



Original Article

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INTRODUCTION

Atlantoaxial dislocation (AAD) can cause severe neurologic deficit which make patients disabled or neck pain results from kyphosis at upper cervical spine.¹⁻⁶ Pathologies of AAD were various such as trauma, inflammation, congenital anomaly, and iatrogenic causes.¹⁻¹⁰ The treatment of AAD has always been a major concern for spine surgeon. Since transarticular screw fixation and interlamina fusion was introduced by Mergel and Brook, posterior C1-2 fusion has been known as an ef-

Analysis of Associating Radiologic Parameters With Clinical Outcomes After Posterior C1-2 Fusion

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Objective: To evaluate which radiologic parameters affect clinical outcomes in patients underwent posterior C1-2 fusion for atlantoaxial dislocation.

Methods: From January 2014 to December 2017, among 98 patients underwent C1-2 posterior fusion, patients with previous cervical surgery or extending to subaxial spine or basilar invagination were excluded. Finally, 38 patients were included. O-C2, C1-2, C1-C7, C2-C7 Cobb angle (CA), T1 slope, C1-7, C2-7 sagittal vertical axis (SVA), and posterior atlantodental interval (PADI) were measured at preoperative and postoperative 1 year. The difference between postoperative and preoperative values for each parameter was designated as Δ value. Postoperative subaxial kyphosis (PSK) was defined to decrease $\geq 10^\circ$ at subaxial spine. Visual analogue scale (VAS), Japanese Orthopedic Association (JOA) score, Neck Disability Index (NDI) were used to evaluate clinical outcomes.

Results: Mean age was 54.4 ± 15.9 . Male to female was 14 to 24. Of radiologic parameters, C1-7 SVA and PADI were significantly changed from 26.4 ± 12.9 mm, 17.1 ± 3.3 mm to 22.6 ± 13.0 mm, 21.6 ± 3.4 mm. Δ C1-2 CA was correlated with Δ C1-7 CA and Δ C2-7 SVA. Δ PADI correlates with Δ O-C2 CA. VAS correlates with Δ C1-7 CA ($p = 0.03$). JOA score also correlates with Δ C2-7 SVA ($p = 0.02$). NDI was associated with Δ PADI ($p < 0.01$). The incidence of PSK was 23.7%, and not significant with clinical outcomes.

Conclusion: Δ C1-2 CA was correlated with Δ C1C7 CA, Δ C2-7 SVA. Δ C1-7 CA, Δ C2-7 SVA, and Δ PADI were the key radiologic parameters to influence clinical outcomes. Postoperative C1-2 angle should be carefully determined as a factor affecting clinical outcomes and cervical sagittal alignment.

Keywords: Atlantoaxial dislocation, Correlation, Cobb angle, Posterior C1-2 fusion, Subaxial kyphosis, Sagittal vertical axis

fective treatment for AAD.^{11,12} As Ham's technique emerged, cervical polyaxial screw and rod fixation system is widely used because of its simplicity of the technique and low risk of vertebral artery injury.¹³

As these surgical techniques have been popularized, some surgeons gradually interested in postoperative changes in cervical sagittal balance.^{14,15} C1-2 fusion led to reciprocal changes in subaxial spine according to its angle, and it is considered to be an important factor for sagittal alignment in subaxial spine.¹⁶ Moreover, some studies stated that these surgical techniques are

associated with complex cervical deformities such as postoperative regional kyphosis, postoperative subaxial kyphosis (PSK), or hyperlordosis.^{17,18}

Previous studies focused on evaluating the relationship between postoperative C1–2 angle and subaxial sagittal alignment, but there were a few studies stated that the association between postoperative radiologic parameters related with sagittal balance and clinical outcomes.^{19,20} In our study, we analyzed the correlation between radiologic parameters in cervical spine before and after posterior C1–2 fusion. Furthermore, we investigated how these changes in radiologic parameters affect clinical outcomes in patients treated posterior C1–2 fusion.

MATERIALS AND METHODS

1. Patient Selection

A retrospective analysis of medical records and radiologic data was performed on patients that had undergone posterior atlantoaxial fusion for AAD at a single center from January 2014 to June 2017. This study was approved by the Institutional Review Board of Catholic Medical Center (OC21RISI0008). Ninety-eight patients treated by posterior C1–2 fusion during this period. Patients had previous cervical surgery history or concomitant with basilar invagination were excluded. In addition, patients needed additional fusion extension to occipital or subaxial spine were also excluded. Finally, 38 patients were included in the study.

2. Surgical Techniques

The patient was placed in prone position with Mayfield head fixator under general anesthesia. The surgeon reduced C1–2 dislocation as much as possible by adjusting patient's head by flexion or extension while pulling out the Mayfield head fixator. C1–2 reduction was confirmed under the C-arm fluoroscopy. When we cannot achieve acceptable reduction by adjusting patients' position, we usually released C1–2 facet joint in order to reduce dislocation additionally by removing the capsule surrounded it during surgery. C2 roots were preserved by protecting root retractor during the releasing of C1–2 facet. All procedures were performed under intraoperative monitoring (IOM). Vascular anomalies were evaluated preoperatively to avoid neurovascular injury. Atlantoaxial fixation was accomplished using a variety of surgical constructs combined with C1 lateral mass to C2 pedicle screw, C2 pars screw, or to C2 lamina screw fixation. We controlled C1–2 angle by compressing or distracting the interspace between 2 polyaxial screws along the rods. Auto-

graft bone harvested from the posterior superior iliac spine was inserted to the interlaminar space of C1–2 to enhance the fusion. Modified brook's Wiring technique between C1 and C2 lamina was performed to fix the autograft bone and obtain additional biomechanical strength.¹¹ Finally, fluoroscopy was used to confirm the reduction and lordotic angle of C1–2 (Fig. 1).

3. Radiologic Parameters

Two neurosurgeons (JTH and JHP) measured all radiologic parameters on cervical standard lateral radiographs using INFINIT PACS (INFINIT Healthcare, Seoul, Korea) using an electrical caliper on 2 occasions. The 4 sets of radiologic parameters measured were then averaged for statistical analysis. Lateral radiographs were obtained in the neutral head position. A standard distance of 1.8 m was maintained between the tube and patients. The following parameters were measured on radiograph before surgery and at 1 year after surgery.

- C2 cobb angle (CA): The angle between the line connecting McGregor line and the inferior endplate of C2 (Fig. 2A).
- C1–2 cobb angle (CA): The angle between the line connecting the middle point of the anterior and posterior arch of C1 and the inferior endplate of C2 (Fig. 2A).
- C1–7 cobb angle (CA): The angle between the line connecting the middle point of the anterior and posterior arch of C1 and the inferior endplate of C7 (Fig. 2 A).
- C2–7 cobb angle (CA): The angle between the inferior endplate of C2 and C7 (Fig. 2A).
- T1 slope: The angle between horizontal line and the T1 superior endplate. (Fig. 2A).
- C1–7 sagittal vertical axis (SVA): The distance between the plumb line from the anterior margin of C1 and posterior superior corner of C7 (Fig. 2B).
- C2–7 sagittal vertical axis (SVA): The distance between the plumb line from the center of C2 and the posterior superior corner of C7 (Fig. 2B).
- Posterior atlantodental interval (PADI): The distance between the line connecting the middle point of the anterior and posterior arch of C1 and the dens of C2 (Fig. 2B).

The difference between preoperative and postoperative values for each parameter was designated as the Δ value.

PSK was defined as the postoperative change of $\geq 10^\circ$ at C2–7 CA.

4. Clinical Outcomes

Clinical outcomes were assessed using visual analogue scale (VAS) for neck pain, Neck Disability Index (NDI)²¹ and Japa-

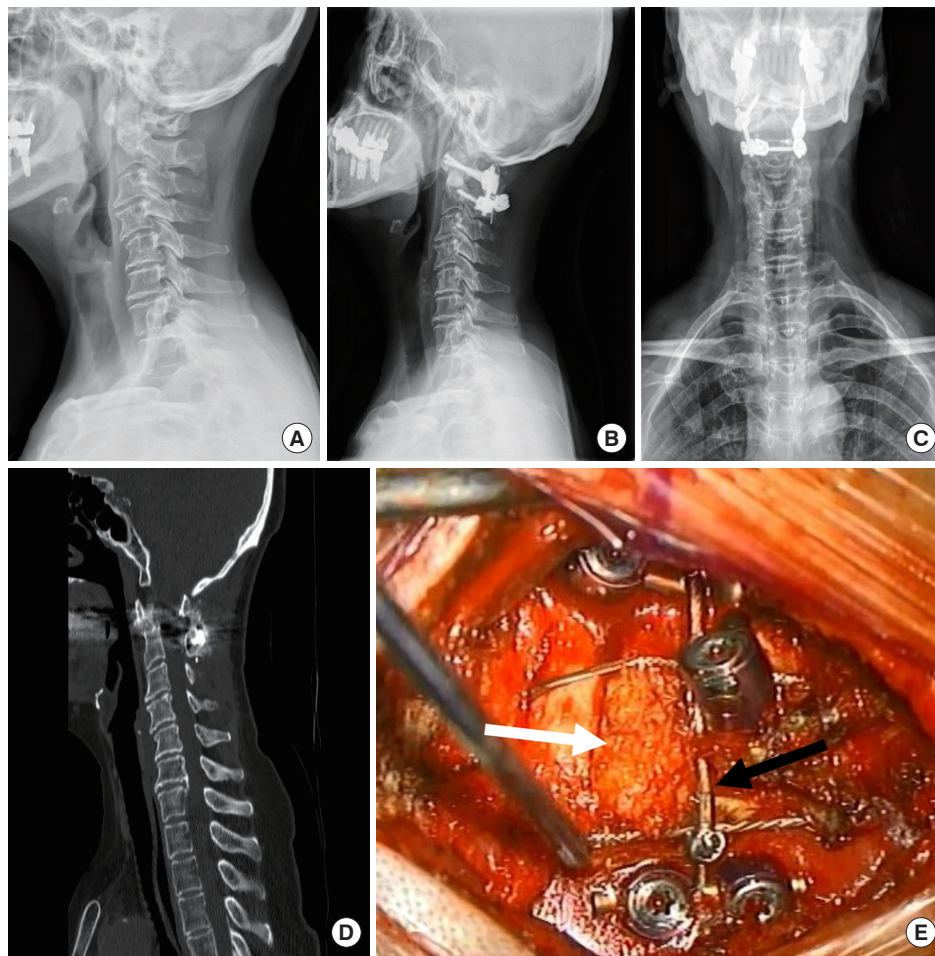


Fig. 1. Radiologic and surgical figures of the patient treated by C1 lateral mass–C2 pars and lamina screw construct wiring interlamina with autograft bone. Preoperative lateral (A) and postoperative lateral (B) and anteroposterior (C) radiographs. (D) Mid-sagittal image of computed tomography after surgery. (E) Intraoperative figure represents wiring interlamina (black arrow) with an autograft bone (white arrow).

nese Orthopedic Association (JOA) scores²² at preoperative and postoperative one year. Improvements in VAS and NDI scores were also expressed as the difference between postoperative and preoperative values. The Δ value was used for the difference between postoperative and preoperative values for each parameter.

5. Statistical Analysis

The Student t-test, the paired t-test, and Mann-Whitney U-test were used to analyze continuous and ordinal variables, as appropriate. Correlation test and a linear logistic regression model were used to evaluate the natures of correlations between the radiologic parameters and clinical outcome. p-values of <0.05 (2-tailed) were considered statistically significant, and IBM SPSS Statistics ver. 20.0 (IBM Co., Armonk, NY, USA) was used for the statistical analysis. The intra-inter reliabilities of radiologic parameters were calculated. Intraclass correlation coef-

ficient values were rated as follows: 0 to 0.2 slight agreement, 0.21 to 0.4 fair agreement, 0.41 to 0.6 moderate agreement, 0.61 to 0.8 substantial agreement, and 0.81 to 1.0 excellent agreement.

RESULTS

Clinical information is summarized in Table 1. There were 14 males and 24 females of mean age 54.4 ± 15.9 years and mean body mass index 23.3 ± 3.6 kg/m². Mean height and weight were 1.6 ± 0.1 m and 59.6 ± 10.8 kg. Twenty patients (52.6%) had rheumatoid arthritis (RA), 11 (29%) had a congenital anomaly, and 7 (18.4%) had degenerative spondylosis as pathologies for AAD. Fourteen patients were fixed with C1 lateral mass –C2 pedicle screw construct, 4 with C1 lateral mass –C2 hybrid construct, and 20 with C1 lateral mass –C2 pars con-

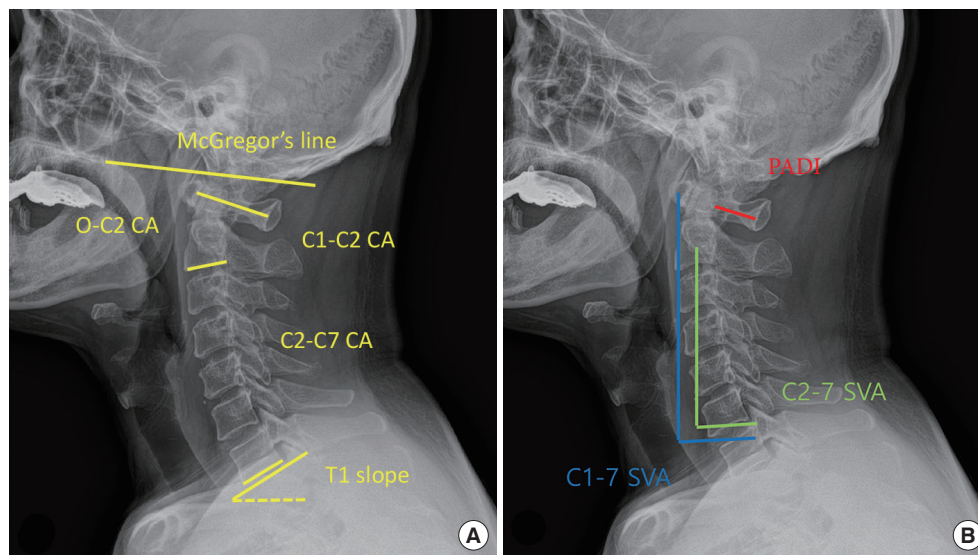


Fig. 2. Radiologic parameters on a cervical lateral plain radiograph in patient with atlantoaxial dislocation. (A) O–C2, C1–2, C1–7, C2–7, T1 slope are measured between the lines on cervical lateral plain radiograph. (B) C1–7 (blue line), C2–C7 sagittal vertical axis (SVA; green line), and posterior atlantodental interval (PADI; red line) are measured on cervical lateral plain radiograph. CA, Cobb angle.

Table 1. Clinical information of the 38 patients with atlantoaxial dislocation

Characteristic	Value
Sex	
Male	14 (36.8)
Female	24 (63.2)
Age (yr)	54.4 ± 15.9
Body mass index (kg/m ²)	23.3 ± 3.6
Height (m)	1.6 ± 0.1
Weight (kg)	59.6 ± 10.8
Pathology (%)	
Spondylosis	7 (18.4)
Rheumatoid arthritis	20 (52.6)
Congenital anomaly	11 (29)
C1–2 constructs (%)	
Lateral mass-pedicle screws	14 (36.8)
Lateral mass-hybrid screws	4 (10.5)
Lateral mass-pars screws	20 (52.6)
Reducibility	
Irreducible AAD	2 (5.3)
Reducible AAD	36 (94.7)
Decompression	
Direct	2 (5.3)
Indirect	36 (94.7)

Values are presented as number (%) or mean ± standard deviation. Hybrid screws, C2 pedicle–pars or translaminar screws; AAD, atlantoaxial dislocation.

Table 2. Comparison of preoperative and postoperative radiologic parameters

Radiologic measurement	Preoperative	Postoperative	p-value
O–C2 CA (°)	11.3 ± 8.6	12.8 ± 6.9	0.175
C1–2 CA (°)	18 ± 11.2	19.5 ± 6.2	0.402
C1–7 CA (°)	35 ± 11.1	33.4 ± 10.6	0.471
C2–7 CA (°)	16.9 ± 10.3	14.0 ± 10.2	0.087
T1 slope (°)	19.9 ± 8.7	19.2 ± 7.2	0.523
C1–7 SVA (mm)	26.4 ± 12.9	22.6 ± 13	0.032*
C2–7 SVA (mm)	11.8 ± 12.1	14.4 ± 10.6	0.141
PADI (mm)	17.1 ± 3.3	21.6 ± 3.4	<0.001*

CA, Cobb angle; SVA, sagittal vertical axis; PADI, posterior atlantoaxial interval.

*p < 0.05, statistical significance.

struct. Two patients were irreducible AAD, then we performed to release of C1–2 facet joint during surgery. There were no patients need anterior approaches for additional decompression. Thirty-six patients were reducible AAD and obtained sufficient reduction of C1–2 dislocation by pushing down the spinous of C2 during connecting the rod. Two patients needed C1 laminectomy for decompression, we usually inserted autograft bone chip into released C1–2 facet joint for using fusion-bed. The remaining 36 patients, only indirect decompression obtained the reduction of atlantoaxial joint was enough.

Table 3. Reciprocal relationship of the difference between preoperative and postoperative radiologic measurements

Radiologic measurements	$\Delta O-C2$ CA	$\Delta C1-2$ CA	$\Delta C1-7$ CA	$\Delta C2-7$ CA	$\Delta T1$ slope	$\Delta C1-7$ SVA	$\Delta C2-7$ SVA	$\Delta PADI$
$\Delta O-C2$ CA	1.000	0.561*	0.128	-0.403*	-0.102	0.065	0.225	0.561*
$\Delta C1-2$ CA	0.561*	1.000	0.624*	-0.225	0.058	0.241	0.384*	0.001
$\Delta C1-7$ CA	0.128	0.624*	1.000	0.621*	0.357*	-0.239	-0.141	-0.203
$\Delta C2-7$ CA	-0.403*	-0.225	0.621*	1.000	0.387*	-0.540*	-0.561*	-0.253
$\Delta T1$ slope	-0.102	0.058	0.357*	0.387*	1.000	0.171	0.197	-0.069
$\Delta C1-7$ SVA	0.065	0.241	-0.239	-0.540*	0.171	1.000	0.953*	0.054
$\Delta C2-7$ SVA	0.225	0.384*	-0.141	-0.561*	0.197	0.953*	1.000	0.099
$\Delta PADI$	0.561*	0.001	-0.203	-0.253	-0.069	0.054	0.099	1.000

CA, Cobb angle; SVA, sagittal vertical axis; PADI, posterior atlantodental interval.

* $p < 0.05$, statistical significance.

1. Radiologic Parameters

Radiologic parameters obtained at preoperative and postoperative are summarized in Table 2. The difference between preoperative and postoperative each CA except C1–7 SVA and PADI was not significant because the values of each CA in some patients were counteracted for each other when analyzing all of the values together. This feature may contribute to small difference between preoperative and postoperative each CA, and it was not significant. T1 slope seemed unchanged statistically at postoperative for the same reason. C1–7 SVA showed a tendency to decrease from 26.4 ± 12.9 to 22.6 ± 13 at postoperative ($p = 0.03$). C2–7 SVA showed slight increase at postoperative, but it was not significant. PADI dramatically increased about 4.5 mm comparing to preoperative value ($p < 0.01$). The intra- and intercorrelations of radiologic parameters were 0.94 and 0.88, respectively. Measurements of radiologic parameters showed excellent degree of agreement.

Correlations between radiologic parameters are presented in Table 3. $\Delta O-C2$ CA correlated positively with $\Delta C1-2$ CA and $\Delta PADI$, and negatively with $\Delta C2-7$ CA. $\Delta C1-2$ CA correlated positively with $\Delta C1-7$ CA and $\Delta C2-7$ SVA. $\Delta C1-7$ CA correlated positively with $\Delta C2-7$ CA and $\Delta T1$ slope. $\Delta C2-7$ CA correlated positively with $\Delta T1$ slope and negatively with $\Delta C1-7$ SVA and $\Delta C2-7$ SVA. $\Delta C1-7$ SVA correlated positively with $\Delta C2-7$ SVA.

2. Clinical Outcomes

VAS, NDI, and JOA score improved significantly at postoperative. Mean VAS decreased from 5.1 ± 2.9 to 1.7 ± 1.6 ($p < 0.01$). Mean JOA scores increase from 13.2 ± 2.7 to 15.3 ± 2.6 ($p = 0.02$). Mean NDI decreased from 22.2 ± 11.0 to 6.7 ± 5.8 ($p < 0.01$). However, 3 patients deteriorated neck pain at postoperative.

One patient suffered severe neck pain at VAS 9. The patient showed that reciprocal kyphotic change from 34° to 1.5° in subaxial spine after surgery. The other presented neck pain at VAS 4. The patient represented slight change of $\Delta C2-7$ CA from 32.5° to 34.4° , but we failed to make lordotic C1–2 angle (from 4.5° to 4.8°) intraoperatively. Another complained neck pain VAS 5. The patient also showed that reciprocal kyphotic change from 10.9° to 2.2° in subaxial spine even though we made kyphotic C1–2 angle from 22.2° to 13.1° . This patient complained neck pain and developed subaxial kyphosis although we tried to underreduce C1–2 angle.

3. Relationship Between Radiologic Parameters and Clinical Outcomes

VAS, NDI, JOA score were associated with several radiologic parameters. ΔVAS correlated with $\Delta C1-7$ CA, $\Delta T1S$ negatively ($r = -0.357$, $p = 0.03$, $r = -0.341$, $p = 0.04$). ΔNDI correlated with $\Delta PADI$ negatively ($r = -0.499$, $p = 0.01$). ΔJOA score correlated with $\Delta C2-7$ SVA positively ($r = 0.354$, $p = 0.03$). In linear logistic regression, $\Delta C1-7$ CA represented negatively linear correlation with ΔVAS , $\Delta PADI$ also showed negatively linear correlation with ΔNDI , $\Delta C2-7$ SVA represented positively linear correlation with ΔJOA score, respectively (Fig. 3).

The incidence of PSK was 23.7%, it was not significantly associated with VAS ($p = 0.26$), NDI ($p = 0.32$), JOA score ($p = 0.97$).

DISCUSSION

Atlantoaxial fusion is frequently associated with sagittal realignment in subaxial spine, and many authors stated the negative correlation between $\Delta C1-2$ CA and $\Delta C2-7$ CA after sur-

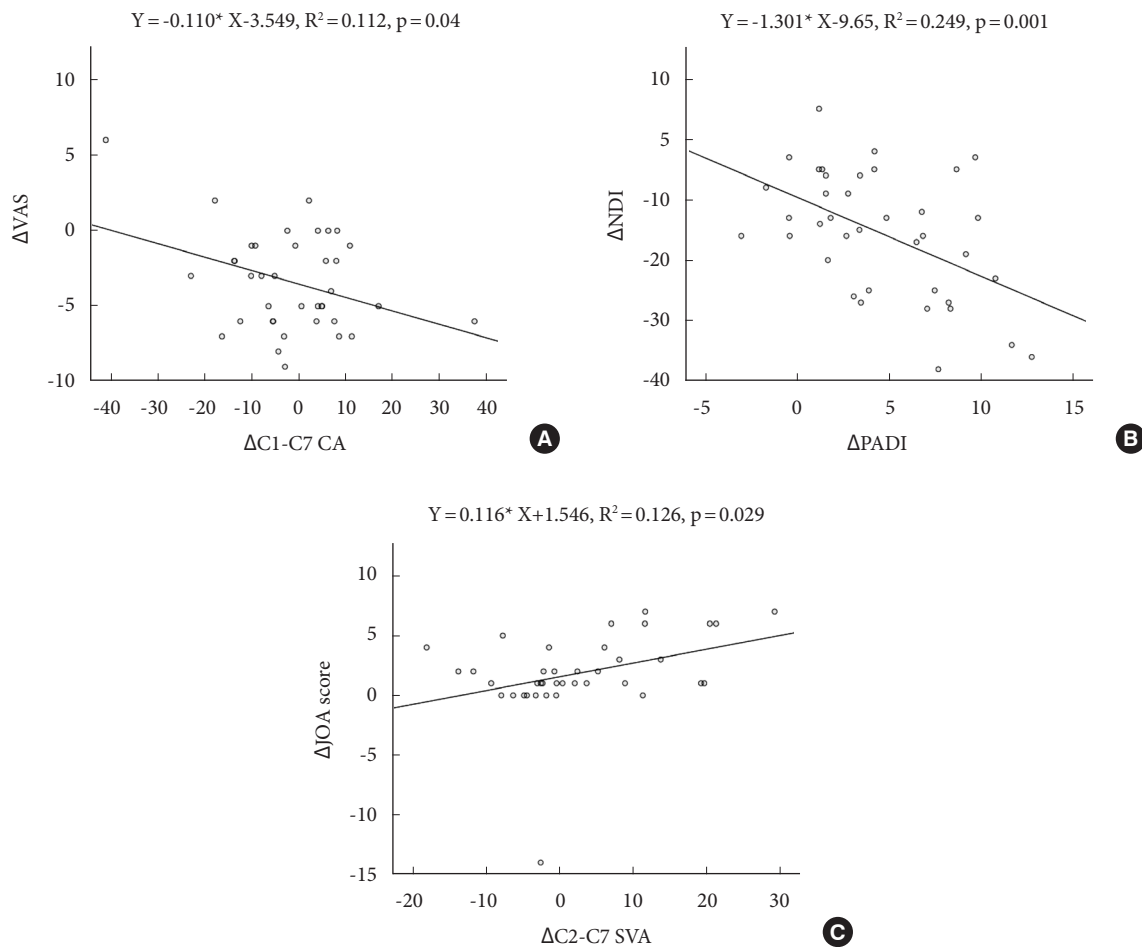


Fig. 3. Linear logistic regression plots between radiologic parameters and clinical outcomes. A linear correlation with $\Delta C1-7$ CA (A), ΔVAS a linear correlation with $\Delta PADI$ (B) and ΔNDI a linear correlation with $\Delta C2-7$ SVA and ΔJOA score (C). CA, Cobb angle; VAS, visual analogue scale; PADI, posterior atlantodental interval; NDI, Neck Disability Index; SVA, sagittal vertical axis; JOA, Japanese Orthopedic Association. Asterisk (*) means multiple.

gery.^{14,15,17,18} However, we observed different results of correlation between $\Delta C1-2$ CA and $\Delta C2-7$ CA. Postoperative sagittal realignment in subaxial spine was occurred in our study. However, the reciprocally negative correlation between $\Delta C1-2$ and $\Delta C2-7$ CA wasn't found although preoperative C1–2 and C2–7 CA represented the negative correlation each other. We found that the reciprocally negative correlation between $\Delta O-C2$ and $\Delta C2-7$ CA, instead of $\Delta C1-2$ CA. We studied why this phenomenon happened in our study unlike other studies. First, $\Delta C1-2$ CA was compensated by $\Delta C2-7$ CA as well as $\Delta O-C1$ CA to maintain the horizontal gaze. The preoperative range of motion (ROM) of C1–2 angle in normal people has about 6° when flexion and extension,²³ and compensate for the change of subaxial spine in available ROM. However, postoperative C1–2 angle is fixed after surgery, and it plays the constant no room to change. It seems that the O–C1 angle plays as a buffer

angle to maintain the horizontal gaze. $\Delta C2-7$ CA was compensated by $\Delta O-C1$ CA instead of the constant C1–2 angle. It seems that postoperative C1–2 CA as the constant does not work on cervical sagittal realignment. $\Delta O-C2$ CA was actually the parameter obtained by adding a constant to $\Delta O-C1$ CA. Therefore, $\Delta O-C2$ CA was correlated with $\Delta C2-7$ CA negatively, not $\Delta C1-2$ CA excluding $\Delta O-C1$ CA. Second, we observed a radiologic feature of patients in this study. The ratio of C1–2 CA and C2–7 CA was different to normal ranged patients. Some authors stated that normal values of C1–2 angle ranged from 25.6° to 28.9° and it accounted for 75%–80% of cervical standing lordosis.^{24,25} However, our patients showed the proportion of cervical lordosis of C1–2 CA was about 52.5%, suggesting that C1–2 CA constitutes a relatively small proportion of cervical lordosis, and the proportion of C2–7 CA is predominant in cervical lordosis compared with others. Therefore,

$\Delta C2-7$ CA is increased relatively compared to other studies. There is the possibility that this feature might contribute that the reciprocal correlation between $\Delta C1-2$ and $\Delta C2-7$ CA was not significant.

The correlation of each radiologic parameter was summarized in Table 3. The important findings of this correlation test is described to 3 things. One thing is that the change of upper cervical spine ($\Delta O-C2$ CA) is correlated with the change of subaxial cervical spine ($\Delta C2-C7$ CA) and this relationship does not be affected before and after surgery. Second thing is that $\Delta C1-2$ CA is associated with cervical kyphosis and flattening of cervical curvature. Third thing is that $\Delta C2-7$ CA is a subjective radiologic parameter affected by various radiologic parameters.

$\Delta C1-2$ CA was associated with $\Delta O-C2$, $\Delta C1-7$ CA, and $\Delta C2-7$ SVA. Moreover, $\Delta C1-7$ CA was negatively correlated with ΔVAS (Fig. 3A). Therefore, it can be expected if $\Delta C1-7$ CA decreased after surgery, neck pain would be unchanged or worse. In addition, $\Delta C2-7$ SVA had a positive correlation with ΔJOA score (Fig. 3C). Therefore, cervical sagittal alignment is significantly related to neck pain as well as cervical myelopathy. Some studies supported our results. Shimizu et al.²⁶ found that a significant correlation between the degree of cervical kyphosis and the amount of cord flattening leading to decreased vascular supply. Cervical sagittal malalignment is strongly related with neck pain. Tang et al.²⁷ also reported that C2–7 SVA directly correlated with NDI and cervical myelopathy. As a result, intraoperative C1–2 angle determined by surgeon was an important factor to affect not only cervical sagittal realignment but also VAS and JOA score.

$\Delta C1-7$ CA was associated with $\Delta C1-2$ CA, $\Delta C2-7$ CA, $\Delta T1$ slope. This correlation is taken for granted that C1–7 CA was the parameter including C1–2 and C2–7 CA. $\Delta T1$ slope was changed according to $\Delta C1-7$ CA.

$\Delta C2-7$ CA also correlated with $\Delta O-C2$ CA, $\Delta C1-7$ CA, $\Delta T1$ slope, $\Delta C1-7$ SVA, and $\Delta C2-7$ SVA. It was the most subjective radiologic parameter that was correlated with various others and also associated with VAS and JOA score such like $\Delta C1-2$ CA. Nevertheless, surgeons can adjust $\Delta C1-2$ CA as determining intraoperative C1–2 CA under C-arm fluoroscopy, but $\Delta C2-7$ CA cannot be controlled intraoperatively and be predicted during follow-up. Therefore, surgeons should carefully observe the change of C2–7 CA in the patient after posterior C1–2 fusion.

$\Delta T1$ slope was relative with $\Delta C1-7$ CA, $\Delta C2-7$ CA. This change in T1 slope explains that $\Delta T1$ slope was complementary

to the change of cervical spine.

$\Delta C2-7$ SVA was correlated with $\Delta C1-2$ CA, $\Delta C2-7$ CA, $\Delta C1-7$ SVA, JOA score. $\Delta C2-7$ SVA was affected simply not only $\Delta C2-7$ CA, but also $\Delta C1-2$ CA. $\Delta C1-7$ SVA was correlated with $\Delta C2-7$ SVA each other. However, $\Delta C1-7$ SVA showed the difference to $\Delta C2-7$ SVA in that there was not correlated with $\Delta C1-2$ CA. This different point interestingly affected that $\Delta C1-7$ SVA was not significant with JOA score.

$\Delta PADI$ correlates with $\Delta O-C2$ CA, and it was a factor associated with ΔNDI . $\Delta PADI$ increased significantly after surgery, it pointed out that most patients obtained enough reduction of AAD intraoperatively. This point explained why the reduction of AAD is important in the improvement of quality of life. Several Authors emphasized the importance of enough reduction of AAD, but this was still controversial. Jun et al.²⁸ suggested that complete reduction of AAD could obviate the need for direct decompression. Goel and Shah²⁹ introduced that facet manipulation and fixation in irreducible AAD facilitated reduction of AAD. Otherwise, Wang et al.³⁰ stated that sufficient decompression by laminectomy and solid fusion for AAD is more important than complete reduction for treatment of AAD. Lang et al.³¹ also reported that incompletely reduced AAD had comparable clinical outcomes with those with complete reduction. Nevertheless, complete reduction of AAD without laminectomy can provide patients with sufficient fusion-bed for bone graft. Because of this advantage, we removed the capsule of C1–2 facet joint and distracted the facet joint by osteotome to release sufficiently in case of irreducible AAD. Finally, we obtained sufficient reduction of AAD in 94.7% of patients except 2 cases performed C1 laminectomy.

The PSK that occurred 23.7% of patients was not correlated with clinical outcomes. There are some studies that PSK was one of causes for postoperative neck pain.³² We also agree that neck pain was associated with PSK. In the present study, patients with PSK showed the tendency to complain of severe neck pain. However, deterioration of neck pain was also observed in patients without PSK in our study. This point resulted in the failure to prove the statistical significance that PSK is related with neck pain. Yoshimoto et al.¹⁸ also observed similar results of ours. The author stated that 12 patients among 44 patients without any progression of PSK complained neck pain aggravated after surgery. For this reason, there was no significance found between PSK and clinical outcomes.

Several studies reported the PSK between the changes in subaxial alignment and intraoperative C1–2 angle.^{17,18,33} Toyama³⁴ investigated 75 cases of interlaminar bone grafting with wiring

and reported that straight, kyphotic, and swan neck deformities occurred after surgery and recommended that the optimum postoperative C1–2 CA is 20°. Kato et al.³⁵ also recommended that the optimum postoperative C1–2 CA should be 20° in patients with the preoperative C1–2 angle of 0°–20° or <0°, but perform an in situ angle in patients with a C1–2 angle of ≥20°. Some authors stated that surgical overreduction of C1–2 CA would be associated with PSK instead of optimal C1–2 angle.^{34–36} These statements will be useful to recover the lordosis of subaxial spine and decrease the kyphosis of subaxial spine postoperatively. However, there is no consensus for optimal C1–2 fusion angle because physiological cervical sagittal alignment is different individually. The understanding of postoperative sagittal alignment is still insufficient. PSK is the result from multiple factors associative with cervical sagittal realignment such as age, postoperative C1–2 angle, the extent of surgical dissection, compensation of adjacent segmental angle. Therefore, it is careful to define the optimal postoperative C1–2 CA. Nevertheless, there are several things that spine surgeon should pay attention to obtain better clinical outcomes during surgery. At first, most patients with AAD have kyphotic C1–2 angle, and it is important that kyphotic C1–2 angle change to physiological lordotic angle. It is because a decrease in the C1–2 and C0–2 angle may likely induce a reduction in the pharyngeal space and can be a predictor of postoperative dysphagia, which is not compensated by the middle or lower cervical spine. At second, it is difficult to adjust C1–2 angle to target angle intraoperatively. We tried to fix postoperative C1–2 CA to 20° under C-arm fluoroscopy, but in some patients C1–2 CA were fixed more or less than 20°. Therefore, the greatest care must be taken to determine C1–2 fixation angle during surgery. Finally, C1 slope should be posteriorly slanted. It is not only because posteriorly slanted C1 slope is important to maintain the C1–2 segment lordosis, but also because the posteriorly slanted C1 slope and kyphotic angulation of the C0–1 segment allows some degree of freedom for neck extension as the space between the occiput and C1 posterior arch and allows some rooms for upper cervical extension to prevent the collision of occiput and implant.

The weaknesses of this study are its retrospective design and small sample size. In addition, patients had various pathologies, which included RA, congenital anomalies, and osteoarthritis. This study included 2 irreducible AAD patients. We performed the releasing of C1–2 facet in these patients, but we could not obtain sufficient reduction of AAD, which may have made a different sagittal realignment comparing to other patients. Moreover, C1–2 constructs for posterior fusion was not mo-

notonous, it composed of hybrid structures such like C2 pedicle, lamina, and pars screws. Although we compressed or distracted the rod under C-arm fluoroscopy to control appropriate C1–2 CA, some patients obtained postoperative C1–2 CA showed a large deviation around 20°. Patient numbers 6 and 36 obtained kyphotic C1–2 angle of 4.8° and 9.4°. Patient numbers 12 and 38 obtained lordotic C1–2 angle of 34.3° and 36°. It is difficult for us to adjust intraoperative C1–2 CA closely as looking images in C-arm fluoroscopy. Finally, the long-term radiographic and clinical outcomes more than one year were not evaluated in the present study.

CONCLUSION

Δ C1–7 CA, Δ C2–7 SVA, and Δ PADI were the key radiologic parameters to influence clinical outcomes. Postoperative C1–2 angle relative to Δ C1–7 CA and Δ C2–7 SVA should be carefully determined as improving individual's pain and neurologic improvement. Indirect decompression obtained by reduction of AAD is also important to increase Δ PADI and then decrease NDI.

NOTES

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REFERENCES

1. Hong JT, Jang WY, Kim IS, et al. Posterior C1 stabilization using superior lateral mass as an entry point in a case with vertebral artery anomaly: technical case report. *Neurosurgery* 2011;68:246-9; discussion 249.
2. Hong JT, Takigawa T, Udayakumar R, et al. Biomechanical effect of the C2 laminar decortication on the stability of C2 intralaminar screw construct and biomechanical compari-

- son of C2 intralaminar screw and C2 pars screw. *Neurosurgery* 2011;69:ons1-6; discussion ons6-7.
3. Jo KW, Park IS, Hong JT. Motion-preserving reduction and fixation of C1 Jefferson fracture using a C1 lateral mass screw construct. *J Clin Neurosci* 2011;18:695-8.
 4. Kim IS, Hong JT, Jang WY, et al. Surgical treatment of os odontoideum. *J Clin Neurosci* 2011;18:481-4.
 5. Hong JT, Kim IS, Kim JY, et al. Risk factor analysis and decision-making of surgical strategy for V3 segment anomaly: significance of preoperative CT angiography for posterior C1 instrumentation. *Spine J* 2016;16:1055-61.
 6. Kim MS, Kim JY, Kim IS, et al. The effect of C1 bursting fracture on comparative anatomical relationship between the internal carotid artery and the atlas. *Eur Spine J* 2016;25:103-9.
 7. Takigawa T, Simon P, Espinoza Orías AA, et al. Biomechanical comparison of occiput-C1-C2 fixation techniques: C0-C1 transarticular screw and direct occiput condyle screw. *Spine (Phila Pa 1976)* 2012;37:E696-701.
 8. Lee HJ, Hong JT, Kim IS, et al. Analysis of measurement accuracy for craniovertebral junction pathology : most reliable method for cephalometric analysis. *J Korean Neurosurg Soc* 2013;54:275-9.
 9. Kim IS, Hong JT, Kim MS, et al. Occipitocervical collision after C1-C2 fusion. *Spine J* 2014;14:1798-9.
 10. Hong JT. human craniovertebral alignment as a "tertiary curvature". *Neurospine* 2019;16:251-4.
 11. Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by the wedge compression method. *J Bone Joint Surg Am* 1978;60:279-84.
 12. Suchomel P, Stulík J, Klézl Z, et al. Transarticular fixation of C1-C2: a multicenter retrospective study. *Acta Chir Orthop Traumatol Cech* 2004;71:6-12.
 13. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. *Spine (Phila Pa 1976)* 2001;26:2467-71.
 14. Toyama Y, Matsumoto M, Chiba K, et al. Realignment of postoperative cervical kyphosis in children by vertebral remodeling. *Spine (Phila Pa 1976)* 1994;19:2565-70.
 15. Mukai Y, Hosono N, Sakaura H, et al. Sagittal alignment of the subaxial cervical spine after C1-C2 transarticular screw fixation in rheumatoid arthritis. *J Spinal Disord Tech* 2007;20:436-41.
 16. Nojiri K, Matsumoto M, Chiba K, et al. Relationship between alignment of upper and lower cervical spine in asymptomatic individuals. *J Neurosurg* 2003;99(1 Suppl):80-3.
 17. Oshima S, Sudo H, Ito M, et al. Subaxial sagittal alignment after atlantoaxial fixation techniques. *J Spinal Disord Tech* 2015;28:E49-55.
 18. Yoshimoto H, Ito M, Abumi K, et al. A retrospective radiographic analysis of subaxial sagittal alignment after posterior C1-C2 fusion. *Spine (Phila Pa 1976)* 2004;29:175-81.
 19. Zhong J, Pan Z, Chen Y, et al. Postoperative cervical sagittal realignment improves patient-reported outcomes in chronic atlantoaxial anterior dislocation. *Oper Neurosurg (Hagerstown)* 2018;15:643-50.
 20. Choi DH, Lee SG, Yoo CJ, et al. Sagittal alignment correlates with the C1-C2 fixation angle and functional outcome after posterior atlantoaxial fixation for traumatic atlantoaxial instability. *J Clin Neurosci* 2019;66:19-25.
 21. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther* 1991;14:409-15.
 22. Association JO. Scoring system for cervical myelopathy. *Nippon Seikeigeka Gakkai Zasshi* 1994;68:490-503.
 23. Kang J, Chen G, Zhai X, et al. In vivo three-dimensional kinematics of the cervical spine during maximal active head rotation. *PLoS One* 2019;14:e0215357.
 24. Sherekar SK, Yadav YR, Basoor AS, et al. Clinical implications of alignment of upper and lower cervical spine. *Neuro India* 2006;54:264-7.
 25. Hardacker JW, Shuford RE, Capicotto PN, et al. Radiographic standing cervical segmental alignment in adult volunteers without neck symptoms. *Spine (Phila Pa 1976)* 1997;22:1472-80; discussion 1480.
 26. Shimizu K, Nakamura M, Nishikawa Y, et al. Spinal kyphosis causes demyelination and neuronal loss in the spinal cord: a new model of kyphotic deformity using juvenile Japanese small game fowls. *Spine (Phila Pa 1976)* 2005;30:2388-92.
 27. Tang JA, Scheer JK, Smith JS, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. *Neurosurgery* 2012;71:662-9; discussion 669.
 28. Jun BY. Complete reduction of retro-odontoid soft tissue mass in os odontoideum following the posterior C1-C2 transarticular screw fixation. *Spine (Phila Pa 1976)* 1999;24:1961-4.
 29. Goel A, Shah A. Atlantoaxial facet locking: treatment by facet manipulation and fixation. Experience in 14 cases. *J Neurosurg Spine* 2011;14:3-9.
 30. Wang L, Gu Y, Chen L, et al. Surgery for chronic traumatic atlantoaxial dislocation associated with myelopathy. *Clin*

- Spine Surg 2017;30:E640-7.
31. Lang Z, Tian W, Liu B, et al. Posterior C1-C2 transarticular screw fixation for atlantoaxial instability assisted by intraoperative 3-dimensional fluoroscopy-based navigation. *Zhonghua Yi Xue Za Zhi* 2013;93:2296-300.
 32. Villavicencio AT, Babuska JM, Ashton A, et al. Prospective, randomized, double-blind clinical study evaluating the correlation of clinical outcomes and cervical sagittal alignment. *Neurosurgery* 2011;68:1309-16; discussion 1316.
 33. Matsumoto M, Chiba K, Nakamura M, et al. Impact of interlaminar graft materials on the fusion status in atlantoaxial transarticular screw fixation. *J Neurosurg Spine* 2005;2:23-6.
 34. Toyama Y. The optimum position of fusion in atlanto-axial arthrodesis. *Cerv Spine Res Soc* 1992;59:134-5.
 35. Kato Y, Itoh T, Kanaya K, et al. Relation between atlantoaxial (C1/2) and cervical alignment (C2-C7) angles with Magerl and Brooks techniques for atlantoaxial subluxation in rheumatoid arthritis. *J Orthop Sci* 2006;11:347-52.
 36. Huang JC, Qian BP, Qiu Y, et al. Surgical overreduction and hyperlordotic fusion of C1-C2 joint are associated with cervical sagittal malalignment. *Arch Orthop Trauma Surg* 2017;137:1631-9.