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Original Article

Surgical Versus Conservative Management for Treating Unstable Atlas Fractures: A Multicenter Study

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Objective: This multicenter study compared radiological parameters and clinical outcomes between surgical and nonsurgical management and investigated treatment characteristics associated with the successful management of unstable atlas fractures.
Methods: We retrospectively evaluated 53 consecutive patients with unstable atlas fracture who underwent halo-vest immobilization (HVI) or surgical fixation. Clinical outcomes were assessed using neck visual analogue scale and disability index. The radiological assessment included total lateral mass displacement (LMD) and the anterior atlantodental interval (AADI).
Results: Thirty-two patients underwent surgical fixation and 21 received HVI (mean follow-up, 24.9 months). In the surgical fixation, but not in the HVI, LMD, and AADI showed statistically significant improvements at the last follow-up. The osseous healing rate and time-to-healing were 100% and 14.3 weeks with surgical fixation, compared with 71.43% and 20.0 weeks with HVI, respectively. Patients treated with HVI showed poorer neck pain and neck disability outcomes than those who received surgical treatment. LMD showed an association with osseous healing outcomes in nonoperative management. Clinical outcomes and osseous healing showed no significant differences according to Dickman's classification of transverse atlantal ligament injuries.
Conclusion: Surgical internal fixation had a higher fusion rate, shorter fracture healing time, more favorable clinical outcomes, and a more significant reduction in LMD and AADI compared to nonoperative management. The pitfalls of external immobilization are inadequate maintenance and a lower probability of reducing fractured lateral masses. Stabilization by surgical reduction with interconnected fixation proved to be a more practical management strategy than nonoperative treatment for unstable atlas fractures.

Keywords: Cervical trauma, Unstable fracture, Jefferson fracture, Atlas fracture, Halo-vest, Surgery

INTRODUCTION

Atlas fracture is rare and accounts for 1.3% to 2% of all spinal injuries and 2% to 13% of all cervical spine fractures.[1,2] Atlas fractures are classified as stable or unstable based on the integrity of the transverse atlantal ligament (TAL).[3] The transverse ligament prevents anterior displacement of the C1 on the C2 and inhibits the translation of lateral masses of the C1 ring. Severe displacement in an atlas fracture incurs potentially life-threatening neurological risk since the atlas lies at the brainstem level, and a TAL tear induces occipito-atlantoaxial instability. It is essential to restore the integrity of the TAL or replace its role with other stabilizers to treat unstable atlas fractures. The “rule of Spence,” according to which a TAL injury can be diagnosed if the total lateral mass displacement (LMD) exceeds 6.9 mm, has been widely used. However, recent studies have shown that existing concepts are inaccurate and should be discarded for predicting TAL integrity or atlantoaxial stability and treatment decision-making.[4,5] Dickman classified TAL injuries using magnetic resonance imaging (MRI); a TAL type I injury, characterized by a rupture in the substance of the ligament, should be implemented with early surgery, whereas a TAL type II injury, involving an avulsion fracture at the insertion site of the ligament, has a successful healing rate when treated nonoperatively.[6]

Various surgical options for treating unstable atlas fractures with favorable outcomes have recently been introduced, such as anterior C1 ring osteosynthesis, C1 open reduction and internal fixation (ORIF), posterior C1–2 fixation, or occipitocervical fusion.[7-9] Nonoperative management with halo-vest immobilization (HVI) or cervical braces often results in nonunion of C1–2, persistent neck pain, pin site loosening, abscess formation, or late atlantoaxial instability. However, some researchers have reported that unstable atlas fractures with TAL rupture can be successfully managed by nonoperative treatment.[10,11] According to Dickman’s suggestion, an atlas avulsion fracture with transverse ligament rupture could be managed by external immobilization, such as a rigid brace or a halo-vest device. Conservative treatments have been widely performed as the method of choice in most cases, while accepted surgical indications are an intraligamentous tear of the TAL, atlantooccipital instability, and an especially unstable atlas fracture. Advocates of surgery have argued that surgical techniques are preferable in fixing fractures as conservative treatments result in delayed atlantoaxial instability, craniovertebral settling, high nonunion rate, and late neurological sequelae.[3,7,12,13] Whether unstable atlas fractures should be treated surgically or conservatively remains a matter of debate.

This multicenter study compared radiological parameters and clinical outcomes: patient-reported pain, neck disability, neurological impairment, and difference in the effectiveness of nonoperative management and surgical fixation in patients with unstable atlas fractures with TAL injuries.

MATERIALS AND METHODS

A retrospective cohort study was conducted with approval from the local ethics committee and Institutional Review Board (approval number: 2018-10-007). In total, 116 consecutive cases with isolated or associated atlas fractures treated from January 2000 to December 2019 were obtained from 4 universities (Yonsei University, Inje University, The Catholic University, and Yeungnam University) for analysis. The inclusion criteria were isolated unstable atlas fractures identified on radiographs, > 6.9-mm LMD and confirmed fractures on 3-dimensional computed tomography (3D CT) or TAL injuries on MRI, nonoperative or surgical management performed during the acute traumatic phase, patient age of over 18 years, and a minimum follow-up period of 12 months. The exclusion criteria were stable fractures, concomitant cervical fractures, and nonacute or pathological fractures. Finally, this study included 53 patients who had unstable fractures with TAL injuries (Fig. 1).

The diagnosis was made using modalities such as radiographs, CT, and MRI. According to the “rule of Spence,” a fracture was determined to be unstable if the total LMD overhang exceeded 6.9 mm on an open-mouth radiograph.[14] The type of transverse ligament injury was assessed with CT or MRI in all patients, and 3D CT angiography was performed to assess fractures, such as the presence of an avulsion fracture at the TAL insertion site, a comminuted fracture, or a lateral mass. MRI was used to assess the TAL injuries, with relevant features including high signal intensity of the TAL on T2-weighted or gradient echo imaging, ligament discontinuity, or insertion site bleeding.[15] The treating surgeon decided upon surgical fixation or nonoperative treat-

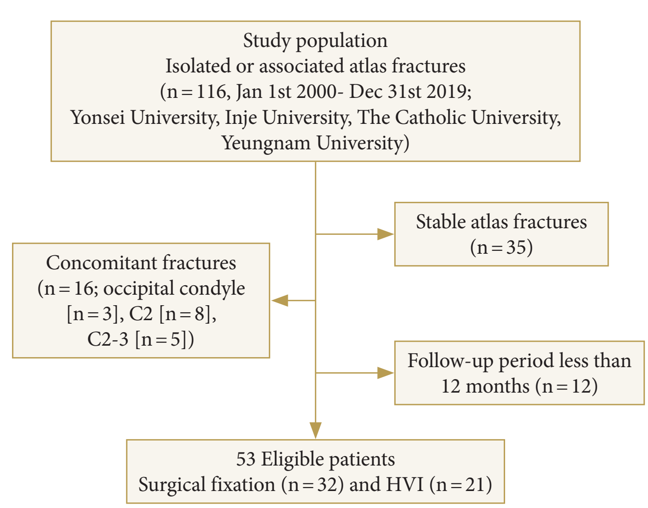

Fig. 1. Patient flowchart. HVI, halo-vest immobilization.

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ment based on the patient's comorbidities, shared decision-making, and the surgeon's preference and experience.

The total LMD and the anterior atlantodental interval (AADI) were calculated. Cervical lordosis was examined using the Cobb angle (Fig. 2). The range of motion (ROM) of C2–7 was determined as the difference in the Cobb angle between flexion and extension at 3, 6, and 12 months postoperatively, but not preoperatively due to the possibility of neurological deterioration. All patients underwent regular follow-up assessments on the seventh day after treatment and at scheduled follow-up appointments. After 12 weeks, dynamic cervical views were ascertained for fracture healing. Osseous healing was defined as confirmation of trabeculation across the fracture on CT scans and stability confirmed by the absence of a difference in the AADI on dynamic observations. Nonunion was defined as unsatisfactory osseous healing, pseudoarthrosis, instability on dynamic films, significant postural pain, or any combination thereof at 6 months. We repeatedly assessed the x-ray every month if osseous healing was not achieved. The halo-vest device for nonsurgical management and neck collars for the surgical operation was continued until bony fusion was confirmed. After 1 year, follow-up radiological outcomes were assessed with dynamic x-rays every 6 months.

A patient-reported visual analogue scale (VAS) for neck pain and the Neck Disability Index (NDI) were measured preoperatively and during the last follow-up visit. The American Spinal Injury Association was used to determine the grade of neurological deficits. All patients received assessments 1 week after surgical treatment, and a follow-up visit was scheduled.

Table 1. Patient demographics (n = 53)

Characteristic	Value
Age (yr)	48.23 ± 14.62
Sex, male:female	32:21
Mechanism of injury	
MVA	37
Fall down	16
BMI (kg/m^2)	26.53 ± 4.26
BMD (T-score)	-1.67 ± 1.38
Smoking	29 (54.7)
Diabetes	11 (20.8)
Management starting time (day)	2.68 ± 1.72
Management	
Surgical reduction with fixation	32 (60.4)
HVI	21 (39.6)
Fracture type†	
II	25 (47.2)
III	28 (52.8)
TAL injury type‡	
I	29 (54.7)
II	24 (45.3)
ASIA grade E	53

Values are presented as mean ± standard deviation or number (%).
MVA, motor vehicle accident; BMI, body mass index; BMD, bone mineral density; HVI, halo-vest immobilization; ASIA, American Spinal Injury Association Impairment Scale; fracture type.
†Landells & Van Peteghem classification. ‡Transverse atlantal ligament injury Dickman classification.

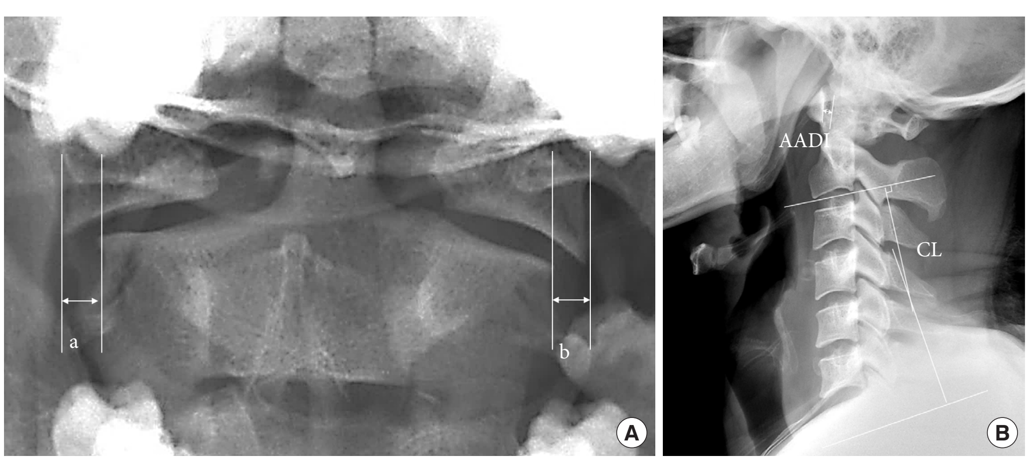

Fig. 2. Radiological measurements. (A) In an open-mouth view, the sum of (a) and (b) is greater than 6.9 mm, and the rule of Spence suggests a transverse ligament injury. (B) The anterior atlantodental interval (AADI) and cervical lordosis (CL) are shown in the picture.

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Data were expressed as mean ± standard deviation or number (percentage). Paired t-test and the chi-square test were used to assess the difference in the intergroup comparison. Receiver operating characteristics (ROC) analysis was done to evaluate the sensitivity and specificity of LMDs as an objective measure of non-combination. The optimal cutoff value for LMD was determined using the maximum Youden index (sensitivity– [1 – specificity]).[16] All data were analyzed by MedCalc v20.106 (MedCalc Software, Belgium). A p-value less than 0.05 was statistically significant.

RESULTS

All 53 patients had unstable atlas fractures according to the "rule of Spence" (> 6.9-mm preoperative LMD); 32 patients underwent surgical reduction with interconnected fixation and 21 patients underwent nonsurgical management (HVI) to achieve osseous healing. The mean age at the time of management was 48.23 ± 14.62 years (range, 23–69 years). Patients were followed for a mean of 24.9 months (range, 15.53–38.61 months). Among the 53 patients, 37 were injured in a vehicle accident, 7 were injured by diving into a pool, and 9 were injured by falling. The mean time from injury to management was 2.68 ± 1.72 days (Table 1).

Thirty-two patients (16 with Landells and Van Peteghem type II and 16 with type III fractures) underwent surgical fixation, and 21 patients (9 with Landells and Van Peteghem type II and 12 with type III fractures) were treated with nonoperative management. Regarding surgical methods, 27 patients received C1–2 fixation with crosslink compressors, 4 were treated with C1 ORIF, and 1 had C1-2-3 fixation.

There were 29 Dickman classification type I TAL injuries (17 in the surgical fixation and 12 in the nonsurgical management groups) and 24 type II injuries (15 in the surgical fixation and 9 in the nonsurgical management groups) (p = 0.776).

1. Comparison of Radiographic Parameters and Clinical Outcomes Between Patients Who Underwent Surgery and Patients Who Did Not

Baseline demographics according to treatment modality are presented in Table 2. There was no significant difference in mean age, sex, or mechanism of injury among the 2 treatment modality groups (Table 2). LMD showed a statistically significant improvement after surgical fixation, and this improvement was

Table 2. Patient demographics according to treatment modality

Variable	Surgical group (n = 32)	Nonsurgical group (n = 21)	p-value
Age (yr)	48.47 ± 15.96	47.86 ± 12.68	0.964
Sex, male:female	17:15	15:6	0.187
Mechanism of injury			0.417
MVA	21	16	
Fall down	11	5	
BMI (kg/m^2)	25.81 ± 2.64	30.33 ± 9.24	0.092
BMD (T-score)	-1.36 ± 1.41	-2.23 ± 1.30	0.340
Smoking	15 (46.9)	14 (66.7)	0.161
Diabetes	5 (15.6)	6 (28.6)	0.260
Management starting time (day)	2.64 ± 1.43	2.71 ± 2.00	0.689
Fracture type†			0.614
II	16 (50.0)	9 (42.9)	
III	16 (50.0)	12 (37.5)	
TAL injury type‡			0.776
I	17 (53.1)	12 (37.5)	
II	15 (46.9)	9 (42.9)	
ASIA grade E	32	21	-

Values are presented as mean ± standard deviation or number (%).
MVA, motor vehicle accident; BMI, body mass index; BMD, bone mineral density; TAL, transverse atlantal ligament; ASIA, American Spinal Injury Association Impairment Scale; fracture type.
†Landells & Van Peteghem classification. ‡Transverse atlantal ligament injury Dickman classification.

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maintained at the last follow-up; however, significant improvement was not seen after nonsurgical management. In the surgery group, there was no evidence of a reduced fracture gap from immediately after surgery until the final follow-up, with measured values of 5.95 ± 2.54 mm at postoperative 7 days, 5.96 ± 2.55 mm at 3 months, and 6.08 ± 2.27 mm at 12 months after surgical fixation. In contrast, in the nonoperative management group, there was a loss of reduction in the fractured atlas ring over time, with values of 7.75 ± 1.54 mm at postoperative 7 days, 8.14 ± 1.95 mm at 3 months, and 8.27 ± 2.02 mm at the last follow-up after HVI (Table 3, Fig. 3). AADI decreased to a statistically significant extent after surgical fixation, but not after nonsurgical management. In the surgical fixation group, the AADI decreased from an initial mean value of 4.95 ± 0.57 mm to 3.00 ± 1.05 mm at the last follow-up. In the nonsurgical management group, the AADI decreased from an initial mean value of 4.90 ± 0.72 mm to 4.30 ± 0.87 mm at the last follow-up (Table 3). The osseous healing rate was 100% (32 of 32 patients) in the surgery group and 71.43% (15 of 21 patients) in the nonoperative management group (Table 3). In other words, the nonunion rate was higher in patients who received nonsurgical management than in those who underwent surgical fixation at 6 months postoperatively. The mean time to osseous healing was higher in the nonsurgical management group (20.02 ± 8.73 weeks) than in the surgical fixation group (14.38 ± 2.93 weeks). The cervical alignment in patients treated with HVI was straighter than in patients treated with surgical fixation at the last follow-up. The cervical dynamic x-rays of patients treated with HVI showed better maintenance of motion at the final follow-up than was observed in patients who underwent posterior cervical reduction and fixation (Table 3).

Patients who received nonsurgical management experienced more severe neck pain than those treated with surgical internal fixation. The preoperative NDI score was higher in the surgical fixation group than in the nonsurgical management group. At the last follow-up, the NDI score was 7.13 ± 2.04 in the surgical

Table 3. Radiological parameters and clinical outcomes according to the treatment modality

Variable	Surgical fixation (n = 32)	Nonsurgical management (n = 21)	p-value
LMD (mm)			
Preoperative	9.86 ± 1.59	9.35 ± 1.21	0.212
Postoperative 7 days	5.95 ± 2.54	7.75 ± 1.54	0.002*
Postoperative 3 months	5.96 ± 2.55	8.14 ± 1.95	0.001*
Postoperative 12 months	6.08 ± 2.27	8.27 ± 2.02	0.001*
AADI (mm)			
Preoperative	4.95 ± 0.57	4.90 ± 0.72	0.986
Postoperative 12 months	3.00 ± 1.05	4.30 ± 0.87	< 0.001*
Osseous healing time (wk)	14.38 ± 2.93	20.02 ± 8.73	0.003*
Healing rate (%)	100	71.43	0.002*
C2–7 Cobb angle (°)			
Preoperative	6.53 ± 4.45	4.06 ± 3.86	0.288
Postoperative 12 months	11.80 ± 7.38	6.54 ± 7.19	0.002*
C2–7 ROM (°)			
Postoperative 12 months	54.38 ± 14.41	63.82 ± 29.24	0.253
Neck VAS			
Preoperative	7.31 ± 0.78	7.19 ± 0.68	0.561
Postoperative 12 months	1.91 ± 0.53	3.00 ± 1.52	0.003*
NDI			
Preoperative	24.25 ± 5.49	21.04 ± 4.59	0.032*
Postoperative 12 months	7.13 ± 2.04	11.29 ± 6.46	0.025*

Values are presented as mean ± standard deviation unless otherwise indicated.
LMD, total lateral mass displacement; AADI, anterior atlantodental interval; ROM, range of motion; VAS, visual analogue scale; NDI, Neck Disability Index.
*$p < 0.05$.

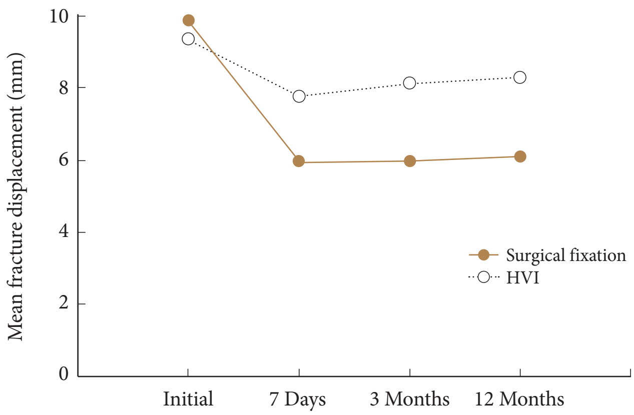

Fig. 3. Reduction of total lateral mass displacement after surgical and nonoperative management. The surgical reduction and fixation group showed no loss of reduction in fractured lateral masses in the initial measurements (9.86 ± 1.59 mm) and those obtained 7 days (5.95 ± 2.54 mm), 3 months (5.96 ± 2.55 mm), and 12 months (6.08 ± 2.27 mm) after surgery. In the nonoperative group treated with HVI, initial (9.35 ± 1.21 mm) cervical traction followed by halo-vest immobilization (HVI) was found to lead to slight reductions in lateral dislocation at 7 days (7.75 ± 1.54 mm), 3 months (8.14 ± 1.95 mm), and 12 months (8.27 ± 2.02 mm) after HVI, but increased displacement continued to occur over time.

Table 4. Radiological parameters and clinical outcomes according to the TAL injury

Variable	Dickman type I (n = 29)	Dickman type II (n = 24)	p-value
Preoperative LMD (mm)	9.79 ± 1.48	9.51 ± 1.45	0.486
Preoperative AADI (mm)	4.93 ± 0.69	4.80 ± 0.57	0.463
Treatment modalities			
Surgical fixation	17	15	
HVI	12	9	0.776
Osseous healing (%)			
Surgical fixation	17/17 (100)	15/15 (100)	-
HVI	9/12 (75)	6/9 (66.7)	0.683
Neck VAS			
Preoperative	7.28 ± 0.75	7.25 ± 0.74	0.900
Postoperative 12 months	2.24 ± 1.24	2.46 ± 1.06	0.264
NDI			
Preoperative	23.24 ± 5.49	22.67 ± 5.26	0.701
Postoperative 12 months	8.72 ± 3.80	8.83 ± 5.82	0.335

Values are presented as mean ± standard deviation or number (%).
TAL injury, transverse atlantal ligament injury Dickman classification; LMD, total lateral mass displacement; AADI, anterior atlantodental interval; HVI, halo-vest immobilization; VAS, visual analogue scale; NDI, Neck Disability Index.

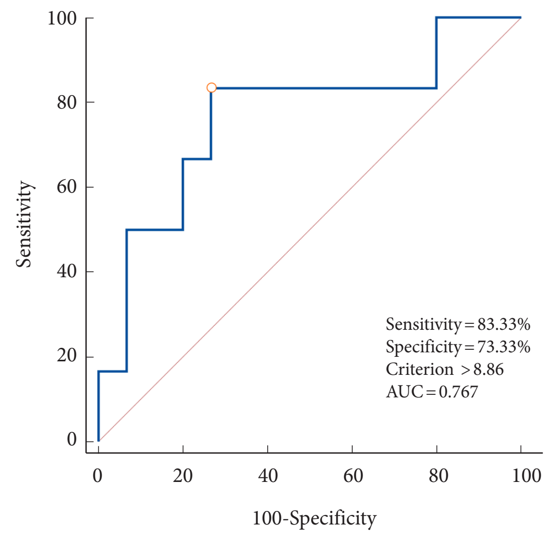

Fig. 4. Receiver operating characteristic (ROC) curves for the preoperative total lateral mass displacement (LMD). The best cutoff value of the preoperative LMD between osseous healing and nonunion was 8.86 mm. The area under the curve (AUC) was 0.767 (95% confidence interval, 0.533–0.921, p = 0.0342).

fixation group and 11.29 ± 6.46 in the nonsurgical management group (Table 3).

2. Radiographic and Clinical Outcomes According to Dickman's TAL Injury Classification

No significant differences in LMD or AADI were found according to Dickman's classification of TAL injuries. The osseous healing rate was not significantly different in the surgical fixation and nonsurgical management groups based on the classification of TAL injuries (Table 4). The neck VAS score and NDI were not significantly different between Dickman's TAL injury types.

3. ROC Analysis of Preoperative LMD

In the nonsurgical management group, the ROC analysis found that the optimal cutoff value of the preoperative LMD between osseous healing and nonunion was 8.86, with sensitivity and specificity values of 83.33% and 73.33%, respectively. The area under the curve was 0.767 (95% confidence interval [CI], 0.533–0.921; p = 0.034) (Fig. 4). In contrast, all patients who underwent surgical fixation showed complete osseous healing. Therefore, the ROC curve did not show an optimal cutoff value of the preoperative LMD for distinguishing between osseous healing and nonunion in the surgical fixation group.

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4. Complications

One of the 32 patients treated with surgical reduction with fixation suffered cerebellar infarction.[8] One patient underwent revision surgery due to malposition of the C1 lateral mass screw. No patients showed hardware failure, dura mater tear, or infection. Nonunion at 6 months postoperatively occurred in 28.57% of patients (6 of 21) who received nonoperative management with HVI. Six patients with pseudoarthrosis declined an additional surgical operation as their neck pain was bearable. Five of the 21 patients (23.81%) who underwent HVI had complications, including frequent pin loosening (9.52%, 2 of 21), wound site infection (4.76%, 1 of 21), and brain abscess (9.52%, 2 of 21).

DISCUSSION

Surgical internal fixation enabled a better reduction of fractured lateral slippage and widened AADI than nonsurgical management. The osseous healing was 100% with surgical internal fixation but 71.43% with nonsurgical management, indicating that external immobilization with halo-vest devices offered insufficient fixation of occipitocervical motion. Clinically, the patients who received nonsurgical management experienced poorer neck pain and more frequent disability compared to those treated with surgical internal fixation. There were no differences in clinical outcomes and osseous healing between surgical and conservative management based on Dickman's classification of TAL injury. A preoperative LMD greater than 8.86 mm predicted poor osseous healing, defined by nonunion, in unstable atlas fractures that underwent nonsurgical management.

1. Outcomes Between Patients Who Underwent Surgical Operation and Patients Who Did Not

The goal for treatment of unstable atlas fractures is to reduce fracture displacement, maintain stabilization, and heal the bony fracture. Various surgical options for treating unstable atlas fractures with ligament tears have been recently described with advanced surgical techniques and good radiological outcomes.[7-9,13,17-20] However, in these times of favorable results by surgery, it still remains debatable whether surgery or conservative management should be used for unstable atlas fractures. Moreover, a change of management for unstable fractures is needed to obtain better clinical outcomes and determine the treatment strategy. Surgery advocates have argued that these surgical techniques to fix fractures are preferable since conservative treatments result in delayed atlantoaxial instability, craniovertebral settling, a high nonunion rate, and late neurological sequelae.[7,21,22] On the other hand, advocates of conservative management have reported that unstable atlas fractures can be managed by HVI or rigid collars.[10,11,23] They argued that HVI or a rigid collar provides traction to align the fractured lateral masses by ligamentotaxis effect and reduces a stress force below C1–2, thereby preventing subluxation and promoting healing.[11,19,23] However, it is doubtful whether the damaged TAL of an unstable atlas fracture can facilitate ligamentotaxis and maintain a lateral slippage until complete healing. In common, osseous injuries heal well with immobilization to treat fractured segments. However, ligamentous injuries are poorly cured by immobilization alone.[24,25] Nonoperative treatment with a halo-vest for stable atlas fractures resulted in a 76.2%–84.2% consolidation rate,[26-28] but there is a lack of research on osseous healing rates for the nonoperative management of unstable atlas fractures. The present study found that osseous healing was accomplished in 71.43% of nonoperative management patients and in all patients who underwent surgical internal fixation. The patients with HVI needed a longer osseous healing time than those undergoing surgical internal fixation. In addition, the LMD and AADI in surgical fixation improved at the last follow-up compared to the preoperative phase. However, the LMD and AADI did not show significant improvements in the nonsurgical management group. Patients treated with HVI had straighter cervical alignment and greater neck stiffness than those treated with surgical fixation, inconsistent with previous reports.[11,23,29] The larger C2–7 Cobb angle in the surgical fixation group might have been due to the kyphotic fixation of C1–2. Clinically, patients treated with HVI had worse neck pain and neck disability than patients treated with surgical treatment. The adverse consequences of nonsurgical management are that the fracture site was not fixed firmly in patients who received external HVI due to an increase in fracture lateral slippage and micromotion while sitting and laying down.[7,20,30,31] The pitfalls of nonoperative management are inadequate maintenance of unstable fractures with a ligament injury and a lower probability of reducing fractured lateral masses (Fig. 5). In contrast, surgical reduction with interconnected fixation secures the fractured site in place without increasing lateral displacement or micromotion (Fig. 6).

2. Outcomes According to Dickman's TAL Injury Classification

Dickman's TAL injury type has been considered a critical factor in determining the stability of atlas fractures and choosing a treatment strategy. Dickman et al. proposed that type I TAL injuries, in which a rupture occurs in the substance of the ligament,

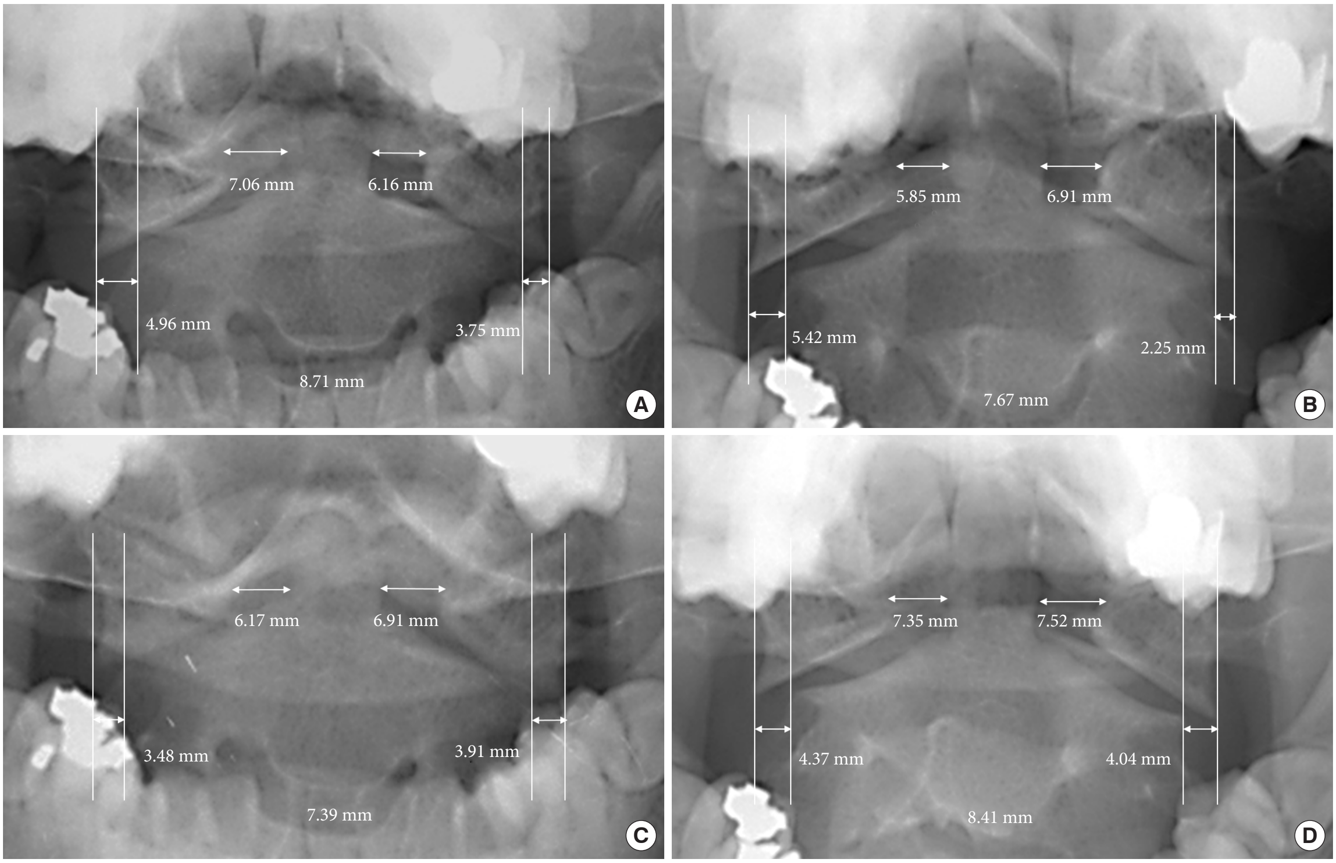

Fig. 5. Halo-vest immobilization. (A) Preoperative open-mouth view with a sum of overhangs of the C1 lateral masses on the C2 facet of 8.71 mm. (B) The sum of lateral displacements of the fractured lateral masses was 7.67 mm 7 days after halo-vest immobilization (HVI). (C) The same value was 7.39 mm 3 months after HVI. (D) The 6-month posttreatment value was 8.41 mm. There was a loss of reduction in the fractured atlas ring over time.

should be implemented early with surgery.[15,32] Type II TAL injuries, which involve avulsion fractures at the insertion sites of TAL, had a 74% success rate when managed nonoperatively.[32] According to Dickman's suggestions, atlas avulsion fractures with transverse ligament rupture could be treated by nonsurgical management with rigid collars or HVI. In most cases, these conservative treatments have been widely performed as the method of choice, while accepted surgical indications are an intraligamentous injury of the transverse ligament, atlantooccipital instability, and an especially unstable atlas fracture. Shatsky et al.[33] reported that atlas fracture reduction and fixation could be performed irrelevant to the ligament injury type without resulting in C1–2 instability. Liu et al.[5] studied 13 adult patients with atlas fractures who were treated nonoperatively at the acute posttraumatic phase and followed up for at least 2 years. They reported that C1–2 stability failed to be restored in 2 cases with Dickman's classification type I injuries (100%), whereas stability was successfully restored in 6 of 7 type II (85.7%) cases that were treated nonoperatively. They concluded that Dickman's classification of TAL injuries is highly accurate for evaluating TAL injuries and shows a significantly consistent association with the prognosis of atlas fractures. However, their study enrolled small number of patients and treated atlas fractures with only nonoperative management. The present study showed no differences in clinical outcomes and osseous healing between surgical and conservative management based on Dickman's classification of TAL injury. Patients who underwent surgical fixation had complete osseous healing regardless of the TAL type, while patients with type I TAL injuries achieved osseous healing more frequently compared to those with type II TAL injuries after nonoperative treatment. However, the significance of Dickman TAL classification in this study was limited to applying to all atlas fractures and predicting outcomes, since only unstable atlas fractures were registered except for stable atlas fractures.

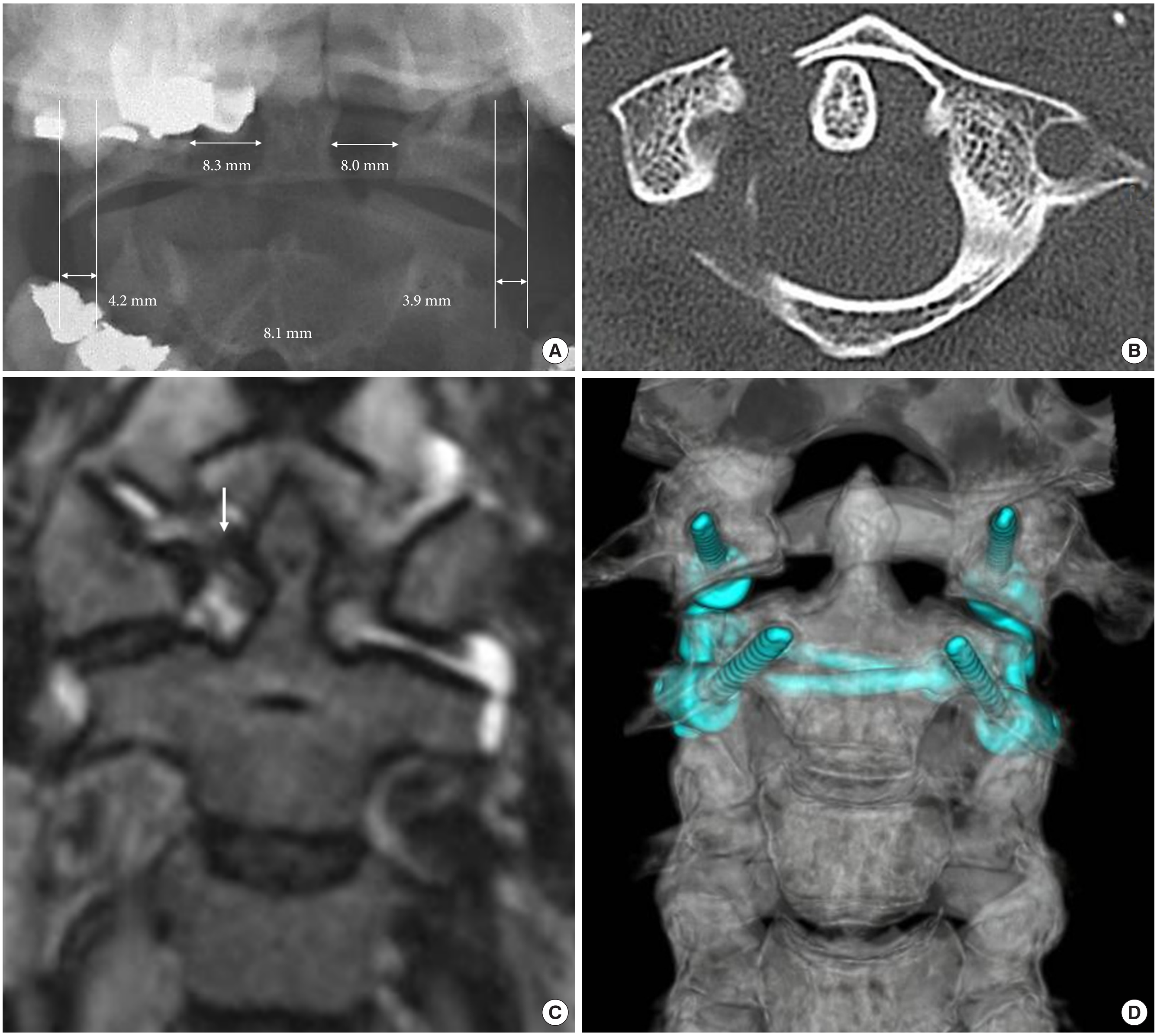

Fig. 6. Surgical reduction and fixation with crosslinking. (A) Preoperative open-mouth view shows that the sum of the overhang of the C1 lateral masses on the C2 facet was 8.1 mm. (B) On computed tomography (axial view), a right anterior arch fracture and right lateral mass fracture (Landells & Van Peteghem type II) are shown. (C) There was a rupture of the transverse atlantal ligament (Dickman type II). A tear of the transverse ligament (arrow). (D) Surgical reduction and fixation with crosslinking were performed. The 12-month postoperative value was 3.8 mm.

3. Correlation of the "Rule of Spence" and TAL Injury

Recent studies have reported that the "rule of Spence" was inaccurate for identifying TAL injuries.[4,5,24,34] Using the criterion of an LMD greater than 6.9 mm, approximately 61% to 90.9% of TAL injuries were missed.[6,15,35] Furthermore, Radcliff et al.[34] previously reported no correlation between bony displacement and the presence of a TAL injury. Woods et al.[4] studied the LMD required for TAL injury using modern biomechanical techniques. The average LMD upon TAL failure was found to be 3.3 ± 1.2 mm (1.7–5.6 mm), and when the LMD exceeded 3.8 mm, there was a high likelihood of TAL failure. Perez-Orribo et al.[36] also reported the comparison study of CT versus MRI on TAL integrity and showed that 90.9% with documented TAL injury on MRI was inconsistent with the "rule of Spence" criterion. The average LMD in these 10 patients with TAL injury was 2.4 mm (range, 0.6–8.7 mm). Heller et al.[37] proposed that the cutoff of

https://doi.org/10.14245/ns.2244352.176

6.9 mm should be adjusted to 8.1 mm due to radiographic magnification. Liu et al.[5] reported that an LMD less than 6.9 mm was inaccurate for excluding TAL injury, whereas an LMD greater than 6.9 mm was accurate for determining the presence of a TAL injury. Using the "rule of Spence," in which an LMD is exceeding 6.9 mm, all TAL injuries were found in the present study. However, since we excluded stable atlas fractures according to the "rule of Spence," we did not evaluate the accuracy of an LMD less than 6.9 mm for predicting TAL injuries.

Kim et al.[1] reported that radiographic measurements at presentation (LMD, AADI) did not predict fusion results. We found that preoperative LMD was associated with osseous healing outcomes in patients who underwent nonoperative management; we could not find an association in those who underwent surgical management since the union was achieved in all cases. Patients with an LMD greater than 8.86 mm had a high probability of nonunion when treated nonoperatively. Surgical fixation is recommended for patients with an LMD greater than 8.86 mm to achieve favorable osseous healing over nonsurgical management. In the future, multicenter studies should be performed to establish a cutoff value for LMD when selecting surgical or nonsurgical external immobilization for atlas fractures.

4. Treatment Strategy

We recommend surgical treatment for unstable and displaced atlas fractures. If a transverse ligament disruption exists with an atlas fracture and the TAL injury violates the rule of Spence or shows predominant signs of TAL injuries (e.g., hypersignal intensity on gradient echo imaging, ligament discontinuity, or insertion site bleeding), surgical reduction and interconnected fixation will correct the incompetence of the transverse ligament (Fig. 6). We insist that the TAL can heal or reduce the scar when it is anatomically aligned with reduction and fixation, consistent with the previous research.[33] Compression using crosslinking, similar to the role of the TAL, is essential to prevent pseudoarthrosis and the late sequelae of atlas fractures according to the TAL injury type. Delayed atlantoaxial instability, pseudoarthrosis, or craniovertebral settling may occur if the crosslink fixation is not performed as the substitute for the injured TAL (Supplementary Fig. 1). We did not analyze the radiological and clinical outcomes of each surgical technique in detail due to the small number of cases (32 total; 27 C1–2 fixation with crosslink compressors, 4 ORIF, and 1 C1-2-3 posterior fixation). Osseous healing occurred within a mean of 14.4 weeks in the surgical fixation group. Surgical treatments of C1 fractures include transoral anterior C1 fixation, C1 ORIF, posterior C1–2 fusion, and occipitocervical fusion. Transoral approach C1 internal fixation can only treat anterior half atlas fractures and has a high risk of deep operative site infection. Posterior ORIF of the C1 ring can maintain C1–2 motion better than standard C1–2 or occipitocervical fusion techniques (Supplementary Fig. 2).[33] However, C1 ORIF has limitations in the reduction and fixation of bony fractures in cases with C1–2 articular facet damage, comminuted fractures of C1, and atlantoaxial or atlantooccipital joint instability. Basilar invagination from cranial settling on occipitocervical lesions may also be a risk, leading to neurological deficits. C1–2 fusion has been reported to have good outcomes as a standard method for unstable Jefferson fractures, while C1–2 fusion restricts head rotation to 35° or less on both sides.[12] Recently, posterior temporary C1–2 screw fixation with removal of screws following C1–2 fixation was reported to preserve atlantoaxial ROM, especially in younger patients.[2] Comparative studies of various surgical techniques for unstable atlas fractures are needed to evaluate radiologic, clinical, and functional outcomes.

5. Choosing the Modality for C1 Fractures

All modalities, such as radiographs, CT, and MRI, should be used to diagnose C1 fractures. Initially, radiographs should be taken, including anteroposterior, lateral, and open-mouth x-rays. The open-mouth view provides effective visualization of the C1, C2 body, atlantoaxial joints, odontoid process, and lateral spaces between the lateral border of the C2 body and lateral masses of C1 (when the patient's shoulders are on the same horizontal plane to prevent rotation and the midsagittal plane is perpendicular to the plane of the table).

CT scan is the screening method of choice in many trauma centers. In this study, CT was performed to assess fractures, such as the presence of an avulsion fracture at the TAL insertion site, a comminuted fracture, or a lateral mass. CT offers a more precise resolution of bony fragments associated with atlas fracture and is not susceptible to magnification error.[37] Even though CT can provide accurate imaging of bony fractures and displacements, the integrity of the transverse ligament cannot be assured.

The transverse ligament should be directly imaged with MRI, as it is a more sensitive indicator of TAL disruption than the "rule of Spence" or CT. MRI scans, including axial and coronal thin-section T1- and T2-weighted images and gradient echo images, should be performed to identify TAL injuries based on anatomical disruption, the presence of fluid signal, ligament discontinuity, or insertion site bleeding. When making decisions regarding treatment and imaging modalities for C1 fractures, transverse ligament injuries with associated C1–2 instability

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were determined based on >6.9-mm LMD on open-mouth radiograph and confirmed fractures, such as avulsion fracture at the TAL insertion site, a comminuted fracture, or a lateral mass on CT and documented disruption of TAL on MRI.

6. Study Limitations

This study, in its nature, has several limitations. First, this was a retrospective study with relatively few patients, and inherent differences between groups were inevitable. In addition, some concerns have been raised regarding late fusion in cases of pseudoarthrosis due to the short-term follow-up. Selection bias due to the multicenter design of the study likely affected the decision to manage unstable fractures. Furthermore, management strategies were determined by the treating surgeon, and differences in regional, institutional, and surgeon preferences might have impacted nonoperative management with HVI or surgical treatment, including whether C1 ORIF, posterior C1–2 fixation, or occipitocervical fusion was performed. An optimal treatment modality for unstable atlas fractures could not be determined from this comparative study as it was a retrospective study with few enrolled patients, which could lead to possible bias. In the future, additional prospective and multicenter studies should be conducted to derive radiological and clinical outcomes in patients who have executed surgical internal fixation or nonsurgical external immobilization for unstable atlas fractures. Nonetheless, we hope that the present study findings will be helpful in the management of patients with unstable atlas fractures.

CONCLUSION

The radiological outcomes of surgical treatment were superior to those of nonsurgical treatment. Surgical internal fixation of unstable atlas fractures had a higher fusion rate, a shorter fracture healing time, and better reduction of fractured lateral masses than nonoperative management. The pitfalls of conservative management for unstable atlas fractures are inadequate maintenance and a lower likelihood of reducing fractured lateral masses. Clinically, patients with nonsurgical management experienced poorer neck pain and disability more frequently compared to those treated with surgical internal fixation. In this study, clinical outcomes and osseous healing were not significantly different between surgical and conservative management based on Dickman's classification of TAL injury. An LMD greater than 8.86 mm was associated with a high probability of poor osseous healing after nonoperative treatment. Therefore, surgical reduction with interconnected fixation for cases with an LMD greater than 8.86 mm may lead to more favorable osseous healing over nonsurgical management.

NOTES

Supplementary Materials: Supplementary Figs. 1-2 can be found via https://doi.org/10.14245/ns.2244352.176.

Supplementary Fig. 1. Atlantoaxial joint fusion without cross-link fixation.

Supplementary Fig. 2. C1 open reduction and internal fixation.

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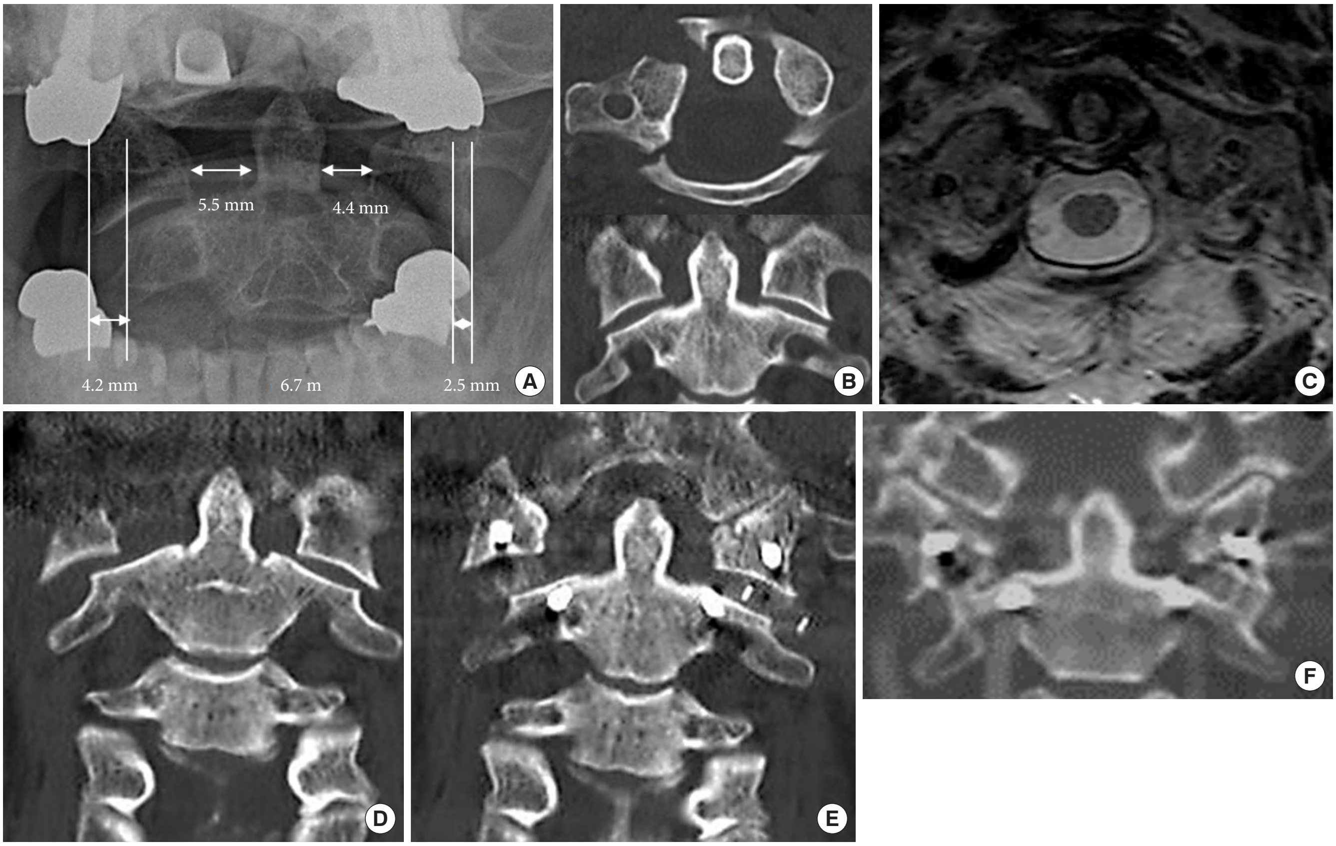

Supplementary Fig. 1. Atlantoaxial joint fusion without crosslink fixation. (A) A preoperative open-mouth view of a 74-year-old male patient with an atlas fracture after a traffic accident. The sum of the overhang of the C1 lateral masses on the C2 facet was 6.7 mm. (B) The computed tomography (CT) findings were classified as type II Landells and Van Peteghem. (C) There was a rupture of the transverse atlantal ligament (Dickman type I). (D) The patient underwent nonoperative management with halo-vest immobilization for 6 weeks. He complained of continuing neck pain and headache. Follow-up CT findings showed additional slippage of the fractured lateral masses compared to the initial phase. (E) Postoperative CT showed C1 lateral mass screw-2 pedicle screw fixation with atlantoaxial joint fusion, but without crosslinking. (F) Twelve-month postoperative CT showed good fusion in the left atlantoaxial joint, but nonunion in the right atlantoaxial joint. The patient's neck pain was tolerable, but neck motion was restricted. (Courtesy of Prof. SW Kim).

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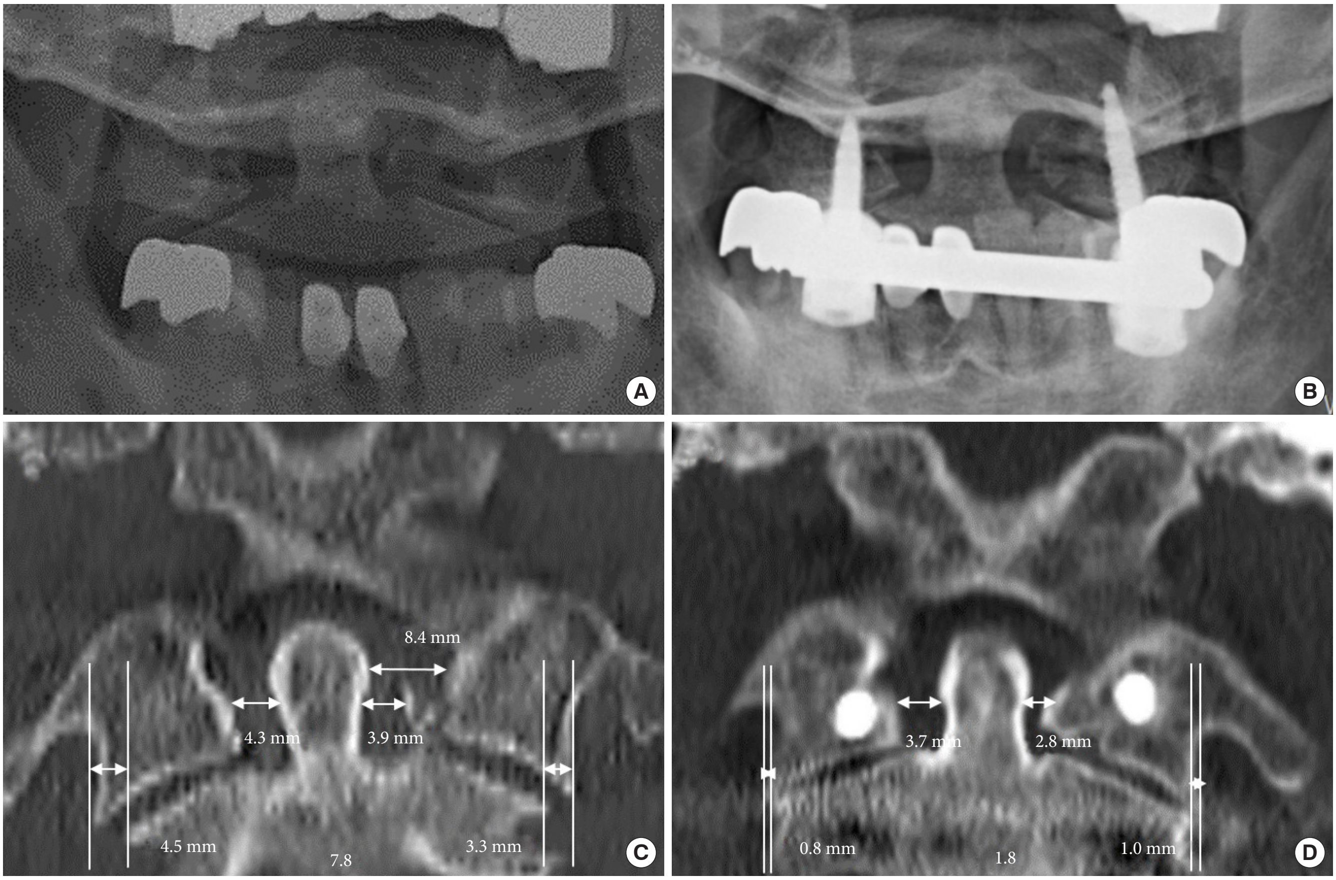

Supplementary Fig. 2. C1 open reduction and internal fixation. (A) Preoperative open-mouth view. (B) C1 open reduction and internal fixation. (C) The sum of the overhang of the C1 lateral masses on the C2 facet was 7.8 mm on the preoperative computed tomography scan. (D) The 12-month postoperative value was 1.8 mm. The reduction and fusion of the fractured atlas were satisfactory.