Uehara et al. BMC Musculoskeletal Disorders (2025) 26:328
https://doi.org/10.1186/s12891-025-08582-3

BMC Musculoskeletal Disorders

RESEARCH

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Higher incidence of delayed bone fusion for atlantoaxial fusion versus occipitocervical fusion with navigation system

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Abstract

Background Due to the high stresses placed on the upper cervical spinal region, achieving firm fixation and solid bony fusion is essential for good surgical outcomes. However, few reports have addressed bony fusion in procedures involving this region. The present investigation evaluated bony union in fusion procedures for surgical treatment of the upper cervical spinal region and searched for factors associated with fusion failure.

Methods The medical data of 84 consecutive patients (38 male and 46 female; mean age: 68.7 years) who underwent upper cervical spinal fusion surgery were retrospectively examined. The surgical techniques used were occipitocervical (O-C) fusion in 45 patients and atlantoaxial fusion with trans-articular screws in 39 patients. To determine the incidence of bony union, the cohort was divided into O-C fusion and atlantoaxial fusion groups and examined for the presence of delayed bony union. Logistic regression models were employed to analyze the prevalence, characteristics, and risk factors of delayed bony union.

Results Overall, 20.2% of upper cervical spinal fusion surgery patients experienced delayed bony union. In comparisons of the O-C fusion and atlantoaxial fusion groups, we observed no remarkable differences for age, gender, or steroid use, although rheumatoid arthritis was significantly more common in the O-C fusion group ($p < 0.001$). Bony fusion rates tended to be higher in the O-C fusion group (86.6%) than in the atlantoaxial fusion group (71.7%). Multivariate analysis identified atlantoaxial fusion to be more strongly associated with delayed bony union (odds ratio: 2.6).

Conclusion Approximately 20% of patients undergoing upper cervical spinal fusion surgery experienced delayed bony union. With an odds ratio of 2.6, atlantoaxial fusion was strongly related to this complication.

Keywords Atlantoaxial fusion, Occipitocervical fusion, Bony union, Complication, Upper cervical

Introduction

The upper cervical spinal region is the area that connects the skull to the spine and is composed of the occipital bone, the annular vertebra, and the axial vertebra. This region is the junction of the skull, a large non-moving bone, with the articulating spine, and is therefore subject to a large load [1]. Spinal disorders in this area can lead to such life-threatening problems as respiratory dysfunction in severe cases.

Several conditions or injuries of the upper cervical spine, including trauma, congenital malformations, and tumors, may cause acute or chronic occipitocervical (O-C) instability and require spinal fusion [2–6]. Due to the high stresses placed on the upper cervical spinal region, achieving firm fixation and solid bony fusion is crucial for good surgical outcomes. In a biomechanical

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study, both O-C fusion and atlantoaxial fusion reduced load on the upper cervical spine, with no significant differences between the methods [7]. However, reports are scarce on bony fusion in upper cervical spinal fusion procedures. The present study assessed bony union rates in fusion surgeries in the upper cervical spinal area and examined for factors associated with fusion failure.

Materials and methods

The protocol of this study was approved by our hospital's institutional review board (no. 6298). Informed written consent was obtained from all patients prior to the investigation. A total of 90 patients underwent upper cervical spinal fusion surgery with preoperative CT-based navigation between January 2000 and May 2024 at our hospital. After excluding 3 patients without grafted bone, 2 patients less than 20 years old, and 1 patient not followed for at least 6 months by postoperative computed tomography (CT), the remaining 84 consecutive patients (38 male and 46 female; mean ± standard deviation age: 68.7 ± 11.0 years) were retrospectively enrolled for analysis. All included patients were followed for a minimum of 6 months. The cohort contained 37 cases of rheumatoid arthritis (RA) cervical lesion, 24 cases of atlantoaxial subluxation, 16 cases of trauma, 6 cases of retro-odontoid pseudotumor, and 4 cases of cervical spondylotic myelopathy. The surgical techniques used were O-C fusion in 45 patients and atlantoaxial fusion with trans-articular screws in 39 patients (Fig. 1). All patients received grafts harvested from the iliac crest bone without the addition of mixed bone substitute material or bone morphogenetic protein 3. O-C fusion was performed by fixation of the occipital plate with cervical pedicle screws or lateral mass screws by rods. The lowest instrumented vertebra in O-C fusion was C2 in 5 patients, C3 in 17 patients, C4 in 6 patients, C5 in 4 patients, C7 in 4 patients, T1 in 6 patients, T2 in 1 patient, and T3 in 2 patients.

The surgical procedure for O-C fusion was as follows. After deployment, pedicle screws or lateral mass screws were inserted under preoperative CT-based navigation. The screw-fixed occipital plate was connected to the pedicle screws or lateral mass screws with rods. Iliac bone was grafted between the occipital bone and the cervical vertebrae using tape [8].

We performed atlantoaxial fusion as follows. After deployment, a pilot hole was created with preoperative CT-based navigation, and a guide wire was inserted under fluoroscopy. Drilling and tapping were followed by transarticular screw insertion. Iliac bone grafting between the C1 posterior arch and C2 was fixed using the McGraw method with tape [9].

We employed CT to evaluate bony union at 6 months or more postoperatively for confirming fusion in all patients. As evidence of a full bony bridge between the posterior arch of C2 and the occipital bone (O-C fusion) or posterior arch of C1 (atlantoaxial fusion), bony union was defined as the cortical union of the allograft and central trabecular continuity [10, 11]. Delayed bone

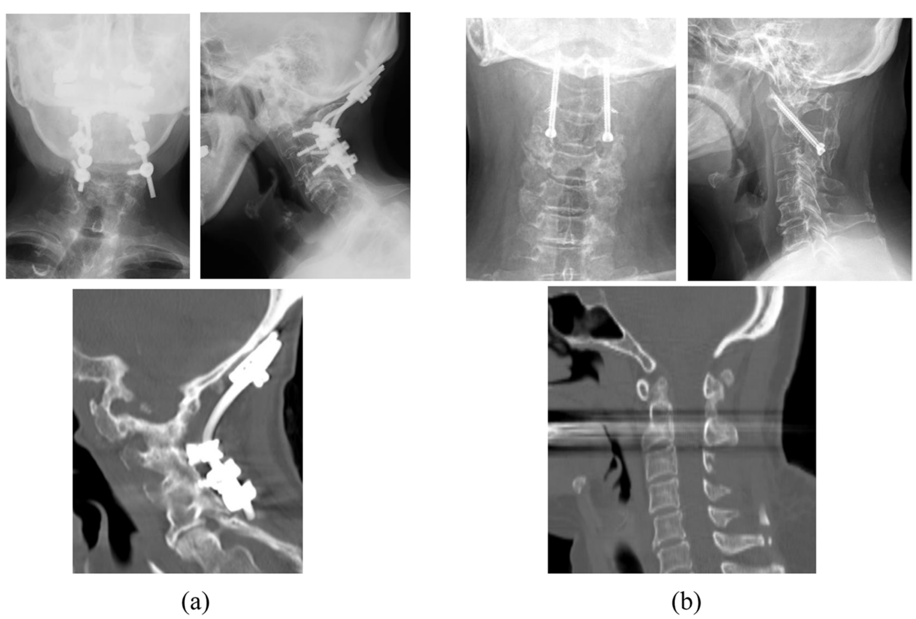

Fig. 1 **a** Representative radiographs (top) and CT image (bottom) of a 77-year-old woman receiving occipitocervical fusion for vertical subluxation due to rheumatoid arthritis. **b** Representative radiographs (top) and CT image (bottom) of a 51-year-old woman who underwent atlantoaxial fusion for atlantoaxial subluxation due to rheumatoid arthritis

union was defined as no apparent bone union on CT at 6 months postoperatively. To analyze the incidence of bony union, the cohort was divided into the O-C fusion and atlantoaxial fusion groups and further according to the presence or absence of delayed bone union, with associated factors examined by multivariate analysis.

Fisher's exact test was adopted for proportional result comparisons, and Welch's *t*-test was used for continuous result analysis. We employed logistic regression models to identify factors associated with non-union using the presence of non-union as the response variable and such patient-related factors as age, sex, disease, steroid use, surgical procedure (atlantoaxial fusion), and comorbidity history (RA) as explanatory variables. Factors exhibiting $p < 0.2$ in univariate analysis, age, and sex were considered for subsequent multivariate analysis. Stepwise model testing using Akaike's information criteria was adopted to select the elements for inclusion in the multivariate analysis. All statistical testing was conducted using EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R (The Foundation for Statistical Computing, Vienna, Austria). EZR is a modified version of R commander designed to add statistical functions frequently used in biostatistics. The level of significance was set at $p < 0.05$.

Table 1 Patient group details

	O-C fusion group ($N=45$)	Atlantoaxial fusion group ($N=39$)	*p*-value
Gender (male: female)	18: 27	20: 19	0.38
Age (years)	69.0 ± 10.3	68.3 ± 11.7	0.78
Disease (AAS: RA: trauma: pseudotumor: CSM)	7: 26: 5: 3: 4	17: 8: 11: 3: 0	< 0.01
Comorbidity			
RA	28 (62.2%)	9 (23.0%)	< 0.01
DM	5 (11.1%)	4 (10.2%)	1.00
Steroid use	5 (11.1%)	1 (2.5%)	0.20
C1 laminectomy	8 (17.7%)	3 (7.6%)	0.20
Bone union	39 (86.6%)	28 (71.7%)	0.10

Values represent the mean ± standard deviation

O-C Occipitocervical, *AAS* Atlantoaxial subluxation, *RA* Rheumatoid arthritis, *CSM* Cervical spondylotic myelopathy, *DM* Diabetes mellitus

Results

Table 1 summarizes the properties of the O-C fusion and atlantoaxial groups. Overall bony fusion rate was 79.8%. We observed no remarkable differences in terms of age, gender, DM, or steroid use between the groups (Table 1). RA was significantly more frequent in the O-C fusion group ($p < 0.001$). Bony fusion rate tended to be higher in the O-C fusion group (86.6%) than in the atlantoaxial fusion group (71.7%), albeit not significantly ($p = 0.10$). Univariate analysis uncovered notable associations with delayed bony union for age (+ 10 years) (odds ratio [OR]: 1.07, 95% confidence interval [95%CI]: 0.65–1.74, $p = 0.79$)], female (OR: 0.91, 95%CI: 0.31–2.65, $p = 0.86$), steroid use (OR: 0.77, 95%CI: 0.084–7.11, $p = 0.82$), RA (OR: 0.45, 95%CI: 0.14–1.44, $p = 0.18$), C1 laminectomy (OR: 1.58, 95%CI: 0.37–6.73, $p = 0.53$), and most prominently atlantoaxial fusion (OR: 2.55, 95%CI: 0.84–7.72, $p = 0.096$). Multivariate analysis of atlantoaxial fusion, age, and gender revealed a relatively higher association with delayed bony union for atlantoaxial fusion (OR: 2.57, 95%CI: 0.84–7.84, $p = 0.096$) (Table 2). Among the 39 patients who received atlantoaxial fusion, 11 had delayed bony union, with 9 of those patients (81.8%) exhibiting failed bony fusion with the C1 posterior arch.

Discussion

This study examined the prevalence of delayed bony union in upper cervical spinal fusion surgery and investigated for patient-based risk variables. Approximately 20% of the 84 patients receiving upper cervical spinal fusion experienced delayed bony union. With a high OR value of 2.6, multivariate analysis demonstrated that atlantoaxial fusion was comparatively more common in such cases,

Table 2 Impact of patient-related factors on delayed bone union

Factor	Univariate		Multivariate	
	Odds ratio (95%CI)	p-value	Odds ratio (95%CI)	*p*-value
Age (+ 10 years)	1.07 (0.65–1.74)	0.79	1.08 (0.66–1.77)	0.75
Female	0.91 (0.31–2.65)	0.86	1.02 (0.34–3.03)	0.97
Steroid use	0.77 (0.084–7.11)	0.82		
RA	0.45 (0.14–1.44)	0.18		
Atlantoaxial fusion	2.55 (0.84–7.72)	0.096	2.57 (0.84–7.84)	0.096
C1 laminectomy	1.58 (0.37–6.73)	0.53		

95%CI 95% Confidence interval, *RA* Rheumatoid arthritis suggesting the need for additional monitoring in this procedure.

The rate of bony union in O-C fusion depends on several factors, including surgical technique and the use of instrumentation. Current approaches for O-C fusion using rigid internal fixation methods, such as polyaxial screws and rods, have yielded fusion rates ranging from 95 to 100%. This high success rate is attributed to improved techniques that minimize the need for postoperative external stabilization and allow for early rehabilitation [12]. Despite the favorable overall fusion rates, however, several studies have reported a significantly higher incidence of pseudarthrosis, particularly in pediatric patients; one investigation described a 25% pseudarthrosis rate in O-C fusion compared with only 2.8% in cervical-only fusion. This finding suggests that fusions involving the occiput carry a higher risk of non-union [13]. Another report focusing on C1 -2 fusions found that after 1 year, only 43% of patients demonstrated bony union, thus highlighting the variability related to the specific surgical approach and patient demographics [14]. Wenning et al. compared the outcomes of O-C fusion and atlantoaxial fusion in upper cervical spine lesions and observed no differences in clinical outcomes or complications, although they did not address bony fusion [15]. In our study, bony fusion rates tended to be higher in the O-C fusion group than in the atlantoaxial fusion group. Moreover, multivariate analysis revealed a comparably stronger association with delayed bony union for atlantoaxial fusion.

We also performed a sub-analysis of patients who had undergone atlantoaxial fusion and saw that most cases of delayed union involved the posterior arch of C1. This structure is small and offers a limited area of contact with the grafted bone. In O-C fusion, although the distance between the occipital bone and the cervical vertebrae is considered unfavorably long for bony fusion, a large area of contact with the grafted bone can be secured. Another reason for poor atlantoaxial bone fusion may have been weaker fixation than by O-C fusion, although an earlier biomechanical study could not confirm this [7]. Meanwhile, the perioperative mortality rate for O-C fusion is reportedly 3–5% [16–18]. Although there were no deaths in our series, this high mortality rate should be kept in mind.

Lastly, the factors of RA and steroid use are reportedly detrimental to bony fusion outcomes [19, 20]. Instrumentation problems in patients with RA are mostly attributable to low bone quality, diminished muscle strength, and connective tissue disorders [20–22]. Although RA was significantly more frequent in the O-C group in our study, bone healing was comparably higher in those patients. RA was not associated with prolonged bone healing in the logistic analysis, implying a less prominent influence in our population. The fact that better bone fusion was achieved in patients who underwent O-C fusion despite the higher number of RA patients, who were considered relatively unfavorable candidates for bone fusion, suggested that O-C fusion might have an even greater advantage for bone fusion than was demonstrated in this study. As it is also more common for older patients to have poor bone fusion rates [23–26], the bone fusion prolongation rate of roughly 20% in this study may have reflected the relatively advanced age of the cohort (68.7 years) as well as high proportion of RA patients (44% of total).

The present study had several limitations, including a small sample size, relatively short follow-up period, and retrospective design. Moreover, the choice of atlantoaxial or O-C fusion was left to the surgeon based on disease status and other factors. Another limitation of this investigation was that the influence of treatment choice on outcomes could not be excluded. The follow-up period of 6 months may also have been too short for definitive bone fusion evaluation. Nevertheless, our analysis of outcomes in 84 patients receiving upper cervical spine fusion surgery uncovered a 20.2% incidence of delayed bony union, with higher associations for atlantoaxial fusion. While the OR of atlantoaxial fusion was 2.6 for delayed bony union, the actual difference in fusion rates was statistically comparable, which diminished the impact of our findings; additional studies are needed.

Conclusion

Approximately 20% of individuals undergoing upper cervical spinal fusion surgery experienced delayed bony union. With a high OR of 2.6, atlantoaxial fusion was strongly associated with this complication. In procedures including atlantoaxial fusion, extra care may be warranted to improve results and prevent postoperative problems. O-C fusion may be considered for cases with a high degree of instability or requiring firm bony fusion.

Acknowledgements
Not applicable.

Authors' contributions
Conceptualization, Masashi Uehara; methodology, Masashi Uehara; validation, Masashi Uehara, Shota Ikegami, and Hiroki Oba.; formal analysis, Masashi Uehara, Shota Ikegami, and Hiroki Oba; investigation, Masashi Uehara, Shota Ikegami, Hiroki Oba, Terue Hatakenaka, and Jun Takahashi; data curation, Masashi Uehara, Shota Ikegami, Hiroki Oba, Terue Hatakenaka, Daisuke Kurogochi, Takuma Fukuzawa, Shinji Sasao, Tetsuhiko Mimura, and Jun Takahashi; writing—original draft preparation, Masashi Uehara; writing—review and editing, Shota Ikegami, Hiroki Oba, Terue Hatakenaka, Daisuke Kurogochi, Takuma Fukuzawa, Shinji Sasao, Tetsuhiko Mimura, and Jun Takahashi; and supervision, Jun Takahashi. All authors have read and agreed to the published version of the manuscript.

Funding
Not applicable.

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent participate
The protocol of this study was approved by Shinshu University Hospital Institutional Review Board (no. 6298). Informed written consent was obtained from all the patients prior to the study.
This research was conducted in accordance with the Declaration of Helsinki.

Consent for publication
Not relevant.

Competing interests
The authors declare no competing interests.

Received: 13 December 2024 Accepted: 25 March 2025
Published online: 03 April 2025

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