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# Comparison of radiological and clinical outcomes after surgical reduction with fixation or halo-vest immobilization for treating unstable atlas fractures

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## Abstract

**Background** Unstable atlas fractures with concomitant transverse atlantal ligament (TAL) injury may be conservatively managed by halo-vest immobilization (HVI) or surgically treated by various fixation techniques. Many surgeons prefer surgical management due to complications, nonunion, and further dislocations with HVI. There are no comparative studies on surgical and nonsurgical management of unstable atlas fractures. We retrospectively assessed the radiological and clinical outcomes of surgical reduction with fixation vs. non-operative treatments for unstable atlas fractures with TAL rupture.

**Methods** We analyzed records of 24 patients (15 men, 9 women; mean age, 48.3 years) with at least 1 year of follow-up. They underwent HVI or surgical reduction with fixation for unstable atlas fracture combined with TAL injury. Clinical outcomes, including neck visual analog scale and neck disability index (NDI), and radiological measurements, including degree of fracture displacement, atlantodental interval (ADI), range of motion (ROM), cervical alignment, fusion rate, and time-to-fusion, were assessed.

**Results** Of the 24 patients, 13 were treated by surgical reduction with fixation (C1 lateral mass screw-C2 pedicle screw with a cross-link) and 11 by HVI. A significant reduction in lateral displacement of fractured lateral masses was identified in surgical reduction with fixation ($3.21 \pm 1.21$ mm) compared with HVI ($0.97 \pm 2.69$ mm). The mean reduction in ADI was $1.47 \pm 1.08$ mm with surgical fixation and $0.66 \pm 1.02$ mm with HVI. The bony rate and time-to-fusion were 100% and $14.91 \pm 3.9$ weeks with surgical reduction, and 72.7% and $22.31 \pm 10.85$ weeks with HVI. The postoperative neck pain relief and NDI after surgical fixation were higher than those after HVI.

**Conclusions** Compared with HVI, surgical reduction with fixation reduces fractured lateral mass displacements, increases fusion rate, and reduces time-to-fusion while maintaining cervical curvature and improving neck pain and daily activities.

**Keywords** Atlas fracture · Cervical trauma · Halo-vest · Jefferson fracture · Surgery

## Introduction

Atlas fractures are classified into stable or unstable fractures based on the presence of concomitant transverse atlantal ligament (TAL) injury, which is the primary stabilizing component against translational forces at C1–C2 [6, 16, 19, 20]. Stable

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atlas fractures without TAL injury are successfully managed by soft or hard collar immobilization [29]. For the treatment of unstable atlas fractures associated with TAL rupture, initial reduction of the fracture with cervical traction, followed by halo-vest immobilization (HVI), has been commonly suggested [9, 17, 18]. Unfortunately, nonsurgical treatment with HVI frequently results in nonunion of C1–C2, persistent neck pain, or atlantoaxial instability [2, 13, 15].

Recently, various surgical options for the treatment of unstable atlas fractures with TAL injury have been reported, such as transoral internal fixation, C1 open reduction and internal fixation (ORIF), occipitocervical fusion, or posterior C1–C2 fixation [2, 4, 24, 26]. Many surgeons prefer surgical techniques to fix atlas fractures because of complications, discomfort, and high nonunion rate associated with HVI [1, 2, 4, 7].

In this study, we compared data on clinical outcomes and radiological measurements between patients who underwent non-operative management and those who underwent surgical reduction with fixation. To our knowledge, this is the first series to compare clinical and radiological measurements between surgical and non-operative treatments.

## Material and methods

This study was approved by Inje University's Institutional Review Board (IRB Number, SGPAIK 2018-10-007). Between January 2000 and December 2016, we treated 48 consecutive patients with isolated or associated atlas fractures at our institute. In this retrospective analysis, we excluded 10 patients who had stable atlas fractures without TAL ligament injury and underwent conservative management using soft or hard neck collars. Four patients were excluded as they had adjacent-level fractures of either the C2 (3 patients) or occipital condyle (1 patient). Ten patients with less than 1 year of follow-up or missing radiographs were also excluded. We excluded patients with pathological fractures resulting from malignancy, infection, metabolic disease, congenital cervical spine anomalies, chronic C1 fracture, or nonunion cases after previous treatments in other hospitals. Finally, this study included 24 patients (15 men, 9 women; mean age, 48.26 ± 15.69 years; range, 24~68 years) who had unstable atlas fractures combined with TAL injury. All 24 patients underwent either non-operative management (HVI) or surgery (internal fixation by posterior reduction and fixation) to achieve osseous healing. Eighteen patients had isolated atlas burst fractures, 4 patients had unstable atlas fractures with concomitant thoracolumbar fractures (3 thoracic compression fractures, T7 and T9; 1 lumbar and 2 transverse process fractures), and 2 patients had unstable atlas fractures with concomitant C7 spinous process fractures not requiring interventions.

Diagnosis was made by radiography, including standard anteroposterior, lateral, and open-mouth radiographs. In addition, three-dimensional computed tomography (3D-CT) was performed to assess the fracture type and precisely define the combined cervical fracture. Magnetic resonance imaging (MRI) was performed in all patients to assess the integrity of intervertebral discs and ligamentous injury or evaluate spinal cord contusion or compression, if clinically warranted.

The choice of surgical operation or non-operative treatment was at the surgeon's discretion based on their preference and patients' condition in this retrospective study. After the explanation of associated anesthesia risks, such as pulmonary problems and congestive heart failure, and obtaining proper informed consent, the decision for surgical or conservative treatment was made. Before February 2007, the surgeons at our institute preferred cervical immobilization treated with halo-vest orthosis because it had fewer risks compared with

surgical operations. Subsequently, various surgical techniques and instrumentations were introduced to treat atlas fractures with instabilities, and surgical operations were performed routinely unless there was a major reason not to perform surgery. All but two cases, in the surgical treatment groups, were enrolled after March 2007. These two patients refused surgical operation initially and underwent HVI.

Once the diagnosis of unstable atlas fractures with TAL injury was defined by radiography (plain X-ray, 3D-CT, and MRI), we performed non-operative management or surgical operations as soon as possible if patient's informed consent was obtained and if general conditions were stable.

### HVI

Initially, cervical traction using Gardner-Wells tongs was performed with a weight of 5–6 lbs before HVI. The halo-vest devices (Bremer Medical Inc., Jacksonville, FL, USA) were applied in a standardized manner based on the usual clinical method. The patient was placed in the supine position with the head supported by a wooden board. The skin was thoroughly scrubbed and, along with the underlying periosteum at the four pin sites, infiltrated with a 1% lidocaine solution. The four cranial pins were inserted until they were in contact with the bone. The surgeon and the assistant simultaneously tightened each diametrically opposite pin using the torque screwdriver to a maximum torque of 8 in./lb. Decisions regarding when to remove the halo-vest were made on the basis of radiographs with evidence of union and lack of or minimal neck pain.

### Surgical technique

We performed posterior cervical fixation including C1 lateral mass screw-C2 pedicle screw fixation and a cross-link over the C1 arch to interconnect the sides. After induction, baseline motor-evoked potentials and somatosensory-evoked potentials (NIM-ECLIPSE® Spinal system, Medtronic Inc., Memphis, TN, USA) were executed and maintained during surgical positioning and operation. We first performed transpedicular screw fixation through the C2 pedicles with the patient in the prone position. Then, a C1 lateral mass screw was inserted according to Harm's technique [8]. To facilitate C1 lateral mass screw insertion, the inferior surface of the posterior arch was drilled with a 2-mm high-speed drill. The drilling proceeded towards the C1 vertebral body keeping an inclination of approximately 5–10° inwards and 10–15° upward in the axial and sagittal planes under a fluoroscope, respectively. Drilling was performed gradually and cautiously to pass through the posterior part of the lateral mass, fracture site, and true lateral mass, stopping just before entering the anterior region of the C1 anterior arch. Tapping was performed with a 3.0-mm tip, followed by insertion of polyaxial

screws of 3.5 mm in diameter (Vertex, Medtronic, Memphis, TN, USA; Summit, Depuy Spine, Raynham, MA, USA). The length of screws used was appropriately selected to achieve accommodation of the rod (26–30 mm). The direct compression reduction and fixation technique was performed using horizontal rods and in situ compressors to reduce the fissure of unstable atlas fracture particles. After compression to reduce the fissure of C1 fractured lateral mass, C1 locking nuts were tightened firmly. After placement of cross-link over the C1 arch, connectors were placed and tightened between the cross-linked rod and C2 screw heads. Decortications of the posterior vertebral portions were performed with a burr, and autologous iliac cancellous bone was grafted onto the vertebrae after applying the internal fixation system. Closure of the wound was performed in layers using a suction drain, which was removed within 48 h after surgery. No intraoperative adverse events in motor-evoked potentials or somatosensory-evoked potentials were found during the operation. Immediate postoperative plain radiographs and cervical 3D-CT scans were taken to ensure well-positioning of the screws. All patients were placed in a Philadelphia cervical collar for 8–12 weeks and weaned off after neck pain subsided.

### Radiological assessments

Digital radiographs of the fracture site were reviewed using the picture archiving and communication system. In the open-mouth view, the sum of the right and left lateral masses of C1 that hung over the lateral masses of C1 was measured according to the rule of Spence [28] (Fig. 1(A)).

The atlantodental interval (ADI), described as the horizontal distance between the posterior cortex of the anterior arch of the atlas and the anterior cortex of the dens of the axis, was used to diagnose injuries of the atlas and axis [15, 25] (Fig. 1(B)).

Cervical lordosis (CL) was assessed by the C2–C7 Cobb angle and defined as the angle subtended by lines drawn parallel to the inferior endplate of the C2 vertebral body and to the inferior endplate of the C7 vertebral body. The C1–C2 angle was defined as the angle subtended by lines drawn parallel to the inferior aspect of C1 and to the inferior endplate of C2 (Fig. 1(B)). The range of motion (ROM) of CL and C1–C2 angle was estimated as the difference between the lordotic and kyphotic angles at neck extension and flexion.

We defined the fusion criteria as evidence of trabeculation across the fracture, invisibility of the fracture line on CT scans, and absence of movement on a flexion-extension view. We defined failure as unsatisfactory healing, pseudoarthrosis, instability on dynamic films, significant postural pain, development of neurologic symptoms, or any combination of these.

All patients underwent routine follow-up evaluations at 1 week after treatment and at scheduled follow-up visits. Patient progress was reviewed after 4, 8, and 12 weeks.

After 12 weeks, cervical dynamic views (flexion and extension radiographs) were obtained to check the bony healing. If there was no C1–C2 instability, we performed cervical 3D-CT to confirm solid bony healing. If bony healing of fractures was not achieved, we repeatedly obtained radiographs in patients every month for 6 months. Until bony fusion was confirmed, we performed HVI continuously in patients who underwent non-operative management and used neck collars (Philadelphia brace) in those who underwent surgical operation. After 1 year, radiological follow-up assessments were performed with cervical dynamic radiographs obtained once every 6 months.

### Clinical evaluation

The clinical outcome was ascertained by reviewing hospital charts and telephone survey. During the study period, patients were contacted and the quality of life measures was assessed by an independent examiner, using the neck pain visual analog scale (VAS) and neck disability index (NDI). The neck VAS score was determined from the preoperative and postoperative visits as documented in medical records. The following questions were included on the patient satisfaction survey: "If necessary, would you accept the halo-vest immobilization or surgical treatment again?" "Would you recommend halo-vest immobilization or surgical operation to other patients?" We decided that "yes" answers to both questions were satisfactory.

We evaluated the neurological status using grades defined by the American Spinal Injury Association (ASIA) to quantify the severity of neurological deficits. All patients underwent routine follow-up evaluations 1 week after the surgical treatment and subsequent follow-up visits were scheduled at that time.

### Statistical analysis

All values are expressed as mean ± standard deviation or percentage. Normally distributed data were compared using Student's $t$ test or a chi-squared test, as appropriate for the data set. Data with a non-normal distribution were evaluated using nonparametric analysis, and the Mann-Whitney $U$ test was used to evaluate differences between the two groups. The Mann-Whitney $U$ test was used for nonparametric analysis of differences between preoperative and postoperative values. All statistical analyses were conducted using MedCalc version 18.9.1 software (MedCalc, Mariakerke, Belgium). $P$ values < 0.05 were considered statistically significant.

## Results

A total of 24 patients enrolled in this study were treated by posterior reduction and fixation with horizontal rod
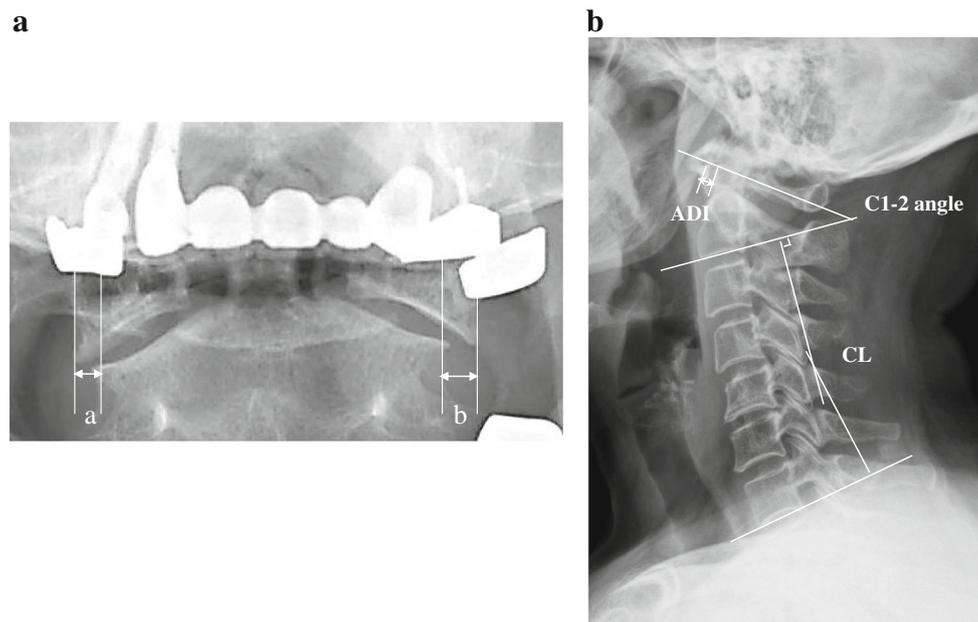
**a**



**b**



**Fig. 1** (A) In an open-mouth view, the combined measurements of the right (a) and left (b) lateral masses of C1 hung over the lateral masses of C2. If the sum of (a) and (b) is more than 6.9 mm, the rule of Spence would suggest that there should be concern for transverse ligament injury. (B) The atlantodental interval (ADI) is the horizontal distance between the posterior cortex of the anterior arch of the atlas and the anterior cortex of the dens of the axis. The C1–C2 angle is the angle subtended by lines drawn parallel to the inferior aspect of C1 and to the inferior endplate of C2. Cervical lordosis (CL) was assessed by the C2–C7 Cobb angle and is the angle subtended by lines drawn parallel to the inferior endplate of the C2 vertebral body and to the inferior endplate of the C7 vertebral body

compression or HVI. Nineteen cases were due to a motor vehicle accident, two cases were due to an accident from jumping into water at the pool side, and three patients were injured from falling down the stairs.

Among 24 patients, 13 (5 type II and 8 type III Landells and Van Peteghem classification [20]; 13 type IIIb Gehweiler classification [8]) underwent posterior reduction and fixation on C1–C2 using C1 lateral mass screw and C2 pedicle screw fixation supplemented with cross-link compressors [4]. Eleven patients underwent HVI for unstable atlas fractures (8 type II and 3 type III Landells and Van Peteghem classification; 11 type IIIb Gehweiler classification). Patients were followed for an average of 23.93 months (range 15.53–37.29 months).

The mean duration from trauma to management initiation was $2.67 \pm 1.61$ days in the surgical group and $2.72 \pm 2.10$ days in the HVI group, with no significant difference ($P = 0.8506$). The two groups did not differ in sex, patients' age, BMD, smoking, hypertension, and diabetes mellitus, which could affect bone fusion (Table 1).

## Clinical outcomes

The overall neck VAS scores decreased from a preoperative mean value of $7.05 \pm 0.01$ to $2.49 \pm 0.75$ postoperatively ($P < 0.0001$): from $6.92 \pm 0.76$ to $2.08 \pm 0.64$ in the surgical group and from $7.18 \pm 0.75$ to $2.91 \pm 1.70$ in the HVI group.

Patients who underwent non-operative treatment using HVI had more pain in the posterior neck at postoperative 12 months than those who underwent the surgical fixation ($P = 0.1156$).

The overall clinical outcome was an NDI score of $9.04 \pm 4.42$ at about 12 months after treatments. The NDI score was $7.15 \pm 1.95$ for surgical reduction with fixation and $11.27 \pm 5.49$ for HVI ($P = 0.0191$) (Table 2).

In the patient satisfaction survey, we were able to obtain responses from 23 patients. Of the 10 patients with HVI, three patients (30.0%) said "satisfaction" and 7 (70.0%) replied "dissatisfaction." Of the 13 patients with surgical operation, 10 patients (76.9%) said "satisfaction" and 3 (23.1%) replied "dissatisfaction."

The initial ASIA spinal cord injury grades denoted no neurological deficits (all 24 patients in ASIA grade "E") with only severe neck pain and dysesthesia in the posterior neck area. After surgical or non-operative treatments, all patients maintained ASIA E neurological status.

In surgical reduction with fixation, no patient developed the "cock-robin" deformity at the last follow-up. Three patients who underwent HVI had complaints of occipital neck pain on rotation but did not have the "cock-robin" deformity.

## Radiographic outcomes

The overall sum of overhang lateral translation was $9.84 \pm 0.28$ mm at the preoperative phase and $7.75 \pm 0.17$ mm at

**Table 1** Clinical characteristics of 24 patients with unstable atlas fractures

|  | Surgical group ($n = 13$) | HVI group ($n = 11$) |
|---|---|---|
| Age (years old) | $49.62 \pm 18.15$ | $46.91 \pm 13.22$ |
| Sex (male:female) | 7:6 | 8:3 |
| Management starting time (day) | $2.67 \pm 1.61$ | $2.72 \pm 2.10$ |
| Fracture type |  |  |
| II | 5 | 8 |
| III | 8 | 3 |
| Sum of fracture displacement (mm) | $10.31 \pm 1.57$ | $9.37 \pm 1.18$ |
| ADI (mm) | $4.98 \pm 0.62$ | $4.98 \pm 0.75$ |
| BMD $T$ score | $-1.90 \pm 0.99$ | $-1.65 \pm 1.91$ |
| ASIA grade E | 13 | 11 |

*ADI*, atlantodental interval; *ASIA*, American Spinal Injury Association Impairment Scale; *BMD*, bone mineral density; *HVI*, halo-vest immobilization

Fracture type is based on Landells and Van Peteghem classification

the final follow-up ($P = 0.0001$). In the surgical fixation group, the sum of lateral translation was from a preoperative mean value of $10.31 \pm 1.57$ to $7.10 \pm 1.85$ mm at postoperative 12 months ($P < 0.0001$). There was no evidence showing loss of reduction in the fractured atlas ring from the immediate postoperative period to the final follow-up (Fig. 2). In the HVI treatment group, the sum of lateral translation changed from a preoperative mean value of $9.37 \pm 1.18$ to $8.40 \pm 2.09$ mm at 12 months postoperatively ($P = 0.2600$). There was loss of reduction in the fractured atlas ring over time, with $7.96 \pm 1.53$ mm at postoperative 7 days, $8.37 \pm 1.93$ mm at 3 months, and $8.40 \pm 2.09$ mm at 12 months after HVI (Fig. 2). The mean reduction of fracture displacement was $3.21 \pm 1.21$ mm in the surgical group and $0.97 \pm 2.69$ mm in the HVI treatment group. The reduction in overhang translation values differed significantly between the two groups ($P = 0.0129$) (Table 2).

Overall, the initial ADI was $4.98 \pm 0.67$ mm and that at the last follow-up was $3.88 \pm 0.88$ mm ($P = 0.0001$). In the surgical group, the ADI changed from a preoperative mean value of $4.98 \pm 0.62$ to $3.51 \pm 0.67$ mm at 12 months postoperatively ($P = 0.0004$). In the HVI group, the ADI changed from a preoperative mean value of $4.98 \pm 0.75$ to $4.32 \pm 0.93$ mm at 12 months postoperatively ($P = 0.0580$). The mean reduction in ADI was $1.47 \pm 1.08$ mm in the surgical group and $0.66 \pm 1.02$ mm in the HVI treatment group. There was no significant difference in the reduction of ADI values ($P = 0.0559$) (Table 2).

## Bony fusion

The overall fusion rate was 87.5% (21/24) at the final follow-up: 100% (13/13 patients) in the surgical fixation group and 72.73% (8/11 patients) in the HVI treatment group. Dynamic films and cervical 3D-CT demonstrated that bony fusion was achieved in all patients at 18.30 weeks (range, 10.0 to 30.14 weeks). The mean time to solid fusion was $14.91 \pm 3.9$ weeks in the surgical group and $22.31 \pm 10.85$ weeks in

**Table 2** Radiological and clinical outcomes according to group

|  | Surgical group ($n = 13$) | HVI group ($n = 11$) | $P$ |
|---|---|---|---|
| Fracture displacement restoration (mm) | $3.21 \pm 1.21$ | $0.97 \pm 2.69$ | 0.0129* |
| ADI restoration (mm) | $1.47 \pm 1.08$ | $0.66 \pm 1.02$ | 0.0559 |
| Bony healing time (weeks) | $14.91 \pm 3.9$ | $22.31 \pm 10.85$ | 0.0316* |
| Healing rate (%) | 100 | 72.73 | 0.0815 |
| Cervical lordosis (°), postop 12m | $10.9 \pm 7.07$ | $7.0 \pm 9.15$ | 0.0987 |
| ROM of C2–C7 angle (°), postop 12m | $61.57 \pm 11.40$ | $77.60 \pm 24.67$ | 0.3017 |
| ROM of C1–C2 angle (°), postop 12m | $45.77 \pm 12.39$ | $61.5 \pm 11.16$ | 0.1011 |
| Neck VAS, postop 12m | $2.08 \pm 0.64$ | $2.91 \pm 1.70$ | 0.1156 |
| NDI, postop 12m | $7.15 \pm 1.95$ | $11.27 \pm 5.49$ | 0.0191* |

*ADI*, atlantodental interval; *HVI*, halo-vest immobilization; *NDI*, neck disability index; *postop 12m*, postoperative 12 months; *ROM*, range of motion; *VAS*, visual analog scale

*$P$ value $< 0.05$

**Fig. 2** Initial cervical traction followed by halo-vest immobilization (HVI) was found to slightly reduce lateral dislocation at 7 days after HVI, but an increase in displacement continuously occurred over time. In contrast, in the surgical fixation group, there was no loss of reduction in the fractured atlas ring over time. HVI, halo-vest immobilization; Surgical fixation, surgical reduction with fixation
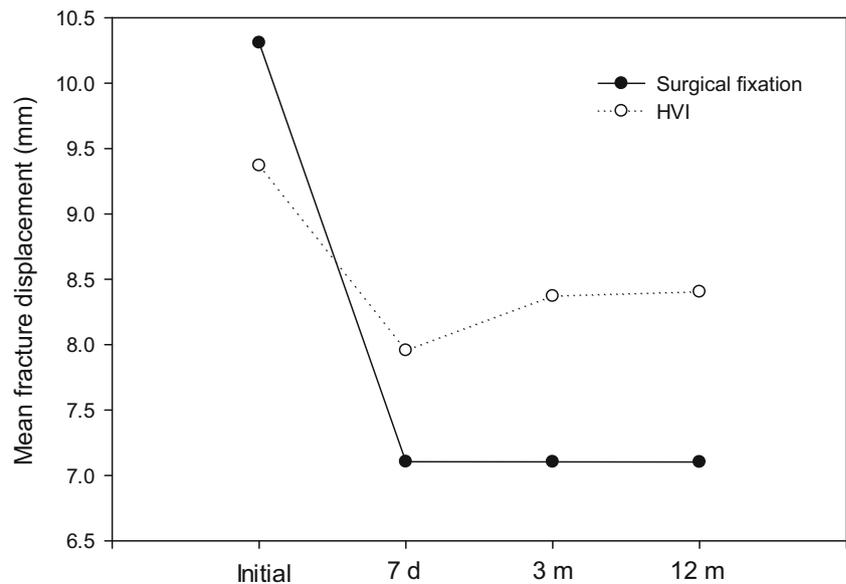


the HVI treatment group ($P = 0.0316$). There was no significant difference in bony healing time between the nonsurgical and surgical groups (Table 2). Patients who underwent HVI had a longer fusion time than those who underwent surgical reduction with fixation. In addition, three patients who underwent HVI had persistent neck pain over 6 months and their CT findings demonstrated nonunion.

### ROM

In the aspect of cervical lordosis, the cervical curvature in patients who underwent HVI (mean 7.0°; range, − 8.2 to 17.8°) was straighter than that in patients who underwent surgical reduction and fixation (mean 10.9°; range, 3.1–27.7°) ($P = 0.392$).

The cervical dynamic radiographs of patients who underwent HVI revealed better maintenance of neck motion at 12-month follow-up than those of patients who underwent surgical fixation. The mean ROM of the cervical global spine was 77.60° (range, 54.3–98.2°) in patients who underwent HVI: 47.7° (range, 32–60.9°) in flexion and 29.9° (range, 22.1–43.2°) in extension. In contrast, the mean ROM of cervical global spine was 61.57° (range, 49.6–72.3°) in patients who underwent surgical reduction with fixation: 30.3° (range, 26–33.9°) in flexion and 31.2° (range, 15.7–41.2°) in extension. There was no significant difference in C2–C7 ROM between the two groups ($P = 0.3017$) (Table 2).

Particularly, in patients who underwent HVI, the average C1–C2 ROM was 61.5° (range, 49.2–71°): 28.9° (range, 21.4–36°) at flexion and 32.5° (range, 27.5–39°) at extension. In patients who underwent surgical reduction with fixation, the average C1–C2 ROM was 45.8° (range, 34.8–59.2°): 21.9° (range, 16.3–27.6°) at flexion and 23.8° (range, 18.5–

31.6°) at extension. There was no significant difference in C1–C2 ROM between the two groups ($P = 0.1011$) (Table 2).

### Complications

Pseudoarthrosis, defined by non-fusion at 12 months postoperatively, developed in 27.27% of cases (3/11 patients) in the HVI group. For the three patients with pseudoarthrosis, we did not perform additional surgery because they refused surgical fixation and their neck pain was tolerable. Four (36.36%) of the 11 patients who underwent HVI experienced complications; the most common complications were frequent pin loosening (11.18%; 2/11), pin site infection (9.09%; 1/11), and brain abscess (9.09%; 1/11).

One of the 13 patients who underwent posterior reduction with fixation experienced cerebellar infarction with unilateral vertebral artery occlusion [3]. No patient had hardware failure, dural tear, or infections.

### Discussion

Unstable atlas fractures have been managed with HVI or surgical options including occiput–C2 fusion and C1–C2 fusion. The treatment goal for unstable atlas fracture is mainly to obtain good clinical outcome and patient satisfaction. This study showed that surgical fixation improved neck pain and patients' daily life, using the NDI, more than the non-operative management with HVI. Patients who underwent surgery experienced a higher successful fusion rate and shorter time to fracture healing than those who underwent non-operative management. Surgical reduction with fixation achieved significantly fractured

lateral mass reduction, whereas external immobilization did not. On the satisfaction survey, the satisfaction was 30% in patients who underwent HVI and 76.9% in those who underwent surgery. Patients with HVI complained about inconveniences in sleeping and personal hygiene and appearing conspicuous for such a long time.

A few authors have reported successful conservative management of unstable atlas burst fractures in their case series [9, 18]. Levine and Edwards demonstrated a 96% union rate in 34 atlas fractured patients with no late instability after non-operative treatment with HVI [17]. However, as external immobilization has poor control over the upper cervical vertebrae, it has a low healing rate and long-healing time. Hein et al. reported that external immobilization offered insufficient lasting reduction of laterally displaced lateral masses, followed by chronic neck pain [4, 11]. He et al. described a fusion rate of 100% with mild pain in 22 patients after operative management of unstable atlas fractures [10, 11]. These findings are consistent with those of our reports [4, 11].

When the combined overhang of displaced C1 lateral masses on C2 superior articular process is more than 6.9 mm, a loss in structural properties of TAL is suggested [28]. Heller et al. suggested that the gauge of 6.9 mm should be adjusted to 8.1 mm because of radiographic magnification [12]; the average sum of lateral mass displacement was 7.1–7.5 mm before surgery in previous reports [14, 27]. The average sum of lateral mass displacement in our series was 9.84 mm, which is compatible with all TAL injuries based on Heller's criteria [12]. A significant reduction in lateral displacement of fractured lateral masses was identified in surgical reduction with fixation $(3.21 \pm 1.21$ mm) compared with HVI $(0.97 \pm 2.69$ mm). An additional radiological tool for assessing instability is widening of the anterior ADI to more than 3 mm in functional lateral X-ray images [21]. In a cadaveric study, ADI is useful to detect ruptured TALs, which is defined as stability vs. instability [22]. When the ADI is about 3–5 mm, it can be diagnosed as a torn ligament or atlantoaxial instability. When the ADI is about 5–10 mm, it suggests a transverse ligament rupture with some auxiliary ligament rupture [21]. The average initial ADI was 4.98 mm in this study, which reduced to 3.51 mm with surgical reduction and fixation, but no reduction was observed with HVI.

After compressed force was directly applied to reduce fissure of the anterior arch, lateral mass, and posterior arch of the fractured C1, posterior C1–C2 fixation with cross-link was performed for treatment of unstable Jefferson fractures. In contrast, in cases of non-operative management, we initially performed cervical traction, followed by HVI, application of distraction force, and periodic tightening of the pin. Initial cervical traction followed by HVI was found to slightly reduce lateral

dislocation at 7 days after HVI application, but an increase in displacement continuously occurred over time, thereby lowering the probability of ligament and bone consolidation (Fig. 3). Over time, the surgical fixation group had no loss of reduction in the fractured atlas ring, whereas the non-operative management group had significant loss of reduction at the last follow-up (Fig. 4). We considered that the cross-link to reduce fractured lateral masses was maintained just like TAL. This is consistent with the findings of previous reports, which demonstrated that reduction of an unstable atlas fracture is achieved by transverse compression of the C1 screws, which is secured by a cross-link fixation [2, 27].

With regard to cervical alignment, patients who underwent HVI experienced more straight cervical alignment and neck stiffness than those who underwent surgical fixation. External reposition of the lateral masses requires the use of a halo-vest with axial distraction, which has repeatedly failed to maintain the initially achieved reduction, leading to incongruence of C0–C1 and C1–C2 joints [11]. Although we periodically readjusted the cervical alignment by radiologic checkup, HVI had no capacity to maintain cervical lordotic curvature. In contrast, Oshima et al. reported increasing lordotic change in the C1–C2 angle after C1–C2 fixation, while C2–C7 global angle became kyphotic [23]. Further investigations are required with longer follow-up periods to evaluate the relationship between cervical alignment changes and neck stiffness.

Motion adjacent to the C1 vertebra is responsible for 50% of flexion and extension and 50% of rotation through its articulations with the occipital condyles and the C2 superior articular facet [30]. Surgical fusion techniques sacrifice normal ROM, such as C1–C2 rotation and occiput–C1 flexion/extension, and the incidence of degeneration of the subaxial cervical spine may be increased [24, 26]. C1–C2 fusion leads to restriction of the head rotation to 35° or less on both sides [1]. On 3D finite element model, C1–C2 fusion reduced ROM by more than 90% compared with unstable models in flexion/extension, lateral bending, and axial rotation [5]. External HVI offers the advantage to maintain C1–C2 rotation [11]. Although we did not perform functional CT to measure the rotatory motion of C1–C2 joint before and after treatments, non-operative treatment using HVI could preserve the physiological C1–C2 dynamic motion, but surgical operation with C1–C2 fusion had restriction on the C1–C2 joint motion. Recently, internal fixation of the C1 ring (ORIF) or transoral reduction has been reported to maintain atlantoaxial motion over standard techniques of C1–C2 or occiput–C2 fusion for unstable atlas fractures with irrelevant TAL injury [26, 27]. This technique is a good option to save C1–C2 joint motion from unstable atlas fractures.
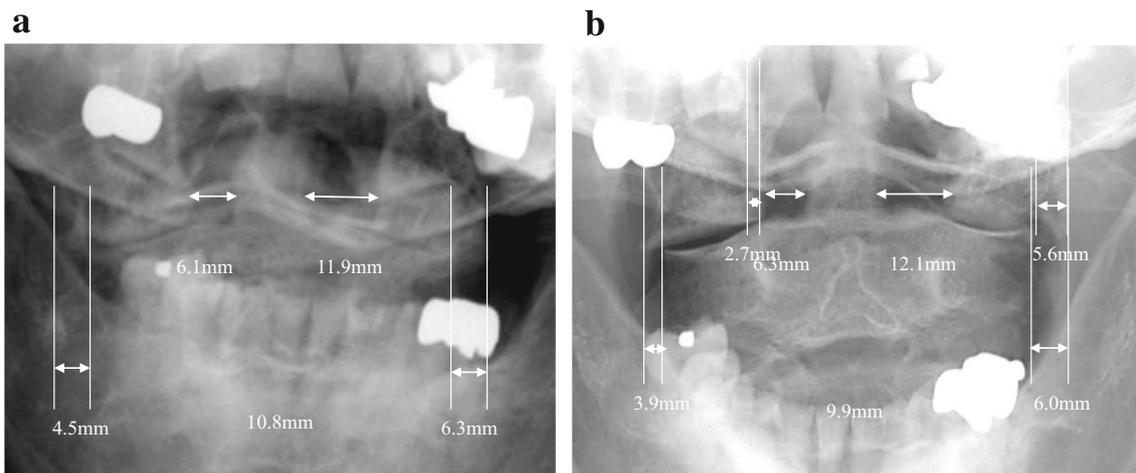
**Fig. 3** (A) Preoperative open-mouth view showing 10.8 mm as the sum of overhangs of C1 lateral masses on the C2 facet. (B) The 12-month post-treatment value was 9.9 mm. The fractured lateral masses was not markedly reduced by halo-vest immobilization

Limitations are the small number of patients and the retrospective design of this study which potentially bias our findings. Particularly, there was the selection bias inherent in choosing surgical operation or non-operative treatment. Before February 2007, surgeons at our institute preferred cervical immobilization with halo-vest orthosis. Since then, surgical operations were performed preferentially unless there was a major reason not to perform surgery. In addition, there was the lack of clinical data on the rotatory mobility of the cervical spine, so the preserved motion is not quantified. In the future, prospective studies enrolling a large number of cases may offer better control for follow-up time and have the potential to include more standardized treatments for unstable atlas fractures.

When evaluating the above results, immobilization with halo-vest for stabilization of unstable C1 burst fractures could not reposition and fix firmly the dislocated lateral masses.

This property may influence the course of healing, clinical outcome, and patient satisfaction. To obtain better clinical and radiological outcomes, we recommend surgical reduction and fixation for unstable atlas fracture with TAL injury, particularly marked lateral displacement of fractured lateral masses. Surgeons using a halo-vest in the treatment of unstable atlas fracture should be aware of its potential drawbacks and inform patients about possible outcomes.

## Conclusions

In this study, the radiological and clinical outcomes of surgical operation were better than those of non-operative treatment. Particularly, surgical fixation for unstable atlas fractures has a higher successful fusion rate, shorter time to fracture healing, and better reduction of fractured lateral slippage than non-
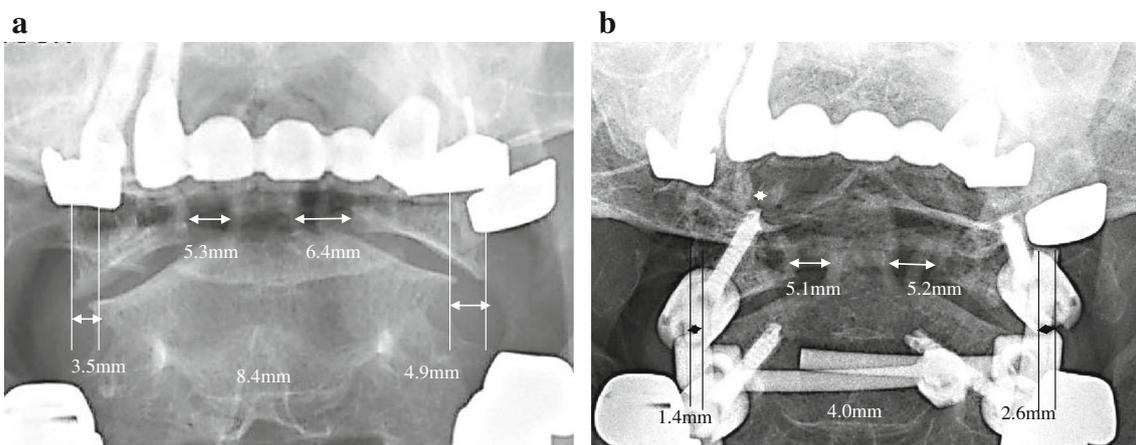


**Fig. 4** (A) Preoperative open-mouth view showing 8.4 mm as the sum of overhang of C1 lateral masses on the C2 facet. (B) The 12-month postoperative value was 4.0 mm. A significant reduction in the lateral displacement of fractured lateral masses was identified after surgical reduction with fixation

operative management. Patients who underwent surgical treatments showed clinically better improvements in neck pain, daily activities, and satisfaction than those who underwent nonsurgical treatments. Based on our results, surgical treatment of unstable atlas fractures with TAL injuries proved to be a more efficacious management strategy compared with non-operative treatment.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflicts of interest.

**Ethical approval** All human and animal studies were approved by the appropriate ethics committee and were performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

**Study Design** Retrospective cohort study

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