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Direct Internal Fixation for Unstable Atlas Fractures

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Purpose: To investigate the radiologic and clinical outcomes of direct internal fixation for unstable atlas fractures.
Materials and Methods: This retrospective study included 12 patients with unstable atlas fractures surgically treated using C1 lateral mass screws, rods, and transverse connector constructs. Nine lateral mass fractures with transverse atlantal ligament (TAL) avulsion injury and three 4-part fractures with TAL injury (two avulsion injuries, one TAL substance tear) were treated. Radiologic outcomes included the anterior atlantodental interval (AADI) in flexion and extension cervical spine lateral radiographs at 6 months and 1 year after treatment. CT was also performed to visualize bony healing of the atlas at 6 months and 1 year. Visual Analog Scale (VAS) scores for neck pain, Neck Disability Index (NDI) values, and cervical range of motion (flexion, extension, and rotation) were recorded at 6 months after surgery.
Results: The mean postoperative extension and flexion AADIs were 3.79±1.56 (mean±SD) and 3.13±1.01 mm, respectively. Then mean AADI was 3.42±1.34 and 3.33±1.24 mm at 6 months and 1 year after surgery, respectively. At 1 year after surgery, 11 patients showed bony healing of the atlas on CT images. Only one patient underwent revision surgery 8 months after primary surgery due to nonunion and instability findings. The mean VAS score for neck pain was 0.92±0.99, and the mean NDI value was 8.08±5.70.
Conclusion: C1 motion-preserving direct internal fixation technique results in good reduction and stabilization of unstable atlas fractures. This technique allows for the preservation of craniocervical and atlantoaxial motion.

Key Words: Neck injury, cervical atlas, spinal injuries, cervical vertebrae, spinal fractures

INTRODUCTION

Burst fracture involving the bony arches of the atlas, also referred to as a Jefferson fracture, occurs as a result of either neck hyperextension or posterior axial loading. A transverse atlantal ligament (TAL) injury distinguishes an unstable atlas fracture from a stable one.[1,2] Incongruence of the C0–C1 and C1–C2 joints occurs as a result of lateral mass displacement and is observed in unstable fractures. Traditionally, conventional treatments for unstable atlas fractures include skull traction with halo-vest stabilization, transoral or posterior atlantoaxial fusion, and craniocervical fusion, although there is controversy as to which is the optimal treatment method.[1,3-8] However, the O-C1-C2 joints have a large range of motion. Therefore, we performed direct internal fixation of the atlas to preserve upper cervical motion.

The purpose of this study was to evaluate the efficacy of direct internal fixation of the atlas for unstable fractures.

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•The authors have no potential conflicts of interest to disclose.

MATERIALS AND METHODS

Patient demographics and clinical data

This study was performed as a retrospective single-center review of 12 patients (8 male and 4 female) with unstable atlas fractures treated with direct internal fixation of C1 using C1 lateral mass screws, rods, and transverse connector systems from 2014 to 2018. The study was approved by the Institutional Review Board of Gangnam Severance Hospital, Yonsei University College of Medicine (Approval number: 3-2020-0385). The requirement for informed consent was waived due to the retrospective nature of the study. The average patient age was 37 years (range, 21–63 years). The nature of the injuries was as follows: five cases of motor vehicle accidents, five cases of falls from height, and two cases of physical assault. Presenting symptoms included neck pain and stiffness; no patient had neurologic symptoms. There were nine lateral mass fractures with TAL avulsion injury and three 4-part fractures with TAL injury (two avulsion injuries, one TAL substance tear) (Table 1).

Surgical technique

Patients were placed in a prone reverse-Trendelenburg position on a Jackson table with skull traction (5 kg). This position allowed for good visualization of the atlas' posterior arch and partially contributed to fracture reduction. Intraoperative fluoroscopic guidance using the C-arm was used to check the fracture reduction.

A posterior midline skin incision, approximately 7 cm in length, was made from the occiput to the C2 spinous process. This incision was then followed by subperiosteal dissection of the posterior arch of C1, approximately 30 mm lateral to the midline. Meticulous dissection along the inferior border of the C1 posterior arch was required due to the epidural venous plexus in the area. Rectus capitis posterior major and obliquus capitis inferior muscle attachments to the C2 spinous process were preserved. The entry points of the C1 lateral mass screws were identified. Two Penfield dissectors were used to protect the C2 nerve root and vertebral artery. A 2-mm burr was used to make a notch at the lateral mass, and a pilot hole was made using a drill bit. The trajectory of the pilot hole and the length of the screw to be used were confirmed based on measurements. A 3.5-mm or 4.0-mm tap was used. Two 3.5-mm or 4.0-mm titanium polyaxial screws were inserted. The two screws were connected with a rod and transverse connector. Unilateral tightening of the transverse connector nut was performed. A compressor device gently compressed the two C1 lateral mass screws to facilitate fracture reduction while the contralateral transverse connector nut was tightened. Satisfactory fracture reduction was confirmed using the intraoperative C-arm (Fig. 1).

Postoperative treatment

Ambulation was encouraged on the first postoperative day, and antibiotics were administered for up to 24 hours postoperatively. A Miami J brace was used for 3 months. At 6 months and 1-year postoperative follow up, flexion-extension lateral cervical X-ray and CT scans were obtained to assess bony union.

Radiologic and clinical evaluation

All imaging studies were reviewed by two orthopedic surgeons, and all radiographic parameters were measured using the medical imaging software Centricity (Enterprise Web 3.0; GE Healthcare 500 W, Chicago, IL, USA). Postoperative lateral flexion-extension anterior atlantodental interval (AADI) is the distance between the odontoid process and the posterior border of the anterior arch of the atlas on lateral flexion-extension X-ray. Instability was defined as a difference in AADI between flexion and extension >3 mm. Bony healing of the atlas was evaluated through CT images at 6 months and 1 year after surgery.

Neck range of motion (flexion or extension, 0–5', rotation, 0–80'), Visual Analog Scale (VAS, 0–10) scores for neck pain, and Neck Disability Index (NDI, 0–50) scores were obtained postoperatively.

Statistical analysis

Radiographic and clinical parameters are reported as means and standard deviations. Intra- and inter-observer agreements were assessed using intraclass correlation coefficients (ICCs). ICCs, with 95% confidence intervals, were also calculated by

Table 1. Patient Demographics and Clinical Data

No.	Age/sex	Injury cause	Fracture type	Postop neck pain VAS	Postop NDI	Postop JOA	Postop neck flexion	Postop neck extension	Postop neck rotation	Hardware removal
1	33/M	PA	B	0	10	16	40	40	75	O
2	24/M	MVA	B	3	20	13	27	43	70	X
3	34/F	Fall	A	0	0	17	30	30	80	O
4	27/M	MVA	B	1	8	15	41	42	75	O
5	45/F	Fall	B	1	12	12	37	35	80	O
6	52/M	PA	B	2	4	16	41	45	80	X
7	34/M	MVA	A	2	3	14	27	43	75	X
8	36/M	MVA	B	0	7	17	35	30	80	O
9	43/F	Fall	B	0	5	13	40	45	75	O
10	21/M	MVA	B	1	15	14	41	45	75	X
11	63/M	Fall	B	3	10	17	35	40	75	X
12	34/F	Fall	A	1	10	14	40	40	70	O

M, male; F, female; PA, physical assault; MVA, motor vehicle accident; NDI, Neck Disability Index; JOA, Japanese Orthopedic Association score; VAS, visual analog scale; Fracture type A, 4-part atlas fracture with transverse atlantal ligament injury; Fracture type B, lateral mass fractures with transverse atlantal ligament avulsion injury.

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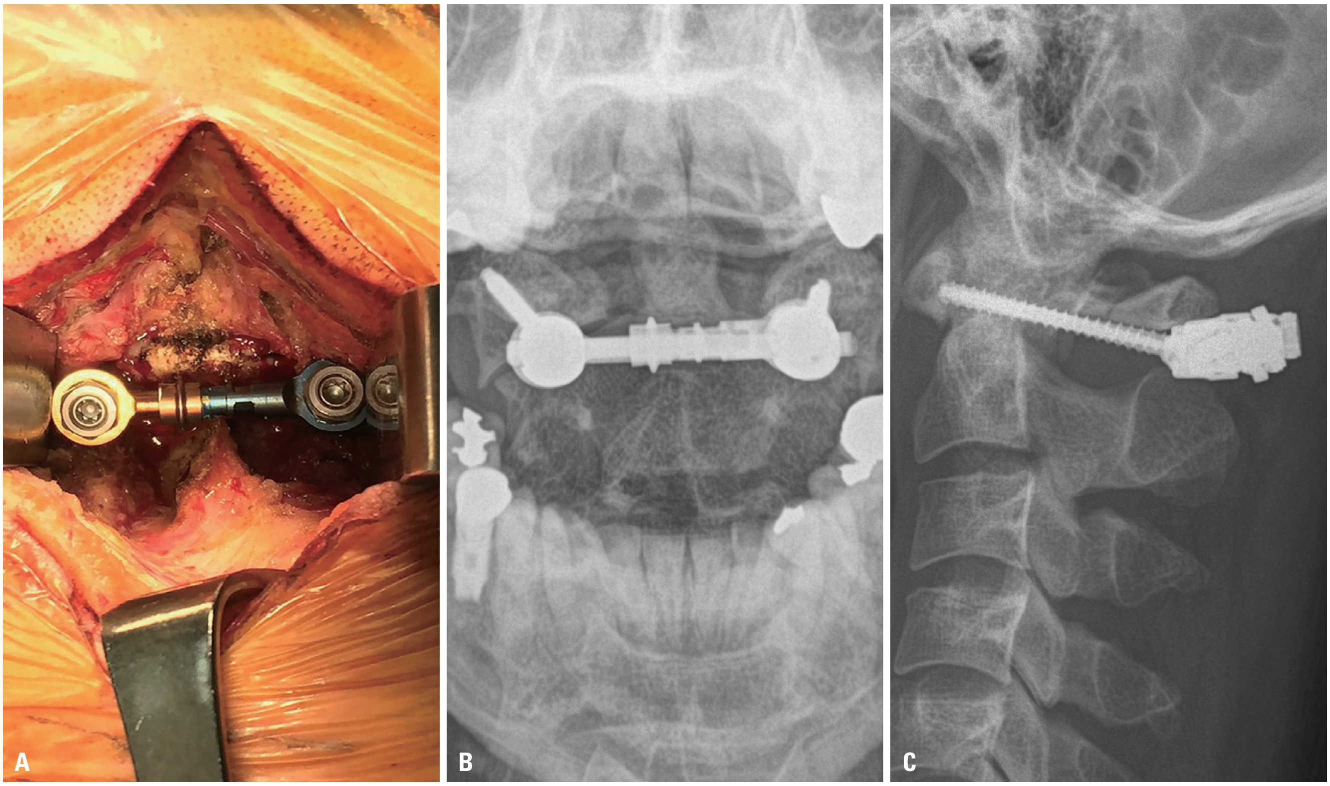

Fig. 1. Photograph and radiographs after C1 direct internal fixation. (A) Operative field photograph. (B) Open mouth radiograph taken immediately after surgery. (C) Lateral cervical radiograph taken immediately after surgery.

comparing the mean of both trials for two observers. ICCs of <0.40, 0.40–0.75, and 0.75–1.00 indicated poor, fair to good, and excellent reliability, respectively. Statistical analyses were performed using SPSS software version 22.0 (IBM Corp., Armonk, NY, USA). A p value <0.05 was considered significant for all analyses.

RESULTS

The mean operation time for all 12 patients was 111.92±7.14 (mean±SD) minutes, mean blood loss was 125±78.33 cc, and mean hospital stay was 3.23±1.02 days. The mean postoperative flexion and extension AADI values were 3.79±1.56 (range, 1.2–5.0) and 3.13±1.01 (range, 1.4–7.2) mm at 6 months after surgery, respectively. Only one patient showed instability on postoperative dynamic radiographs. The mean AADI was 3.42±1.34 and 3.33±1.24 mm at 6 months and 1 year after surgery, respectively. At 6 months after surgery, CT images for nine patients showed bone union. Eleven showed complete bone union at 1 year after surgery on CT images (Fig. 2).

Regarding clinical outcomes, the mean neck pain VAS and NDI scores were 0.92±0.99 (range, 0–3) and 8.08±5.70 (range, 0–20), respectively. All patients showed good postoperative range of motion, as shown in (Fig. 3). The mean neck flexion was 36.17°±5.42° (range, 27°–41°), neck extension was 40°±5.79° (range, 30°–45°), and neck rotation was 75.83°±3.59° (range, 70°–80°). Assessment of intra- and inter-observer reliability showed excellent agreement for all investigated radiologic parameters (all ICCs between 0.751 and 0.812).

Seven patients underwent hardware removal approximately 12 months after the initial surgery. No post-hardware removal instability or fracture nonunion was observed for any of the seven patients (Fig. 4). No implant failures were observed in any of the patients with well-preserved range of motion in the upper cervical spine. No surgical complications, such as neurologic deficit, vertebral artery injury, or wound infection, were observed in any of the patients. However, one patient displayed C1–2 instability after surgery and continued to have neck pain, for which C1–2 fusion was performed at 8 months after the initial surgery.

DISCUSSION

The conventional treatments for unstable atlas fractures with TAL injury are atlantoaxial fusion and craniocervical fusion. These surgeries, however, sacrifice a large range of motion of the upper cervical area and limit motion, leading to disability. These injuries occur frequently in young people who engage in sports activity (average age of 37 in this study), and it is important to preserve upper cervical motion in these young patients. With this in mind, C1 direct fixation, which can preserve O-C1-C2

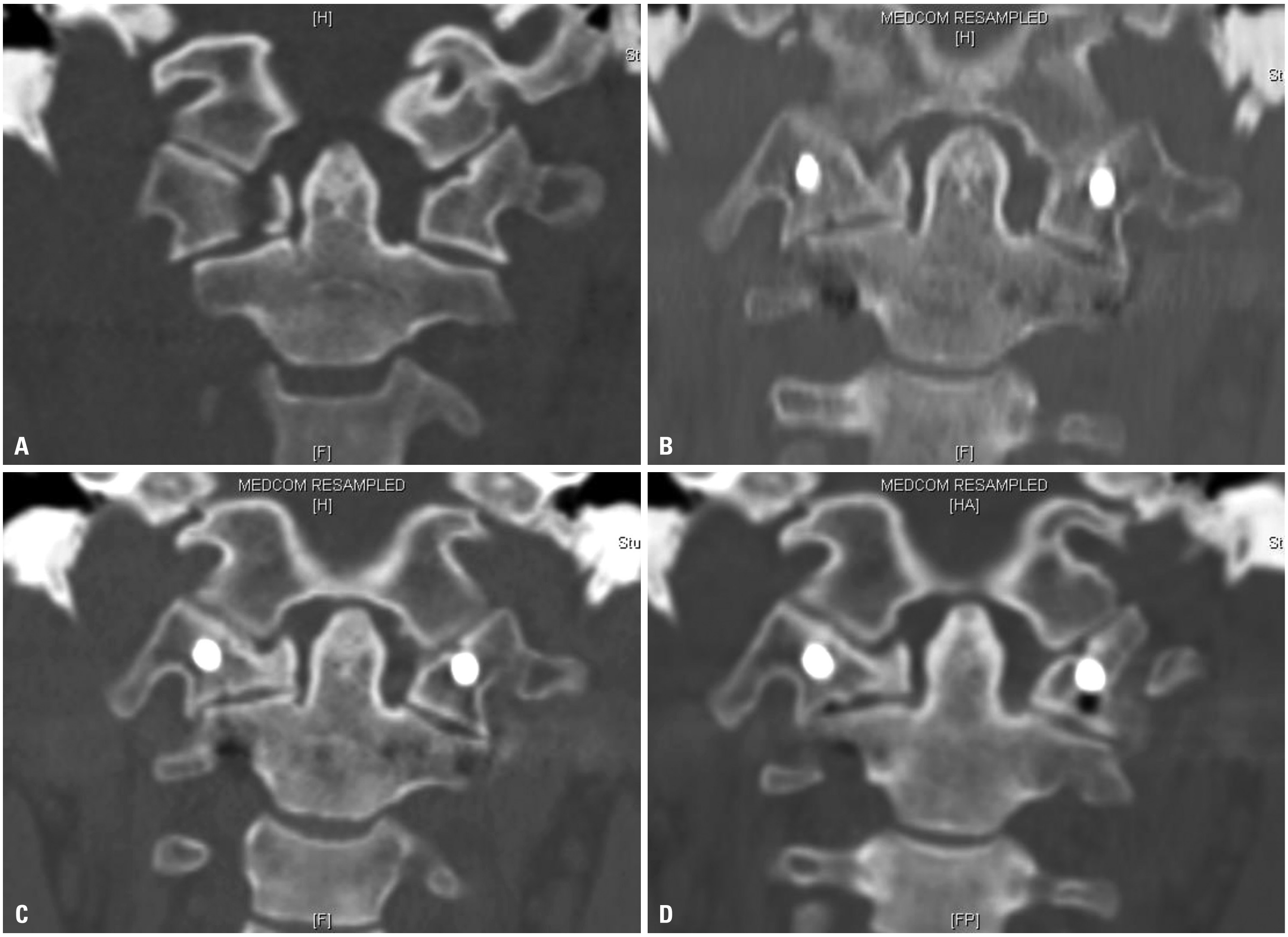

Fig. 2. Coronal plane of upper cervical spine computed tomography scans (A) pre-surgery and at (B) 6 months, (C) 1 year, and (D) 2 years after surgery.

Fig. 3. Images of a 36-year-old male patient showing full rotation of the neck after C1 direct internal fixation. These photographs were taken 1 year after surgery, before hardware removal.

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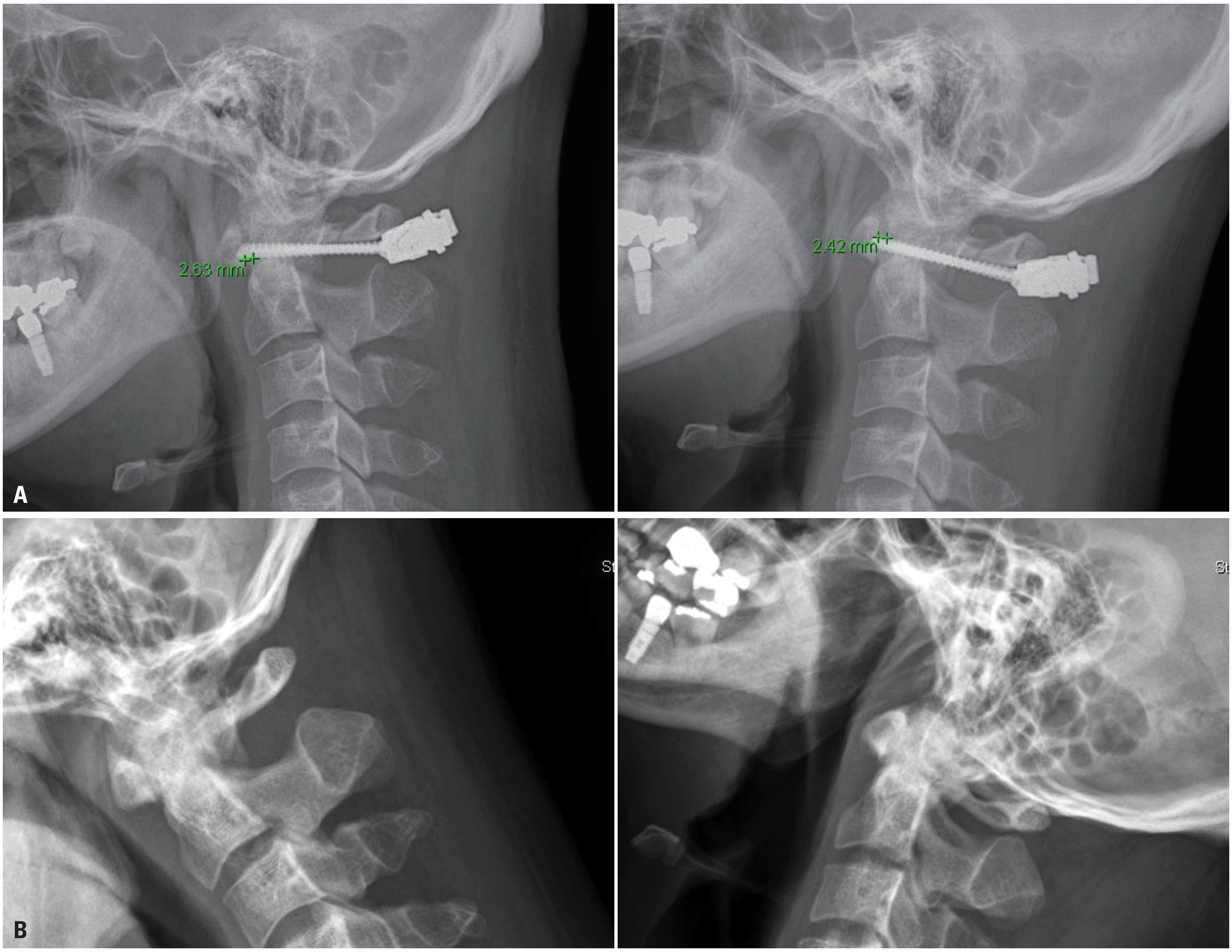

Fig. 4. Dynamic cervical radiographs at follow-up. (A) Minimal instability is observed on dynamic cervical radiographs at the 6-month follow-up evaluation after C1 direct internal fixation. (B) Consistent minimal instability is observed on dynamic cervical radiographs at the 18-month follow-up evaluation after hardware removal.

joint motion, was performed. However, researchers have noted that the most important point in this surgery is that there ought not be C1–2 instability after surgery and that the congruity of the OC joint should be preserved so that post-operative osteoarthritis of the joint is avoided.[9-11] Therefore, we assessed AADI and bone healing status after surgery to evaluate the efficacy of direct internal fixation, and stability and bone healing were achieved in 11 of 12 surgical patients. However, in one patient, C1–2 instability persisted after direct internal fixation of C1, and C1–2 fusion was performed at 8 months after the initial surgery.[12]

An important point to consider when performing this surgery is that the atlas is in an unstable state, thus, care must be taken to avoid vertebral artery injury during procedures, such as drilling. Taking this into consideration, if an electric drill is used instead of a hand drill, movement of bone fragments due to pressure from a hand drill can be prevented, avoiding additional injuries. Another method may be to achieve safe fixation using O-arm navigation.

Zhang, et al. reported surgical outcomes using a monoaxial screw-rod system to treat unstable atlas fractures, demonstrating that anatomical reduction was possible using this surgical method and that TAL incompetence was not a contraindication for this surgery.[13-15] While a polyaxial screw was also used in this study, a rod and a transverse connector were additionally used to strengthen the structure. Unlike the previous report, hardware removal was performed in seven patients between 12 and 24 months following surgery, and complications of nonunion were not observed even after implant removal. In addition, CT scans were performed at 6 months, 1 year and 2 years after surgery (Fig. 5) to track lateral mass displacement and gradual bone union, confirming that this bone union was maintained even after hardware removal in most patients.[16,17] Interestingly, Ma, et al.[18] reported that in six patients with Jefferson fractures with transverse ligament injuries, anatomical reduction could be achieved using a trans-oral approach, direct open reduction, and instrumentation. Postoperative nonunion, C1–2 instability, and range of motion limitations were not observed in their patients. However, given the risk of wound complica-

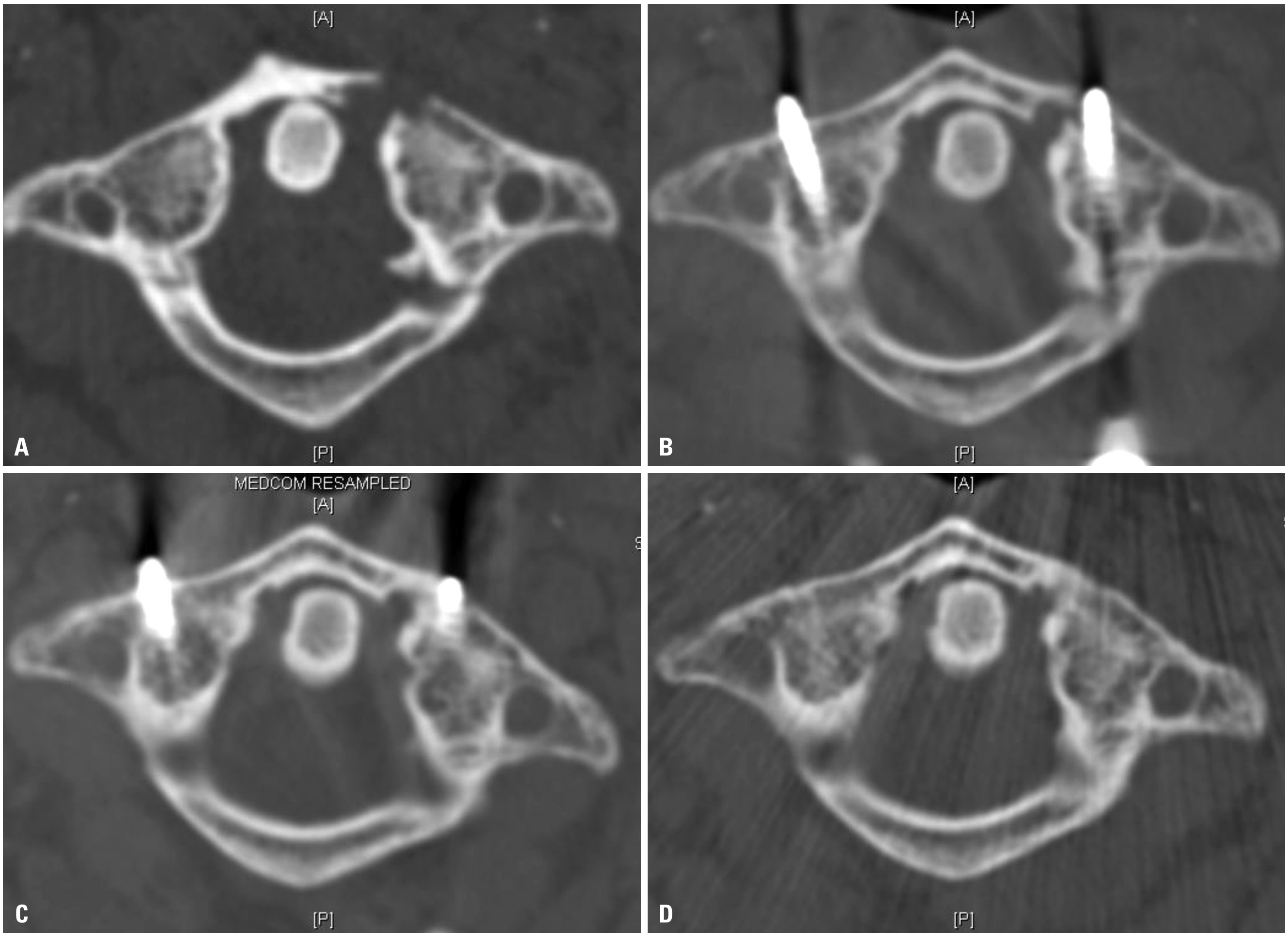

Fig. 5. Axial plane of upper cervical spine CT scans pre-surgery and at 6 months, 1 year, and 2 years after surgery. (A) Displaced unilateral C1 anterior and posterior arch fractures are observed on preoperative CT scans. (B) Good reduction status and bone healing are observed on 6-month follow-up CT scans. (C) Almost complete bone healing is observed on 1-year follow-up CT scans. (D) Complete bone healing of the previous fracture and hardware sites is observed on CT scans acquired at follow-up after hardware removal. The CT scans also confirm that the dens were maintained without deviation. CT, computed tomography.

tions, it is not a commonly performed surgery.

The C1 motion-preserving direct internal fixation technique has some advantages, compared with fusion surgery. These include short hospitalization, early mobilization, early return to activities of daily living, no requirement for halo-vest stabilization, preserved range of motion, and good reduction with good union.[19]

The small sample size was the primary limitation of this study. However, unstable atlas fractures are rare, and previous reports feature similar sample sizes. The second limitation is the high proportion of follow-up loss among the seven patients who underwent hardware removal, making it difficult to track outcomes for these patients after hardware removal. Thus, in this study, there were no long-term follow-up data beyond 2 years.

In conclusion, C1 motion-preserving direct internal fixation technique results in good reduction and stabilization of unstable atlas fractures. This technique allows for the preservation of craniocervical and atlantoaxial motion.

AUTHOR CONTRIBUTIONS

Conceptualization: Jae-Won Shin and Kyung-Soo Suk. Data curation: Jae-Won Shin. Formal analysis: Jae-Won Shin and Kyung-Soo Suk. Funding acquisition: Jae-Won Shin. Investigation: Jae-Won Shin. Methodology: Kyung-Soo Suk. Project administration: Kyung-Soo Suk. Resources: Jae-Won Shin and Kyung-Soo Suk. Software: Jae-Won Shin. Supervision: all authors. Validation: Jae-Won Shin. Visualization: Jae-Won Shin. Writing—original draft: Jae-Won Shin and Kyung-Soo Suk. Writing—review & editing: Jae-Won Shin, Jae-Ho Yang, and Ji-Won Kwon. Approval of final manuscript: all authors.

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