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Evaluating intraoperative C2 slope as a radiographic guide for cervical deformity correction

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Achieving and maintaining optimal sagittal alignment is a key goal in cervical deformity correction, yet reliable intraoperative tools to guide alignment remain limited. The C2 slope (C2S) is a simple parameter that reflects the relationship between the upper thoracic and cervical spine and has been associated with health-related quality of life. However, its role as an intraoperative guide for alignment correction has not been fully explored. This study analyzed 45 patients with cervical deformity who underwent correction with at least 2-year follow-up. Intraoperative lateral radiographs were obtained before final construct assembly, and C2S was actively measured and used to guide correction through surgical adjustments. Radiographic parameters—including C2S, C2–7 lordosis, T1 slope, T1 slope minus cervical lordosis (T1S–CL), and sagittal vertical axis—were evaluated preoperatively, intraoperatively, and during follow-up. Clinical outcomes included visual analog scale for neck and arm pain, Neck Disability Index, Japanese Orthopedic Association score, and EQ-5D. Both C2S and T1S–CL demonstrated significant correction which remained stable during follow-up. Final C2S and T1S–CL also showed significant correlations with clinical outcomes. These findings suggest that intraoperative C2 slope may serve as a practical reference for guiding alignment correction and could contribute to favorable radiographic and clinical outcomes.

Keywords Cervical spine, Cervical deformity, C2 slope, Sagittal alignment, Clinical outcome

Cervical spine deformity (CSD) can lead to substantial impairments in health-related quality of life (HRQoL) by causing pain, functional disability, loss of horizontal gaze, and neurologic deficits[1,2]. Surgical correction is often associated with meaningful improvement in these symptoms[3,4]. As a result, recent efforts have increasingly focused on refining the assessment, classification, and management of CSD[5–7]. In particular, numerous radiographic parameters have been proposed to quantify cervical alignment and guide treatment planning[8].

Among the proposed parameters, the C2 slope (C2S), T1 slope minus cervical lordosis (T1S-CL), and cervical sagittal vertical axis (SVA), have demonstrated correlations with HRQoL in patients with CSD[9–12]. Accordingly, optimal correction is often reflected by improvements in these metrics. However, CSD remains complex and challenging condition to manage, particularly in determining the degree of alignment correction required[8]. Only recently have studies begun to define radiographic targets for ideal postoperative alignment[9,10,13,14]. Despite these advances, reliable intraoperative indicators to guide real-time surgical decision-making remain limited.

Given these challenges, we hypothesized that intraoperative measurement of C2S could provide meaningful intraoperative feedback and help predict postoperative alignment. This study aimed to evaluate the utility of intraoperative C2S as a radiographic parameter for guiding alignment correction in CSD surgery.

Material and methods

Patient selection

This retrospective study was approved by the Yonsei University Gangnam Severance Hospital Institutional Review Board (approval number: 9-2023-0148). All methods were performed in accordance with relevant guidelines and regulations, and the requirement for informed consent was waived by the Yonsei University Gangnam Severance Hospital Institutional Review Board.

We identified patients aged ≥ 18 years who underwent posterior or combined anterior–posterior cervical fusion spanning ≥ 3 levels between 2014 and 2020. Exclusion criteria included follow-up < 2 years, insufficient radiographic or clinical data, and surgery for trauma, tumor, infection, or cerebral palsy. Patients were also

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excluded if they had a history of prior cervical spine surgery, underwent additional spinal surgery during the follow-up period, or presented with concomitant upper cervical pathology.

Among eligible cases, patients were included if they met radiographic criteria for cervical deformity, defined by at least one of the following: anteroposterior Cobb angle > 10°, C2–7 kyphosis > 10°, C2–7 sagittal vertical axis > 40 mm, or chin-brow vertical angle > 25°[14,15] (Fig. 1).

Demographics and surgical data

Baseline demographic data were collected, including age, sex, body mass index (BMI), smoking and alcohol use, presence of osteoporosis, Charlson Comorbidity Index (CCI), American Society of Anesthesiologists (ASA) classification, and symptom duration. Surgical and perioperative variables—such as estimated blood loss (EBL), number of fused levels, operative duration, surgical approach, length of hospital stay, and follow-up duration—were also recorded.

Radiographic parameters

Radiographic evaluation included full-length standing anteroposterior (AP) and lateral films, as well as cervical spine radiographs in neutral, flexion, and extension positions, obtained preoperatively and postoperatively. Intraoperative imaging consisted of lateral cervical radiographs. The following sagittal alignment parameters were measured at each time point: C2 slope (C2S), T1 slope (T1S), C2–7 lordosis (CL), T1 slope minus C2–7 lordosis (T1S–CL), and C2–7 sagittal vertical axis (SVA).

Intraoperative lateral radiographs were acquired with patients in the prone position on a Jackson table (Modular Table System, Mizuho OSI, CA, USA) set to a precise 10° reverse Trendelenburg angle. The imaging cassette was mounted in a frame parallel to the floor, ensuring that the image plane remained orthogonal to gravity. Patients' hips and knees were fully extended, and the feet were secured against a footboard fixed to the table, keeping the body axis parallel to the tabletop. Images were rotated 90° and uploaded to the picture archiving and communication system (PACS; Enterprise Web ver. 3.0, GE Healthcare, Chicago, IL, USA). As a result of this consistent setup, intraoperative measurements of C2S and T1S were 10° greater than upright images. Intraoperative C2–7 SVA was similarly affected by this positional deviation (Fig. 2). This positioning protocol was strictly standardized and applied to all patients throughout the procedure.

All patients wore a rigid cervical collar postoperatively. Only radiographs obtained after collar removal—typically at 3 months—were included in the final analysis.

C2S as an intraoperative alignment guide

During surgery, a lateral cervical radiograph was obtained prior to final rod assembly and graft placement. The C2 slope (C2S) measured on this intraoperative image served as a real-time reference for achieving the desired sagittal alignment. Based on previous literature, an ideal postoperative C2S is considered to be < 20°, and preferably < 10°[10,13]. Given the known 10° overestimation caused by the reverse Trendelenburg setup, a target intraoperative C2S of approximately 0° or slightly below was used. To achieve this alignment, adjustments were made by increasing lordosis—through cervical extension and/or cantilever correction—or by decreasing lordosis using the opposite maneuvers.

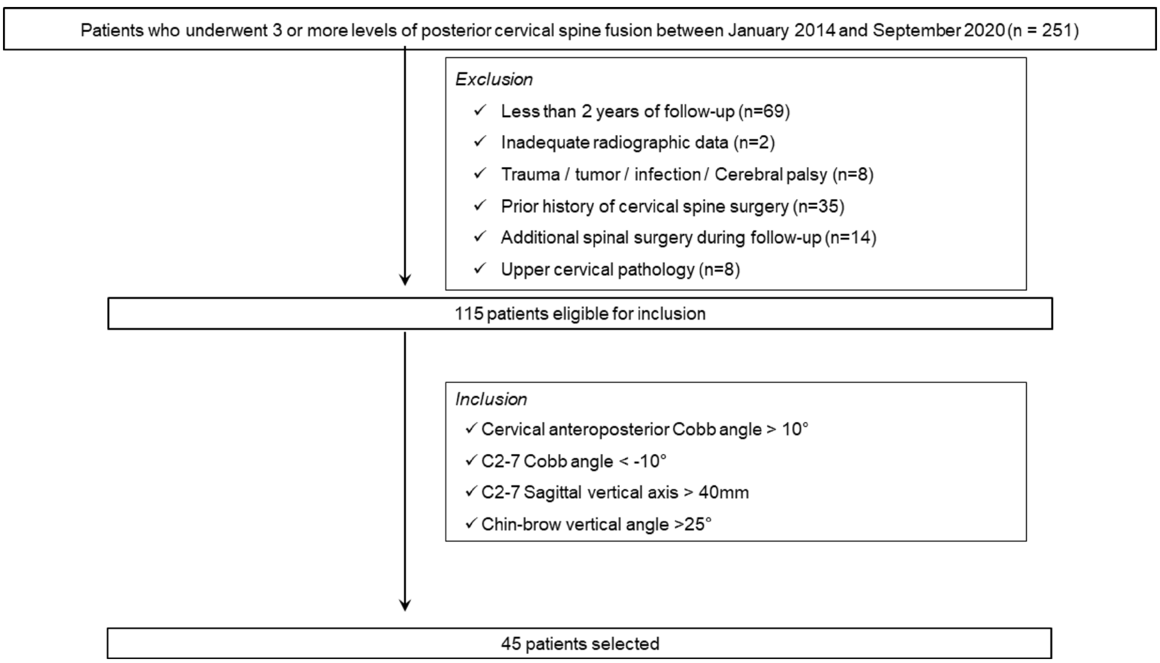

Fig. 1. Flowchart for selecting cervical deformity patients.

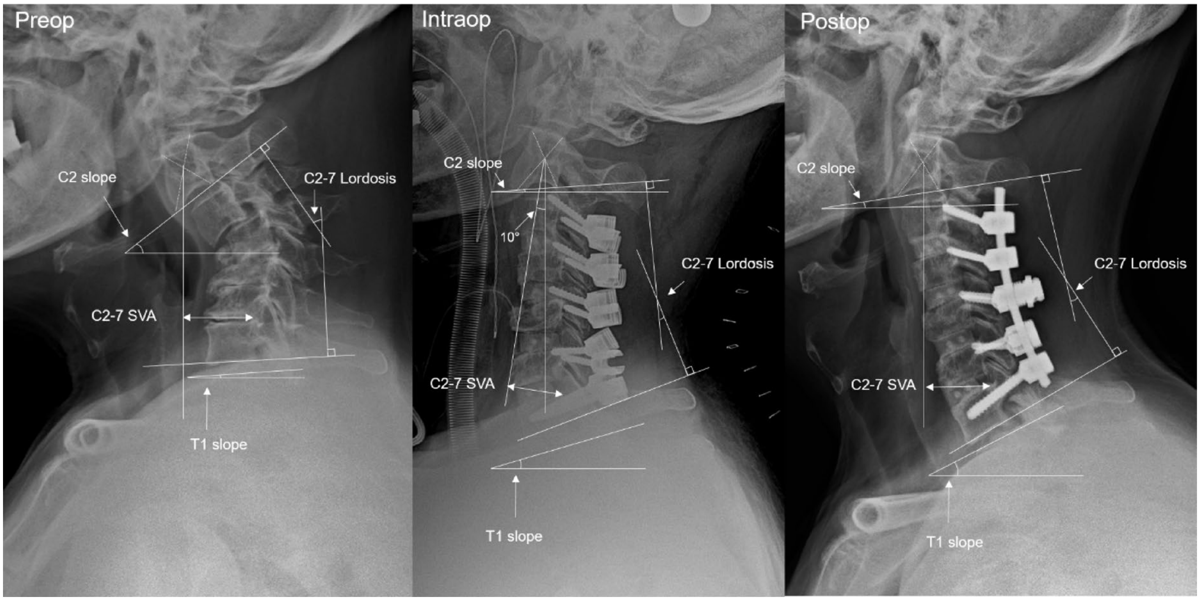

Fig. 2. Radiographic measurements used in this study. The intraoperative film is taken with the patient in prone position with the table in 10° reverse Trendelenburg position. As a result, the axis is deviated by 10° causing 10° exaggerations of C2S and T1S.

Clinical outcome measures

Clinical outcome measures were collected at baseline and during follow-up and included the visual analog scale (VAS) for neck and arm pain, Neck Disability Index (NDI)[16], Japanese Orthopedic Association (JOA) score[17], patient-reported subjective improvement rate (IR, %), and EuroQol-5 Dimension (EQ-5D). The total NDI score was converted into a percentage to account for non-drivers.

Statistical analysis

Demographic, radiographic, and clinical outcome variables are reported as means with standard deviations (± SD) or as frequencies and percentages, as appropriate. After testing for normality, paired t-tests, repeated-measures ANOVA with post hoc comparisons, and Pearson correlation analyses were performed. Subgroup comparisons according to achievement of the intraoperative C2S target were performed using independent *t*-tests or Mann–Whitney U tests for continuous variables, and chi-square or Fisher's exact tests for categorical variables. A p-value < 0.05 was considered statistically significant. All analyses were conducted using IBM SPSS Statistics (version 26; IBM Corp, Armonk, NY, USA).

Results

Cohort overview

Following application of the inclusion and exclusion criteria, 45 patients were included in the final analysis. The mean age was 60.1 ± 9.8 years, and 26 patients (57.8%) were male. The average BM) was 25.7 ± 3.7 kg/m^2. Most patients were non-smokers (n = 34, 75.6%) and non-drinkers (n = 33, 73.3%). Osteoporosis was present in 2 patients (4.4%). The mean CCI was 2.0 ± 1.3, and 19 patients (42.2%) were classified as ASA physical status class III. The mean duration of symptoms prior to surgery was 11.0 ± 15.1 months. None of the patients presented with isolated coronal deformity; all who met the coronal Cobb angle criterion also demonstrated concomitant sagittal deformity.

Surgical data revealed a mean fusion length of 4.3 ± 0.8 levels (range, 3–7), with an average EBL of 490 ± 341.7 mL and mean operative time of 250.3 ± 144.0 min. Two patients (4.4%) underwent posterior-only fusion, while the remainder received combined anterior–posterior procedures. The mean hospital length of stay was 12.4 ± 5.7 days, and the mean follow-up duration was 35.9 ± 15.0 months (Table 1).

Clinical outcomes following deformity correction

Baseline clinical outcome measures included a mean neck pain VAS of 6.3 ± 2.2, arm pain VAS of 6.3 ± 1.0, NDI of 44.7 ± 16.9%, JOA score of 11.6 ± 2.7, and EQ-5D VAS of 45.1 ± 9.9. At final follow-up, all clinical outcomes demonstrated statistically significant improvement. Neck pain VAS improved to 1.1 ± 1.7, arm pain VAS to 0.6 ± 1.3, NDI to 21.6 ± 15.0%, JOA score to 15.9 ± 1.8, and EQ-5D VAS to 80.6 ± 15.4. The mean JOA recovery rate was 77.6 ± 31.9% (Table 2).

Radiographic parameters over time

Radiographic measurements over time are summarized in Table 3 and Figs. 3–7.

Variable	Value
Baseline demographics	
Age (years)	60.1 ± 9.8
Sex	
Male	26 (57.8)
Female	19 (42.2)
BMI (kg/m^2)	25.7 ± 3.7
Smoking	
Non-smoker	34 (75.6)
Ex-smoker	4 (8.9)
Current smoker	7 (15.6)
Alcohol	
Non-drinker	33 (73.3)
Ex-drinker	1 (2.2)
Current drinker	11 (24.4)
Osteoporosis	
Yes	2 (4.4)
No	43 (95.6)
Charlson comorbidity index	2.0 ± 1.3
ASA classification	
1	8 (17.8)
2	18 (40.0)
3	19 (42.2)
Symptom duration (months)	11.0 ± 15.1
Surgical details	
Number of fused levels	4.3 ± 0.8
Estimated blood loss (mL)	490.0 ± 341.7
Operation duration (minutes)	250.3 ± 144.0
Surgical approach	
Posterior only	2 (4.4)
Anterior + Posterior combined	43 (95.6)
Perioperative data	
Length of stay (days)	12.4 ± 5.7
Length of follow-up (months)	35.9 ± 15.0

Table 1. Patient data overall. Data are expressed as either: Mean ± standard deviation or total number (%). BMI, Body mass index; ASA, American Society of Anesthesiologists.

Parameters	Preop	Final follow up	p-value
Neck pain VAS	6.3 ± 2.2	1.1 ± 1.7	< 0.001*
Arm pain VAS	6.3 ± 1.9	0.6 ± 1.3	< 0.001*
JOA score	11.6 ± 2.7	15.9 ± 1.8	< 0.001*
JOA recovery rate (%)		77.6 ± 31.9	
NDI (%)	44.7 ± 16.9	21.6 ± 15.0	< 0.001*
EQ-5D VAS	45.1 ± 9.9	80.6 ± 15.4	< 0.001*

Table 2. Change of clinical outcome parameters. Data are expressed as mean ± standard deviation. VAS, Visual Analog Scale; JOA, Japanese Orthopedic Association; NDI, Neck Disability Index; EQ-5D, EuroQol-5 Dimension. *Indicates significance.

C2S decreased significantly from 19.9 ± 7.2° preoperatively to 8.8 ± 6.4° intraoperatively ($p < 0.001$). A significant increase was observed between the intraoperative and 3-month postoperative periods (11.6 ± 6.8°, $p = 0.002$), with no further significant change between 3 months and final follow-up (12.4 ± 7.1°, $p = 0.951$) (Fig. 3).

T1S increased significantly from 18.4 ± 10.2° preoperatively to 25.4 ± 8.8° intraoperatively ($p < 0.001$). No significant difference was found between the intraoperative and 3-month periods (26.7 ± 6.6°, $p = 0.280$); however, a significant decrease was noted between 3 months and final follow-up (24.8 ± 6.2°, $p = 0.010$) (Fig. 4).

Parameters	Preop	Intraop	Postop 3M	Last follow up
C2 Slope (°)	19.9 ± 7.2	8.8 ± 6.4	11.6 ± 6.8	12.4 ± 7.1
T1 Slope (°)	18.4 ± 10.2	25.4 ± 8.8	26.7 ± 6.6	24.8 ± 6.2
C2-7 Lordosis (°)	-3.6 ± 14.6	16.8 ± 10.1	15.3 ± 9.1	13.1 ± 8.6
T1S minus CL (°)	21.9 ± 9.0	8.2 ± 6.5	11.1 ± 6.5	11.5 ± 6.9
C2-7 SVA (mm)	24.7 ± 12.6	21.0 ± 12.3	22.5 ± 10.3	22.6 ± 12.1

Table 3. Radiographic parameters pre-, intra-, and postoperatively. Data are expressed as mean ± standard deviation. T1S, T1 slope; CL, C2–7 Lordosis; SVA, Sagittal vertical axis.

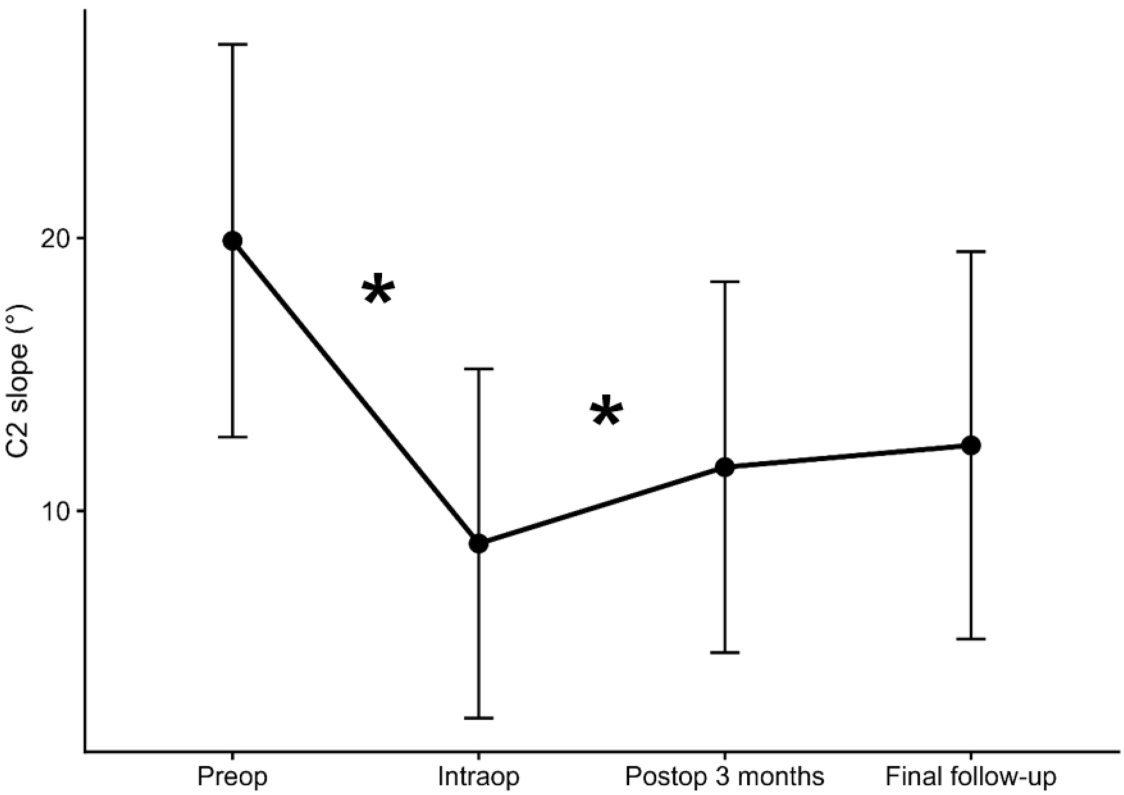

Fig. 3. The change of C2 slope through follow up. * indicates significance.

CL improved significantly from − 3.6 ± 14.6° to 16.8 ± 10.1° intraoperatively ($p < 0.001$). No significant change occurred between the intraoperative and 3-month measurements (15.3 ± 9.1°, $p = 0.897$), while a significant decrease was observed between 3 months and final follow-up (13.1 ± 8.6°, $p = 0.006$) (Fig. 5).

T1S–CL decreased significantly from 21.9 ± 9.0° preoperatively to 8.2 ± 6.5° intraoperatively ($p < 0.001$), followed by a significant increase at 3 months (11.1 ± 6.5°, $p = 0.001$). However, no further significant change was noted at final follow-up (11.5 ± 6.9°, $p = 0.99$) (Fig. 6).

C2–7 SVA did not demonstrate significant differences across any time points (Fig. 7).

Correlation between radiographic parameters and clinical outcomes

Final follow-up C2S values demonstrated significant correlations with several clinical outcome measures, including neck pain VAS ($R = 0.514$, $p < 0.001$), NDI ($R = 0.380$, $p = 0.010$), JOA score ($R = -0.301$, $p = 0.044$), JOA recovery rate ($R = -0.395$, $p = 0.007$), EQ-5D index ($R = -0.342$, $p = 0.026$), EQ-5D VAS ($R = -0.338$, $p = 0.025$), and improvement rate (IR) ($R = -0.336$, $p = 0.024$).

T1S–CL was also significantly associated with neck pain VAS ($R = 0.479$, $p = 0.001$), NDI ($R = 0.393$, $p = 0.008$), JOA score ($R = -0.314$, $p = 0.036$), JOA recovery rate ($R = -0.414$, $p = 0.005$), EQ-5D index ($R = -0.329$, $p = 0.033$), EQ-5D VAS ($R = -0.345$, $p = 0.022$), and IR ($R = -0.361$, $p = 0.015$).

CL correlated with neck pain VAS ($R = -0.397$, $p = 0.007$), EQ-5D VAS ($R = 0.345$, $p = 0.022$), and IR ($R = 0.341$, $p = 0.022$). In contrast, neither T1S nor C2–7 SVA showed significant correlations with any clinical outcome parameters (Table 4).

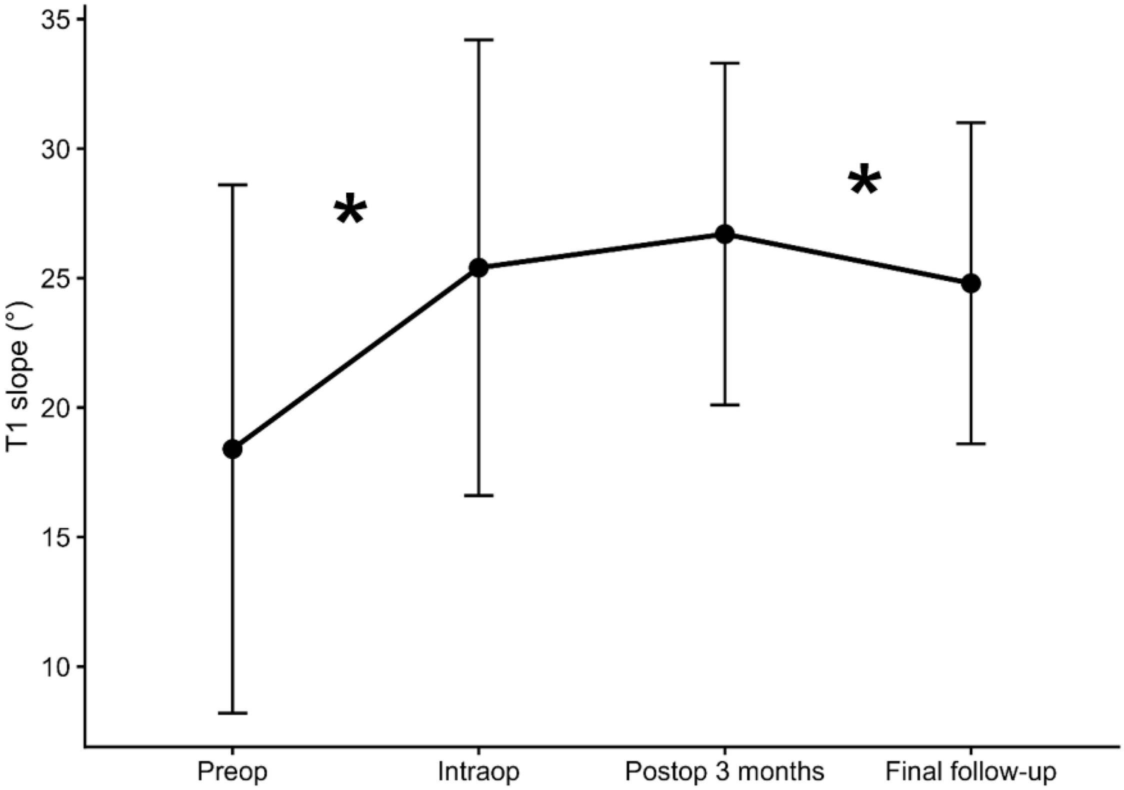

Fig. 4. The change of T1 slope through follow up. * indicates significance.

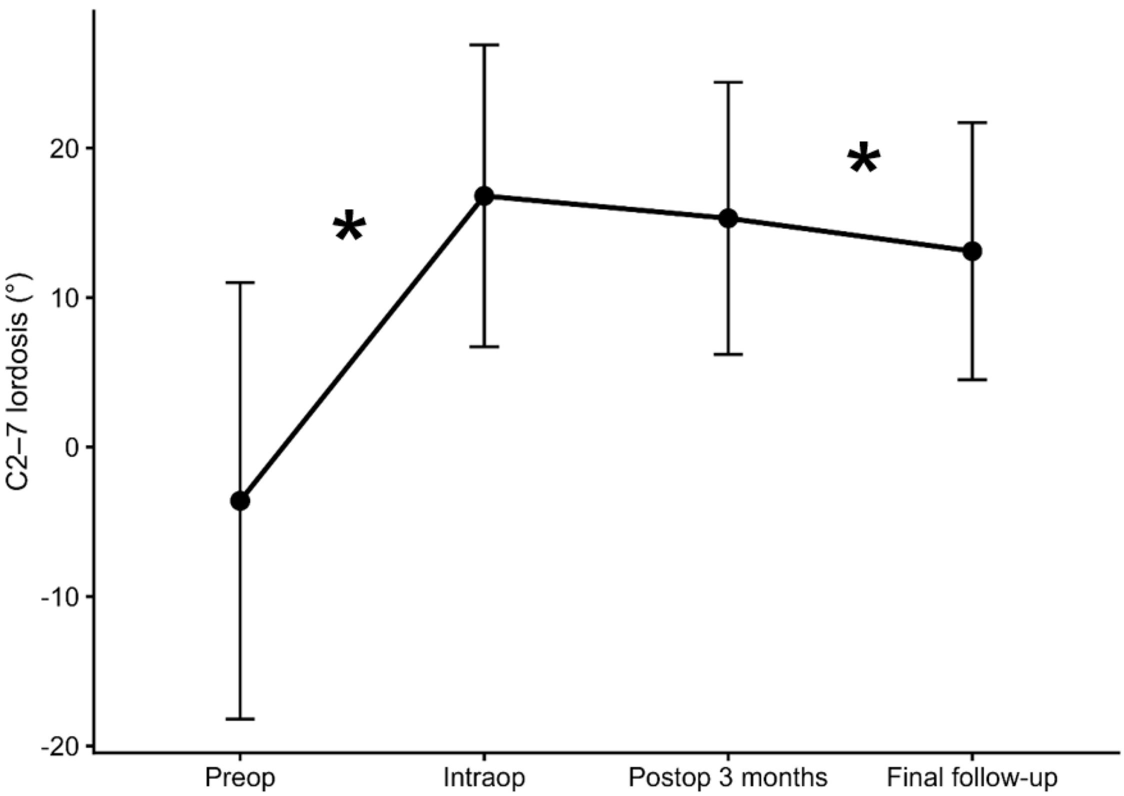

Fig. 5. The change of C2-7 lordosis through follow up. * indicates significance.

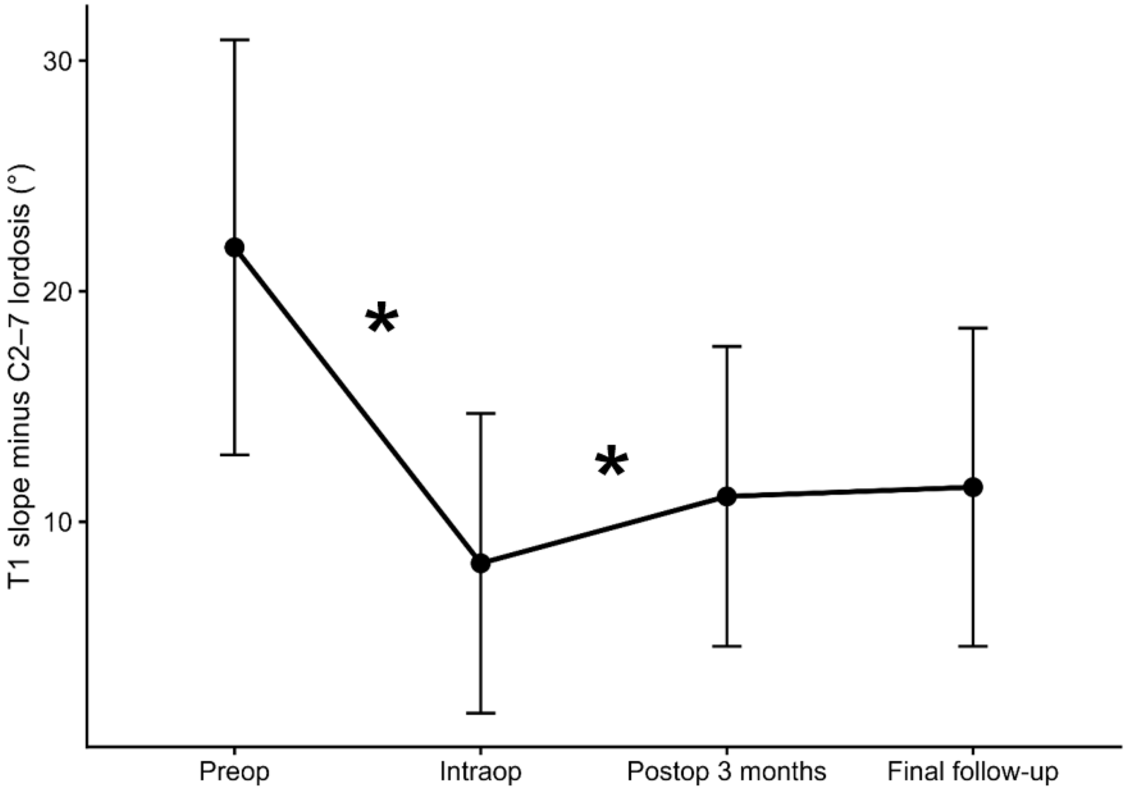

Fig. 6. The change of T1 slope minus C2-7 lordosis through follow up. * indicates significance.

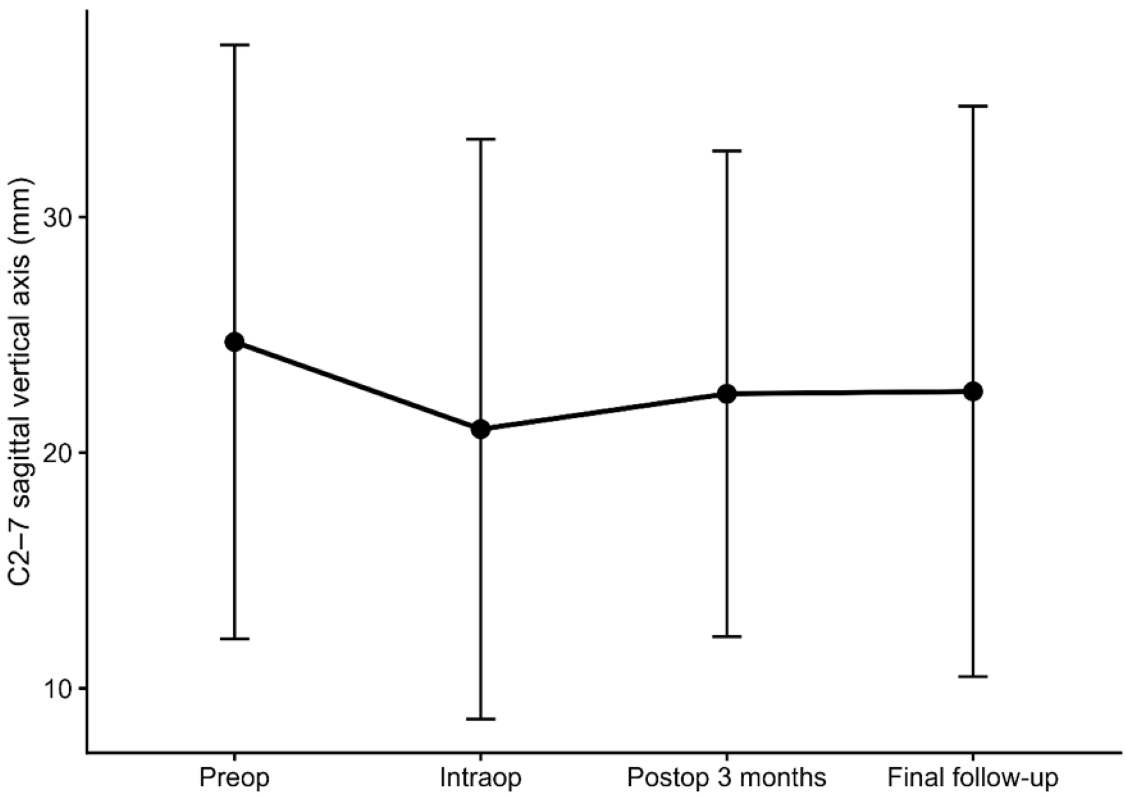

Fig. 7. The change of C2-7 Sagittal Vertical Axis through follow up.

Parameters		Neck pain VAS	Arm pain VAS	NDI	JOA	JOA recovery	EQ-5D index	EQ-5D VAS	IR
C2 Slope	R	0.514	0.135	0.380	−0.301	−0.395	−0.342	−0.338	−0.336
	p	< 0.001	n/s	0.010	0.044	0.007	0.026	0.025	0.024
T1 Slope	R	−0.021	0.223	0.113	−0.113	−0.063	−0.105	0.097	0.074
	p	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s
C2-7 Lordosis	R	−0.397	0.053	−0.233	0.170	0.285	0.190	0.345	0.341
	p	0.007	n/s	n/s	n/s	n/s	n/s	0.022	0.022
T1S minus CL	R	0.479	0.134	0.393	−0.314	−0.414	−0.329	−0.345	−0.361
	p	0.001	n/s	0.008	0.036	0.005	0.033	0.022	0.015
C2-7 SVA	R	0.131	−0.029	0.161	0.025	−0.061	−0.141	−0.177	−0.206
	p	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s

Table 4. Correlation of radiographic parameters and clinical outcome measures at final follow up. T1S, T1 slope; CL, C2–7 Lordosis; SVA, Sagittal Vertical Axis; VAS, Visual Analogue Scale; NDI, Neck Disability Index; JOA, Japanese Orthopedic Association score; EQ5D, EuroQol-5 Dimension; IR, self-reported Improvement Rate; n/s, not significant. *Indicates significance.

Subgroup analysis
Patients who achieved an intraoperative C2 slope ≤ 0° had significantly lower C2 slope, greater C2–7 lordosis, and reduced T1S–CL mismatch at final follow-up. Clinically, this group reported lower neck pain and a higher proportion achieved JOA recovery MCID. No significant differences were observed in NDI, NDI MCID achievement, and EQ–5D VAS (Table 5).

Discussion
The results of this study demonstrate that following CSD correction, C2 slope (C2S) and T1 slope minus cervical lordosis (T1S–CL) improved significantly and remained stable throughout follow-up. In contrast, while T1 slope (T1S) and C2–7 lordosis (CL) also improved postoperatively, their correction was not maintained over time. Similar longitudinal stability of C2S and T1S–CL has been reported in asymptomatic populations[18,19]. In the present surgical cohort, this preservation may be partially attributed to the patients' capacity to maintain horizontal gaze post-correction.

Both parameters showed significant correlations with HRQoL measures at final follow-up. Given that C2S is a mathematical approximation of T1S–CL, it may serve as a practical surrogate intraoperatively[11]. The T1S–CL represents the balance between the upper thoracic and cervical spine, which is known to influence neutral head posture and line of sight[9,20]. Imbalances in this relationship may lead to compensatory muscle overuse, contributing to neck pain and disability—reflected in this study's correlations between these parameters and both neck pain VAS and NDI scores. Consistent with prior research, C2S and T1S–CL were also significantly associated with JOA scores and JOA recovery rates[10,11]. In particular, our subgroup analysis demonstrated that achieving an intraoperative C2S ≤ 0° was associated with a higher likelihood of achieving the MCID for JOA recovery. Cervical malalignment may cause spinal cord stretch and draping over ventral pathology, leading to ischemia, increased cord tension, and subsequent neurological decline[21,22]. Therefore, adequate sagittal correction—as reflected by achieving an appropriate C2S—may contribute not only to sagittal balance but also to neurological recovery in patients with cervical myelopathy. Although not directly evaluated here, optimizing C2S may also help mitigate complications such as distal junctional failure[13].

Taken together, the reproducibility of C2S over time and its significant association with patient-reported outcomes support its utility as a reliable intraoperative alignment guide. In addition, our subgroup analysis revealed that achieving an intraoperative C2S ≤ 0° was associated with more favorable sagittal alignment and improved clinical outcomes at final follow-up. Given the limited sample size, these findings should be regarded as exploratory, but they suggest that targeting C2S may serve as a practical intraoperative reference.

Surgeons employ various methods to assess spinal alignment intraoperatively. This study focused on using the C2S as a guide due to its potential advantages over alternative parameters. C2S requires only a single angular measurement, simplifying intraoperative assessment and minimizing interobserver variability[10,11]. Its simplicity and ease of use make it particularly well-suited to the surgical setting, where precise calculations and complex measurements may be impractical. Moreover, the C2 vertebra is consistently visible on cervical spine radiographs, enhancing the reliability of C2S compared to other parameters—such as T1S or CL—that depend on visualization of the lower cervical spine or cervicothoracic junction, which are often obscured in plain radiographs[23–25].

Some surgeons use the C2–7 SVA to guide intraoperative alignment, as values less than 40 mm have been associated with favorable outcomes[12]. However, SVA is a linear measurement that requires radiographic calibration, which can vary considerably between imaging setups. This variability makes linear parameters less practical for intraoperative use compared to angular measurements[26]. Cervical deformity correction often necessitates multilevel fusion, typically performed via posterior or combined anterior–posterior approaches. During posterior procedures, patients are commonly positioned prone in a reverse Trendelenburg orientation to reduce intraocular pressure and intraoperative bleeding[4,27]. This positioning alters the body axis relative to the imaging plane, complicating the accuracy of C2–7 SVA measurement. In contrast, angular parameters such as

Variable	Intraoperative C2S ≤ 0° (n = 27)	Intraoperative C2S > 0° (n = 18)	p-value
Radiographic outcomes at final follow-up			
C2 Slope (°)	9.4 ± 6.7	16.9 ± 5.2	< 0.001*
T1 Slope (°)	25.1 ± 6.3	24.4 ± 6.1	0.682
C2–7 Lordosis (°)	16.4 ± 8.9	8.3 ± 5.5	< 0.001*
T1S minus CL (°)	8.8 ± 6.2	16.1 ± 5.5	< 0.001*
C2–7 SVA (mm)	22.0 ± 12.1	23.7 ± 12.3	0.637
Clinical outcomes at final follow-up			
Neck pain VAS	0.5 ± 1.1	2.1 ± 2.0	0.001*
Arm pain VAS	0.4 ± 1.1	0.9 ± 1.6	0.166
NDI (%)	17.5 ± 11.0	27.8- + 18.2	0.050
NDI MCID achieved	16 (59.3%)	11 (61.1%)	0.901
JOA score	16.3 ± 1.0	15.2 ± 2.5	0.095
JOA recovery rate (%)	85.5 ± 23.9	65.8 ± 38.9	0.068
JOA recovery rate MCID achieved	25 (92.6%)	12 (66.7%)	0.045*
EQ-5D VAS	82.8 ± 16.9	77.1 ± 12.3	0.234

Table 5. Comparison of radiographic and clinical outcomes at final follow-up according to intraoperative C2S. Data are expressed as mean ± standard deviation or number (%). C2S, C2 slope; T1S, T1 slope; CL, C2-7 Lordosis; SVA, Sagittal Vertical Axis; VAS, Visual Analogue Scale; NDI, Neck Disability Index; MCID, Minimal Clinically Important Difference; JOA, Japanese Orthopedic Association score; EQ-5D, EuroQol-5 Dimension. *Indicates significance.

C2S are less susceptible to these positional distortions and may offer a more reliable alternative in the operative setting. Moreover, although a C2–7 SVA < 40 mm has been widely cited as a radiographic goal, prior studies have demonstrated that this threshold corresponds to a T1S–CL and C2S of approximately 20°[10,28]. Thus, while intraoperative SVA measurements may be difficult to standardize, C2S offers an alternative that aligns closely with established SVA targets.

In this study, the reverse Trendelenburg angle was standardized at 10°, resulting in a 10° overestimation of slope angles on intraoperative radiographs. Based on prior studies recommending a final C2S of less than 10°[13], the intraoperative target was set to a "level" C2—defined as a C2S of 0°—or slightly negative. This approach provided a simple and reproducible visual reference to guide real-time assessment and determine the extent of alignment correction required.

An alternative method employed by some surgeons is the "occiput-to-back" technique, which involves aligning the patient's occiput with the posterior thorax while prone. Although this method may help assess translational alignment, it does not account for angular deformity and lacks validated correlation with sagittal balance. Its clinical reliability remains uncertain due to a lack of supporting evidence in the literature. In contrast, C2S has been shown to correlate with both T1S–CL and C2–7 SVA, providing a more evidence-based and quantifiable intraoperative reference.

This study has several limitations. Although data collection followed a prospective protocol, the retrospective nature of the analysis may not have been ideal for evaluating intraoperative decision-making. Final radiographs were not consistently acquired in the same reverse Trendelenburg position due to intraoperative factors such as hypotension or prolonged surgical time. As a result, post-assembly radiographs were excluded from analysis, which may have contributed to the observed variation in C2S between intraoperative imaging and the 3-month follow-up. Nevertheless, the authors believe that using radiographs obtained prior to final construct assembly more accurately reflects alignment adjustments made during surgery.

The relatively small sample size was a consequence of strict inclusion and exclusion criteria designed to minimize bias. In addition, the relative rarity of cervical deformity further limited the patient population. As a result, this constraint substantially restricted our ability to classify deformity subtypes or perform stratified analyses. Larger, preferably multi-institutional studies will be necessary to determine whether intraoperative use of the C2S is broadly applicable across different cervical deformity patterns. Accordingly, our findings should be regarded as preliminary evidence that highlights the potential utility of intraoperative C2S as a practical surgical guide.

Another limitation is that our cohort may not have fully represented the most severe forms of cervical deformity. Although the definition of "severity" remains inconsistent in the existing literature, it is possible that some of the most extreme cases were not included. Nevertheless, the mean preoperative C2S (19.9°) and T1S–CL (21.9°) corresponded to high modifier scores within the Ames–ISSG classification[7], indicating at least moderate to markedly abnormal values in our cohort. Even so, the possible absence of the most severe deformities suggests that our findings should be considered preliminary, and validation in larger, more diverse cohorts will be necessary.

The limited sample size and selection of patients may have contributed to the lack of significant changes in C2–7 SVA across follow-up. However, a prospective multicenter study reported that only one-third of adult cervical deformity patients demonstrated improvement in C2–7 SVA modifier grade following surgery, whereas the majority showed no change[29]. Our findings appear consistent with these results.

Additionally, the lack of long cassette radiographs in the operating room precluded measurement of global sagittal alignment parameters, such as the T1 pelvic angle or cervical-thoracic pelvic angle. Future studies incorporating advanced intraoperative imaging may help overcome this limitation.

Despite these constraints, to the authors' knowledge, this is the first study to describe the intraoperative application of C2S as an alignment guide and to demonstrate its postoperative preservation over a minimum two-year follow-up period.

Conclusions

C2S is a simple and reproducible radiographic parameter that may serve as a practical and reliable intraoperative guide during cervical deformity correction. Intraoperative correction of C2S was maintained over time and demonstrated significant associations with radiographic restoration and clinical improvement. These findings suggest that intraoperative C2S has potential as a useful real-time reference for optimizing sagittal alignment.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to the inclusion of patient clinical information, but are available from the corresponding author on reasonable request.

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Author contributions
N.K. and K.-S.S. contributed to the conceptualization and design of the study. Data collection and processing were performed by N.K., K.-S.S., J.-W.K., S.-R.P., J.S., and B.H.L. Data analysis was conducted by N.K., K.-S.S., S.-Y.P., J.-O.P., S.-H.M., and H.-S.K. Manuscript drafting and revision were carried out by N.K., K.-S.S., J.-W.K., S.-Y.P., J.-O.P., S.-H.M., and H.-S.K. All authors contributed to the supervision of the study and approved the final version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval and consent to participate

This study was approved by the Yonsei University Gangnam Severance Hospital Institutional Review Board (approval number: 9–2023-0148). All methods were performed in accordance with relevant guidelines and regulations. In light of the retrospective nature of the study, the requirement for informed consent was waived by the Yonsei University Gangnam Severance Hospital Institutional Review Board.

Additional information

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