.²¹ These clinical findings were corroborated by finite element model (FEM) analysis.^{12,22,23} Based on these findings, it can be inferred that increased utilization of pedicle screws in the lower cervical levels, which are crucial for sagittal alignment, may enhance alignment correction due to their favorable load-sharing and maintenance properties.

Secondly, additional correction of lordosis may be achieved during rod application. In lumbar spine surgeries, pedicle screws are primarily utilized. During rod application, further correction can occur through the rearrangement of the

Table 4. Preoperative and Postoperative Clinical Outcome Measures

		Group 1 (C7P ^a , N = 47)	Group 2 (C67P ^a , N = 29)	Group 3 (C567P ^a , N = 32)	P-value
Preop	Neck pain VAS	7.42 ± 1.38	7.65 ± 1.29	7.51 ± 1.41	0.58
	Arm pain VAS	7.78 ± 1.16	7.64 ± 1.20	7.71 ± 1.19	0.65
	NDI	32.17 ± 10.92	34.03 ± 11.35	30.89 ± 12.14	0.52
	JOA	10.46 ± 2.02	10.59 ± 2.15	10.27 ± 2.23	0.67
POD 3 month	Neck pain VAS	3.61 ± 1.31	3.42 ± 1.38	3.57 ± 1.33	0.73
	Arm pain VAS	1.92 ± 1.27	2.81 ± 1.24	2.75 ± 1.36	0.70
	NDI	18.83 ± 9.12	17.45 ± 10.01	19.06 ± 9.87	0.64
	JOA	13.94 ± 2.17	14.11 ± 1.95	13.88 ± 2.21	0.80
POD 1 year	Neck pain VAS	3.21 ± 1.16	3.18 ± 1.23	3.09 ± 1.19	0.76
	Arm pain VAS	1.48 ± 1.19	2.35 ± 1.13	2.41 ± 1.22	0.84
	NDI	16.07 ± 8.23	15.26 ± 9.41	17.32 ± 8.87	0.61
	JOA	14.32 ± 1.91	14.21 ± 2.06	14.37 ± 1.88	0.88

^aC7P, pedicle screw fixation at C7 only; C67P, pedicle screw fixation at C6 and C7; C567P, pedicle screw fixation at C5, C6, and C7.

screw heads along the rod's curvature.^{24,25} In cases involving lateral mass screws, in situ fixation is mainly occurred during rod application. Conversely, in cases involving pedicle screws, the screw heads are repositioned closer to each other, allowing for additional correction of sagittal alignment. These screws exert a substantial corrective force, often enabling sagittal alignment correction through their repositioning (Figures 3 and 4).

This study has several limitations. First, this study is limited by its retrospective design, which may introduce selection bias and residual confounding. However, given that multi-level cervical pedicle screw fixation is a technically demanding procedure and not widely performed, conducting large-scale prospective studies remains challenging. Therefore, retrospective analyses such as this study may provide valuable clinical insights in this field. Secondly, the total number of cases is low, which may limit the statistical power of this study to confirm the advantage of utilizing more pedicle screws. Due to the limited sample size, we were not able to apply propensity score matching and therefore

conducted analyses using the entire cohort. However, it is important to note that the extensive use of pedicle screws in this study is relatively unique. Therefore, the number of subjects in this study can be considered a strength, as it provides valuable insights and data that are not commonly available in other studies. Thirdly, no significant differences were observed in C2-7 SVA and C2 SVA among the groups. This may be because these parameters reflect global sagittal alignment rather than isolated cervical alignment, and are therefore influenced by multiple factors including thoracolumbar alignment and compensatory mechanisms. In addition, although improvements in cervical lordosis and T1S-CL were observed, the 1-year follow-up period may be insufficient for these radiographic changes to translate into measurable differences in clinical outcomes. Furthermore, although cases involving hypermobile C7-T1 segments were excluded from the current analysis to maintain cohort homogeneity, it is evident that a rigid pedicle screw construct extending to C7 would exert biomechanical influences on the adjacent C7-T1 segment. Therefore, longer-term follow-up

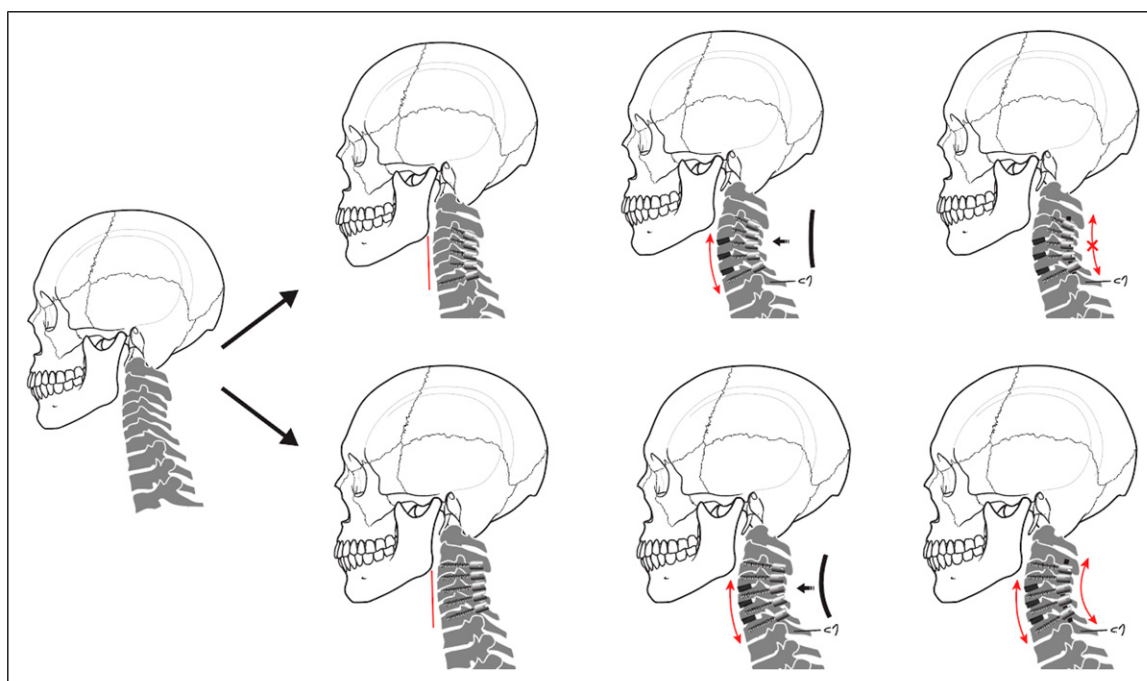


Figure 3. Schematic diagram illustrating the difference in sagittal alignment correction during rod application between lateral mass screws (LMS) and pedicle screws (PS). In the upper panel, LMS fixation results in primarily in-situ fixation during rod application, with minimal additional lordotic correction. In the lower panel, PS fixation allows repositioning of screw heads along the rod curvature, producing additional lordosis correction through controlled compression, which contributes to improved sagittal alignment

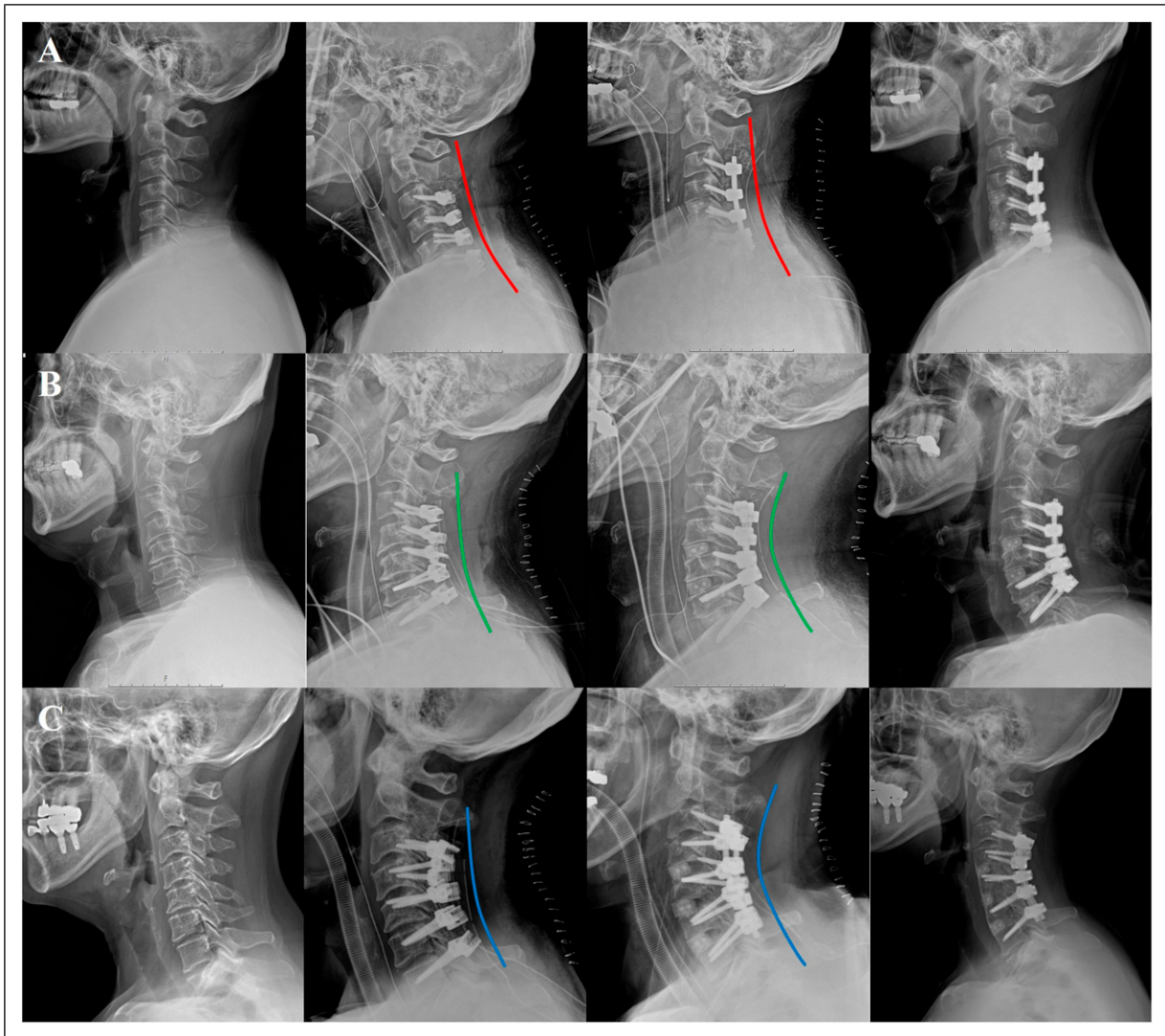


Figure 4. Representative lateral cervical radiographs from each group: (A) Group 1 (C7 PS only), (B) Group 2 (C6-C7 PS), and (C) Group 3 (C5-C7 PS). Immediate postoperative images show that Groups 2 and 3 achieved additional lordotic correction after rod application compared to Group 1. Follow-up radiographs at 1 year demonstrate maintenance of the corrected sagittal alignment in Groups 2 and 3, whereas Group 1 shows less pronounced correction

studies are required to clarify the relationship between radiographic alignment and clinical outcome.²⁶

Conclusion

Increased use of pedicle screws in the lower subaxial cervical spine significantly improved sagittal alignment, particularly by increasing cervical lordosis and reducing T1 slope minus cervical lordosis, with these corrections maintained for at least one year. However, extending pedicle screw fixation beyond C6-7 to include C5 did not result in a statistically significant additional benefit at 1-year follow-up. In addition, no significant differences in clinical outcomes were observed among the groups, suggesting that further long-term follow-up is required to

determine whether these radiographic differences translate into meaningful clinical benefits.

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Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (IRB)

(or Ethics Committee) of Severance Hospital, College of Medicine, Yonsei University (IRB No. 3-2024-0072).

Consent to Participate

The requirement for informed consent was waived by the Institutional Review Board due to the retrospective nature of the study.

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Declaration of Conflicting Interests

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Not publicly available due to patient privacy.

Supplemental Material

Supplemental material for this article is available online.

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