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Radiological evaluation of atlantoaxial fusion using C2 translaminar screws and C2 pedicle screws

Does the screw halo sign imply fusion failure?

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Abstract

The purpose of this study was to identify the criteria for atlantoaxial (AA) fusion by comparing follow-up lateral radiographs and computed tomography (CT) images. We retrospectively analyzed data from 161 consecutive patients undergoing AA fusion. Patients with a minimum of 1 year of CT follow-up after AA fusion surgery using C2 pedicle screws or translaminar screws (C2TLS) were included. Patients were followed up radiographically at 3, 6, and 12 months after surgery, and dynamic lateral radiographs were also evaluated. A total of 49 patients were analyzed, with a mean CT image follow-up of 41.6 ± 37.6 months. Thirty eight patients had C2 pedicle screw placement, and 11 patients underwent planned C2TLS. AA fusion with bridging bone mass formation was achieved in 45/49 (91.8%) patients. Screw halos were observed in 14/49 (28.6%) patients. Among them, final fusion failure occurred in 2 (14.3%) patients. The last follow-up CT showed no difference in the fusion failure rate according to the presence or absence of a screw halo (no halo, 5.7%; halo, 14.3%; $P = .33$). The differences in C1-2 segmental angles (SA) in flexion-extension dynamic lateral radiographs were 1.99 ± 1.62° in the fusion group and 4.37 ± 2.13° in the non-fusion group ($P = .01$). The likelihood of fusion failure increased when the SA gap was greater than 2.62° ($P = .05$). C2TLS placement had a significantly higher incidence of screw halos. However, the halo sign was not significantly related to final bone fusion. Bone fusion could be predicted when the SA gap of C1-2 was less than 2.62° on the dynamic radiograph.

Abbreviations: AA = atlantoaxial, ANOVA = analysis of variance, C2PS = C2 pedicle screw, C2TLS = C2 translaminar screw, CT = computed tomography, ROM = range of motion, SA = segmental angle.

Keywords: atlantoaxial fixation, cervical fusion, pedicle screw, screw loosening, translaminar screw

1. Introduction

Various methods have been reported for obtaining robust fixation and a higher fusion rate during surgery for atlantoaxial (AA) instability. Screw placement of the atlas and axis and connecting them with rod assembly techniques have been widely used since they were first introduced by Harms and Goel.[1,2] C1 lateral mass screws and C2 pedicle screws (C2PS) are standard, with reported fusion rates ranging from 88.2% to 100%.[3,4] Most spine surgeons would agree that C2PS has the greatest pullout strength, followed by C2 translaminar screws (C2TLS) or pars screws.[5] When it is difficult to safely place C2PS due to vertebral artery anomaly or a narrowed C2 pedicle, C2TLS is considered.[6,7] C2TLS is known to have acceptable clinical results compared with C2PS; however, some inferiorities in biomechanical stability and fusion rate have also been reported.[8-11] The AA segment has a diverse and wider range of motion (ROM) compared with other spinal segments. Therefore, specific radiographic evaluation criteria for the AA segment are required. To date, several papers have reported the surgical outcomes of various AA fixation methods; however, they did not use a unified definition for AA fusion.[5,12-14]

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This type of study does not require informed consent.

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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Computed tomography (CT) evaluation at least 1 year after surgery is the most reliable methods for defining AA fusion. However, although cervical spine radiograph images within 1 year after surgery are inexpensive, and evaluation of instrument failure or early instability is straightforward; most surgeons commonly use serial radiographs including dynamic radiographs in regular outpatient clinics. Thus, cervical spine radiograph findings were included when evaluating the outcomes of AA fusion surgery. According to studies dealing with AA fusion, fusion failure was defined as the presence of motion between flexion and extension,[12] an inter-spinous distance greater than 2 mm,[14] or a screw halo (peri-screw lucency) on dynamic radiography.[13] However, a definite set of criteria to define fusion or non-fusion on postoperative radiographs remains controversial.

The purpose of the present study was to compare the radiographic findings of C2PS and C2TLS in AA fusion surgery and to define objective radiological parameters for fusion evaluation by comparing the radiographic findings with follow-up CT scan results after a minimum of 1 year.

2. Methods

2.1. Patient enrollment and data collection

This retrospective cohort study enrolled 161 consecutive patients with AA instability treated at the Department of Neurosurgery at a single center between May 2006 and April 2019. The inclusion criteria were patients who underwent instrumentation with a screw rod connecting the C1 lateral mass screw and C2PS or C2TLS, who subsequently underwent regular X-ray image follow-up and CT scans for a minimum of 1 year after surgery. Patients with occipitocervical fusion or subaxial cervical spinal fusion were excluded. Clinical data were obtained from the institutional electronic medical records. We recorded patient age, sex, diagnosis, and surgical complications (surgical site infection, screw malposition, and bone harvest-related complications). The institutional review board of our institution approved this retrospective study (IRB 2021-11-023-004).

2.2. Surgical technique and bone grafting

After the induction of general anesthesia, the patients were placed in the prone position with a Mayfield head clamp fixation. A standard open posterior approach was then used via a midline skin incision. The neck muscles were dissected and detached by subperiosteal dissection to expose the C1 and C2 screw insertion points. Intraoperative fluoroscopy was used to guide the screw placement. For C1 lateral mass screw placement, we performed a conventional Harms and Melcher technique, or used a higher entry point through the notch between the C1 posterior arch and C1 lateral mass.[2,15] For C2TLS placement, an entry hole was made at 1 side of the spinolaminar junction. To avoid breach of the dorsal lamina and to stay within the cancellous bone, the hole was hand-drilled with a 3.0-mm drill bit towards the contralateral lamina.[7] The prepared tract was then palpated with a ball-tipped probe to ensure that the lamina was not violated. A 4.0-mm diameter Vertex (Medtronic Sofamor Danek, Memphis, TN) or Synapse (DePuy Synthes Spine, Raynham, MA) was then inserted manually. For bone fusion, we routinely harvested iliac autobone from 1 side of the posterior superior iliac spines. Then, we tightly packed the bone graft between the C1 posterior arch and C2 lamina, if possible, or performed an onlay graft onto the dorsal surface of the decorticated fusion bed.

2.3. Radiographic assessment and definitions of fusion

Patients were followed up by taking simple cervical spine radiographs at 3, 6, and 12 months after surgery, and dynamic lateral radiographs were similarly evaluated. Screw halo positivity was defined as when peri-screw lucency was observed on any follow-up postoperative radiographs and peri-screw lucency was still present on CT a minimum of 1 year after surgery. The C1-2 segmental angle (SA) between flexion and extension was measured on dynamic radiographs. Bone union with posterior bone graft was graded on CT images as follows: grade 0, no visible bone mass or amorphous noncontiguous bone; grade 1, amorphous contiguous bone; and grade 2, definite corticalization with bone graft. C1-2 bone fusion positivity was defined as C1-2 facet joint bone bridge formation or posterior bone union grades 1 and 2 confirmed by CT scan at least 1 year after surgery. The measurements and analysis were performed on 150% magnified images using PiView digital image viewing software (INFINITT Healthcare Co. Ltd., Seoul, Korea). All of the above parameters were measured by an independent researcher.

2.4. Statistical analysis

All statistical analyses were performed using SPSS version 20 (IBM Corp., Armonk, NY). Categorical variables in the 2 groups were expressed as number (%) and compared using the χ^2 or Fisher's exact test, and continuous variables were expressed as mean ± standard deviation and compared using unpaired Student's t-tests or Mann–Whitney U-tests, with statistical significance defined as $P < .05$. C1-2 SA and O-C2 SA in the 2 groups over the entire follow-up period (preoperative, immediate postoperative, and final follow-up evaluations) were compared using repeated-measures analysis of variance (ANOVA). p-values < 0.05 denoted statistically significant differences in time and group effects, as well as time*group interactions by repeated-measures ANOVA with Mauchly's test of sphericity or the Greenhouse–Geisser correction. The receiver operating characteristic curve was used to determine the best cutoff value of the parameters for predicting bone fusion on the final CT.

3. Results

Of the 161 patients who underwent AA fusion surgery, a total of 49 patients (27 men [55.1%] and 22 women [44.9%]) aged 55.9 ± 15.34 years were included in this study. The follow-up period, including CT imaging, was 41.6 ± 37.6 months. The most common disease was degenerative disease (40.8%) (Table 1).

A total of 14/49 (28.6%) patients with AA fusion showed screw halos within 12 months after surgery on the follow-up radiograph. Among them, the final CT images showed fusion failure in 2 (14.3%) patients. The final follow-up CT images showed no difference in the rate of fusion failure according to the presence or absence of a screw halo (no halo 5.7% vs halo 14.3%, $P = .33$).

In 23/49 (46.9%) patients, a bony bridge was formed the around the C1-2 facet joint. In most cases, cortical bone continuity was confirmed at the lateral end of the C1-2 facet joint. The incidence of joint fusion was significantly higher in the no halo group (n = 35) than in the screw halo (n = 14) group ($P = .004$). As a result of evaluating posterior fusion bone formation at the onlay graft, 15 (30.6%) patients showed grade 2 fusion, and 25 (51.0%) patients showed grade 1 fusion. Overall, 45/49 (91.8%) patients achieved AA fusion with bridging bone mass formation. There was no significant difference in the fusion failure rates between the no halo (n = 35) and screw halo (n = 14) groups, as observed on postoperative CT images at the final follow-up ($P = .325$).

Two patients in the screw halo group underwent revision surgery due to fusion failure. Both had C2PS. The screw halo group had a significantly higher rate of revision surgery ($P = .024$). One patient had a surgical site infection that resolved with medical treatment. The other patient had malposition of the C1

Table 1

Summary of patient characteristics.

	Total (n = 49)	No halo (n = 35)	Screw halo (n = 14)	p-value
Age (years)	55.90 ± 15.34	55.14 ± 15.82	57.79 ± 15.06	0.595
Sex (male/female)	27 (55.1%)/ 22	18 (51.4%)/ 17	9 (64.3%)/ 5	0.414
CT follow-up period (months)	41.55 ± 37.57	46.94 ± 40.01	28.07 ± 29.31	0.177
Disease entity				
Degenerative	20 (40.8%)	13 (65.0%)	7 (35.0%)	0.696
Trauma	15 (30.6%)	12 (80.0%)	3 (20.0%)	
Developmental anomaly	9 (18.4%)	7 (77.8%)	2 (22.2%)	
Rheumatoid arthritis	5 (10.2%)	3 (60.0%)	2 (40.0%)	
C2 Screw types				
C2PS	38 (77.6%)	30 (78.9%)	8 (21.1%)	0.030*
C2TLS	11 (22.4%)	5 (45.5%)	6 (54.5%)	
Fusion rate using the CT criteria				
Joint fusion	23 (46.9%)	21 (60.0%)	2 (14.3%)	0.004*
Posterior fusion grade 2	15 (30.6%)	14 (40.0%)	1 (7.1%)	0.055
Posterior fusion grade 1	25 (51.0%)	16 (45.7%)	9 (64.3%)	
Fusion failure	4 (8.2%)	2 (5.7%)	2 (14.3%)	0.325
Complication type				
Revision d/t failure	2 (4.1%)	0	2 (14.3%) C2PS: 2/ C2TLS: 0	0.024*
Surgical site infection	1 (2.0%)	0	1 (7.1%) C2PS: 1/ C2TLS: 0	0.115
Screw malposition	1 (2.0%)	0	1 (7.1%) C2PS: 0/ C2TLS: 1	0.115

*statistically significant

CT = computed tomography, C2PS = C2 pedicle screw, C2TLS = C2 translaminar screw; d/t, due to.

lateral mass screw and underwent screw replacement surgery (Table 1).

Repeated-measures ANOVA for evaluating time course and group interactions showed no significant differences in C1-2 or O-C2 SA over time and between the no halo and screw halo groups (Table 2). Repeated-measures ANOVA for evaluating time course and group interactions showed no significant differences in C1-2 or O-C2 SA over time and between the C2PS and C2TLS groups (Table 3). The data in Tables 2 and 3 indicate that the occurrence of a screw halo or the use of C2TLS does not make a significant difference in the correction loss of the SA over time (Fig. 1).

The dynamic radiographs showed that the C1-2 SA gap between flexion and extension was significantly larger in patients with fusion failure (n = 4). The cutoff value for determining fusion failure, i.e., the existence of "motion," was 2.62° ($P = .008$), with 75.0% sensitivity and 75.6% specificity according to the curve analysis (Table 4).

3.1. Illustrative cases

3.1.1. Case 1 A 65-years-old man chiefly complaining of quadriparesis was diagnosed with OS odontoideum. He underwent C1-2 fusion surgery with C2TLS placement. A screw halo was observed around the C2TLS in the radiograph performed 6 months after surgery, and the C1-2 SA gap between flexion and extension was 1.76°. The remaining screw halos were observed on the 1-year follow-up CT. Nevertheless, grade 2 posterior bone fusion was successfully achieved (Fig. 2).

3.1.2. Case 2 A 17-years-old male patient presented with a C1-2 dislocation due to trauma while diving. He underwent C1-2 fusion surgery with C2TLS. In the dynamic radiograph obtained 6 months after surgery, the C1-2 SA gap was 4.02°, and there was no screw halo. Two years after surgery, no screw halo was visible on follow-up CT; however, the C1-2 SA gap on the dynamic radiograph was 4.54°. At 53 months postoperatively, myelopathy recurred due to fusion failure;

Table 2

Changes in segmental angles over time in patients with or without postoperative peri-screw lucency (halo).

	No halo (n = 35)	Screw halo (n = 14)	p-value
C1-2 segmental angle			
Preoperative	18.04 ± 10.56	18.39 ± 14.55	0.924
Immediately postoperative	14.80 ± 10.22	16.38 ± 10.05	0.626
Final f/u	15.66 ± 9.37	16.62 ± 9.67	0.749
Time	$P = .073$		
Group	$P = .753$		
Time*group	$P = .819$		
O-C2 segmental angle			
Preoperative	9.38 ± 10.74	7.24 ± 11.60	0.540
Immediately postoperative	6.76 ± 9.17	6.55 ± 6.71	0.938
Final f/u	8.08 ± 10.83	7.90 ± 9.26	0.958
Time	$P = .399$		
Group	$P = .765$		
Time*group	$P = .685$		

f/u = follow up.

Table 3

Changes in segmental angles over time in patients who received C2 pedicle screws or C2 translaminar screws.

	C2 pedicle screws (n = 51)	C2 translaminar screws (n = 20)	p-value
C1-2 segmental angle			
Preoperative	17.24 ± 11.87	21.26 ± 10.87	0.320
Immediately postoperative	15.37 ± 10.12	14.84 ± 10.46	0.881
Final f/u	15.62 ± 9.35	17.02 ± 9.78	0.668
Time	$P = .006$		
Group	$P = .623$		
Time*group	$P = .191$		
0-C2 segmental angle			
Preoperative	8.26 ± 11.28	10.51 ± 9.82	0.553
Immediately postoperative	6.50 ± 8.33	7.41 ± 9.35	0.756
Final f/u	8.04 ± 10.85	7.99 ± 8.63	0.990
Time	$P = .222$		
Group	$P = .734$		
Time*group	$P = .713$		

f/u = follow up.

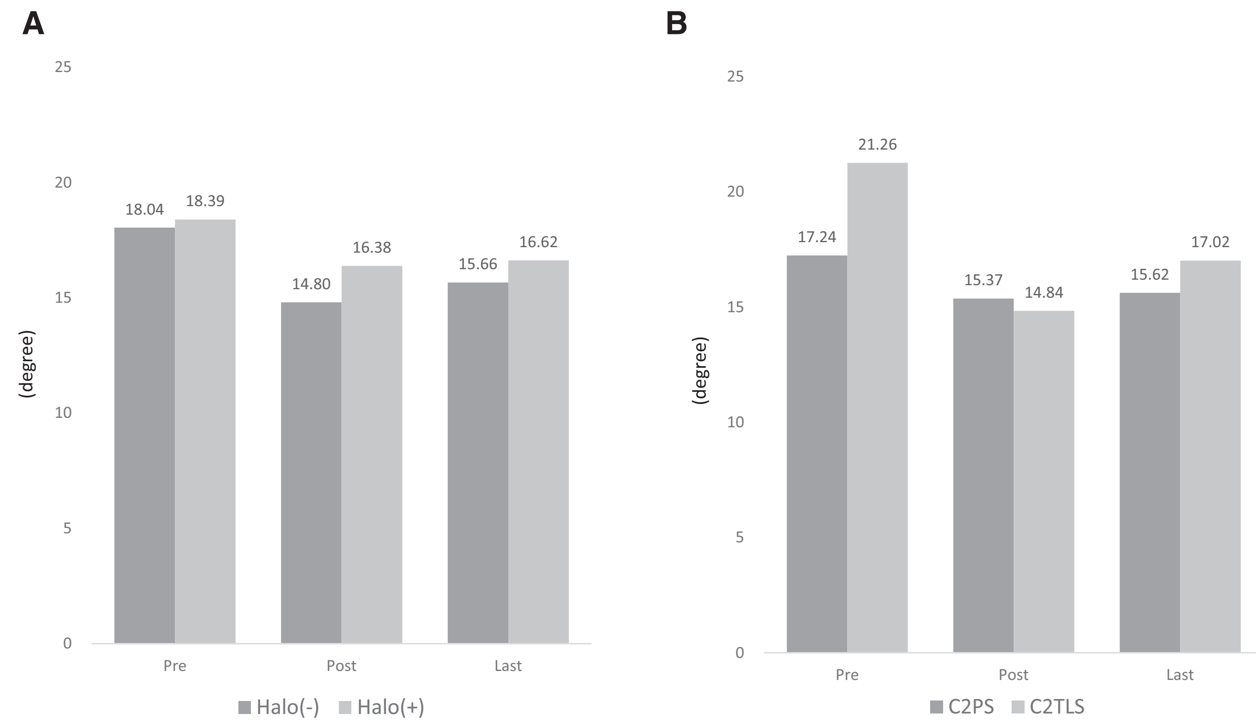

Figure 1. Change in C1-2 segmental angle (°, degrees) over time to evaluate the correction loss of C1-2. A: Comparison of differences with and without screw halo. B: Comparison of differences between the use of C2PS and C2TLS. When C2TLS was used, the correction loss was larger than that when C2PS was used from immediately after surgery to the last follow-up. ΔC2TLS was 2.18° (14.84° – 17.02°) and ΔC2PS was 0.25° (15.37° – 15.62°); however, there was no statistical significance. C2PS, C2 pedicle screw; C2TLS, C2 translaminar screw. C2PS = C2 pedicle screw, C2TLS = C2 translaminar screw.

Table 4

Flexion-extension dynamic segmental angle gap between fusion and fusion failure.

	Total (n = 49)	Fusion (n = 45)	Fusion failure (n = 4)	p-value
C1-2 segmental angle gap	2.35 ± 2.24°	1.99 ± 1.62°	4.37 ± 2.13°	0.008*

*statistically significant

screw halos were observed on CT scans, and the C1-2 SA gap increased to 9.31°. The patient underwent revision surgery, and C2TLS was changed to C2PS. The C1-2 SA gap on the 6-months follow-up dynamic radiograph was 1.55°. Follow-up CT 1 year postoperatively showed a definite screw halo; however, grade 1 posterior bone fusion was successfully achieved (Fig. 3).

4. Discussion

The present study aimed to investigate the definite criteria for radiographic findings to evaluate the achievement of bone fusion after AA instrumentation. The AA segment is a unique joint with a large ROM and a multifaceted motion. Therefore, specific fusion criteria for radiographs, different

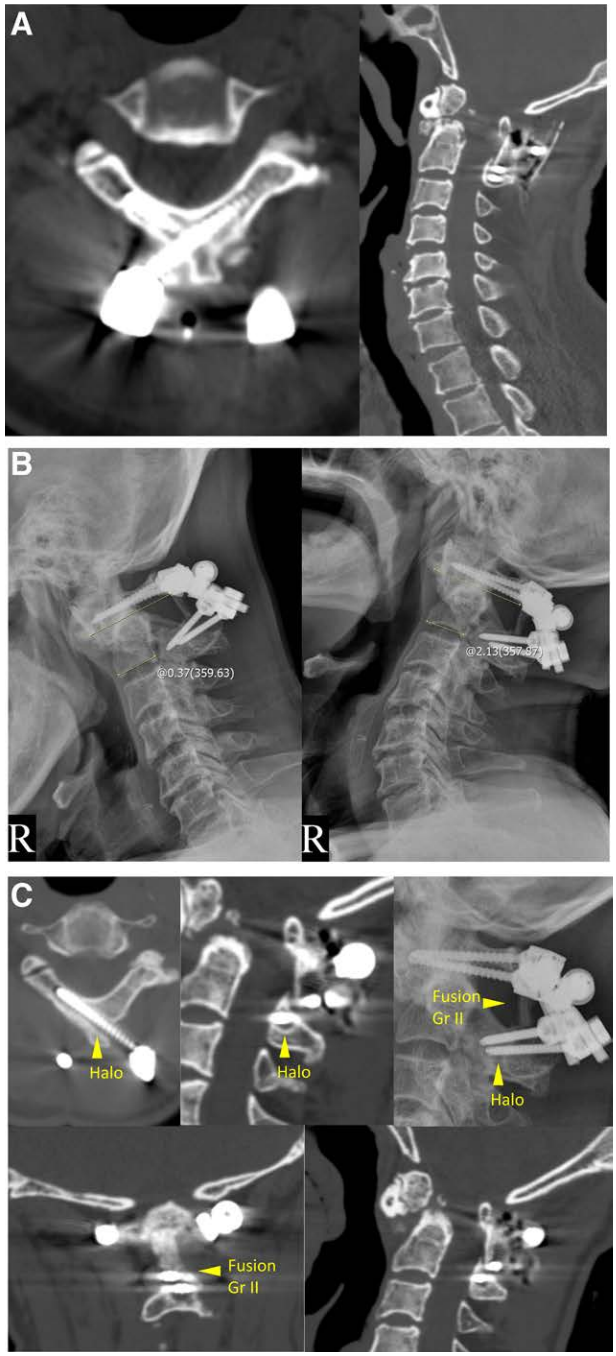

Figure 2. Postoperative follow-up images of a 65-years-old male patient. The patient underwent AA fusion surgery using C2TLS for os odontoideum. A: The screw halo is not visible on CT immediately after surgery. B: 6 months after surgery, the C1-2 segmental angle gap was 1.76° on dynamic X-ray. A screw halo was seen around the C2TLS. C: Follow-up CT at 1 year after surgery. A clear halo around the C2TLS periphery is visible; however, grade 2 posterior fusion was successfully achieved. AA = atlantoaxial, C2TLS = C2 translaminar screw, CT = computed tomography.

from the subaxial cervical spine or thoracolumbar spine, are required. However, the findings of studies about AA fusion have been controversial.[5,12-14] This is the first study to compare plain X-ray images with CT images taken a minimum of 12 (mean 41.6 ± 37.6) months after surgery, which is generally considered the gold standard method for fusion assessment. The results showed that peri-screw lucency that occurs after AA instrumentation might not be indicative of fusion failure.

In addition, we found that fusion failure could be predicted when the C1-2 SA between flexion and extension exceeds 2.62° on dynamic X-ray. The goal of AA surgery is reducing and maintaining the atlantodental interval and odontoid process projection, which are directly related to the clinical outcomes of AA subluxation, instability, and basilar invagination. In other words, the stabilization of the C1-2 SA in flexion-extension motion is a critical factor. Our results suggest that the SA gap as a fusion predictor supports the empirical knowledge of surgeons regarding AA fusion.

Until recently, both the prevalence of loosening (ranging from 1% – 60% in the literature) and its functional prognosis remained unclear.[16,17] Screw loosening is usually a consequence of pseudoarthrosis and may occasionally be associated with screw breakage and loss of correction.[18] Although it has been shown that the appearance of peri-screw lucency significantly decreases the extraction torque of implants, no conclusion can be reached about its clinical significance.[19] Despite a number of clinical studies reporting the rate of loosened screws, there is no clear evidence regarding the real significance of this problem in clinical practice. Moreover, there are no published studies elucidating the meaning of the screw halo, specifically for the AA segment.

Screw loosening occurred at a higher rate in C2TLS than in C2PS. The differences in fusion rates and loss of correction were insignificant. C2TLS is known to have comparable clinical outcomes to those of C2PS. In assessments of the accumulated biomechanical data on C2TLS, it appears that C2TLS performs relatively similarly to C2PS and may outperform C2 pars screws by most biomechanical measures in intact spine models.[13] These in vitro studies are consistent with our surgical results comparing C2PS and C2TLS.

Some inferiorities of C2TLS in biomechanical stability have also been reported. Specifically, it does not provide as much resistance to lateral bending motion as C2PS.[8,10,20] Since the in vitro biomechanical study was not an in vivo study, the clinical significance of those findings remains uncertain.[13] The biomechanical data and studies of bone fusion for AA joint fit into the framework of translational medicine.[21,22] Our findings could help to bridge the gap between basic sciences and clinical implications in this area. One of the characteristics of C2TLS that allowed slight ROM in lateral bending was a higher screw loosening rate. However, since the fixation force of flexion-extension motion was comparable to that of C2PS,[8] it did not lead to a difference in fusion rates and clinical outcomes. Based on previous biomechanical studies and our clinical data, we consider limited flexion-extension motion to be the most critical factor for determining AA fusion. In addition, there was no significant difference between C2PS and C2TLS in repeated-measures ANOVA performed to evaluate the loss of correction over time. The results of this study allow us to explain the clinical significance of the biomechanical properties of C2TLS.

When C2TLS was used, clinical AA stabilization and radiological fusion could be achieved even if ROM in lateral bending remained. The reason for this might be that the degree of motion limitation imposed by AA instrumentation is insignificant compared with flexion-extension or axial rotation. Intact lateral bending ROM is less than intact axial rotation and flexion/extension ROM; therefore, stabilization reduces lateral bending ROM to a relatively lesser extent.[8] We believe this is the reason why C2TLS causes more frequent screw halos that are not related to final AA stabilization.

This study included only patients who received posterior onlay autograft grafts from their posterior superior iliac spines.

Using this homogeneous bone graft method, we compared the fusion rates of C2PS and C2TLS without bias. Allobone and autobone are known to have comparable fusion rates; however, autograft achieved fusion earlier in comparisons up to 12 months prior.[12] Although screw halos were observed in a relatively large proportion of patients (14/49, 28.6%), 91.8% of radiological

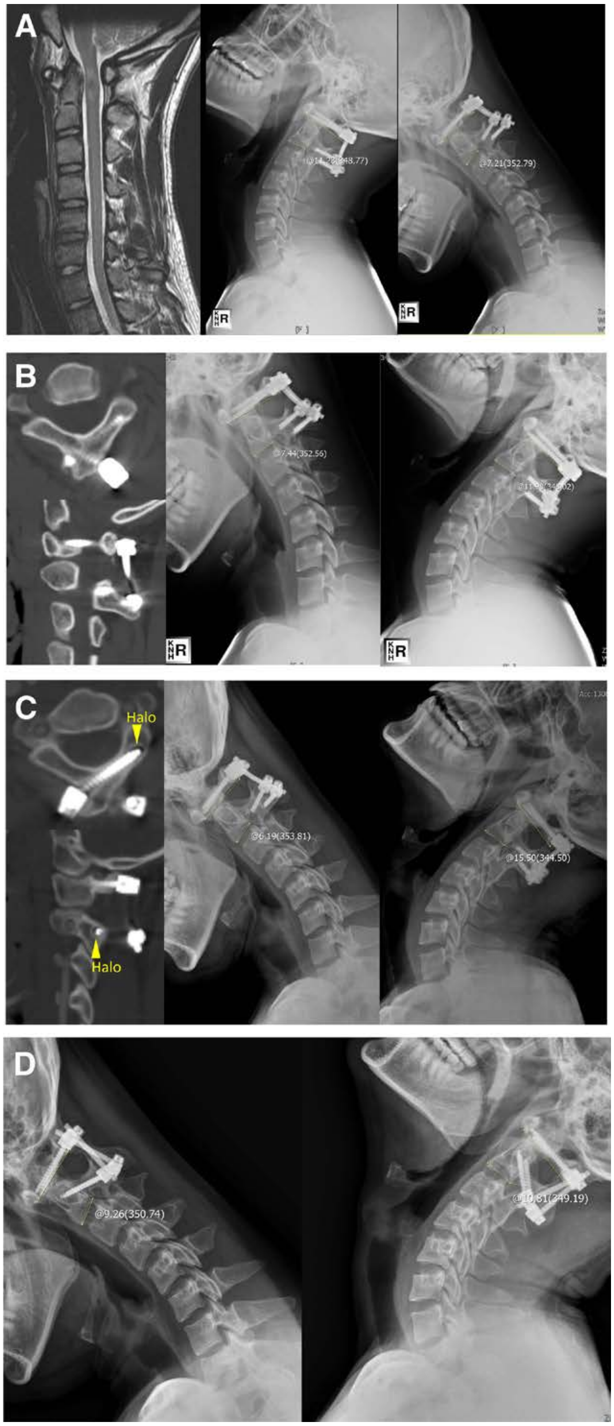

Figure 3. A 17-years-old male patient presented with traumatic C1-2 dislocation with spinal cord injury. A: High signal intensity on the spinal cord at C1-2 level was seen in T2-weighted magnetic resonance imaging before surgery. He underwent AA fusion surgery using C2TLS, and the C1-2 SA gap was 4.02° on dynamic X-ray 6 months after surgery. B: The C1-2 SA gap had increased slightly to 4.54° on dynamic X-ray 2 years after surgery. The screw halo was not seen on CT 2 years after surgery. C: At 4 years and 5 months after surgery, the C1-2 SA gap was 9.31°, and the halo of C2TLS was seen on the CT scan at this time. D: The patient underwent revision surgery, and C2TLS was changed to C2PS. At 6 months after revision surgery, the C1-2 SA gap had decreased significantly to 1.55° on dynamic X-ray. E: One year after reoperation, a C2PS screw halo was seen on CT; however, grade 1 posterior fusion and clinical stabilization were achieved. AA = atlantoaxial, C2TLS = C2 translaminar screw, SA = segmental angle, CT = computed tomography, C2PS = C2 pedicle screw.

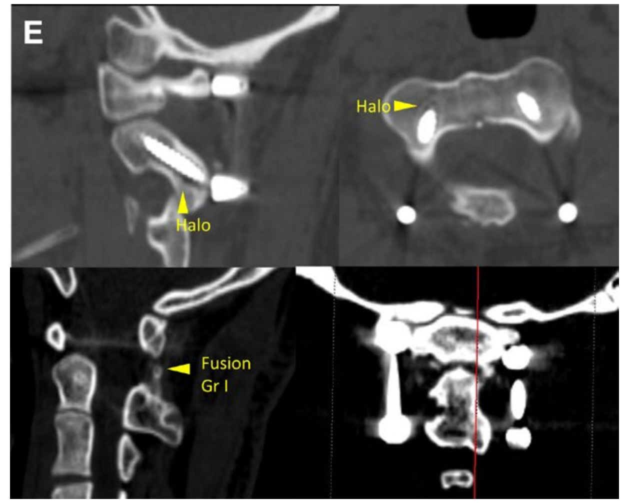

Figure 3. Continued

bone fusion and 95.9% of clinical AA stabilization were possibly achieved due to the use of autobone in all surgeries.

This study has several limitations. First, it had a retrospective observational design, and patient enrollment was not randomized, resulting in a possible selection bias. Second, it was a single institutional study and only included a small number of patients. Furthermore, radiographic measures of subaxial cervical alignment were not addressed. Nevertheless, the present study suggested specific fusion criteria based on radiographic images after AA instrumentation which, to the best of our knowledge, has never been reported before.

5. Conclusion

Compared with C2PS, C2TLS placement was associated with a significantly higher incidence of screw halos. However, there was no difference in the fusion rates of C2PS and C2TLS. Our results suggest that screw halo appearance within 12 months after AA fusion surgery was not associated with fusion failure. AA fusion could be predicted when the C1-2 SA gap was less than 2.62° on the flexion-extension dynamic radiograph.

Author contributions

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