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# The clinical related research in the field of cervical spine

**Edited by**
Fuxin Wei, Xinghuo Wu, Feifei Zhou, Lee Tan
and Takashi Kaito

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# The clinical related research in the field of cervical spine

**Topic editors**
Fuxin Wei — Sun Yat-sen University, China
Xinghuo Wu — Huazhong University of Science and Technology, China
Feifei Zhou — Peking University Third Hospital, China
Lee Tan — University of California, San Francisco, United States
Takashi Kaito — Osaka University, Japan

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Peng Yin,
Capital Medical University, China
Chao Chen,
Huazhong University of Science and Technology, China
Chen Xu,
Shanghai Changzheng Hospital, China

*CORRESPONDENCE
Shi-Bao Lu
spinelu@163.com

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# Changes in T1 slope and cervical sagittal vertical axis correlate to improved neurological function recovery after cervical laminoplasty

Dong-Fan Wang[1,2], Xiang-Yu Li[1,2], Chao Kong[1,2], Cheng-Xin Liu[1,2], Bin Shi[1,2] and Shi-Bao Lu[1,2]*

[1]Department of Orthopedics, Xuanwu Hospital, Capital Medical University, Beijing, China, [2]National Clinical Research Center for Geriatric Diseases, Xuanwu Hospital, Capital Medical University, Beijing, China

**Purpose:** To investigate the influence of changes in T1 slope (T1S) and cervical sagittal vertical axis (CSVA) on cervical laminoplasty outcomes.
**Methods:** Eighty-one patients with cervical spondylotic myelopathy (CSM) treated with cervical laminoplasty were enrolled in this study. Demographic parameters included age and follow-up time. Imaging data included occiput-C2 lordosis (OC2), C2–C7 Cobb angle (CL), T1S, CSVA. Outcome assessment indicators included the Japanese Orthopedic Association (JOA) score, JOA recovery rate, and neck disability index (NDI). All patients were grouped based on preoperative T1S and variation in CL after surgery, respectively. Patients with decreased CL postoperatively were further grouped according to whether they were combined with T1S reduction.
**Results:** There were no significant differences in the final JOA score, JOA recovery rate, or NDI between patients with different T1S. Patients with loss of CL postoperatively had lower JOA score and JOA recovery rate, but higher NDI than patients with sustained CL. Furthermore, patients with CL loss but compensate for it with reduction in T1S had lower CSVA, higher JOA score and JOA recovery rate than those with CL loss alone.
**Conclusions:** Decreased T1S postoperatively prevents the tendency of the cervical spine to tilt forward by regulating CSVA and facilitates recovery of neurological function after cervical laminoplasty.

KEYWORDS

cervical laminoplasty, T1 slope, clinical outcomes, compensation mechanism, sagittal balance

## Introduction

Cervical spondylotic myelopathy (CSM) results from the nearly universal process of degeneration of the discs and joints of the cervical spine, which has been one of the most common causes of acquired spinal cord dysfunction, including paresthesia, motor weakness, gait disturbance, neck pain/radicular arm pain, hyperreflexia, even bowel/bladder dysfunction (1, 2). Posterior expansive open-door laminoplasty (EOLP) is a mature procedure for halting neurological function deterioration and improving the quality of life for patients with CSM who are unresponsive to conservative treatment (3). This technique reduces intramedullary pressure by allowing the cervical spinal cord to shift backwards through posterior decompression (4). The most significant advantage of EOLP is that it can be applied to multi-level compression cases and preserve the posterior stabilizing elements simultaneously (5). However, there are still possible postoperative complications such as axial pain, decreased range of motion, and loss of lordosis (5).

In recent years, the roles of spinal sagittal parameters in predicting outcomes and neurological function recovery after cervical surgery have become a focus of attention. Research by Chen et al. revealed preoperative cervical sagittal vertical axis (CSVA) was closely associated with neck pain in CSM patients treated by laminoplasty and proposed a cut-off value of the CSVA was 28.9 mm degreed with visual analogue scale >4 (6). In a retrospective study contained 64 patients who underwent cervical laminoplasty for cervical ossification of the posterior longitudinal ligament, Kim et al. demonstrated patients with higher preoperative T1 slope (T1S) had more loss of cervical lordosis (CL) after surgery and might predispose to worse clinical outcomes (7).

However, univariate analyses of the correlation between preoperative sagittal parameters and clinical outcomes are incomprehensive as the cervical and adjacent segments may change simultaneously after surgery to maintain sagittal balance and horizontal gaze (8). Therefore, figuring out the impact of variation in cervical sagittal parameters on suboptimal surgical outcomes after cervical laminoplasty could serve as a significant reference for clinical practice. We present the following hypotheses: (1) preoperative T1S is uncorrelated with postoperative clinical outcomes and (2) the reduction of T1S after cervical laminoplasty is a compensatory mechanism of loss of cervical lordosis (CL) and can halt CSVA tilting forward, which may contribute to the improvement of clinical outcomes. We conduct the present study with the following aims: (1) to measure changes in T1S and CSVA after EOLP and (2) to investigate how variations in T1S and CSVA affect clinical outcomes after cervical laminoplasty.

# Materials and methods

## Patient population

After being approved by the Ethics Committee of Capital Medical University Xuanwu Hospital (approval number: 2018014), a retrospective review of patients who underwent cervical laminoplasty between February 2018 and October 2020 was performed. The inclusion criteria were: (1) age >18 years; (2) clinical presentations indicating cervical spinal cord compression; (3) imaging and neuroelectrophysiological examinations revealing developmental cervical spinal stenosis, multilevel cervical disk herniation, or ossification of the posterior longitudinal ligament; (4) treated by EOLP; and (5) follow-up for at least 12 months. The exclusion criteria were: (1) history of other spine surgery; (2) combined with tumors, tuberculosis, or trauma; and (3) incomplete follow-up or imaging data. A total of 81 patients were eligible eventually.

## Groups

All patients were grouped according to a median preoperative T1S to assess the correlation between T1S and clinical outcomes. For probing variations in sagittal parameters after surgery, patients were divided into the CL sustained group and the CL loss group based on whether they were complicated with loss of CL after laminoplasty. Furthermore, patients with postoperative CL decreasing were further grouped into the T1S sustained subgroup and the T1S decreased subgroup to investigate the compensatory mechanism of T1S to cervical sagittal malalignment. **Figure 1** illustrates the flow chart of this study.

## Surgical procedures

The surgical procedure was performed based on the Hirabayashi method (9) with some modifications. The patient was placed in the prone position with an upward cranial angle of 15–20°. A Mayfield skull clamp was used to immobilize the head. An incision was made on the posterior midline of the cervical spine. The spinous process, lamina, and bilateral lateral mass were exposed. Some of the spinous processes were removed using a rongeur. The paraspinal muscle of C2, especially the semispinalis, was preserved. A high-speed drill was used to create gutters on the bilateral laminae at the border of the laminae and facets. The lamina of the side with more significant clinical symptoms was completely severed and used as the open side. The other side of the lamina was partially cut, with the ventral cortex preserved to form the hinge side. A thin-bladed Kerrison rongeur was used to remove ligamentum flava at the cranial and caudal ends of the intended laminar expansion to facilitate opening the lamina. The laminae were then lifted carefully to prevent hinge breakage and expand the spinal canal diameter. The appropriate-sized Centerpiece laminoplasty plate (Medtronic Sofamor Danek) was placed at each level secured by a single screw onto the lamina and two screws at the level of the lateral masses. The excised spinous process mixed with artificial bone was used for bone grafting on the hinge side. The surgical wound was closed in layers after all the cervical levels had a laminoplasty plate. Patients

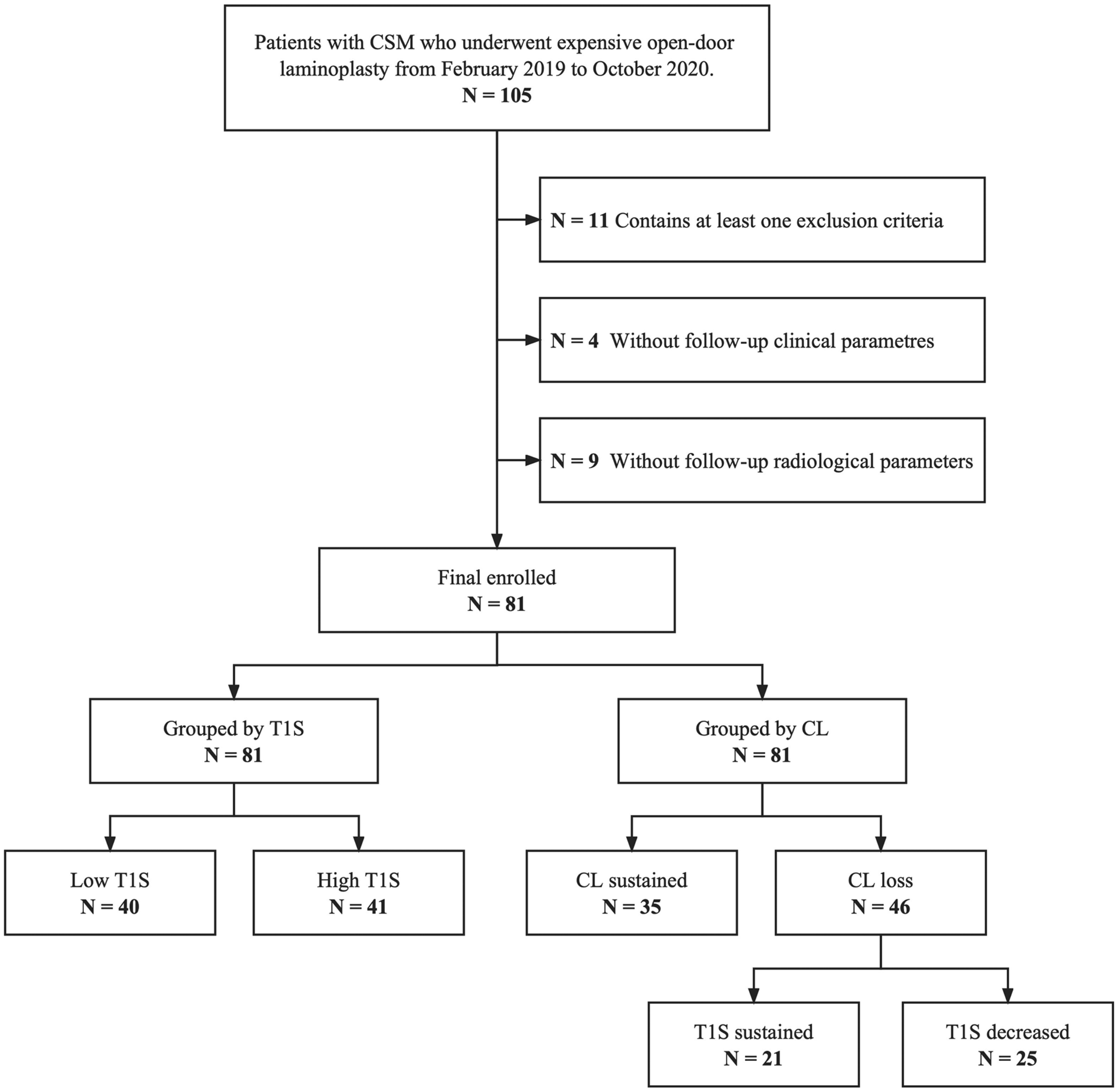


FIGURE 1
Flowchart of this study.

were asked to wear a collar for 4–6 weeks postoperatively. All operations were performed by the same surgeon.

## Radiological parameters

A standing neutral lateral radiograph of the cervical and the global spine was obtained with patients facing forward and in a horizontal gaze (defined as $-10° \leq$ chin-brow to vertical angle $\leq 10°$ (10) before surgery and at the last follow-up. Radiological parameters measured included: occiput-C2 lordosis (OC2, the angle between the McGregor line and the inferior endplate of the C2), cervical lordosis (CL, the angle between the inferior endplate of C2 and the inferior endplate of C7), T1 slope (T1S, the angle between a horizontal line and the superior endplate of T1), CSVA (the distance from the posterior, superior corner of C7 to the plumbline from the centroid of C2). To patients with invisible T1S on the cervical radiography, the value of superior C7 slope was utilized to substitute for T1S (11, 12). Cervical parameters were measured using neutral lateral cervical x-rays. Changes of parameters were calculated as final follow-up data minus preoperative data. All the radiographic evaluations were completed by 2 independent spine surgeons who were not involved in the program. Measurements of sagittal parameters are illustrated in Figure 2.

## Clinical parameters

Japanese Orthopedic Association (JOA) score and neck disability index (NDI) were performed to assessment health-related quality of life (HRQOL) (13, 14). The JOA recovery rate, calculated as (postoperative JOA score—preoperative JOA score)/(full score—preoperative JOA score) × 100%, was used to evaluate the improvement of cervical neurological function. A JOA recovery rate of 100% indicated being cured; >60% indicated significantly effective; 25%–60% indicated effective; <25% indicated ineffective. An NDI <10% indicated no disability; 10%–30% indicated mild disability; 30%–50% indicated moderate disability; 50%–70% indicated severe disability; >70% indicated complete disability. Preoperative data were obtained from the medical records. Postoperative data were collected from outpatient follow-up records.

## Statistical analysis

All data were analyzed using SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA). Continuous variables were compared between groups using the independent-samples *t*-test, Mann-Whitney *U* test, and paired-sample *t*-test. The chi-square test was used to compare composition ratios. Statistical significance was set at a level of $P < 0.05$. The results were presented as mean value ± standard deviation.

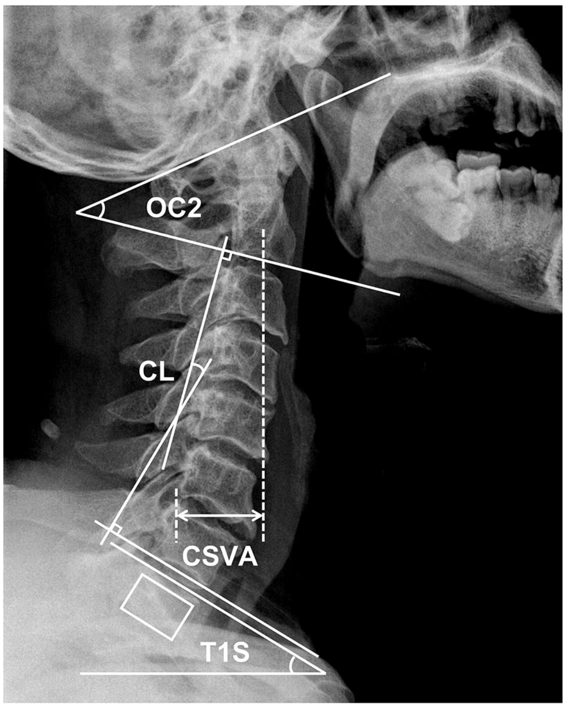


FIGURE 2
Measurements of cervical sagittal parameters utilized in this study.

# Results

A total of 81 patients (48 males and 33 females, average age 64.69 ± 9.73 years) with a 17.88 ± 6.43 months follow-up were included. Table 1 summarizes cervical radiological and clinical parameters changes between the preoperative period and final follow-up. OC2 increased from 24.62 ± 6.92° to 27.63 ± 7.49°. CL decreased from 14.00 ± 8.59° to 10.30 ± 8.38°. Patients benefited from EOLP with an increase in JOA score and a decrease in NDI.

To investigate the influence of preoperative T1S on clinical outcomes, patients were grouped according to the median preoperative T1S. Mean age of the low T1S group was younger than that of the high T1S group. Radiological parameters in terms of CL, T1S, and CSVA were significant greater in the high T1S group, while changes in these three parameters after cervical laminoplasty showed no difference in statistics. Concerning the clinical parameters, the final JOA score, JOA recovery rate, and final NDI were similar between groups (Table 2).

Since the preoperative T1S did not make an influence on clinical outcomes of patients with CSM based on our data, patients were regrouped by the change of CL: patients with decreased CL postoperatively belonged to the CL loss group, patients with unchanged or increased CL belonged to the CL sustained group. Compared with that in the CL loss group, the final JOA score and JOA recovery rate were statistically greater, the final NDI was lower in the CL sustained group. Moreover, though there was no significant difference in

TABLE 1 Changes of radiological parameters and clinical parameters between preoperative period and final follow-up period.

| Parameters | Preoperative ($n = 81$) | Final follow-up ($n = 81$) | *P* |
|---|---|---|---|
| OC2 (°) | 24.62 ± 6.92 | 27.63 ± 7.49 | 0.000* |
| CL (°) | 14.00 ± 8.59 | 10.30 ± 8.38 | 0.000* |
| T1S (°) | 24.24 ± 6.18 | 24.17 ± 7.07 | 0.928 |
| CSVA (mm) | 23.25 ± 12.12 | 24.35 ± 12.59 | 0.425 |
| JOA score | 12.00 ± 1.88 | 14.72 ± 1.20 | 0.000* |
| NDI (%) | 30.43 ± 18.44 | 13.80 ± 10.04 | 0.000* |

OC2, occiput-C2 lordosis; CL, cervical lordosis; T1S, T1 slope; CSVA, cervical sagittal vertical axis; JOA, Japanese orthopedic association; NDI, neck disability index.
*$P < 0.01$.

TABLE 2 Comparison of radiological parameters and clinical parameters between the low T1S group and the high T1S group.

| Parameters | Low T1S ($n = 40$) | High T1S ($n = 41$) | $P$ |
|---|---|---|---|
| Demographic parameters | | | |
| Age (years) | 61.80 ± 8.61 | 68.81 ± 9.93 | 0.010* |
| Follow-up (months) | 17.53 ± 6.30 | 18.38 ± 6.73 | 0.648 |
| Operation level | | | 0.696 |
| C3–6 | 9 | 12 | |
| C4–7 | 13 | 14 | |
| C3–7 | 18 | 15 | |
| Radiological parameters | | | |
| Pre-op OC2 (°) | 25.99 ± 6.78 | 22.67 ± 6.79 | 0.093 |
| ΔOC2 (°) | 0.14 ± 0.24 | 0.16 ± 0.22 | 0.794 |
| Pre-op CL (°) | 11.60 ± 7.98 | 17.44 ± 8.43 | 0.015* |
| ΔCL (°) | −3.82 ± 5.74 | −3.53 ± 4.11 | 0.844 |
| Pre-op T1S (°) | 20.17 ± 3.91 | 30.06 ± 3.60 | 0.000** |
| ΔT1S (°) | −1.98 ± 5.76 | −0.46 ± 4.61 | 0.320 |
| Pre-op CSVA (mm) | 20.43 ± 8.99 | 27.28 ± 14.87 | 0.046* |
| ΔCSVA (mm) | 1.61 ± 10.56 | 0.37 ± 8.70 | 0.658 |
| Clinical parameters | | | |
| Pre-op JOA score | 12.00 ± 2.00 | 12.00 ± 1.73 | 1.000 |
| Final JOA score | 14.70 ± 1.32 | 14.76 ± 1.04 | 0.858 |
| JOA recovery rate (%) | 52.78 ± 24.78 | 53.98 ± 17.43 | 0.849 |
| Pre-op NDI (%) | 30.93 ± 16.66 | 29.71 ± 21.14 | 0.819 |
| Final NDI (%) | 14.60 ± 9.81 | 12.67 ± 10.49 | 0.504 |

OC2, occiput-C2 lordosis; CL, cervical lordosis; T1S, T1 slope; CSVA, cervical sagittal vertical axis; JOA, Japanese orthopedic association; NDI, neck disability index.
*$P < 0.05$.
**$P < 0.01$.

TABLE 3 Comparison of radiological parameters and clinical parameters between the CL sustained group and the CL loss group.

| Parameters | CL sustained ($n = 35$) | CL loss ($n = 46$) | $P$ |
|---|---|---|---|
| Demographic parameters | | | |
| Age (years) | 63.75 ± 9.67 | 65.29 ± 9.87 | 0.586 |
| Follow-up (months) | 16.10 ± 5.25 | 19.03 ± 6.92 | 0.112 |
| Operation level | | | 0.563 |
| C3–6 | 11 | 10 | |
| C4–7 | 10 | 17 | |
| C3–7 | 14 | 19 | |
| Radiological parameters | | | |
| Pre-op OC2 (°) | 24.43 ± 7.18 | 24.74 ± 6.87 | 0.875 |
| ΔOC2 (°) | 0.07 ± 0.21 | 0.19 ± 0.23 | 0.065 |
| Pre-op CL (°) | 12.92 ± 7.52 | 14.70 ± 9.26 | 0.473 |
| ΔCL (°) | 0.17 ± 1.58 | −6.20 ± 5.01 | 0.000** |
| Pre-op T1S (°) | 24.97 ± 6.80 | 23.77 ± 5.82 | 0.505 |
| ΔT1S (°) | 1.00 ± 4.05 | −2.88 ± 5.54 | 0.010* |
| Pre-op CSVA (mm) | 24.65 ± 11.25 | 22.35 ± 12.75 | 0.515 |
| ΔCSVA (mm) | −0.55 ± 9.93 | 2.16 ± 9.67 | 0.337 |
| Clinical parameters | | | |
| Pre-op JOA score | 12.55 ± 1.73 | 11.64 ± 1.91 | 0.093 |
| Final JOA score | 15.45 ± 0.89 | 14.26 ± 1.15 | 0.000** |
| JOA recovery rate (%) | 63.14 ± 23.82 | 46.91 ± 18.19 | 0.008** |
| Pre-op NDI (%) | 30.30 ± 19.28 | 30.52 ± 18.20 | 0.968 |
| Final NDI (%) | 9.90 ± 8.30 | 16.32 ± 10.38 | 0.024* |

OC2, occiput-C2 lordosis; CL, cervical lordosis; T1S, T1 slope; CSVA, cervical sagittal vertical axis; JOA, Japanese Orthopedic Association; NDI, neck disability index.
*$P < 0.05$.
**$P < 0.01$.

preoperative T1S between the groups, T1S decreased significantly in the CL loss group (Table 3).

We hypothesized that the reduction of T1S in the CL loss group might affect the clinical outcomes. Thus, patients with postoperative LCL were further divided into two subgroups according to whether T1S decreased. Most notably, the T1S decreased subgroup had greater final JOA score and JOA recovery rate in statistics than the T1S sustained subgroup. CSVA tended to increase in the T1S sustained subgroup, while it reduced significantly in the T1S decreased subgroup (Table 4).

## Discussion

Posterior laminoplasty generates an indirect decompression effect resulting from the posterior shift of the spinal cord from the anterior compressive lesions. This procedure successfully manages patients with CSM. Previous studies demonstrated that patients could achieve acceptable recovery of neurological function after posterior laminoplasty (15, 16). Nevertheless, there remain potential postoperative complications. Because of the destruction of the facet joint or damage to the paravertebral muscles and their attachments to the spinous processes, the cervical spine might show loss of lordosis and a tendency to tilt forward (17, 18). Diminished lordosis may elevate spinal intramedullary pressure and affect neurological function recovery (19). In the present study, LCL occurred after surgery in 46 (56.8%) patients.

Many previous studies explored the relationship between preoperative sagittal parameters and outcomes after cervical laminoplasty. Rao et al. reported that T1S-CL mismatching (T1S-CL > 20°) predicted worse postoperative NDI and JOA recovery rate in patients with CSM who underwent EOLP (20). Furthermore, Oshima et al. showd CSM patients with preoperative SVA > 50 mm had lower clinical outcome scores

TABLE 4 Comparison of radiological parameters and clinical parameters between the T1S sustained subgroup and the T1S decreased subgroup.

| Parameters | T1S sustained ($n = 21$) | T1S decreased ($n = 25$) | *P* |
|---|---|---|---|
| Demographic parameters | | | |
| Age (years) | 65.00 ± 10.70 | 65.50 ± 9.54 | 0.892 |
| Follow-up (months) | 18.92 ± 6.73 | 19.11 ± 7.25 | 0.942 |
| Operation level | | | 0.911 |
| C3–6 | 5 | 5 | |
| C4–7 | 8 | 9 | |
| C3–7 | 8 | 11 | |
| Radiological parameters | | | |
| Pre-op OC2 (°) | 23.35 ± 8.36 | 25.76 ± 5.60 | 0.343 |
| ΔOC2 (°) | 0.14 ± 0.26 | 0.24 ± 0.21 | 0.287 |
| Pre-op CL (°) | 18.25 ± 11.54 | 12.14 ± 6.49 | 0.069 |
| ΔCL (°) | −6.45 ± 3.84 | −6.03 ± 5.82 | 0.823 |
| Pre-op T1S (°) | 26.45 ± 4.25 | 21.83 ± 6.12 | 0.026* |
| ΔT1S (°) | 1.98 ± 3.58 | −6.39 ± 3.75 | 0.000** |
| Pre-op CSVA (mm) | 21.98 ± 12.41 | 22.63 ± 13.34 | 0.891 |
| ΔCSVA (mm) | 7.82 ± 8.73 | −1.92 ± 8.32 | 0.004** |
| Clinical parameters | | | |
| Pre-op JOA score | 11.77 ± 1.69 | 11.56 ± 2.09 | 0.764 |
| Final JOA score | 13.77 ± 0.93 | 14.61 ± 1.20 | 0.043* |
| JOA recovery rate (%) | 36.91 ± 8.02 | 54.13 ± 20.17 | 0.003** |
| Pre-op NDI (%) | 29.85 ± 19.07 | 31.00 ± 18.09 | 0.865 |
| Final NDI (%) | 16.46 ± 11.20 | 16.22 ± 10.08 | 0.951 |

OC2, occiput-C2 lordosis; CL, cervical lordosis; T1S, T1 slope; CSVA, cervical sagittal vertical axis; JOA, Japanese orthopedic association; NDI, neck disability index.
*$P < 0.05$.
**$P < 0.01$.

after cervical laminoplasty (21). Nori et al. also demonstrated C7 slope ≥30° correlated to lower postoperative JOA score and JOA recovery rate (22). Among all the sagittal parameters, T1S is closely associated with the shape of the cervical spine pre- and postoperatively (23, 24). Zhang et al. demonstrated that preoperative T1S was significantly correlated with LCL after laminoplasty in patients with CSM (25). Pan et al. showed that CSM patients with lower preoperative T1S had less neck pain during postoperative follow-up (17). In the present study, although there were differences in the preoperative cervical spine alignment between the lower T1S group and the greater T1S group, there were no significant variations in the JOA score, JOA recovery rate, or NDI at final follow-up (**Table 2**). Consistent with our research, Cho et al. showed that VAS, JOA score, NDI, and SF-36 at final follow-up were not affected by preoperative T1S in patients with CSM who underwent laminoplasty (26). The thoracolumbar sagittal balance influences T1S, and it changes reciprocally with the variation of spinal sagittal alignment. Hence, univariate analysis of the correlation between preoperative T1S and final clinical outcomes may be biased.

As mentioned previously, postoperative LCL after cervical laminoplasty is a common phenomenon which might exert a negative impact on clinical outcomes (5). Patients were divided into the CL sustained group and the CL loss group, and radiological/clinical parameters were compared between groups (**Table 3**). LCL contributes to progressive kyphotic alignment change, leading to postoperative residual anterior compression and worse outcomes at long-term follow-up (27). Consistently, the CL loss group had a lower final JOA score and JOA recovery rate, but higher final NDI at the final follow-up in our study. Similarly, Xu et al. found that postoperative LCL indicated worse JOA score and JOA recovery rate in laminoplasty treated patients (28). Moreover, we also found that T1S decreased significantly after surgery in the CL loss group. T1S was positively correlated with CL, which means a greater T1S yielded a greater magnitude of CL in the asymptomatic population (10). Thus, we speculated that the decrease of T1S in the CL loss group was a compensatory mechanism of LCL after cervical laminoplasty to maintain an appropriate alignment.

It remains unclear whether the decrease of T1S improves outcomes in patients who undergo cervical laminoplasty. According to the change of T1S, the CL loss group was further divided into the T1S sustained and T1S decreased subgroups. Results illustrated there was no significant difference in preoperative cervical sagittal parameters and thoracolumbar sagittal parameters except for T1S between the two subgroups (**Table 4**). The T1S sustained subgroup had lower JOA scores and JOA recovery rate at the final follow-up. The variation in CSVA was positive and significantly higher in the T1S sustained group, which means the cervical spine tended to tilt forward. Smith et al. assessed 56 patients with CSM and reported that improved JOA score was negatively correlated with CSVA (29). In a study of 249 patients who underwent EOLP, Zhang et al. also showed that preoperative CSVA and postoperative CSVA were both associated with postoperative axial symptoms (30). Larger CSVA correlated with higher intramedullary cord pressure, which results in histologic changes in the spinal cord and deterioration of neurological function (19, 31). The reduction of T1S improved neurological function recovery after cervical laminoplasty by regulating CSVA.

OC2 (a description of upper cervical shape) is measured by the angle subtended by the McGregor line of sight and a parallel line along the inferior endplate of C2. Previous studies demonstrated that OC2 and CL work inversely. Loss of lordosis in the subaxial cervical spine can be compensated for by the hyperlordotic upper cervical spine (8, 32, 33). In our study, the increase of OC2 compensated for LCL in patients

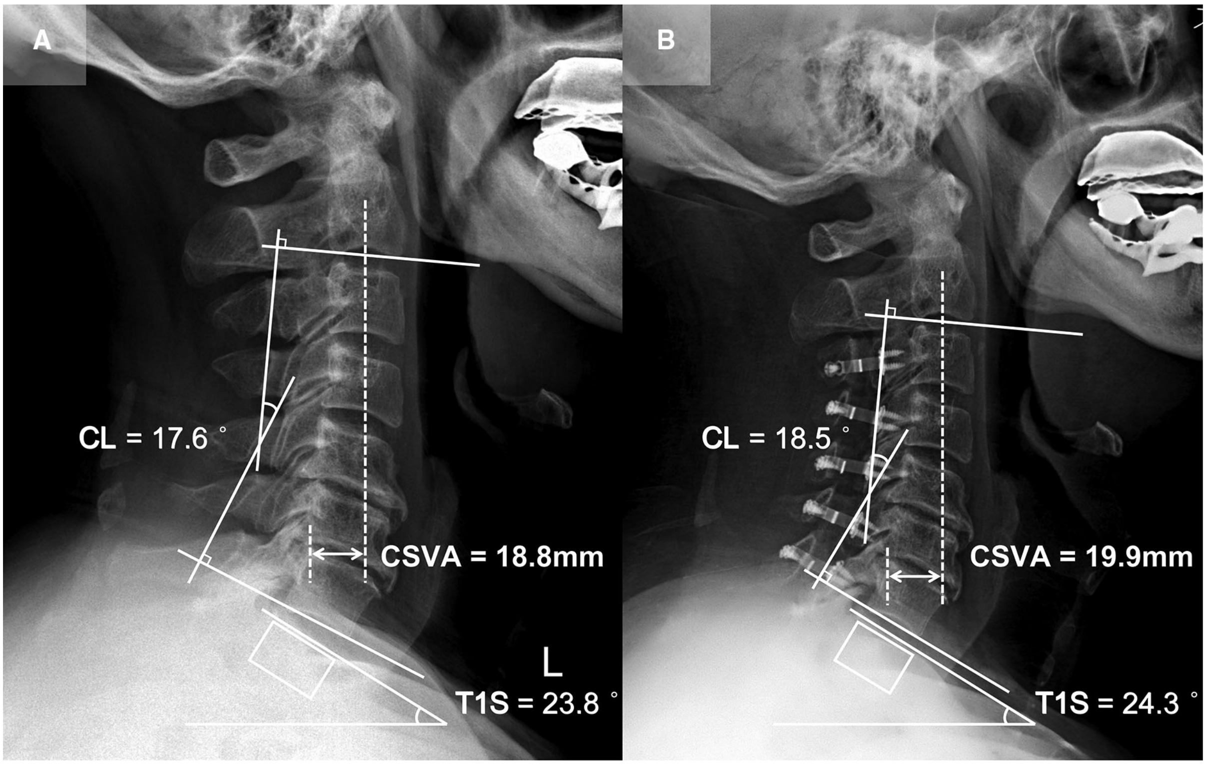


FIGURE 3
Patient case of the CL sustained group. (A) Preoperative lateral cervical radiograph (CL = 17.6°, T1S = 23.8°, CSVA = 18.8 mm). (B) Lateral cervical radiograph at final follow-up (15 months after surgery, CL = 18.5°, T1S = 24.3°, CSVA = 19.9 mm).

who underwent cervical laminoplasty (Table 1). Nevertheless, there were no significant differences in preoperative OC2 or change of OC2 between the CL sustained group and the CL loss group. These findings suggest that decreased T1S is the primary compensatory mechanism of CL loss and contributes to postoperative function recovery, while the increase of OC2 might be responsible for maintaining horizontal gaze.

There are still several limitations in this study. First, because of the study's retrospective nature, only the data contained in the medical records could be analyzed. Second, the sample size was relatively small and from a single center. Third, postoperative thoracolumbar parameters, which could influence the change of T1S, were not included. Prospective and well-designed studies will be necessary to identify the compensatory mechanisms associated with postoperative neurological function recovery.

## Patient presentation

Patient 1 (CL sustained group; Figure 3): A 65-year-old male with a 15-month follow-up. The preoperative CL was 17.6°, the preoperative T1S was 23.8°. Preoperative JOA score and NDI were 12 and 12%, respectively. CL and T1S were 18.5° and 24.3° at final follow-up, respectively. The change of CSVA was +1.1 mm. JOA score increased from 12 to 16, while NDI decreased from 12% to 6%. The JOA recovery rate was 80%.

Patient 2 (CL loss group, T1S decreased subgroup; Figure 4): A 65-year-old male with a 15-month follow-up. The preoperative CL was 7.1°, the preoperative T1S was 26.5°. Preoperative JOA score and NDI were 12 and 10%, respectively. CL and T1S were 2.3° and 21.4° at final follow-up, respectively. The change of CSVA was −2 mm. JOA score increased from 12 to 15, while NDI decreased from 10% to 6%. The JOA recovery rate was 60%.

Patient 3 (CL loss group, T1S sustained subgroup; Figure 5): A 56-year-old female with a 14-month follow-up. The preoperative CL was 18.8°, the preoperative T1S was 23.1°. Preoperative JOA score and NDI were 11 and 30%, respectively. CL and T1S were 10.5° and 23.3° at final follow-up, respectively. The change of CSVA was +5.7 mm. JOA score increased from 11 to 14, while NDI decreased from 30% to 14%. The JOA recovery rate was 50%.

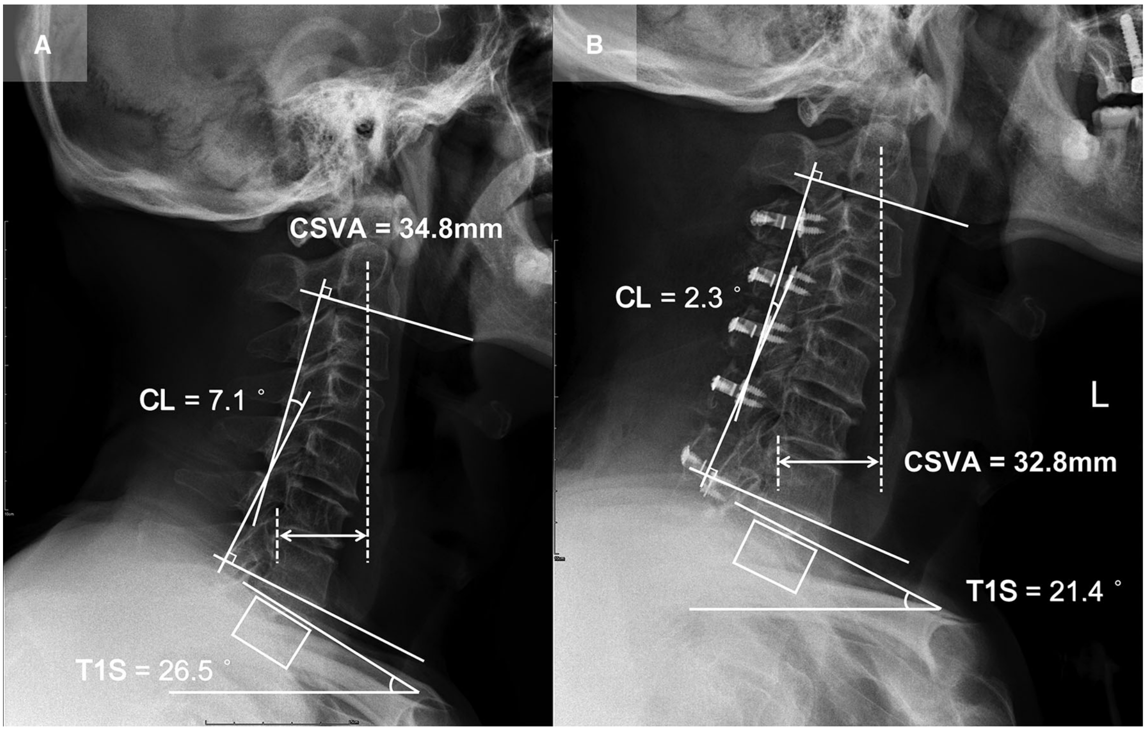


FIGURE 4
Patient case of the CL loss group, T1S decreased subgroup. (A) Preoperative lateral cervical radiograph (CL = 7.1°, T1S = 26.5°, CSVA = 34.8 mm). (B) Lateral cervical radiograph at final follow-up (15 months after surgery, CL = 2.3°, T1S = 21.4°, CSVA = 32.8 mm).

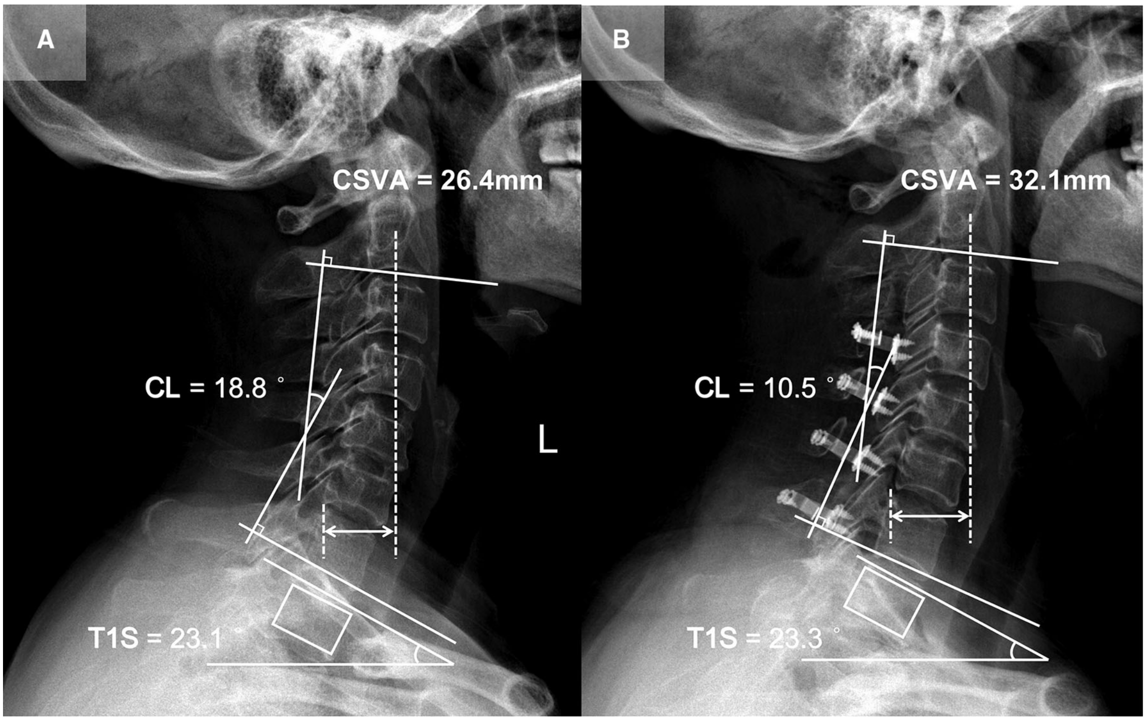


FIGURE 5
Patient case of the CL loss group, T1S sustained subgroup. (A) Preoperative lateral cervical radiograph (CL = 18.8°, T1S = 23.1°, CSVA = 26.4 mm). (B) Lateral cervical radiograph at final follow-up (14 months after surgery, CL = 10.5°, T1S = 23.3°, CSVA = 32.1 mm).

## Conclusion

The decrease of T1S is a compensatory mechanism of LCL in patients who undergo cervical laminoplasty. Decreased T1S prevents the tendency of the cervical spine to tilt forward by regulating CSVA, which facilitates the recovery of neurological function postoperatively.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

## Ethics statement

The studies involving human participants were reviewed and approved by The Ethics Committee of Capital Medical University Xuanwu Hospital (approval number: 2018014). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

## Author contributions

D-FW: Writing, Reviewing, Editing, Methodology and Data Curation; X-YL: Writing, Data Curation and Supervision; C-XL, BS: Resources; CK: Validation and software; S-BL: Supervision. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Fuxin Wei,
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REVIEWED BY
Kong Chao,
Xuanwu Hospital, Capital Medical University, China
Wenyuan Ding,
Third Hospital of Hebei Medical University, China

*CORRESPONDENCE
Jun Zou
jzou@suda.edu.cn

†These authors have contributed equally to this work

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# Are surgical outcomes for one level anterior decompression and fusion associated with MRI parameters for degenerative cervical myelopathy?

Luqiang Qu[1,2†], Shaofeng Yang[1†], Lijie Yuan[2], Junjie Niu[1], Dawei Song[1], Songping Yang[3], Huilin Yang[1] and Jun Zou[1]*

[1]Department of Orthopaedic Surgery, The First Affiliated Hospital of Soochow University, Suzhou, China, [2]Department of Orthopaedic Surgery, Taicang Affiliated Hospital of Soochow University, Taicang, China, [3]Department of Operating Room, The First Affiliated Hospital of Soochow University, Suzhou, China

**Background:** Our study is to determine the correlation between preoperative MRI parameters of spinal cord compression and the effects of anterior surgery in patients with degenerative cervical myelopathy (DCM).
**Methods:** 24 normal subjects with no evident abnormalities were selected as group A. 79 patients with DCM underwent single-segment (C4–5/C5–6) ACDF surgery formed the operation group, and separated into group B (without high signal) and group C (with high signal) according to the absence or presence of high signal in the spinal cord on preoperative T2-weighted MRI respectively. MRI parameters (MCC, maximum canal compromise; MSCC, maximum spinal cord compression; CR, spinal cord compression rate; RCSCDS, ratio of cervical spinal cord to dura sac) were measured. The JOA score was used to evaluate cervical spinal cord function and recovery rate (RR) was used to evaluate postoperative efficacy. The relationship between preoperative MRI parameters and postoperative efficacy was analyzed.
**Results:** The preoperative JOA score and RR of group B were higher than that of group C. MCC and MSCC in group B were significantly lower than those in groups C. The multiple linear regression equation was the fitted postoperative JOA score = 13.371–2.940 * MCC –5.660 * RCSCDS +0.471 * preoperative JOA score. The fitted RR = 1.451–0.472 * MCC –1.313 * RCSCDS.
**Conclusion:** The occurrence of high signal on T2-weighted images could reflect more serious spinal cord injury. The postoperative JOA score was significantly correlated with MCC, RCSCDS, and preoperative JOA score, while RR was significantly associated with MCC and RCSCDS.

KEYWORDS
DCM, ACDF, MCC, MSCC, CR, RCSCDS

## Introduction

Degenerative cervical myelopathy (DCM) describes a chronic cervical spine disease characterized by a set of clinical signs and symptoms caused by cervical degeneration and cervical spinal cord compression. Patients with DCM may experience numbness in the limbs, a sense of tightness in the chest, decreased fine motor skills in the hands, a sense of "cotton under the feet" and sphincter dysfunction (1). Diagnosis of DCM mainly rely on clinical evaluation supported by magnetic resonance imaging (MRI). MRI not only reveals anatomical factors of spinal cord compression, but also pathological changes in the spinal canal (2–4). Takahashi first described high signal in the spinal cord on T2-weighted MRI in patients with DCM (5). Some authors subsequently reported that high signal in the spinal cord predicted a worse prognosis after decompression surgery (6). In contrast, others found no correlation between high signal (s) in the spinal cord and postoperative outcomes (7, 8). As such, controversy persists regarding the pathophysiology of spinal cord's T2-weighted signal changes and their relationship with clinical prognosis.

Several attempts have been made to correlate the degree of spinal cord compression on MRI with clinical severity including others' recent work (9). Quantitative MRI measurements have been, and commonly used measurement parameters include spinal cord cross-sectional area (TA) and spinal cord compression rate (CR) (10, 11). In addition, the ratio of cervical spinal cord to dural sac (RCSCDS), which objectively reflects the relative size of the spinal cord and dural sac during the development of DCM, as well as the degree of spinal cord compression, is a commonly used MRI measurement parameter. Studies have also shown that RCSCDS has important diagnostic and prognostic value in DCM. Okada et al. measured the transverse area of the spinal canal, the dural tube and the spinal cord using MRI in normal adults and patients of DCM and found the ratio of the spinal cord to the spinal canal showed significant correlations with the severity of neurological symptoms. High ratio of the spinal cord to the spinal canal was a responsible static factor for DCM (12). In this study, sagittal measurement parameters, including MCC and MSCC, and transection measurement parameters, including CR and RCSCDS, were used to assess the degree of spinal cord compression (**Figure 1**).

Surgical strategies for cervical DCM are either anterior, posterior, or combined anterior and posterior approaches. Anterior surgery can either be anterior cervical decompression and fusion (ACDF) or anterior cervical corpectomy and fusion (ACCF). ACDF is considered the gold standard for the management of DCM involving one to two segments, commonly C4–5 or C5–6 (13, 14). Posterior surgery is more suitable for DCM patients with >3 affected segments.

Whether the presence of high signal intensity on T2-weighted MRI in patients of DCM indicated worse prognosis is full of controversy. Chi-Jen Chen et al. found when the high signal intensity was predominantly faint with a fuzzy border there was no significant difference in prognosis. Whilst, when the high signal intensity was predominantly intense and well-defined border the prognosis became worse (15). However, Wada believed that high intensity areas on T2-weighted MRI were not correlated with the severity or surgical outcomes of DCM (8). More studies need to be undertaken to investigate the relationships between MRI indicators and prognosis or surgical outcome in patients of DCM.

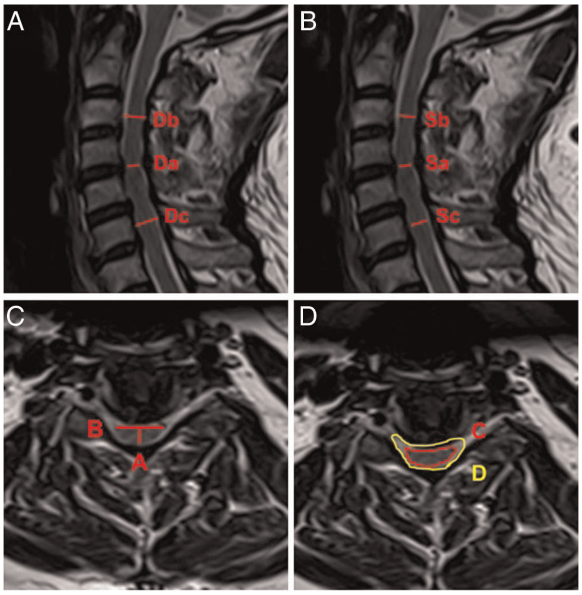


FIGURE 1
Schematic diagram of spinal cord compression parameter measurement on MRI. (A) MCC = [1 − 2Da/(Db + Dc)] × 100%. (B) MSCC = [1 − 2Sa/(Sb + Sc)] × 100%. (C) CR = A/B × 100%. (D) RCSCDS = C/D.

The purpose of this study was to investigate the correlation between preoperative MRI indicators reflecting spinal cord compression (i.e., MCC, MSCC, CR, and RCSCDS) and the efficacy of anterior surgery in patients with DCM with the goal of providing some imaging references for the prognosis of DCM.

## Materials and methods

The clinical study was approved by the Ethics Committee of the authors' affiliated institutions and written informed consents were obtained from all participants. This is a prospective uncontrolled non-randomized study performed pragmatically where patients having undergone 1 level ACDF for DCM were separated based on cord signal changes and then compared to a cohort of healthy volunteers for MRI findings. The control group (group A) consisted of 24 subjects [10 male, 14 female; mean (±SD) age 49.5 ± 6.21 years] who underwent MRI of the cervical spine in the outpatient department and exhibited no obvious abnormalities or surgical indications (**Table 1**). From January 2017 to December 2018, 79 patients with DCM underwent single-segment (C4–5/C5–6) ACDF were selected as the operation

TABLE 1 Comparison of baseline characteristics of patients between three groups.

| Index | Group A | Group B | Group C |
|---|---|---|---|
| Age (Y) | 49.5 ± 6.21 | 54.1 ± 5.23 | 59.3 ± 3.89 |
| Male (N) | 10 | 30 | 17 |
| Female (N) | 14 | 22 | 10 |
| Segment (C4–5) | 15 | 29 | 15 |
| Segment (C5–6) | 9 | 23 | 12 |
| Total (N) | 24 | 52 | 27 |

group, which was subdivided into group B (without high signal) and group C (with high signal) according to the presence or absence of high signal in the spinal cord on T2-weighted images on preoperative MRI. There were 52 patients in group B, including 30 males and 22 females, with an average age of 54.1 ± 5.23 years. A total of 29 patients underwent ACDF at C4–5 and 23 underwent ACDF at C5–6 levels. There were 27 patients in group C, including 17 males and 10 females, with an average age of 59.3 ± 3.89 years. A total of 15 patients underwent ACDF at C4–5 and 12 underwent ACDF at C5–6; all patients underwent preoperative MRI examination. The inclusion criteria for the operation group (groups B and C) were signs and symptoms of DCM; MRI revealing spinal cord compression; underwent anterior cervical surgery at one level between C4 and C6; and had no history of cervical spine surgery. Individuals with other types of cervical spondylosis, such as nerve root compression, sympathetic symptoms, esophageal and vertebral artery pathology, those with ankylosing spondylitis, a history of cervical spine trauma, rheumatoid arthritis, cervical tuberculosis, tumor(s), amyotrophic lateral sclerosis, ACDF surgery for ≥2 segments, and those who underwent ACCF or non-C4 to C6 single-segment ACDF surgery, were excluded.

Preoperative MRI of the cervical spine was performed in all patients, and parameters were measured at the most severe level of spinal cord compression in the sagittal position and the transverse position using T2-weighted imaging. The main parameters measured in the sagittal position were maximum canal compression (MCC) and maximum spinal cord compression (MSCC). The main parameters measured in the transverse position were CR and RCSCDS. The measurement methods for each parameter were as follows: MCC = [1 − 2Da/(Db + Dc)] × 100%, in which Da, Db, and Dc represent the sagittal diameter of the spinal canal in the stenotic segment, the sagittal diameter of the spinal canal in the segment above the stenotic segment, and the sagittal diameter of spinal canal in the segment below the stenotic segment, respectively (**Figure 1A**); MSCC = [1 − 2Sa/(Sb + Sc)] × 100%, in which Sa, Sb, and Sc, represent the sagittal diameter of the spinal cord in the stenotic segment, the sagittal diameter of the spinal cord in the segment above the stenotic segment, and the sagittal diameter of the spinal cord in the segment below the stenotic segment, respectively (**Figure 1B**); CR = A/B × 100%, in which A and B represent the minimum vector diameter and maximum transverse diameter of the compressed part of the spinal cord, respectively (**Figure 1C**); and, finally, RCSCDS = C/D, in which C and D, represent the area of the spinal cord and the area of the dural sac at the transverse position of spinal cord compression, respectively (**Figure 1D**). All measurements were independently recorded by two orthopedic surgeons; each indicator was measured three times by each surgeon and the mean value was calculated and used in the analysis.

The evaluation criteria of spinal cord function developed by the Japanese Orthopedic Association (JOA) were used. The postoperative recovery rate (RR) was used to evaluate the effect of surgery according to the following equation:

$$RR = (\text{postoperative JOA score} - \text{preoperative JOA score}) / (17 - \text{preoperative JOA score}) \times 100\%$$

Sigma plot version 14 (Systat Software Inc, San Jose, CA, USA) was used to analyze the data, which are expressed as mean ± standard deviation, and comparison among groups was performed using one way analysis of variance (ANOVA). Pearson correlation analysis was used to analyze the correlation between MRI parameters, JOA score, and RR. When the absolute value of the correlation coefficient is greater than 0.7, it is defined as high correlation, when it is between 0.4 and 0.7, it is defined as moderate correlation, and when it is less than 0.4, it is defined as mild correlation. Multiple linear regression analysis was used to obtain the fitted postoperative JOA score and RR, and Pearson correlation coefficient was used to test the correlation between the indexes. Differences with $P < 0.05$ were considered to be statistically significant.

## Results

The mean MCC (**Figure 2A**), MSCC (**Figure 2B**), CR (**Figure 2C**) and RCSCDS (**Figure 2D**) in group A, B, and C were calculated in **Figure 2**. The four MRI parameters of spinal cord compression in the operation group were larger than those in the control group, while in the operation group, when there was high signal in the spinal cord, the MCC and MSCC increased.

As shown in **Figure 3**, in the operation group, preoperative JOA score, postoperative JOA score (**Figure 3A**), and RR (**Figure 3B**) were significantly reduced when high signal in the spinal cord was present (group C), indicating more severe DCM and worse postoperative efficacy when a high signal was present in the spinal cord.

The correlation between postoperative JOA score and MRI parameters of spinal cord compression preoperative JOA score

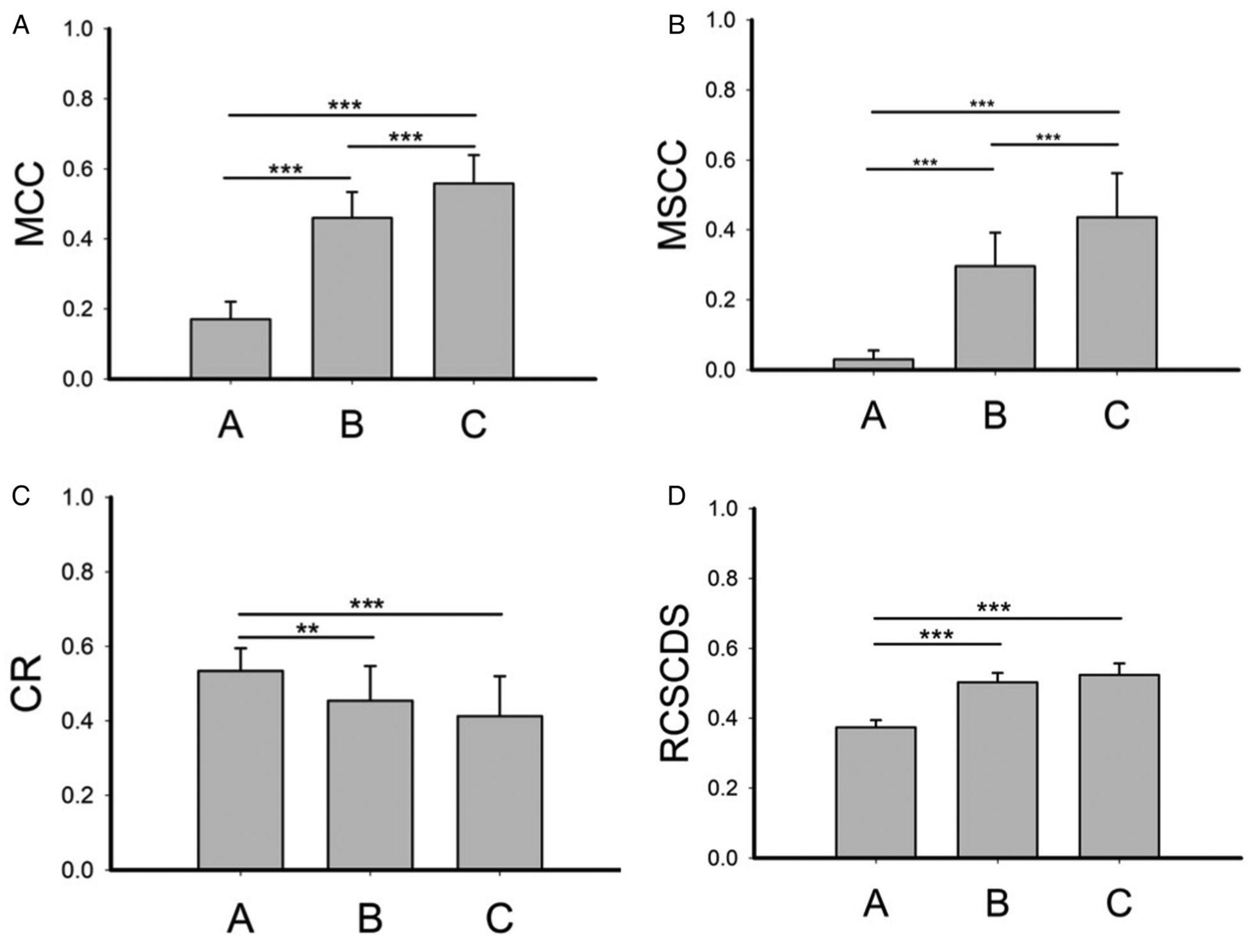


FIGURE 2
The spinal cord compression parameters of each group. MCC, maximum canal compromise; MSCC, maximum spinal cord compression; CR, compression ratio; RCSCDS, ratio of cervical spinal cord to dura sac. $**P < 0.01$; $***P < 0.001$.

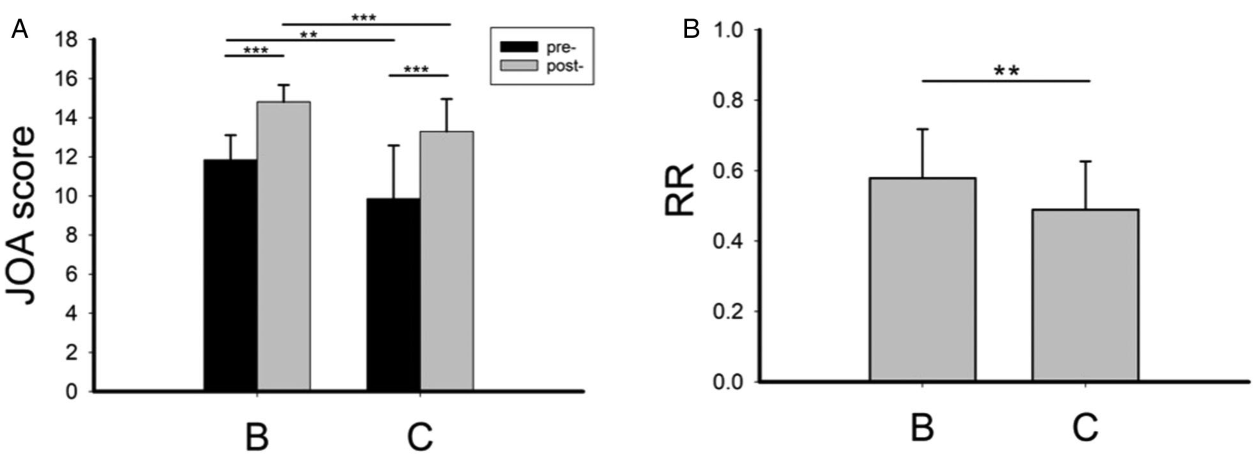


FIGURE 3
The preoperative and postoperative JOA score (A) and postoperative recovery rate (B) in group B and group C. RR, recovery rate. $**P < 0.01$; $***P < 0.001$.

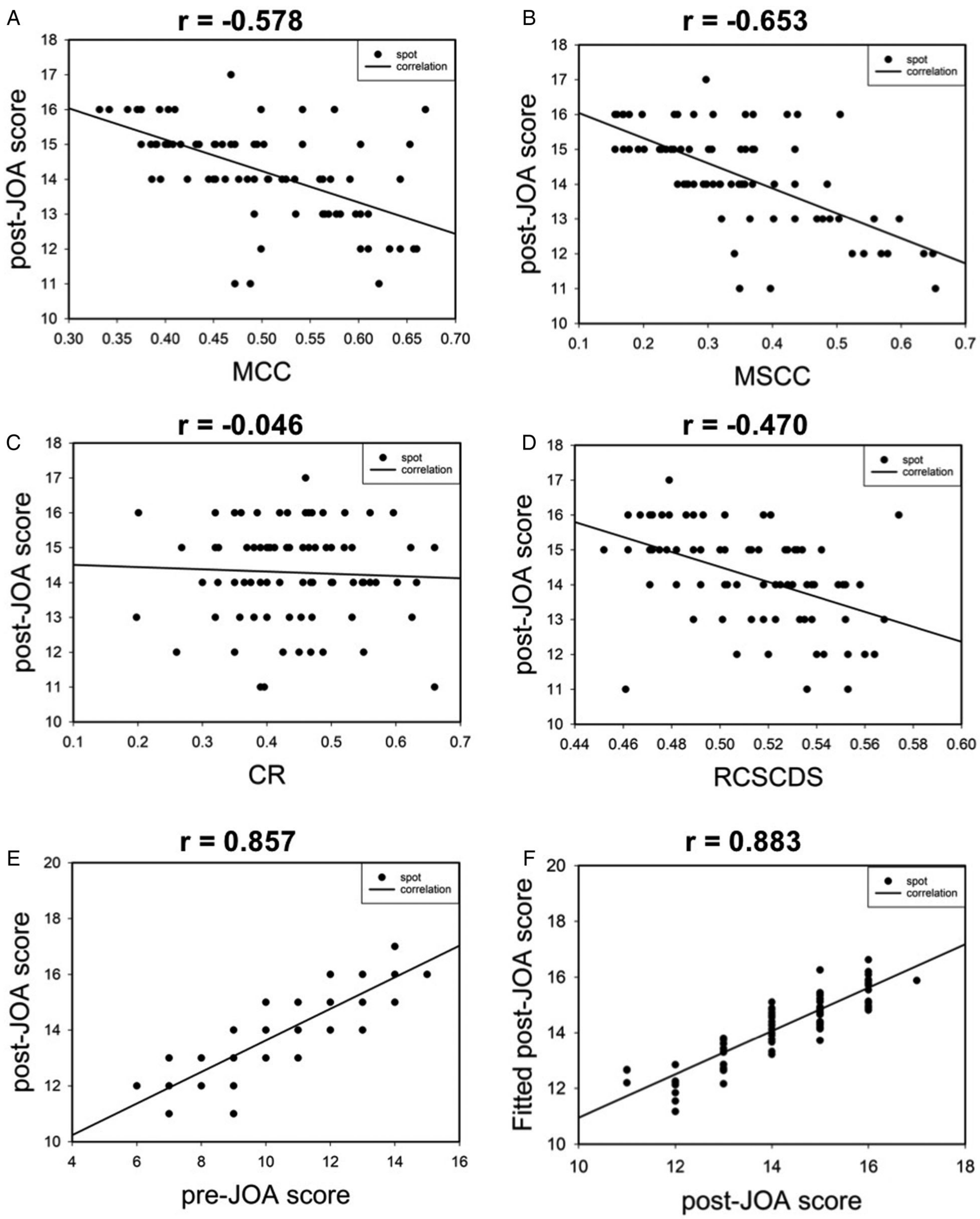


FIGURE 4
The scatter plot of correlation between postoperative JOA score and preoperative spinal cord compression parameters (A–D). Correlation between postoperative JOA score and preoperative JOA score (E). Correlation between postoperative JOA score and fitted postoperative JOA score (F).

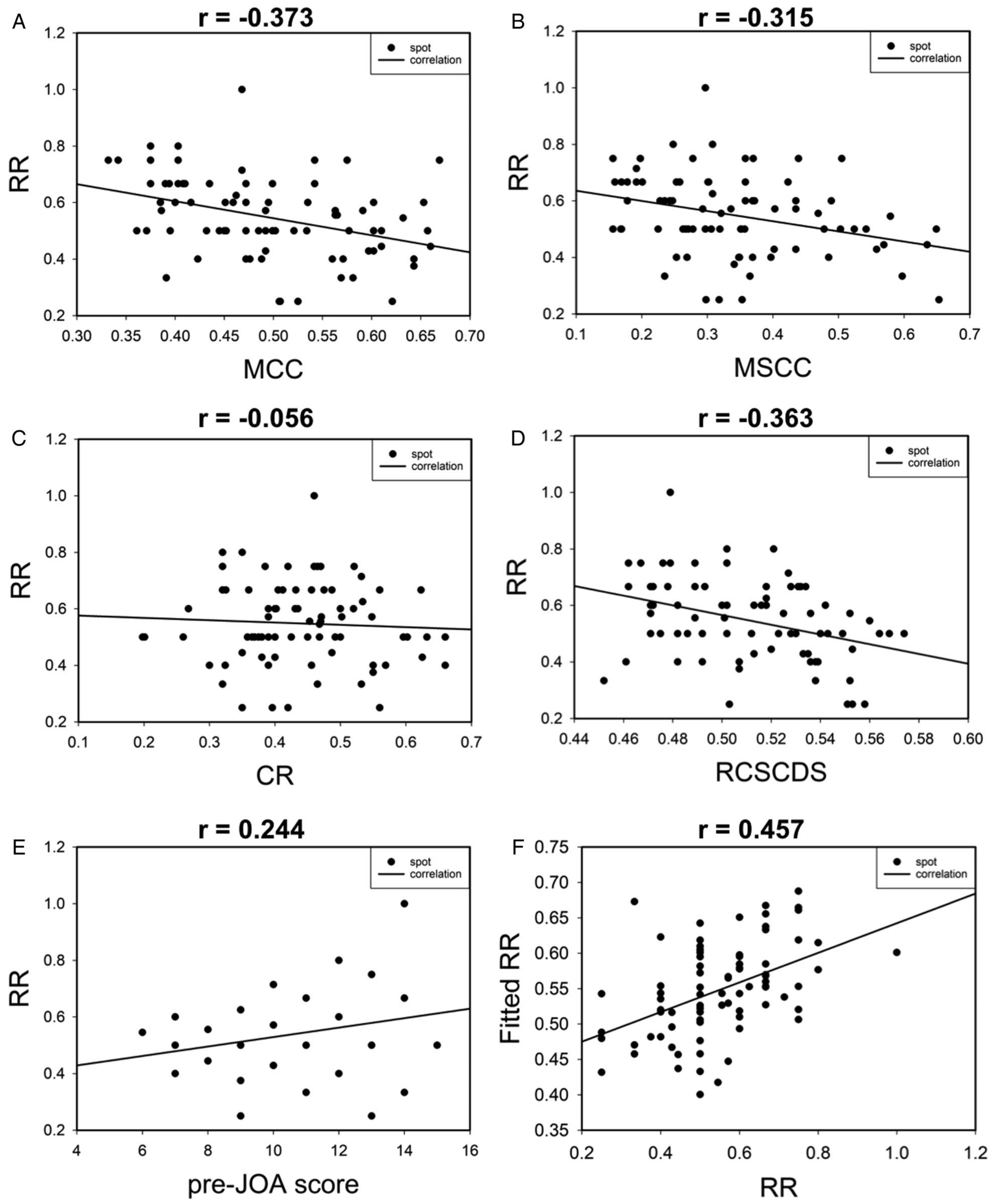


FIGURE 5
The scatter plot of correlation between postoperative recovery rate and preoperative spinal cord compression parameters (A–D). Correlation between postoperative recovery rate and preoperative JOA score (E). Correlation between postoperative recovery rate and fitted postoperative recovery rate (F).

were analyzed. Results revealed that there were moderate, moderate, not correlated, moderate, and high correlation between postoperative JOA score and MCC, MSCC, CR, RCSCDS, and preoperative JOA score, respectively. In addition, the results of multiple linear regression analysis are shown in **Figure 4**, and the equation was as follows: fitted postoperative JOA score = 13.371 – 2.940 ∗ MCC − 5.660 ∗ RCSCDS + 0.471 ∗ preoperative JOA score. As shown in **Figure 4F**, the actual postoperative JOA score was highly correlated with the fitted postoperative JOA score, with a correlation coefficient of 0.883 ($P < 0.05$).

The correlation between RR and MRI parameters of spinal cord compression and preoperative JOA score was analyzed. The results revealed moderate, moderate, not correlated, moderate, and moderate correlations between RR and MCC, MSCC, CR, RCSCDS, and preoperative JOA score, respectively. In addition, the results of multiple linear regression analysis are shown in **Figure 5**, and the equation was as follows: fitted RR = 1.451–0.472 * MCC −1.313 * RCSCDS. The actual RR was highly correlated with the fitted RR, with a correlation coefficient of 0.457 ($P < 0.05$) (**Figure 5F**).

## Discussion

DCM occurs mainly due to the degeneration of cervical region structures in the spine, causing spinal stenosis and spinal cord compression, resulting in a series of clinical symptoms. There are several measures available to determine the degree of spinal cord compression. Fehlings et al. used MCC, MSCC, CR, and TA to reflect the degree of spinal cord compression (16). The space between the cervical spinal canal and the cervical spinal cord reflects the compensatory ability of DCM patients when the cervical spinal cord is compressed. The RCSCDS reflects the relative size of the spinal cord and dural sac in the process of DCM development. Compared to TA (i.e., cross-sectional area of the spinal cord), RCSCDS better reflects the degree of spinal cord compression; therefore, we selected RCSCDS as one of the measurement indicators in this study.

Many studies have investigated predictors of surgical outcome (s) for DCM. Okada et al. believed that the postoperative outcome of DCM was significantly related to the cross-sectional area of the most severely affected segment of spinal cord compression, disease course, and high signal intensity in the spinal cord (10). In addition, Jinkins et al. found that the cross-sectional area of the most severely affected segment of spinal cord compression was related to signal intensity in the spinal cord (3, 17). We found that factors influencing postoperative JOA score included MCC, RCSCDS, and preoperative JOA score, excluding MSCC and CR. Furthermore, Nouri and Tetraault et al. found a significant correlation between post- and preoperative spinal cord function in those with DCM (18, 19). In addition, the coefficient of MCC and RCSCDS in the regression analysis was negative, and the coefficient of preoperative JOA score was positive. This indicates that the larger the MCC and RCSCDS, the smaller the reserve space in the direction of sagittal and transverse position of the spinal cord, and the lower the functional score in the spinal cord, the worse the function of the spinal cord. Higher preoperative JOA score was associated with better postoperative spinal cord function. The factors affecting RR included MCC and RCSCDS. In addition, the coefficient of MCC and RCSCDS in the regression analysis was negative, indicating that the greater the MCC and RCSCDS, the worse the postoperative efficacy.

The present study has several shortcomings and limitations. First, the retrospective design led to an inherent bias, which, together with the relatively small number of cases, may have made the results prone to error. Furthermore, the JOA score and MRI parameter measurements were manually scored and processed using Picture Archiving and Communication software, which is prone to measurement deviation. Second, the JOA score and RR may be affected by many other factors, including age, disease course, high signal intensity in the spinal cord, and operation time. Although we divided the operation group into groups B and C, we did not analyze high signal in the spinal cord as an influencing factor.

## Conclusion

In conclusion, MCC, MSCC, CR, and RCSCDS reflected spinal cord compression on MRI and preliminarily suggested whether there is an objective indication for surgery. The occurrence of high signal in the spinal cord on T2-weighted images could reflect more serious spinal cord injury, and also suggested that early intervention should be performed before the occurrence of high signal in DCM. MCC and MSCC could, to some extent, reflect the severity of spinal cord compression. JOA score was significantly correlated with MCC, RCSCDS, and preoperative JOA score. The RR was significantly related to MCC and RCSCDS.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The clinical study was approved by the Ethics Committee of the first affiliated hospital of Soochow University, and written informed consents were obtained from all participants. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

LQ and SY were responsible for design and drafting of the paper. LY, DS, SY and JN performed the data collection and statistical analysis. HY and JZ made critical revision of the manuscript for content. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Feng Wang,
Third Hospital of Hebei Medical University, China
Dingjun Hao,
Xi'an Honghui Hospital, China

*CORRESPONDENCE
Han Wu
wu_han@jlu.edu.cn

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# Analysis between preoperative cervical radiographic parameters represented by the K-line tilt and the short-term prognosis of laminoplasty for posterior longitudinal ligament ossification: A retrospective study

Baixing Wei[1], Wanting Liu[2] and Han Wu[1]*

[1]Department of Orthopedics, China-Japan Union Hospital of Jilin University, Changchun, China, [2]Department of Clinical Medicine, First Affiliated Hospital of Harbin Medical University, Harbin, China

**Objectives:** To investigate the relationship between preoperative radiographic parameters and the short-term prognosis of patients with cervical ossification of the posterior longitudinal ligament (OPLL) who underwent laminoplasty (LAMP).
**Methods:** A retrospective analysis of Cervical OPLL 50 patients with K-line (+) OPLL with no cervical kyphosis who received LAMP was performed. Based on preoperative neutral position x-ray, the K-line tilt, C2–C7 SVA (sagittal vertical axis), CL (cervical lordosis), T1 slope, and T1 slope-CL were recorded. The JOA (Japanese orthopaedic association scores) score and the cervical kyphosis change were recorded 1 year after surgery. Patients were divided into good and poor prognosis groups according to the median (12.5) of the postoperative JOA score.
**Results:** There were differences between the two groups in K-line tilt, C2–C7 SVA, and T1 slope (all *p*s < 0.05). There was a strong linear correlation between the three, K-Line tilt, JOA score, and C2–C7 SVA. The degree of influence of K-line tilt, C2–C7 SVA, T1 slope on postoperative JOA score was analyzed using multiple linear regression, and the absolute value of the standardized coefficient Beta were 0.550, 0.319, 0.185, respectively. There was no cervical kyphosis change 1 year after surgery.
**Conclusion:** As preoperative cervical parameters, the influence of K-line tilt, C2–C7 SVA, and T1 slope on postoperative JOA score decreases in order. There was a linear relationship between preoperative K-line tilt and postoperative JOA score, implying that patients with cervical OPLL with high

Abbreviations
OPLL, ossification of the posterior longitudinal ligament; ADF, anterior decompression with fusion; PDF, posterior decompression with fusion; APDF, combined anterior and posterior decompression with fusion; LAMP, laminoplasty; C2–C7 SVA, C2–C7 cervical sagittal vertical axis; CL, cervical lordosis; T1 slope-CL, T1 slope-cervical lordosis; JOA, Japanese orthopaedic association scores; NDI, neck disability index; CT, computed tomography; MRI, magnetic resonance imaging

K-line tilt were not eligible for LAMP. K-line tilt was not predictive of cervical kyphosis change after LAMP in patients with OPLL at short-term follow-up.

KEYWORDS

ossification of the posterior longitudinal ligament, laminoplasty, cervical radiographic parameters, K-line, quality of life

# 1. Introduction

Ossification of the posterior longitudinal ligament (OPLL) is a common disease leading to spinal or radicular cervical spondylosis. It has a prevalence of 1.9%–4.3% in the East Asian population (1). This disease frequently necessitates surgical treatment. The most common surgical approaches are (2): anterior decompression with fusion (ADF), posterior decompression with fusion (PDF), combined anterior and posterior decompression with fusion (APDF) (3), and double/single-door laminoplasty (LAMP) (4). Although ADF decompression is more direct and complete in patients with severe spinal canal encroachment, the posterior decompression technique, especially LAMP, is more commonly used in clinical practice due to its simplicity, safety, and low complication rate (5, 6).

Fujiyosh (7) defined K-line as a straight line drawn from the midpoints of the C2 and C7 spinal canals on a neutral lateral x-ray. When the ossified part does not exceed the K-line, it is referred to as K-line (+), and when it does, it is referred to as K-line (−). In the study, Fujiyosh (7) discovered that K-line (−) patients who underwent LAMP had a poor prognosis due to insufficient decompression. Furthermore, preoperative K-line (+) patients recovered neurologically better than preoperative K-line (−) patients in cervical OPLL patients who underwent LAMP (8).

K-line, C2–C7 cervical sagittal vertical axis (C2–C7 SVA), T1 slope, cervical lordosis (CL), and T1 slope-cervical lordosis (T1 slope-CL) are all cervical radiographic parameters measured preoperatively on neutral lateral x-ray. These parameters can predict the prognosis of cervical spine surgery (9, 10).

Kim (11) introduced the K-line tilt in 2018, and it is a derivative form of K-line, defined as an angle between the K-line and the plumb line of the horizon. Combined with the findings of subsequent studies (12–14), K-line tilt can be used as a new preoperative cervical radiographic parameter to predict cervical spine surgery prognosis.

Since there have been few studies on K-line tilt, the primary goal of this study was to investigate the relationship between the preoperative K-line tilt and the short-term prognosis of patients with cervical OPLL who underwent LAMP, with prognosis measured by the JOA score, as well as the correlation with other preoperative cervical radiographic parameters.

# 2. Materials and methods

## 2.1. Ethics and patient consent

This study was approved by the Ethics Committee of the China-Japan Union Hospital of Jilin University. All the patients provided written informed consent in this study.

## 2.2. Materials

The study design was a retrospective collection of data of patients who underwent LAMP for cervical OPLL at the Department of Spine Surgery, China-Japan Union Hospital, between January 2017 and December 2020. Their preoperative and postoperative clinical and imaging data were also collected. All patients were diagnosed after a thorough medical history interview, physical examination, and imaging.

## 2.3. Criteria for acceptance and exclusion

### 2.3.1. Criteria for acceptance

(1) Complete preoperative and follow-up radiological data, all preoperative radiological data within 2 weeks, postoperative follow-up data 1 year after surgery; (2) x-ray diagnosis of cervical OPLL with K-line (+) and no cervical kyphosis; (3) preoperative CT determined that OPLL involved two or more vertebrae; (4) preoperative CT/MRI revealed cervical spinal stenosis and significant spinal cord compression; (5) physical examination revealed clear signs and symptoms of spinal cervical spondylosis, necessitating LAMP treatment and anticipated neurological recovery from surgery.

### 2.3.2. Criteria for exclusion

(1) History of cervical spine surgery; (2) patients with severe underlying diseases; (3) combined cervical spine trauma and spinal cord injury; (4) combined psychiatric disorders preventing treatment and follow-up; (5) patients with severe combined osteoporosis; (6) exclusion of patients with difficulty measuring x-ray parameters (e.g., Obstruction of T1 vertebrae due to sternal or rib obstruction or obesity); (7) Tumors of the cervical spine.

## 2.4. Surgical methodology

The Surgical approach was performed using the LAMP described by Tomita (15). Separate the paravertebral muscles from the spinous processes to expose the laminae. If the operating segment was C3–C6, the procedure was as follows: when laminae were separated, and the ligamentum flavum of C2–C3 and C6–C7 was excised to expose the midline epidural space for decompression. A wire saw was inserted from the C6–C7 midline epidural space and threaded through C2–C3 midline epidural space. The spinous process was split centrally by repeated pulling with the wire saw. The outer layer of cortical bone and some cancellous bone on the medial side of the articular eminence on both sides of C3–C6 were removed using a high-speed air-burr drill. They were made into V-shaped bone grooves on both sides of the laminae which served as the portal axes of the double doors. The bone cortex on either side of the groove was incompletely fractured. The residual ligamentum flavum and epidural adhesions were also removed. The spinal canal was sufficiently enlarged. Using the high-speed air-burr drill, holes were created in the root of the split spinous process on both sides. Four trapezoidal homogeneous bone blocks were fixed to the C3–C6 bilateral spinous processes with double 10-gauge wire, and the knots were checked and firmly fixed. When faced with C2 decompression, we performed Dome-like Expansive LAMP (16, 17) (**Figure 1**). Briefly, a drill was applied to make a dome-like groove on the caudal surface of the C2, removed part of the anterior portion of the laminae, and then carefully excised the excess hypertrophic ligamentum flavum and part laminae. When faced with C7 decompression, we opened the C7 laminae and operate the same procedure as above.

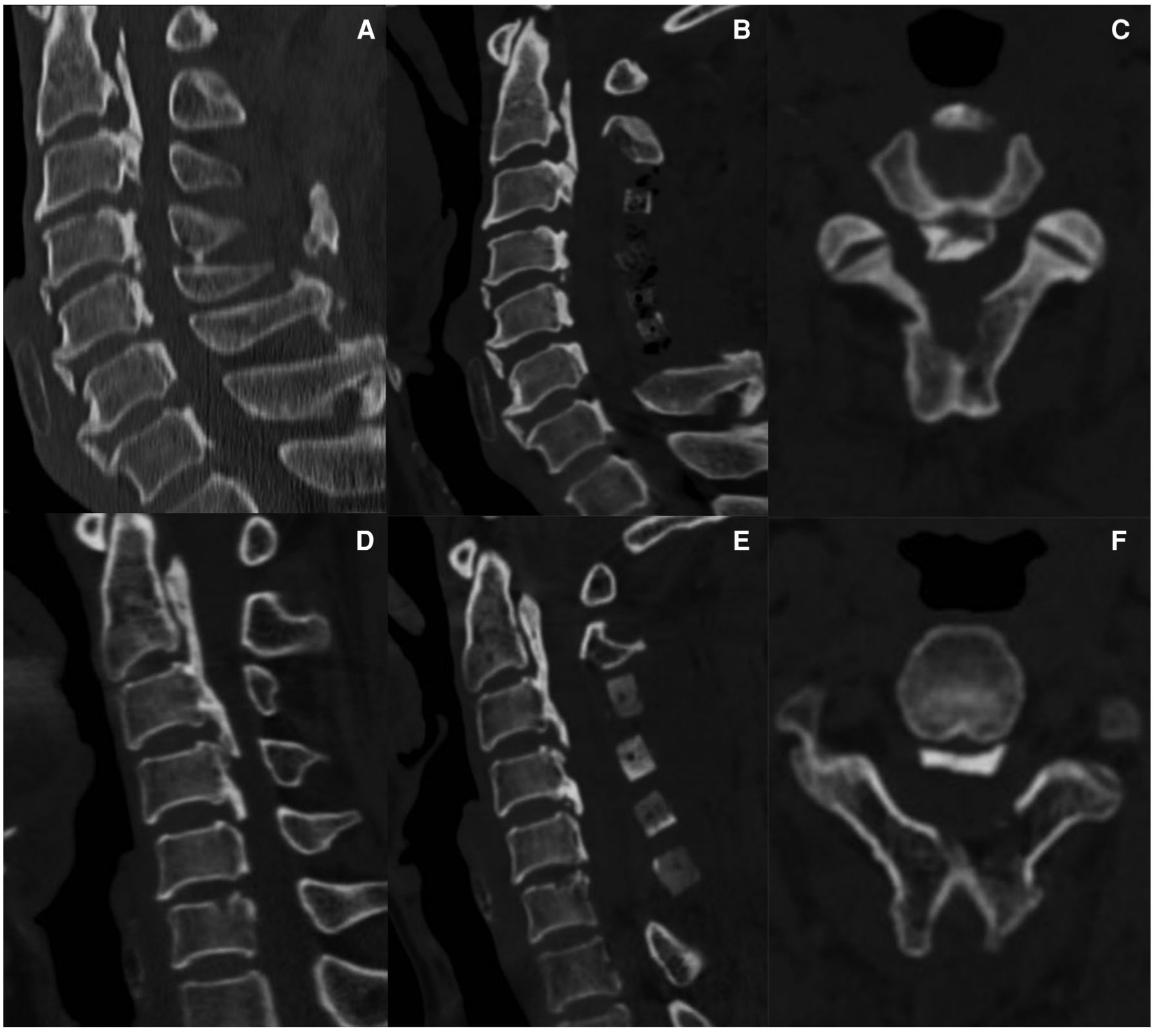


FIGURE 1
Dome-like Expansive LAMP for C2 decompression.

### 2.4.1. Management and observation following surgery

To prevent infection, antibiotics were given intravenously 24 h before surgery, as well as during the intraoperative and 48-h postoperative periods. The drainage device was removed when the drainage volume was less than 30 ml 24 h after surgery. Patients are discharged from the hospital after they can get out of bed with their neck external fixation and move around on their own and eat normally, usually 3–4 days after surgery. At discharge, the patient was instructed to stay in bed for most of the month, gradually increase the time of sitting and walking, and the neck external fixation must be worn during activities. After 1 month, the patient can no longer wear the neck external fixation and begin functional exercises of the cervical range of motion training. At discharge, the x-ray, CT and MRI results were reviewed. All patients had their x-rays reviewed again about 1 year after surgery.

### 2.4.2. Statistics and categorization

#### *2.4.2.1. Imagery data*

The patients' neutral lateral cervical x-rays were analyzed during their hospitalization and 1 year after surgery. The following parameters were measured on x-rays (**Figure 2**): (1) K-line; (2) K-line tilt (°): the angle formed by the K-line and a line perpendicular to the horizon. (3) C2–C7 SVA (mm): the distance between the vertical line of C2 vertebral body and the posterior upper corner of C7; (4) T1 slope (°): the angle between the upper endplate of the first thoracic vertebra and the horizontal plane; (5) CL (°): cervical curvature, defined as the angle between the superior endplate of C2 and the inferior endplate of C7, <5° was defined as cervical kyphosis, >5° but <10° as straightening of cervical curvature, and >10° as cervical lordosis (18); (6) T1 slope-CL (°): the difference between T1 slope and cervical curvature. Notably, the above parameters were measured at three different time points before being averaged. In addition, the patient's ossification type (continuous, focal, mixed, and segmental) was recorded (**Figure 3**).

#### *2.4.2.2. Prognostic data*

The sagittal x-rays of the cervical spine were reviewed 1 year after the patients' observation, the presence or absence of cervical kyphosis changes in the patients was recorded, and the patients' operating segments were recorded. At the 1-year follow-up following discharge, JOA score were collected and expressed as a score to assess neck function. The lower the score, the worse the prognosis. According to the postoperative JOA score of the patients included in the study, the patients were divided into two groups by the median postoperative JOA score: those with a low JOA score with a better prognosis and those with a high JOA score with a worse prognosis.

## 2.5. Statistical evaluation

SPSS 25.0 software was used for statistical analysis (IBM Corp., Armonk, New York, USA). All quantitative data were carried out with homogeneity test of variance, and variables meeting the test were presented as mean ± standard deviation. Independent-samples *T* tests were used for group comparisons. The chi-square test was used for the comparison of counts variables. Correlation tests between different parameters were performed using Pearson correlation test. The relationship between cervical sagittal parameters and postoperative JOA score was analyzed by multiple linear regression analysis. $p < 0.05$ indicated that the difference was statistically significant.

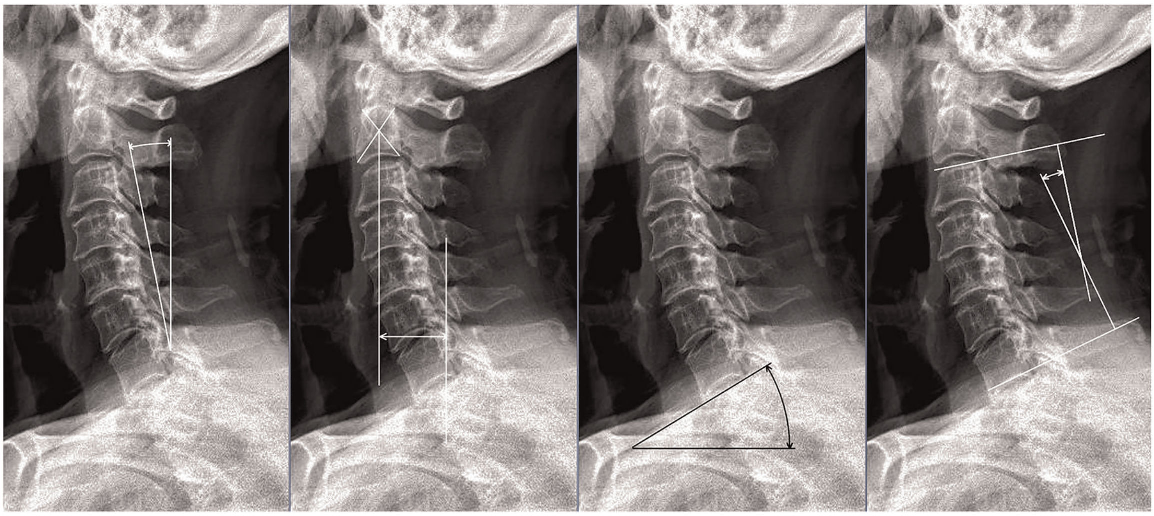

FIGURE 2
K-line tilt; C2-C7 SVA; T1 slope; CL, respectively.

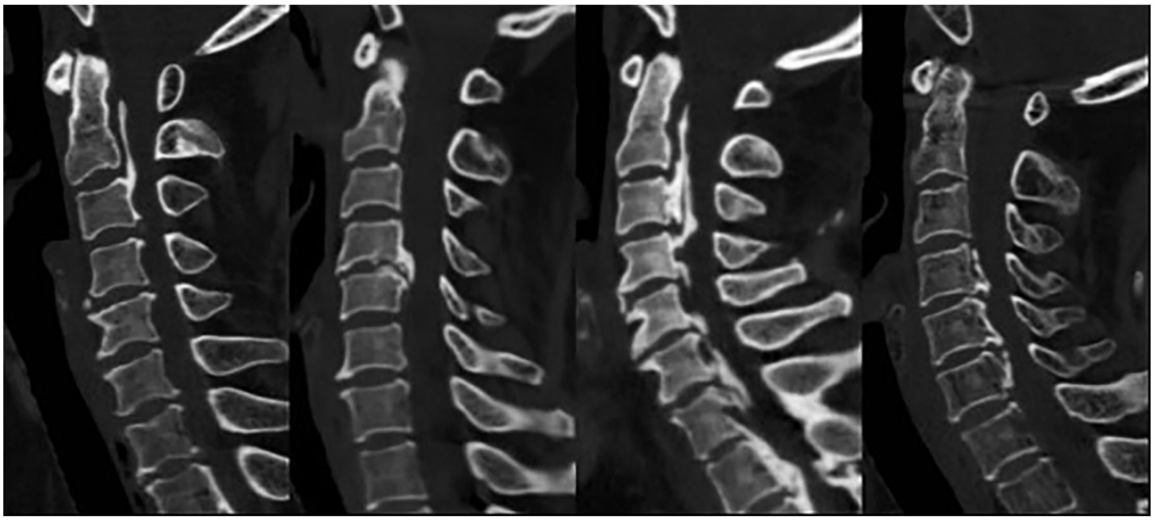

FIGURE 3
The four types of cervical OPLL: continuous, local, mixed, and segmental.

TABLE 1 Fundamental patient information.

| | Mean ± standard deviation |
|---|---|
| Age | 57.46 ± 7.19 |
| Sex | |
| Male | 34 |
| Female | 16 |
| Type | |
| Local | 7 |
| Segmental | 18 |
| Continuous | 12 |
| Mixed | 13 |
| Surgical segments | |
| C2–C6 | 3 |
| C3–C6 | 39 |
| C3–C7 | 8 |
| Postoperative JOA score | 12.36 ± 2.02 |
| K-line tilt (°) | 12.31 ± 5.61 |
| C2–C7 SVA (mm) | 21.10 ± 7.60 |
| T1 slope (°) | 23.03 ± 4.23 |
| CL (°) | 19.31 ± 5.08 |
| T1 slope-CL (°) | 3.98 ± 6.27 |

# 3. Results

## 3.1. Fundamental patient information

Table 1 summarizes the basic information of the 50 patients who participated in the study. The average age (years) was 57.46 ± 7.19, with 34 men and 16 women. The type of OPLL could be grouped into: localized 7, segmental 18, continuous 12, and mixed 13. The surgical segments could be grouped into: 3 cases of C2–C6, 39 cases of C3–C6, and 8 cases of C3–C7. The postoperative JOA score of the patients was 12.36 ± 2.02 with a median of 12.5. The K-line tilt (°) was 12.31 ± 5.61, C2–C7 SVA (mm) was 21.10 ± 7.5, T1 slope (°) was 23.03 ± 4.23, CL (°) was 19.31 ± 5.08, and T1 slope-CL (°) was 3.98 ± 6.27.

## 3.2. Comparison of preoperative and postoperative cervical radiographic parameters, as well as postoperative prognostic parameters

Patients were divided into two groups based on the median postoperative JOA score (12.5): those with a high postoperative JOA score with a better prognosis ($n = 25$; JOA score < 12.5) and those with a low postoperative JOA score with a worse prognosis ($n = 25$; JOA score > 12.5) (Table 2). The cervical radiographic parameters measured by preoperative x-rays were compared between the two groups, as well as postoperative cervical kyphosis changes. In the preoperative period, both groups were K-line (+) and had no cervical kyphosis. There were no significant differences in age, sex ratio, type, or surgical segments between the two groups. In terms of radiographic parameters, there were no significant differences between the two groups in terms of CL, T1 slope-CL, and postoperative kyphosis changes. However, the results of the two groups differed significantly in the comparison of three parameters, K-line tilt, C2–C7 SVA, and T1 slope ($p = 0.000$; $p = 0.001$; $p = 0.000$; and $p = 0.029$).

TABLE 2 Comparison of preoperative and postoperative cervical radiographic parameters, as well as postoperative prognostic parameters.

| | Postoperative high JOA score group ($n = 25$) | Postoperative low JOA score group ($n = 25$) | $p$ |
|---|---|---|---|
| K-line (+:−) | 25:0 | 25:0 | |
| Lordosis: kyphosis | 25:0 | 25:0 | |
| Age | 59.32 ± 7.15 | 55.60 ± 6.86 | 0.067 |
| Sex | 18:7 | 16:9 | 0.544 |
| Type | | | 0.590 |
| Local | 2 | 5 | |
| Segmental | 10 | 8 | |
| Continuous | 7 | 5 | |
| Mixed | 6 | 7 | |
| Surgical segments | | | 0.364 |
| 2–6 | 1 | 2 | |
| 3–6 | 21 | 18 | |
| 3–7 | 3 | 5 | |
| K-line tilt (°) | 8.91 ± 4.66 | 13.71 ± 4.29 | 0.001 |
| C2–C7 SVA (mm) | 17.27 ± 6.50 | 24.9 ± 6.71 | 0.000 |
| T1 slope (°) | 21.74 ± 3.32 | 24.32 ± 4.69 | 0.029 |
| CL (°) | 19.57 ± 4.82 | 19.05 ± 5.41 | 0.726 |
| T1 slope-CL (°) | 2.70 ± 5.79 | 5.26 ± 6.59 | 0.151 |
| Kyphosis change | 0 | 0 | - |

$p < 0.05$ means statistically significant.

## 3.3. Correlation analysis of each cervical radiographic parameter and JOA score

The correlation between cervical sagittal parameters and postoperative JOA score is presented in **Table 3**. Since these variables were found to be normally distributed, the correlations between cervical radiographic parameters and postoperative JOA score were examined in pairs. The corresponding Pearson correlation coefficients and $p$ values were presented, revealing a strong linear relationship between each of the three parameters, K-Line tilt, postoperative JOA score, and C2–C7 SVA ($r = -0.843$, $p = 0.000$; $r = -0.783$, $p = 0.000$; $r = 0.779$, $p = 0.000$), while the linear relationship between T1 slope and postoperative JOA score was moderate ($r = -0.377$, $p = 0.005$) (**Table 3**).

Using linear regression analysis, the four groups of variables with linear relationships were plotted and the regression lines labeled. There was a strong linear correlation between the three, K-Line tilt, JOA score, and C2–C7 SVA. $R^2$ are 0.711, 0.6129, 0.6252 respectively (**Figure 4**) (note: $R^2$ is a tabulation that indicates the goodness of fit of the linear regression equation and accepts values ranging from 0 to 1, with values closer to 1 indicating a better fit).

## 3.4. The degree of influence of preoperative K-line tilt, C2–C7 SVA, and T1 slope on postoperative JOA score

As demonstrated in **Table 2**, the results confirmed that the differences in K-line tilt, T1 slope, and C2–C7 SVA between the two groups were significant, and **Table 3** confirmed a strong correlation between postoperative JOA score and the above three. As a result, a multiple linear regression analysis was performed with the above three indicators as independent variables and the postoperative JOA score as the dependent variable, and the results are shown in **Table 4** below. Stepwise linear regression analysis yielded the equation $Y = -0.2X1 -0.086X2 -0.089X3 +18.679$ ($Y$ = postoperative JOA score; $X1$ = K-line tilt; $X2$ = C2–C7 SVA; $X3$ = T1 slope; $R^2 = 0.769$). The $R^2$ values obtained showed that the model was a good fit. The $F = 55.488$ of the regression model, $p = 0.00 <0.05$, proved that the model was statistically significant, and in the significance test of the regression coefficients of respective variables, the corresponding $p$-values of K-line tilt, C2–C7 SVA, and T1 slope were 0.000, 0.005, and 0.012, which are all less than 0.05, proving that all three parameters also possess statistical inference significance. Furthermore, the VIF of these three data sets were 2.602, 1.061, and 2.544, all of which were less than 10, demonstrating no covariance among these three independent variables, and the results of multiple regression analysis were reliable. For the absolute value of the standardized coefficient Beta, K-line tilt > C2–C7 SVA > T1 slope, proving that the influence of these three preoperative imaging parameters on influencing postoperative JOA score was, from the largest to smallest, K-line tilt > C2–C7 SVA > T1 slope, respectively.

## 3.5. Case study presentation

1. Here we present the two typical and comparable patients from the two groups (**Figure 5**), patient 1 from the high JOA score group and patient 2 from the low JOA score group. In both patients, spinal cord compression was seen on preoperative MRI, both were segmental OPLL, both were K-line (+), both OPLL were located at C5 and C6, and both had enlarged spinal canal volume after lamp. However, they had different postoperative outcomes. Although no abnormalities were seen on x-ray, all preoperative cervical radiographic parameters were generally consistent with the findings indicated by the above results.
2. The **Figure 6** depicts x-rays of the cervical spine of a 65-year-old man with cervical OPLL who underwent LAMP and whose CL angles were 26.5°, 21.7°, 17.5°, 10.5°, and −1.8° at 3 days preoperatively, 3, 6, 12, and 24 months

TABLE 3 Pearson correlation analysis of each cervical radiographic parameter.

| | Postoperative JOA score | K-line tilt | C2–C7 SVA | CL | T1 slope | T1 slope-CL |
|---|---|---|---|---|---|---|
| Postoperative JOA score | | | | | | |
| Pearson coefficients | 1 | −0.843** | −0.783** | 0.091 | −0.377** | −0.314* |
| P | | 0.000 | 0.000 | 0.55 | 0.005 | 0.027 |
| N | 50 | 50 | 50 | 50 | 50 | 50 |
| K-line tilt | | | | | | |
| Pearson coefficients | | 1 | 0.779** | −0.072 | 0.24 | 0.232 |
| P | | | 0.000 | 0.617 | 0.094 | 0.104 |
| N | | 50 | 50 | 50 | 50 | 50 |
| C2–C7 SVA | | | | | | |
| Pearson coefficients | | | 1 | −0.016 | 0.19 | 0.157 |
| P | | | | 0.91 | 0.187 | 0.276 |
| N | | | 50 | 50 | 50 | 50 |
| CL | | | | | | |
| Pearson coefficients | | | | 1 | 0.051 | −0.721** |
| P | | | | | 0.725 | 0.000 |
| N | | | | 50 | 50 | 50 |
| T1 slope | | | | | | |
| Pearson coefficients | | | | | 1 | 0.590** |
| P | | | | | | 0.000 |
| N | | | | | 50 | 50 |
| T1 slope-CL | | | | | | |
| Pearson coefficients | | | | | | 1 |
| P | | | | | | |
| N | | | | | | 50 |

*$p < 0.05$.
**$p < 0.01$.

postoperatively, respectively. The cervical spine CL angle became negative on the last radiograph, and the cervical spine changed from lordosis to kyphosis.

## 4. Discussion

Studies have shown that K-line (−) or high canal occupying ratio OPLL patients usually have a poor prognosis after LAMP (1, 7, 9–21). The K-line (+) OPLL is the best indication for LAMP, while the K-line (−) OPLL is not. Therefore, only K-line (+) patients were included in this study in order to exclude the biasing effect of lower JOA score of K-line (−) patients on the study results.

This study demonstrated that there was a linear correspondence between K-line tilt and postoperative JOA score. Prior to this, only four studies have been conducted on K-line tilt, Kim (11) found that the patient had severe neck pain when the K-line tilt >25°. Lan (12) found severe neck pain in patients with cervical disc herniation when the K-line tilt >23.75° underwent ACDF. Rao (13) found that the greater the preoperative K-line tilt, the greater the probability of developing postoperative cervical kyphosis change and postoperative neck pain. Sakai (14) found that preoperative K-line tilt >20° was a risk factor for cervical kyphosis change after cervical LAMP. In our study, according to the regression equation established by the postoperative JOA score and the preoperative K-line tilt, the larger the K-line tilt, the lower the postoperative JOA score. This means that when the preoperative K-line tilt is high, OPLL patients have a poor prognosis and severe neck discomfort after 1 year of LAMP treatment.

The following two factors may explain the higher postoperative JOA score in patients with a higher preoperative K-line tilt. For one side, the LAMP procedure is performed by stripping the muscles attached to the cervical spine laminae, thereby exposing and opening the laminae. While the procedure clearly expands the volume of the spinal canal, it disrupts the muscle attachments and cuts the supraspinous and interspinous ligaments, changing the structure of the posterior part of the vertebral body, which are the stabilizing factors that maintain the balance of the cervical spine. The consequence of disrupting these structures is that the muscles

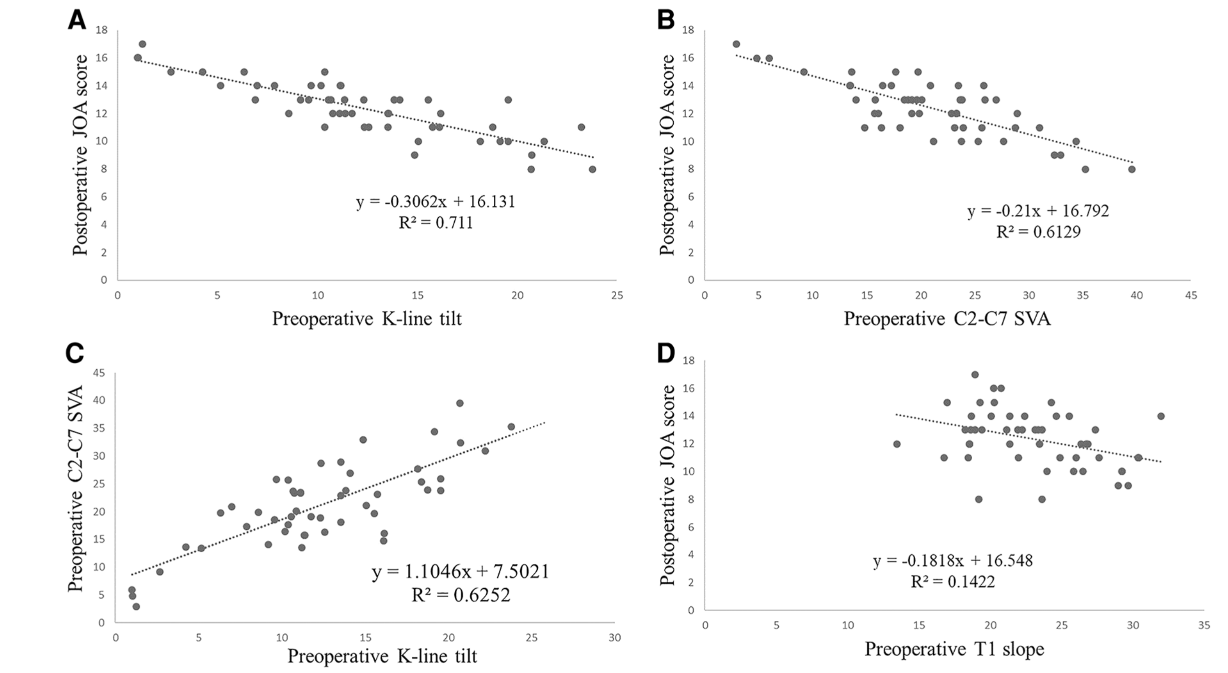


FIGURE 4
Correlation analysis of each cervical radiographic parameter and JOA score.

TABLE 4 The degree of influence of preoperative K-line tilt, C2–C7 SVA, and T1 slope on postoperative JOA score.

| | Unstandardized coefficients B | Unstandardized coefficients std. error | Standardized coefficients beta | *t* | *t* sig. (*p*) | VIF |
|---|---|---|---|---|---|---|
| K-line tilt | −0.2 | 0.04 | −0.550 | −4.973 | 0.000 | 2.602 |
| C2–C7 SVA | −0.086 | 0.029 | −0.319 | −2.916 | 0.005 | 2.544 |
| T1 slope | −0.089 | 0.034 | −0.185 | −2.614 | 0.012 | 1.061 |
| Constant | 18.679 | 0.819 | | 22.801 | 0.000 | |

$p < 0.05$ means statistically significant; VIF < 10 means there is no covariance between independent variables.

of the posterior cervical spine must take on more responsibility and expend more energy to maintain the balance of the head after surgery. For the other side, without considering surgical factors, the higher the K-line tilt, the more the cervical spine tilts forward, the greater the tension required from the posterior cervical muscles, and the more likely the posterior cervical muscles are to fatigue.

This study confirmed a linear relationship between preoperative C2–C7 SVA and preoperative K-line tilt and postoperative JOA score. This is similar to previous findings. Kim (11) and Sakai (14) have also confirmed a linear relationship between C2–C7 SVA and K-line tilt. Furthermore, Tang (22) found a significant positive linear correlation between C2–C7 SVA and NDI score (Neck disability index, an index to assess cervical pain and disability that can be used to assess surgical prognosis).

This study also demonstrated a moderate predictive effect of preoperative T1 slope on postoperative JOA score. Before this study, Xu (23) disclosed that T1 slope, gender, and age were all correlated with the prognosis of cervical spine surgery. Furthermore, Kontt (24) indicated a strong correlation between T1 slope and C2–C7 SVA and that the cervical sagittal is imbalanced when T1-slope was >25° or <13°. However, Cho (25) found that preoperative T1 slope did not aggravate cervical sagittal imbalance. So, controversy remains about the relationship between T1 slope and cervical sagittal balance. In the present study, the preoperative T1 slope significantly differed between the high and low postoperative JOA score groups. It was moderately correlated by linear correlation analysis, while $R^2$ was too small after listing the linear regression equation, and the equation was not well fitted. In the results analyzed by the multiple linear regression

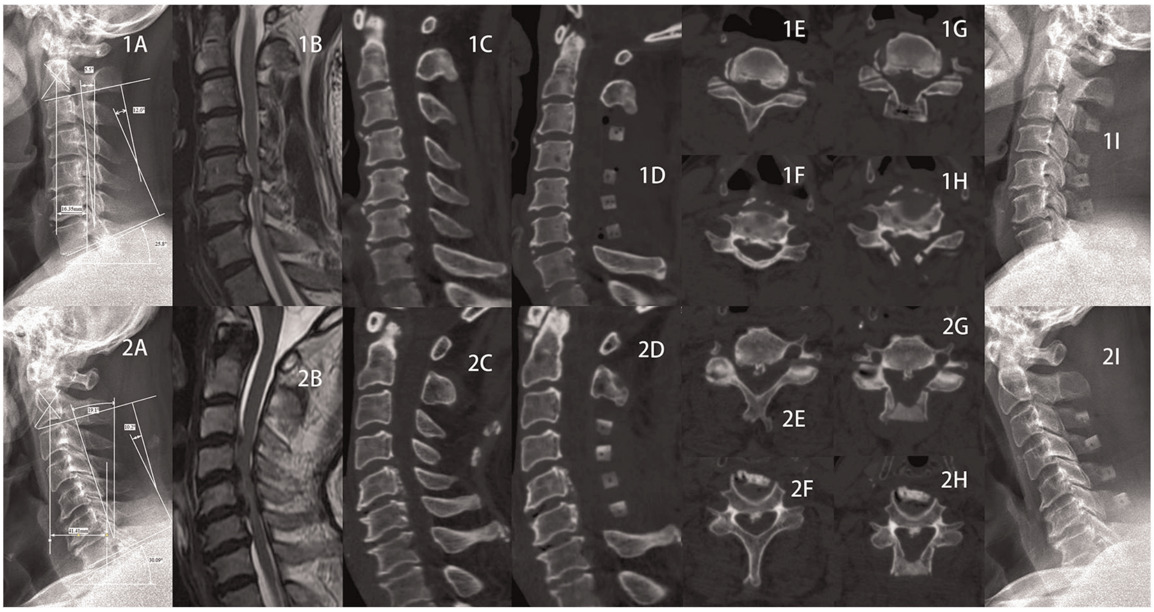


FIGURE 5
Case Study Presentation 1.

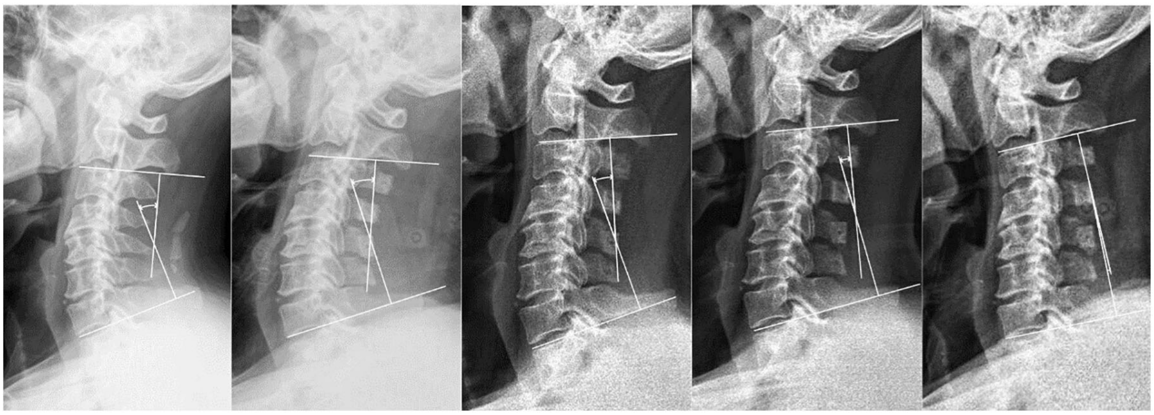

FIGURE 6
Case Study Presentation 2.

equation, it was demonstrated that T1 slope, although weaker than K-line tilt and C2–C7 SVA, remains an important influence on postoperative JOA score that cannot be ignored.

In the present study, although there was a linear relationship between preoperative T1 slope and CL and T1 slope-CL, there was no linear relationship between these three parameters and K-line tilt. The above reasons can be speculated as follows: T1 slope reflects the degree of kyphosis at the junction of the cervical and thoracic spine, and T1 slope is affected by thoracic spine alignment (26). There are differences in each individual, and although the K-line tilt also varies by thoracic spine alignment, the degree and mechanism by which these two parameters are affected are different.

Patients with LAMP-treated OPLL tend to have postoperative kyphosis change which means poor postoperative prognosis (14). This study had no kyphosis change patient at 1 year after surgery in both the high and low JOA score groups; however, kyphosis change patients was observed at a longer follow-up. Here is a case of a kyphosis change patient (**Figure 6**), it is hypothesized that the postoperative imbalance in the anterior-posterior muscles tension balance of the cervical spine led to the kyphosis change. In previous studies, Sakai (14) and Lee (27) discovered that a large preoperative K-line tilt is a risk factor for cervical kyphosis change in LAMP treated cervical OPLL. They concluded that a higher K-line tilt meant that the patient's head center of gravity was farther from the midline, and this exacerbated the rate and degree of kyphosis change. They all had a follow-up of more than 2 years. Therefore, we speculate that the lack of correlation between preoperative K-line tilt and postoperative kyphosis change in this study may be due to the short follow-up period in this study.

In summary, it can be concluded that T1 slope has limitations. It is difficult to clearly identify the thoracic spine on lateral x-rays because of rib or sternal occlusion, making it difficult to examine. It is difficult to clearly identify the thoracic spine on lateral x-rays because of rib or sternal occlusion, making it difficult to examine (11). As a length parameter, C2–C7 SVA is easily affected by image magnification and reduction and is difficult to measure if not read in a hospital x-rays reading system. K-line tilt can almost completely solve both problems. K-line tilt is linearly related to C2–C7 SVA, and K-line tilt plays a much larger role in influencing postoperative JOA score than T1 slope and is also easier to measure than it. K-line tilt, as an angular parameter, can be quantified as a linear relationship instead of C2–C7 SVA.

The shortcomings of this study were the small sample size and the fact that it was a single-center study. More importantly, the study did not take into account long-term outcomes. Nevertheless, K-line tilt could be used as a novel cervical sagittal parameter for surgical approach reference and prognostic prediction.

## 5. Conclusion

As preoperative cervical parameters, the influence of K-line tilt, C2–C7 SVA, and T1 slope on postoperative JOA score decreases in order. There was a linear relationship between preoperative K-line tilt and postoperative JOA score, implying that patients with cervical OPLL with high K-line tilt were not eligible for LAMP. K-line tilt was not predictive of cervical kyphosis change after LAMP in patients with OPLL at short-term follow-up.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

Written informed consent was obtained from the individual (s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

BW: conceptualization, methodology, writing—original draft, data analysis. WL: data analysis. HW: conceptualization, funding acquisition, supervision, writing—review and editing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Guangzhou Li,
The Affiliated Hospital of Southwest Medical University, China
Mingzhu Zhang,
Capital Medical University, China

*CORRESPONDENCE
Hua Zhang
zhanghua068@zju.edu.cn

†PRESENT ADDRESS
Hua Zhang
Department of Orthopedic Surgery, The Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou, China; Orthopedics Research Institute, Zhejiang University, Hangzhou, China; Key Laboratory of Motor System Disease Research and Precision Therapy of Zhejiang Province, Hangzhou, China; Clinical Research Center of Motor System Disease of Zhejiang Province, Hangzhou, China

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# Cervical single open-door laminoplasty with or without local lateral mass screw fixation and fusion to treat cervical spinal cord injuries accompanied by segmental spinal canal stenosis

Zihao Yu[1,2,3,4], Hongwei Xie[1,2,3,4], Ziyu Ouyang[1,2,3,4] and Hua Zhang[1,2,3,4*†]

[1]Department of Orthopedic Surgery, The Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou, China, [2]Orthopedics Research Institute, Zhejiang University, Hangzhou, China, [3]Key Laboratory of Motor System Disease Research and Precision Therapy of Zhejiang Province, Hangzhou, China, [4]Clinical Research Center of Motor System Disease of Zhejiang Province, Hangzhou, China

**Study Design:** Retrospective.
**Objectives:** To investigate the efficacy of cervical single open-door laminoplasty with and without local lateral mass screw fixation and fusion as treatments for cervical spinal cord injuries accompanied by multisegmental spinal canal stenosis.
**Setting:** The Second Affiliated Hospital, School of Medicine, Zhejiang University.
**Methods:** Of all enrolled patients, 42 formed a stable group who underwent cervical single open-door laminoplasty alone and 14 formed an unstable group who underwent the procedure combined with lateral mass screw fixation and fusion. Neurological function was evaluated before surgery, at discharge, and at final follow-up using the American Spinal Cord Injury Association (ASIA) impairment scale and the Japanese Orthopedic Association (JOA) score.
**Results:** ASIA scores reflected improved neurological function in 52.5% of the stable group (15 with grade-D and 4 with grade-A injuries did not improve) and 45.5% of the unstable group (3 with grade-D and 3 with grade-A injuries did not improve). Postoperative JOA scores reflected 19.1% ± 21.6% improvement in the stable group and 18.6% ± 18.4% improvement in the unstable group ($P > 0.05$). Final follow-up JOA scores reflected 49.2% ± 31.7% improvement in the stable group and 47.1% ± 39.2% improvement in the unstable group ($P > 0.05$).
**Conclusions:** Laminoplasty combined with local fusion aided the treatment of unstable cervical spinal cord injuries and spinal stenosis. Such stenosis is the main pathological factor causing multiple spinal cord compressions in patients with cervical spinal cord injuries.

KEYWORDS
laminoplasty, lateral mass screw fixation, spinal cord injury, cervical spinal canal stenosis, neurological function

Abbreviations
ASIA, American spinal cord injury association; JOA, Japanese orthopedic association; MRI, magnetic resonance imaging; OPLL, ossification of posterior longitudinal ligament.

## Introduction

Many high-energy injuries are osseous in nature; however, many low-energy spinal cord injuries in patients with pre-existing cervical stenosis are not associated with any fracture or other cause of instability. The treatment of central cord syndrome without associated instability remains controversial. Classically, nonsurgical treatment was considered to yield results similar to those of surgery (1). This position has recently been questioned; given the lack of instability, some authors have advocated non-fusion surgeries such as posterior laminoplasty (2–4). Fehlings et al. found that early surgical intervention improved neurological recovery in patients with cervical spinal cord injuries (5–7). However, the optimal surgical treatment, especially for patients with pre-existing stenosis and central cord syndrome, remains unclear. This study was a retrospective analysis of data from patients with cervical spinal cord injuries accompanied by multisegmental spinal canal stenosis treated *via* cervical single open-door laminoplasty. Additional intervertebral disc injuries, anterior longitudinal ligament injuries, and vertebral body avulsion fractures, when present, were stabilized *via* local lateral mass screw fixation and fusion in addition to laminoplasty. The improvements in neurological symptoms afforded by these treatments, the effects of surgical timing, and the risk factors for local instability were also investigated.

## Materials and methods

### Subjects

Between December 2014 and August 2017, 56 patients underwent surgery to treat traumatic cervical spinal cord injuries accompanied by multisegmental cervical spinal canal stenosis. The stenosis and cord injury were examined by magnetic resonance imaging (MRI). All patients evidenced greatly increased T2 signal changes in the spinal cord and cervical spinal canal stenosis [cervical sagittal diameter < 13 mm on MR images (8)] at three or more levels. Some stenoses were developmental [cross-sectional distance from the posterior edge of the vertebral body to the spinous process root < 13 mm on computed tomography (CT) images (9–11)]; other stenoses were attributable to the ossification of the posterior longitudinal ligament (OPLL), multilevel intervertebral disc herniation, and ligamenta flava folds. All patients were followed for at least 6 months. The exclusion criteria were vertebral compression, burst or facet fracture, cervical subluxation or dislocation, history of cervical spine surgery, upper cervical vertebral injury, and cervical kyphotic deformity. Patients who died or were lost to follow-up were excluded. We measured improvements using the American Spinal Cord Injury Association (ASIA) impairment scale and the Japanese Orthopedic Association (JOA) score.

### Surgical procedure

According to MRI and CT findings, the patients were divided into stable and unstable groups. Stability and instability were defined as the absence and presence, respectively, of intervertebral disc or anterior longitudinal ligament rupture or teardrop-like fracture at the anterior edge of the vertebral body. Simple cervical single open-door laminoplasty was indicated for the stable group. The open-door side was that of the most severe symptom. When symptoms on both sides were similar, we chose the side on which stenosis was more obvious on imaging. On the open-door side, fixation was performed using small titanium-alloy plates (ARCH Laminoplasty System, Synthes GmbH, Switzerland) to support the lamina and prevent postoperative “door closing.” Single open-door laminoplasty with local lateral mass screw fixation was indicated for the unstable group. Single open-door laminoplasty was used to treat the stenotic segment, and laminoplasty plus fixation with lateral mass screws was used to treat the local unstable segments. The lateral mass screws were placed on the hinge side and/or the open-door side. The facet joints of fusion segments were decorticated using a high-speed drill. Next, bone fragments from the autogenous spinous process were implanted in the facet joints. Methylprednisolone (80 mg QD) was prescribed for the first 2 postoperative days and was then reduced to 40 mg QD for the next 2 days to prevent spinal cord edema. Cefuroxime was prescribed at 2 g BID for 2 days postoperatively to prevent infection of the incision. The drainage tube was removed 48 h after surgery, or within 8 h when the drainage volume was <50 ml. After tube removal, the patients were encouraged to leave the bed and walk. The patients were told to protect their necks with a cervical collar for 2 weeks after surgery, and then to commence exercises that rehabilitated neck muscle function. Imaging data from a typical case are provided in **Figure 1**.

### Assessments

We recorded patient sex and age, cause of injury, time from injury to operation, duration of operation, amount of intraoperative blood loss, pathological type of cervical spinal stenosis, numbers and distributions of high-signal segments in the cervical spinal cord, and unstable segment pathological type and distribution. Patients’ neurological status was evaluated before surgery, at discharge, and at the final follow-up using the ASIA impairment scale, and was classified as grades A–E based on symptom severity. Improvement was defined as at least one increment of improvement in the ASIA score at the final follow-up assessment. Neurological function

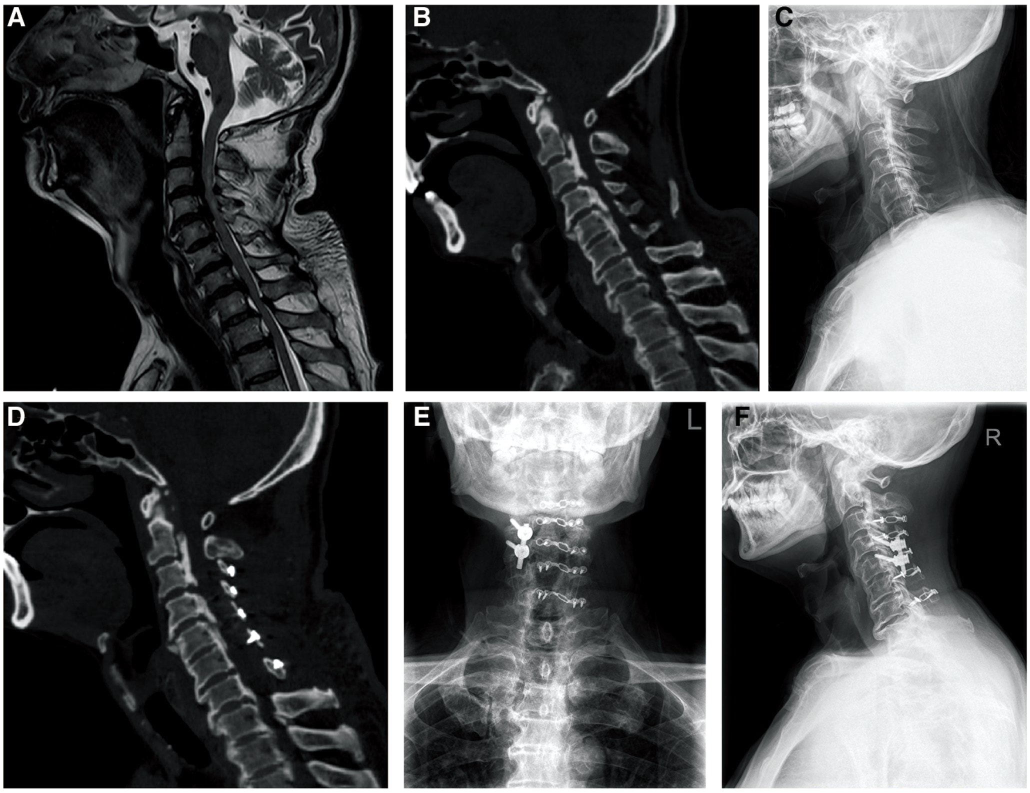


FIGURE 1
Imaging data of a typical case. A 66-year-old male patient with limb numbness caused by falling from height received single open-door laminoplasty and lateral mass screw fixation and fusion. (A) Preoperative MRI showed the rupture of C4/5 intervertebral disc and anterior longitudinal ligament, and the cervical spinal cord signal of C3–C6 increased on T2-weighted image. (B) Preoperative CT scan confirmed ossification of posterior longitudinal ligament and cervical spinal canal stenosis. (C) Preoperative radiograph. (D) Postoperative CT scan showed that the cervical spinal canal was enlarged and the effect of the operation was clear. (E,F). The anteroposterior and lateral radiographs 1 year after surgery suggested that the fixations were in good condition.

was also evaluated using the JOA score before surgery, at discharge, and at the final follow-up. The JOA recovery rates at discharge and final follow-up were calculated using the Hirabayashi method as: [(postoperative JOA score—preoperative JOA score)/(17—preoperative JOA score)] × 100%.

## Statistical analysis

All statistical analyses were performed using SPSS software (ver. 12.0 for Windows; SPSS Inc., Chicago, IL, USA). We present means ± standard deviations. The unpaired independent-samples $t$ test, Mann–Whitney $U$ test, and chi-squared test were used, as appropriate, for group comparisons. $P$ values < 0.05 were considered to be statistically significant.

# Results

The stable group comprised 42 patients (36 males and 6 females), including 1 patient who died and another who was lost to follow-up. The mean age was 59.1 ± 9.5 (range, 34–75) years, and the average time from injury to surgery was 10.1 ± 6.5 (range, 3–32) days. All patients in the stable group underwent cervical single open-door laminoplasty. Thirty-two patients required surgery from C3 to C7, eight patients required C3–C6 laminoplasty, and two patients required C4–C7 laminoplasty. The mean operation time was 128.6 ± 38.1 min and the average intraoperative blood loss was 136.3 ± 120.9 ml. The unstable group consisted of 14 patients (all male), including 3 who died during follow-up; thus, data from only 11 patients are provided in **Table 1**. The average age was 65.5 ± 10.2 (range, 49–84) years. The average time from injury to surgery was 7.7 ± 5.3 (range, 3–22) days. The operative details, including segments treated, are provided in **Table 2**. The average operative time was 134.5 ± 21.6 min and the average blood loss was 154.5 ± 90.7 ml. Patient age, the interval from injury to surgery, the operative time, and the amount of intraoperative blood loss did not differ between groups (all $P > 0.05$). Pre- and postoperative radiographic data from a typical case (from the unstable group) are provided in **Figure 1**.

TABLE 1 Basic information of patients in the unstable group.

| Patient | Gender | Age (year) | Cause of injury | Unstable factors | Operations |
|---|---|---|---|---|---|
| 1 | M | 71 | Falling from standing | Rupture of the C4/5 disc and anterior longitudinal ligament. | C3–7 open-door laminoplasty combined with C4–5 bilateral lateral mass screws fixation and fusion. |
| 2 | M | 84 | Falling from standing | Rupture of the C5/6 disc. | C3–6 open-door laminoplasty combined with C4–5 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 3 | M | 72 | Falling from a height | Rupture of the C3/4 disc. | C3–7 open-door laminoplasty combined with C3–4 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 4 | M | 63 | Traffic | Rupture of the C3/4 disc and teardrop-like fracture at the anterior edge of C3 vertebral body. | C5–7 open-door laminoplasty, C3–4 laminectomy and bilateral lateral mass screws fixation and fusion. |
| 5 | M | 66 | Falling from a height | Rupture of the C4/5 disc and anterior longitudinal ligament. | C3–7 open-door laminoplasty combined with C4–5 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 6 | M | 49 | Falling from a height | Rupture of the C3/4 disc and anterior longitudinal ligament. | C3–7 open-door laminoplasty combined with C3–4 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 7 | M | 68 | Traffic | Rupture of the C3/4 disc and teardrop-like fracture at the anterior edge of C3 vertebral body. | C3–7 open-door laminoplasty combined with C3–4 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 8 | M | 54 | Traffic | Rupture of the C6/7 disc and anterior longitudinal ligament. | C3–7 open-door laminoplasty combined with C6–7 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 9 | M | 53 | Falling from standing | Rupture of the C4/5 and C5/6 discs. | C3–7 open-door laminoplasty combined with C4–6 unilateral (open side) lateral mass screws fixation and fusion. |
| 10 | M | 72 | Traffic | Rupture of the C4/5 disc and anterior longitudinal ligament. | C3–7 open-door laminoplasty combined with C4–5 unilateral (hinge side) lateral mass screws fixation and fusion. |
| 11 | M | 69 | Traffic | Rupture of the C4/5 disc and anterior longitudinal ligament. | C3–7 open-door laminoplasty combined with C4–5 unilateral (hinge side) lateral mass screws fixation and fusion. |

High-energy injuries (falls from heights and car accidents) accounted for 52.5% of injuries in the stable group and 72.7% of injuries in the unstable group ($P = 0.230$). In the stable group, 64.3% of cervical canal stenoses were developmental; 9.5% of these cases were combined with OPLL. OPLL alone was observed in 21.4% of cases and simple multilevel disc herniation was observed in 14.3% of cases in this group. In the unstable group, all cervical spinal canal stenoses were developmental, and 35.7% of them were combined with OPLL ($P = 0.03$). Intervertebral disc injuries and vertebral body avulsion fractures were located principally in the regions of stress concentration in patients with multisegmental OPLL or intervertebral joint stiffness; the proportion of such patients in the unstable group was 57.1%.

Neurological function improvements are shown in Tables 3, 4. ASIA scores reflected improvement at the final follow-up assessment in 52.5% of patients in the stable group (15 patients with grade-D and 4 patients with grade-A function did not improve). Six of seven grade-D central spinal cord syndrome cases in this group remained grade D at the end of follow-up, accounting for 40.0% of unimproved cases. In the unstable group, 45.5% of patients improved (three patients each with grade-D and grade-A function did not). Postoperative JOA scores reflected 19.1% ± 21.6% improvement in the stable group and 18.6% ± 18.4% improvement in the unstable group ($P > 0.05$). JOA scores from the final follow-up assessments reflected 49.2% ± 31.7% improvement in the stable group and 47.1% ± 39.2% improvement in the unstable group. Improvements reflected by JOA scores obtained at discharge and final follow-up did not differ between groups. JOA scores improved in patients with grade-B–D neurological function according to the ASIA impairment scale.

## Discussion

We found that 73.2% of patients with cervical spinal cord injuries but no significant fracture or dislocation had developmental spinal canal stenosis (anteroposterior spinal canal diameter < 13 mm). The relationship between such stenosis and cervical spinal cord injury has been of concern to researchers. In asymptomatic populations, the incidences of cervical spinal cord compression and signal change are related closely to developmental spinal canal stenosis (9). Morishita et al. (11) showed that the kinematic properties of the cervical spine in patients with such stenosis (diameter < 13 mm) explain secondary pathological changes. This type of stenosis is a risk factor for cervical spondylosis (12, 13), and it is associated with a higher incidence of cervical spinal cord injury after mild trauma because it reduces the functional reserve space for the spinal cord. Aarabi et al. (14) reported a cervical spinal canal stenosis rate of 37.4% in a sample of 211 patients with central spinal cord injury syndrome. Aebli (15) found that Pavlov ratios < 0.7 and anteroposterior spinal canal diameter < 8 mm were risk factors for cervical spinal cord injury after mild trauma.

TABLE 2 Comparison of demographic and surgical data between groups.

| | Stable Group ($N = 40$) | Unstable Group ($N = 11$) | *P*-Value |
|---|---|---|---|
| Sex | Male 34 (85%)<br>Female 6 (15%) | Male 11 (100%)<br>Female 0 (0%) | 0.171 |
| Age (yearr) | 59.1 ± 9.5 | 65.5 ± 10.2 | 0.078 |
| Cause of injury | Traffic 16 (40%)<br>Falling from a height 5 (12.5%)<br>Falling from standing 19 (47.5%) | Traffic 5 (45.4%)<br>Falling from a height 3 (27.3%)<br>Falling from standing 3 (27.3%) | 0.353 |
| Injury-surgery interval (days) | 10.1 ± 6.5 | 7.7 ± 5.3 | 0.229 |
| Duration of operation (min) | 128.6 ± 38.1 | 134.5 ± 21.6 | 0.510 |
| Intraoperative blood loss (mL) | 65.5 ± 10.2 | 154.5 ± 90.7 | 0.589 |

$P < 0.05$ was statistically significant.

The use of surgery to treat cervical spinal cord injuries with no significant fracture or dislocation remains controversial. Similar outcomes of nonoperative and operative treatments have been reported (1, 16). However,

TABLE 3 Comparison of the effect of surgical treatment between groups.

| | Stable Group ($N = 40$) | Unstable Group ($N = 11$) | *P*-Value |
|---|---|---|---|
| ASIA scale before surgery | A 4 (10%)<br>B 10 (25%)<br>C 8 (20%)<br>D 18 (45%)<br>E 0 (0%) | A 3 (27.3%)<br>B 1 (9.1%)<br>C 4 (36.4%)<br>D 3 (27.3%)<br>E 0 (0%) | 0.336 |
| ASIA scale at discharge | A 4 (10%)<br>B 9 (22.5%)<br>C 7 (17.5%)<br>D 20 (50%)<br>E 0 (0%) | A 3 (27.3%)<br>B 1 (9.1%)<br>C 2 (18.2%)<br>D 5 (45.4%)<br>E 0 (0%) | 0.580 |
| ASIA scale at the final follow-up | A 4 (10%)<br>B 0 (0%)<br>C 6 (15%)<br>D 27 (67.5%)<br>E 3 (7.5%) | A 3 (27.3%)<br>B 0 (0%)<br>C 1 (9.1%)<br>D 7 (63.6%)<br>E 0 (0%) | 0.244 |
| Improvement at discharge | 3/40 (7.5%) | 2/11 (18.2%) | 0.291 |
| Improvement at the final follow-up | 21/40 (52.5%) | 5/11 (45.4%) | 0.679 |
| JOA score before surgery | 5.2 ± 4.6 | 3.7 ± 4.1 | 0.324 |
| JOA score at discharge | 7.0 ± 5.9 | 5.9 ± 4.9 | 0.528 |
| JOA score at the final follow-up | 10.4 ± 5.4 | 9.5 ± 7.0 | 0.678 |
| JOA recovery rate at discharge (%) | 19.1 ± 21.6 | 18.6 ± 18.4 | 0.939 |
| JOA recovery rate at the final follow-up (%) | 49.2 ± 31.7 | 47.1 ± 39.2 | 0.869 |

$P < 0.05$ was statistically significant.

TABLE 4 Comparison of JOA score between pre-operation and post-operation.

| | Preoperative JOA score | Postoperative JOA score | *P*-value |
|---|---|---|---|
| Stable group ($N = 40$) | 5.2 ± 4.6 | At discharge 7.0 ± 5.9<br>At the final follow-up 10.4 ± 5.4 | <0.001<br><0.001 |
| Unstable group ($N = 11$) | 3.7 ± 4.1 | At discharge 5.9 ± 4.9<br>At the final follow-up 9.5 ± 7.0 | 0.018<br>0.005 |
| Total cases ($N = 51$) | 4.8 ± 4.0 | At discharge 6.7 ± 4.6<br>At the final follow-up 10.2 ± 5.7 | <0.001<br><0.001 |

$P < 0.05$ was statistically significant.

other studies have shown that spinal canal decompression yields better results for patients with stable cervical spinal cord injuries and spinal canal stenosis (3, 4). In a retrospective study, Gu et al. (2) found more improvement, according to JOA and SF-36 scores, among patients with cervical spinal cord injuries and OPLL who underwent laminoplasty ($n = 31$) than among those who underwent nonoperative treatment ($n = 29$ cases). The degree of improvement in the JOA score at the final follow-up was about 50%. The JOA scores of all patients with grade-B–D function improved, whereas those of patients with grade-A function did not; no patient evidenced neurological deterioration after surgery. A prospective study on this topic would be difficult to conduct because the conditions and pathogenic factors of patients with spinal cord injuries are complex. Further research is needed.

The optimal timing of surgery remains controversial. Fehlings et al. (17) found no significant difference in neurological function improvement between early (≤24 h after injury) and late (>24 h after injury) surgery groups. Another study showed that operation within 8 h after injury was better than operation 8–24 h after injury (6). Early surgery is usually defined as that performed within 24 or 72 h. In China, however, primary hospitals lack experienced surgeons and the required surgical equipment, and patients are referred to regional medical centers. Most patients included in this study were referred from local primary hospitals, and some had other serious injuries, such as traumatic brain injuries and chest trauma. Thus, the performance of all emergency operations within 8 or 24 h is difficult. In a retrospective sample of 595 patients from 6 hospitals in China, 212 patients underwent early (<72 h after injury) surgery and 383 patients underwent late (≥72 h after injury) surgery (5). ICU stays were longer but hospital stays were shorter in the early surgery group than in the late surgery group, and the rates of complications (pneumonia, wound infection, and sepsis) did not differ between groups. More importantly, neurological improvements did not differ significantly between groups, but the neurological deterioration and mortality rates were higher in the early surgery group than in the late surgery group. The authors concluded that the performance of surgery >72 h after injury was safer. We also found that surgeries performed at this interval were effective; we noted no postoperative neurological deterioration in these cases. When resources are available and the patient's condition permits, emergency surgery (performed within 8 h of injury) may aid functional recovery in patients with severely impaired neurological function (ASIA grade A). Some authors have recommended emergency surgery for patients exhibiting locking of the bilateral cervical facets with incomplete paralysis or worsening neurological function (6).

A semi-hybrid surgical technique involving laminoplasty and internal screw fixation has been used to treat degenerative cervical diseases, including cervical spondylosis with kyphosis (18, 19) and cervical spondylosis (or OPLL) combined with the presence of unstable segments (20, 21). However, few reports on the use of this technique to treat traumatic cervical spinal cord injuries have been published (22–24). The technique not only reduces the need for operation *via* the anterior approach, but avoids the posterior scar formation and risk of C5 nerve root palsy associated with laminectomy and internal fixation (22, 25). One report describes the treatment of cervical spinal cord injuries in six patients in Korea *via* single open-door laminoplasty combined with internal fixation with unilateral lateral mass screws; the clinical results were good (22). As kyphosis was present, the authors used long-segment lateral mass screw fixation (i.e., with an average of five screws) to correct the cervical deformities. Some surgeons have combined laminoplasty with pedicle screw fixation to treat cervical spinal canal stenosis accompanied by unstable fractures (23, 24). We found that cervical single open-door laminoplasty combined with short-segment lateral mass screw fixation enabled adequate stabilization of local segment instabilities caused by intervertebral disc damage or avulsion fracture, and that the neurological improvement rate did not differ significantly between the stable and unstable groups. We found that many unstable segments were located in regions of stress concentration, such as areas of discontinuous ossification in patients with multisegmental OPLL or intervertebral joint stiffness. Thus, areas of stress concentration constitute a risk factor for local instability after mild trauma.

The limitations of this study include the small sample and slight variation in hybrid techniques employed, specifically the side and number of lateral mass screw implantations, according to surgeons' preferences. More long-term or multicenter data are required. In addition, this study was retrospective and lacked a control group. The evidence does not yet reveal whether the type of operation or the injury-to-operation interval (> or <72 h) affects the neurological outcomes.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

## Ethics statement

The studies involving human participants were reviewed and approved by Human Research Ethics Committee of the Second Affiliated Hospital of Zhejiang University School of Medicine. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

HX: was responsible for writing the manuscript, extracting data, interpreting results and provided feedback on the report. These authors (ZY,HX) contributed equally to this work and should be considered co-first authors. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Ym Xi,
The Affiliated Hospital of Qingdao University, China
Cinthia Castro Do Nascimento

*CORRESPONDENCE
Yue-Hui Zhang
zyhandy8030@126.com
Jiang Shao
shaojiang@xinhuamed.com.cn

†These authors have contributed equally to this work

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# Cervical spine involvement in pediatric mucopolysaccharidosis patients: Clinical features, early diagnosis, and surgical management

Hai-Tao Liu†, Jia Song†, Fu-Chao Zhou, Zhi-Hui Liang, Qiu-Qi Zhang, Yue-Hui Zhang* and Jiang Shao*

Spine Center, Xin Hua Hospital, Affiliated to Shanghai Jiao Tong University School of Medicine, Shanghai, China

Mucopolysaccharidosis (MPS) is a progressive genetic disease that causes a deficiency in lysosomal enzymes, which play an important role in the degradation pathway of glycosaminoglycans. As a result of enzyme defects, mucopolysaccharides cannot be metabolized and thus accumulate. The cervical spine is one of the most commonly involved sites; thus, prompt surgical management before the onset of severe neurological deterioration is critical. However, because of the rarity of the disease, there is no standard treatment. In this review, we characterize the cervical spinal involvement in pediatric patients with MPS, describe the useful imaging technologies for diagnosis, and provide screening procedure for children with MPS. Surgical managements, including indications, surgical methods, possible difficulties, and solutions, are reviewed in detail.

KEYWORDS

mucopolysaccharidoses, cervical spine, surgical managements, occipitocervical fusion, atlantoaxial fusion

## Introduction

Mucopolysaccharidoses (MPSs) are a group of hereditary lysosomal storage diseases caused by a deficiency of an enzyme that plays an important role in the degradation pathway of glycosaminoglycans (GAGs). Except for Hunter syndrome (MPS type II), which has an X-linked recessive inheritance, all MPSs have autosomal recessive inheritance (1). The lack of enzymes leads to the storage of corresponding GAGs, which are considered to be the primary and direct cause of MPS (1). MPSs can be classified into seven types according to the type of the enzyme deficiency, and some of them can be further divided into subcategories (Table 1). In total, there are 12 different types and subtypes of MPSs, including the recently described mucopolysaccharidosis-plus syndrome (MPSPS). In MPSPS, heparan sulfate is stored, but there is no enzyme deficiency (2).

Abbreviation
MPS, mucopolysaccharidosis; CT, computed tomography; MRI, magnetic resonance imaging; CT, computed tomographic angiography; 3D, three-dimensional.

TABLE 1 Different types of MPS.

| Types | Deficient enzyme | Accumulated GAGs | Thoracolumbar kyphosis | Odontoid dysplasia |
|---|---|---|---|---|
| MPS I (Hurler syndrome) | α-L-iduronidase | DS, HS | + | + |
| MPS II* (Hunter syndrome) | Iduronate-2-sulfatase | DS, HS | + | + |
| MPS III (Sanfilippo syndrome) | Subtype A: Heparan-N-sulfatase<br>Subtype B: α-N-acetyglucosaminidase<br>Subtype C: α-glucosaminidase-acetyltransferase<br>Subtype D: N-acetylglucosamin-6-sulfatase | HS | | |
| MPS IV (Morquio syndrome) | Subtype A[a]: N-acetylglucosamin-6-sulfatase<br>Subtype B: β-galactosidase | Subtype A: KS, C6S<br>Subtype B: KS | + | + |
| MPS VI (Maroteaux-Lamy syndrome) | N-acetylgalactosamine-4-sulfatse | DS, C4S | + | + |
| MPS VII (Sly syndrome) | β-glucuronidase | DS, HS, C4S, C6S | + | |
| MPS IX (Natowicz syndrome) | Hyaluronidase I | H | | |
| MPSPS | Not found | HS | + | |

MPSPS, Mucopolysaccharidosis-plus syndrome; DS, dermatan sulfate; HS, heparan sulfate; KS, keratan sulfate; C6S, chondroitin-6-sulfate; C4S, chondroitin-4-sulfate; H, Hyaluronan.
[a]Main type of MPS that influences the cervical spine.

GAGs accumulating in the cells affect cellular processes such as cell adhesion and signaling, causing multiorgan and severe symptoms such as coarse facial features, cognitive retardation, hepatosplenomegaly, hernias, kyphoscoliosis, and corneal clouding (1). Skeletal involvements are the most common manifestations and have been reported in all subtypes of MPS except in MPS type IX. Most MPS types, especially types I and IV, have cervical spine involvement, presenting as an absence of the odontoid process, atlantoaxial dislocation, spinal canal stenosis and compression, and others. In the study of Remondino et al. (3), 43 of 52 patients with MPS had cervical diseases, and odontoid hypoplasia, along with subsequent atlantoaxial instability, was frequently observed in those patients. If it is not addressed, it will develop into myelopathy, which can be life-threatening (4).

Early diagnosis allows early intervention, thus improving the chances of a better outcome. At present, the diagnosis of MPS is relatively mature, including blood and urinary GAG tests, enzyme assays, and genetic tests (1). The development of imaging technology is of great importance in the diagnosis and preoperative evaluation of cervical involvement. Furthermore, close collaboration between clinicians and radiologists is essential (5). However, for those young patients, how to conduct screening and evaluation is still a problem to be solved.

Treatment of the etiology and the corresponding symptoms of MPS in the spine should be comprehensive, involving multiple disciplines. Etiological treatment mainly refers to the disease-specific treatment of MPS, including enzyme replacement therapy and hematopoietic stem cell transplantation, as well as new approaches, such as gene therapy, substrate reduction therapy, chaperone therapy, and combinations of these strategies. However, as MPS is a progressive disease and the lifespan of patients with MPS has increased with improvements in the medical treatment of MPS (6), and considering that the existing strategies cannot correct the pathological damage that has occurred, especially for bone damage, surgical intervention before the onset of serious consequences has become a last-resort, albeit a very effective, strategy.

Generally, the biggest threat to children with MPS may be damage to the heart and respiratory system. However, with the development of diagnostic and treatment technologies, MPS can be diagnosed and treated effectively at an early stage, which means that cardiopulmonary damage can be effectively controlled and the life expectancy can be prolonged. As existing treatments for bones and cognitive damage have limited effectiveness and cannot effectively prevent the progress of bone damage, and coupled with the prevalence of cervical involvement, early diagnosis of cervical involvement and prompt surgical intervention have become more important.

To improve outcomes in patients with MPS, this review characterizes the cervical spinal involvement and related factors, briefly describes the imaging tools for early diagnosis, provides a screening procedure for children with MPS, and discusses the possible surgical interventions for pediatric patients with MPS with cervical involvements.

## Spinal involvements of MPS

Skeletal manifestations have been reported in all subtypes of MPS except in MPS type IX, and spinal manifestations are particularly common in the spectrum of skeletal disease in these patients (4). The degree of severity varies among different subtypes, which may be related to both the type and quantity of the accumulated GAG fragments. Even if they are of the same type, the severity also varies, which is considered to be the result of differences in the exact mutation site among patients (4).

Spinal cord compression in the cranial segment caused by MPS is the most important condition and usually needs surgical intervention. This condition can directly cause neurological damage, which may present as cervical pain, unsteady gait, frequent falls, progressive impairment of autonomous ambulation, and/or acute tetraplegia after even minor trauma (7). The main direct causes of spinal cord compression include atlantoaxial subluxation, thickening of the dura, and hypertrophy of the ligamentum flavum.

Atlantoaxial subluxation is often the direct cause of cervical spinal cord compression, which can occur anteriorly, posteriorly, vertically, laterally, or in combinations (5). A pincer-like effect is caused by atlantoaxial subluxation between the posterior arch of the atlas and the axis, indenting the dorsal aspect of the spinal cord and causing further compression of the cord (5). For patients with MPS, the absence of the odontoid process is common and may be one of the main causes of atlantoaxial joint instability. Cervical spinal cord compression without dens hypoplasia is unusual, and only one such case has been reported (8). An unstable atlantoaxial joint further develops into atlantoaxial subluxation, which leads to spinal cord compression. Combined with relaxed ligaments, which is also common in patients with MPS, the risk of atlantoaxial subluxation greatly increases (4). This unstable situation poses a hidden, yet grave, danger and requires surgical intervention as soon as possible.

In addition, the thickened dura and hypertrophied ligamentum flavum are also important causes of compression of the spinal cord, which may be the result of the accumulation of GAGs. Different from C1-C2 instability, there is no ideal surgical method to address the problem of dura hypertrophy owing to its diffuse nature and important role in accommodating cerebrospinal fluid (CSF) (4).

## Imaging techniques for early diagnosis

Skeletal and spinal manifestations are important clinical manifestations of MPS and may even be the first sign of MPS; for example, kyphosis is often the first sign of MPS type IV in early childhood despite a healthy appearance at birth (1, 9). Therefore, radiographic findings are essential for the diagnosis of MPS, especially for spinal diseases. Atlantoaxial dislocation and kyphosis are the most common spinal manifestations in MPS, which can be detected on roentgenography and three-dimensional computed tomography (3D CT) reconstruction. The presence of characteristic vertebral anomalies, such as a "beaked" vertebral body, provide clues for diagnosing MPS (9). Lateral plain-film flexion-extension studies are typically used to detect atlantoaxial instability, subluxation, and dislocation (5, 10), but their usefulness is limited in some patients with basilar invagination or enlarged mastoid processes, as the C1-C2 level is not clearly visible.

Magnetic resonance imaging (MRI) can visualize the spinal cord and spinal canal; thus, it is the most useful technology for determining whether there is a compression of the spinal cord and for monitoring nervous complication of MPS spinal involvement, which, in turn, helps us determine whether surgical intervention is needed (5). Spinal stenosis with loss of CSF flow on MRI suggests spinal cord compression. It is worth noting that the nervous deficit is not as severe as that suggested by imaging; thus, comprehensive consideration is needed to make an accurate judgment (**Figure 1**).

The development of imaging technology has greatly helped in the diagnosis, but some problems remain. Although CT can clearly show the bony structure, it involves exposure to a large dose of radiation; thus, it should be carried out cautiously in young children. Meanwhile, most young patients find it difficult to tolerate the long examination time and loud noise during MRI examination. The usual practice is to sedate the child, but sedatives have substantial risks that cannot be ignored. To reduce the risk for young patients, we should try to minimize examination times. Anesthetization should be carried out by experienced anesthesiologists.

Owing to the severity and inevitability of cervical spinal cord involvement in patients with MPS, we believe that the following screening procedures are necessary for children with MPS with or without obvious related clinical manifestations, as some patients with MPS (especially type IV) may appear healthy at birth and spinal abnormalities only appear in early childhood (**Figure 2**). First, cervical anterior, lateral, and dynamic lateral flexion-extension radiographs should be performed routinely to detect cervical deformity and joint instability in the early stage. In view of the potential damage of CT and MRI to young patients, if a child has no positive radiographic findings or related symptoms and a negative neurological examination, further radiological examination is not necessary for the time being, but regular follow-up is needed. If there are positive findings, related clinical symptoms, or neurological signs, furtherMRI examinations are recommended to accurately determine the existence and severity of spinal canal stenosis, and spinal cord compression and to determine whether there are surgical indications. As MRI, including active dynamic flexion and extension scans, is the most useful technique to detect spinal cord compression, it was recommended to be carried out every year (11). CT was suggested to be reserved for children who was considered

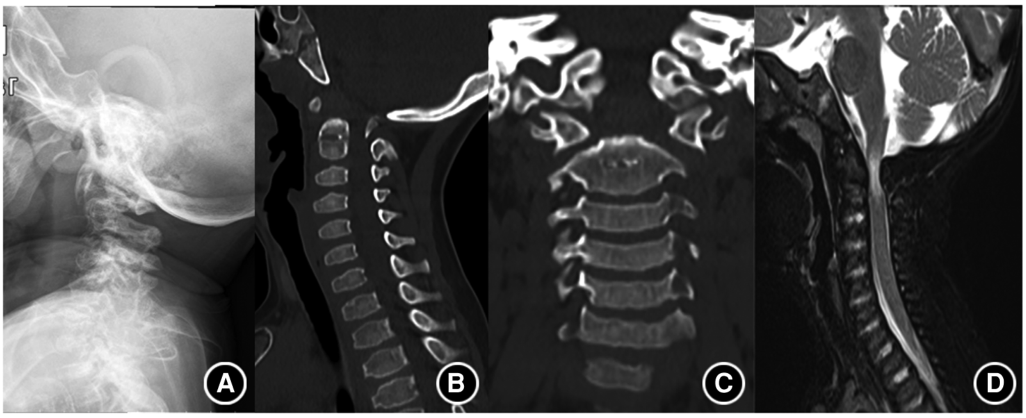


FIGURE 1
Typical imaging findings of MPS. (A) Shows atlantoaxial dislocation on roentgenography. (B,C) Shows the absence of odontoid process. (D) Shows the compression of the spinal cord.

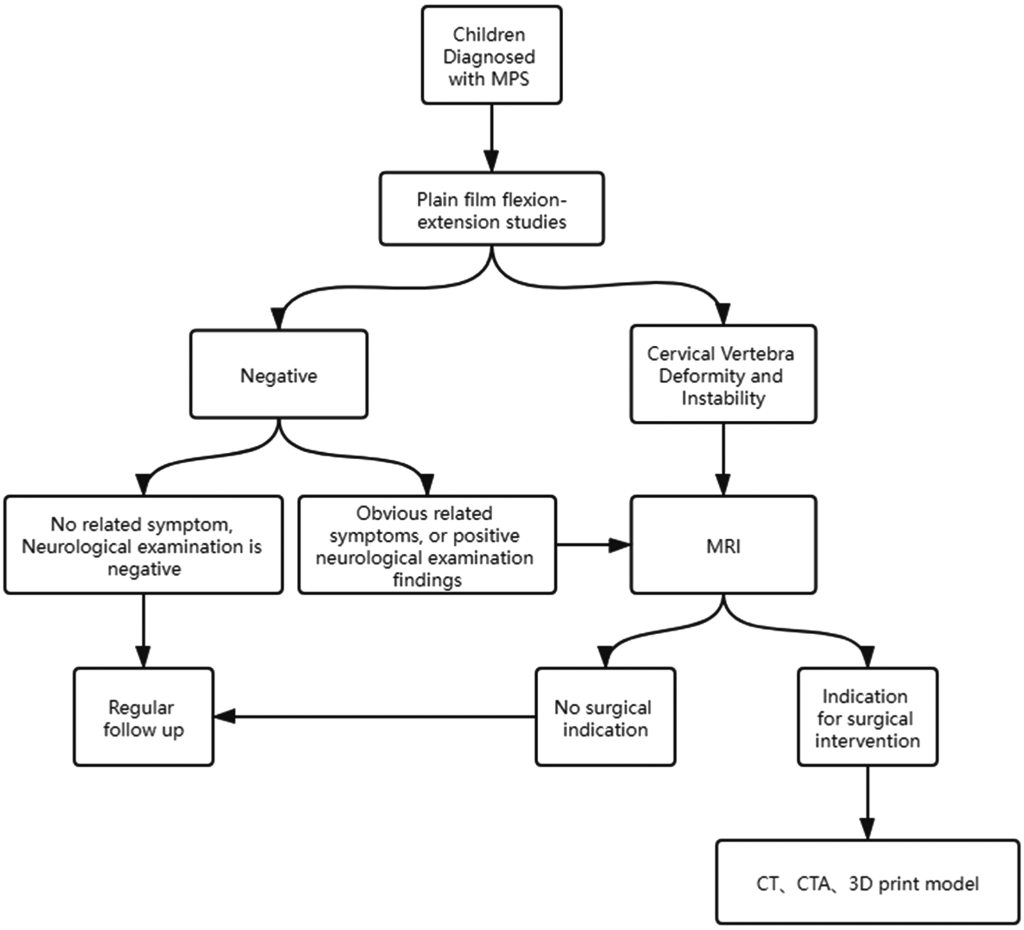


FIGURE 2
Screening procedure for children diagnosed with MPS.

for surgical procedure (7, 11). If there are surgical indications, CT angiography is also recommended before the operation plan is made to determine the location of blood vessels at the surgical site, which is especially important for patients with developmental malformations. We believe that this screening procedures is helpful for the early diagnosis of cervical lesions in children with MPS, and can provide some reference for spinal surgeons.

## Management of spinal involvements

Because of the low incidence of MPS, no unified consensus on surgical indications exists, and applicable literature is scarce (related studies are summarized in **Table 2**). Although some studies believe that surgical interventions do not halt neurological progression in most preoperatively clinically symptomatic patients, surgical intervention at an early age is still advocated because early intervention before clinical symptoms is of vital importance for long-term neurological preservation (10). With the development of imaging technologies, attempts on a more nuanced approach rely on a combination of clinical examination and radiology, particularly on MRI (5, 11). Unfortunately, there seem to be no convincing research results so far. Based on our analysis and summary of existing literature, combined with our clinical experience, we recommend the following indications for surgical intervention: increasing cervical cord compression in MRI, with or without notable myelopathy; evidence of instability on cervical dynamic lateral flexion and extension radiography; progressive clinical neurological signs with seemingly non-progressive radiological changes (10). For children with definite absence of odontoid process, surgical intervention should also be carried out promptly, because this condition has the potential danger of atlantoaxial dislocation and further nerve damage.

The biggest threat to children with MPS may be damage to the heart and respiratory system, which also means great risk of anesthesia. Therefore, adequate preoperative preparation, strict intraoperative monitoring, and postoperative management are very important. Multidisciplinary consultations should be conducted before operation, including anesthesiology, intensive care medicine, pediatric cardiovascular medicine, pediatric respiratory medicine, metabolic and genetic diseases, and spinal surgeons. The assessment of cardiopulmonary function and risk of anesthesia are particularly important. The intensive care unit should be fully prepared before the operation. At the same time, electrophysiological detection equipment should be prepared for intraoperative monitoring, and 3D printed models should be prepared to facilitate surgeons' accurate understanding of complex structures during operation. Fine-cut 3D reconstructed preoperative studies should be carried out to make the most suitable choice among the different surgical options (7). Anesthesia should be performed by an experienced anesthesiologist, and fiberoptic intubation may be useful, considering the GAG-induced tracheal deformities. A right atrial central venous catheter is placed sometimes, as the risk of dangerous cardiac events is increased in patients with MPS (12). Intensive care should be obligatory, owing to the increased risk of pulmonary insufficiency (12).

In view of the rarity of the disease, the choice of surgery is also controversial. A study published in 2017 advocated that, for patients without craniocervical instability, stand-alone craniocervical decompression is feasible and osteosynthesis is not necessary (12). Decompression surgery without prophylactic osteosynthesis reduces procedure time, iatrogenic trauma, and hospital time. The overall mortality in their case series is lower than that in the applicable literature, but their rate of respiratory-related complication is higher (5). In the study of Krenzlin et al. (12), although the first stand-alone decompression surgery yielded good postoperative results, the reoperation rate was high (60% in type I, 40% in type IVA, and 50% in type VI).

Clinically relevant restenosis, which was believed to be caused by underlying MPS, was the main reason for readmission and re-surgery. GAG deposits in connective tissues and dura mater result in increased rigidity, counteracting the anatomical misalignment and anticipated hypermobility. This balance is the basis for stand-alone craniocervical decompression, but with the development of medical treatment in recent years, the medical treatment for the etiology of MPS can be carried out synchronously with the operation at an early age, the deposition of GAG is slowed down, and the structural damage caused by the surgery cannot be compensated quickly, which leads to increased potential risk of instability. Giussani et al. (7) believed that removal of the posterior ring of C1, hypertrophied ligamentum flavum, and occipitoatlantal membrane in posterior decompression surgery inevitably aggravates craniovertebral junction instability and may expose patients to acute post-traumatic myelopathy after even a minor trauma in flexion. Besides, in the study of stand-alone surgery, the average age of those 15 patients was approximately 15 years (i.e., they were old enough for reoperation). However, with the development of diagnostic technology, these patients are being diagnosed at a younger age (i.e., at ∼1 or 2 years), during which surgery is difficult and reoperation seems impossible. Therefore, it is important to perform early internal fixation to stabilize the spine and minimize the possibility of re-surgery.

Occipitocervical fusion is the most commonly used surgical strategy, because it is believed to be difficult to establish satisfactory stability in patients with ligamentous laxity if only C1-C2 fusion is performed (9, 13–15). Besides, as surgical intervention is recommended at an early age in such cases,

TABLE 2 Summary of related researches on surgical treatment of MPS.

| Author & Year | Number of patients | Mean age | MPS type (Type, N) | Surgical Type (extent) | Fixation | Graft | Complications | Follow-up Time and Result |
|---|---|---|---|---|---|---|---|---|
| Marco Crostelli, et al, 2019 (9) | 1 | 4Y6M | I | Posterior occiput-cervical decompression and occipital cervical stabilization (C0-C1) | Rods, occipital screws, and cervical hooks | NR | Soft tissues swelling by protruding instrumentation | 6M: Regained partial use of upper extremities<br>11Y: Complete fusion, with instrumentation completely embedded in fusion mass; full stable neurologic status |
| odrigo G. Remondino, et al, 2019 (3) | 21 | 8Y | I, II, III, IV, V | Cervical decompression without instrumented fusion[a] ($n = 7$)<br>Cervical decompression with instrumented fusion ($n = 6$)<br>Instrumented fusion (C1-C2, $n = 6$)<br>Laminectomies without instrumented fusion ($n = 3$) | Microplate and fiber wire ($n = 2$); Robs, screws and hooks (details NR) | Mixture of local and autologous bone graft | Proximal junctional kyphosis ($n = 6$)<br>Cervical pseudarthrosis ($n = 5$)<br>Neurologic impairment that lead to revision surgery ($n = 6$)<br>Wound infection ($n = 4$) | 4M:<br>Neurologic improvement ($n = 6$)<br>Unchanged neurologic status ($n = 9$)<br>Deterioration of neurologic status ($n = 6$) |
| Harald Krenzlin, et al, 2017 (12) | 15 | 14.9 ± 8.2Y | I ($n = 5$)<br>IVA ($n = 5$)<br>VI ($n = 5$) | Stand-alone decompression | / | / | Restenosis ($n = 7$)<br>Re-opreation ($n = 9$)<br>Rate of respiratory-related complication 13.4% | 6 ± 5 Y: No patient developed signs of C0-C1-C2 instability or progressive myelopathy. |
| A.Broomfield, et al, 2018 (10) | 26 | 6.1 Y (1.45 to 15.24) | IVA | Posterior occipito-cervical fixation and fusion using both instrumentation and bone graft, 7 cases require decompression | Wire fixation | Autologous bone graft from alvarial donor site | Reoperation ($n = 7$):<br>Failure of graft fusion at initial operation with subsequent clinical neurological progression ($n = 2$)<br>Radiological signs of worsening stenosis ($n = 2$);<br>Head fixation-pin-related complications ($n = 3$) | 84M (7 to 191):<br>Of the 14 preoperatively clinically asymptomatic patients: Neurologically stable ($n = 14$)<br>Of the 10 preoperatively clinically symptomatic patients:<br>Initially improved ($n = 2$)<br>Neurological deterioration in perioperative period ($n = 2$);<br>Improved post operation ($n = 1$);<br>Improved and then declined further ($n = 1$);<br>Remained stable ($n = 1$)<br>Continued to deteriorate ($n = 5$) |
| Michael C. Ain, et al, 2006 (38) | 7 | 12Y (3 to 46) | IVA | Cervical arthrodesis<br>C1-2 ($n = 4$)<br>C0-4 ($n = 1$)<br>C1-4 ($n = 1$)<br>C0-2 ($n = 1$) | Wire fixation; robs; screws; (details NR) | Iliac crest | None | 5.2M<br>Osseous union:7<br>Neurologic improvement: 4<br>Unresolved neurologic manifestation:1<br>Normal neurologic function:2 |
| John K. Houten, et al, 2011 (37) | 1 | 17Y | IVA | Posterior fusion (C0-C4) | Instrumentation with screw fixation in the occiput, C3 and C4 lateral masses and C2 pars | Allograft ribs wrapped with bmp-2 sponges | None | The patient's gait and hand strength improved, and she remains neurologically stable at the 5-year follow-up. A CT scan 10 months following surgery documented maintenance of anatomic alignment and a solid fusion. |

(*continued*)

TABLE 2 Continued

| Author & Year | Number of patients | Mean age | MPS type (Type, N) | Surgical Type (extent) | Fixation | Graft | Complications | Follow-up Time and Result |
|---|---|---|---|---|---|---|---|---|
| Klane K. White, et al, 2009 (36) | 1 | 5Y | IVA | Posterior decompression of C1 and fusion from the occiput to C2 (C0-C2) | Wire fixation | Gallie bone graft | None | 26 Y: He slowly regained full neurological function and walking ability. Radiographic examination demonstrated propagation of the fusion down to C3 at the time of the most recent follow-up. |
| Petr Vanek, et al, 2015 (39) | 4 | 12Y (10 to 14) | IVA | Decompression and instrumented fusion (C0–C2) | 2 occiput rods; 1 occipital plate; 2 C2 bilateral laminar screws | A mixture of local bone together with bone graft substitute | None | 2Y: Neurologically stable; The control CT scan revealed a stable position of the treated segments, but solid bony fusion was not registered in any patient. |
| EunJi Moon, et al, 2020 (14) | 1 | 3Y | IVA | Atlantoaxial fixation with C1 and C2 pedicle screw insertion and decompression (C1-C2) | Pedicle screw at the left C2 vertebra; translaminar screw at the right C2 lamina; C1 pedicle screw; rod connection | Local bone chips harvested from the C2 spinous process into both facet joint spaces | None | 8M: Postoperative stable C1-C2 fixation. Able to stand up and walk with minimal assistance in a short time;<br>8 months postoperatively, the patient's quadriparesis was improved to nearly grade V, with the ability to walk dependently. Also, the cervical devices and subaxial alignment were stable. |

NR indicates not reported; Values are *n*.
[a]Halo vests were used only to protect the spinal fusion in those cases with non-instrumented fusions and a better fusion rate with instrumented fusion was found.

the small size of these young patients is the main challenge for spinal surgeons when establishing stability *via* C1-C2 fusion alone because there is no dedicated cervical pediatric instrumentation available and even the smallest one for an adult is too big compared with the smaller vertebral dimensions. This makes it more difficult to put the screws into the correct position, especially for those with developmental deformity of the cervical vertebra (9, 14). However, in our center, we still prefer C1-C2 fusion because we try to preserve the child's cervical spine flexion-extension capacity as much as possible. Reducing unnecessary disabilities are of great importance in improving the children's quality of life and integrating them into society. Besides, C1-C2 fusion can also make the surgery possible for patients who cannot afford expensive treatments. Based on our experience and study of the literature, C1-C2 fusion is feasible and appropriate even for young children, especially with the help of new technologies such as 3D printing and intraoperative 3D image-based navigation system. Our center has successfully performed several cases of C1-C2 fusion operations for children with MPS type IVA, and all of them have achieved satisfactory prognosis. The youngest patient was only 2 years old, and the clinical symptoms associated with cervical spinal cord compression improved remarkably after the operation; however, other problems occurred in the thoracolumbar segment a few months later.

Posterior cervical C1-C2 fusion is an important, yet difficult and risky, procedure in spinal surgery, and effective internal fixation techniques reduce the risk of the operation and improve the fusion rate. In 1910, Mixter and Osgood (16) first reported the technique of C1-C2 stabilization by tying the odontoid with silk to treat a chronic non-healing odontoid fracture. Although the silk was replaced by wires and various modifications to the technique have been made in subsequent years, the disadvantages of the sublaminar wire technology are obvious: first, the spinal cord can be easily be injured during the passing of two separate sublaminar wires under both C1 and C2 laminae (17); second, the fixation offers poor rotational stability; and third, the early micro-movement reduces the fusion rate. Besides, the C1 posterior arch and C2 lamina/spinous processes should be intact (17). The use of interlaminar clamps and transarticular screw fixation of C1-C2 were first introduced in 1975 and 1979, which improved biomechanical stability and fusion rate (18–21). Goel and Laheri (22) used C1 lateral mass–C2 pars screw construct connected by posterior cervical plates to achieve posterior fixation, and Harms and Melcher (23) then modified the Goel technique. They used C1 lateral mass screws and C2 pedicle screws connected by rods to achieve rigid fixation, which provided great stability and fixation rate and reduced injury to the nerve root and vertebral artery. The Harms technique has been widely accepted by spine surgeons worldwide and is considered the gold standard (24, 25). For patients with MPS, the rate of structural variation of the cervical vertebrae is very high, and the standard Harms technique may not be achieved; thus, some alternatives are needed. The C1 "pedicle" screw fixation technique provides higher pull-out strength and avoidance of the neurovascular elements, but the risk of injury to the vertebral artery is higher than that of C1 lateral mass screws, and fracture may occur in the posterior arch. The C1 posterior arch crossing screw technique can be used as an alternative for failed conventional atlantoaxial screw placement or failed screw placement. C2 intralaminar screw fixation provided a salvage technique in cases of failed C2 pedicle screw placement or instances of high-riding vertebral artery (26, 27). Because of considerable anatomic variability, none of the previously described techniques allow absolute safety, and there are some hybrid constructs of those techniques to address complex clinical situations (17).

Cervical pedicle screws (CPSs) and rods offer greater stability than other techniques, but the risk of serious complications, such as injury to the vertebral artery, spinal cord, and nerve roots, remains. Computer-assisted surgery serves as an effective tool in improving accuracy. Preoperative and postoperative CT data do not match because they were obtained at different positions. Intraoperative 3D image-based navigation can reduce the discrepancy and facilitate safe and accurate insertion (28–32). The O-arm is an intraoperation image system that allows high-definition 3D navigation and thus facilitates a more accurate, convenient, and quick insertion of the screws. The O-arm-based navigation can reduce CPS malposition but cannot completely prevent it. As the position of the cervical structure can easily change, especially in young patients whose cervical structure is very small, the discrepancy of alignment between 3D image and CPS insertion reduces the accuracy. In our practice, we use the O-arm-based navigation system to determine insertion points and explore insertion paths using a micro-grinding drill. According to our practice, 3D printing may make this difficult and dangerous operation easier and safer, especially for patients with severe deformities that make placement of screws difficult.

With the in-depth understanding of MPS, advances in related monitoring tools, and progress in anesthetic techniques, the surgery for MPS has become safer than ever; thus, we advocate early decompression, posterior fixation and fusion of C1-C2 with CPS, and bone graft for children with MPS. Based on the experience of our center, we believe this is the most beneficial surgical management patients with MPS with for cervical involvement. (Typical case is presented in **Figure 3**).

Two main types of bone grafts are available for fusion: autogenous and allogenous. Allograft technologies were most commonly used to eliminate donor-site morbidity and complications related to autogenous bone graft. A study in

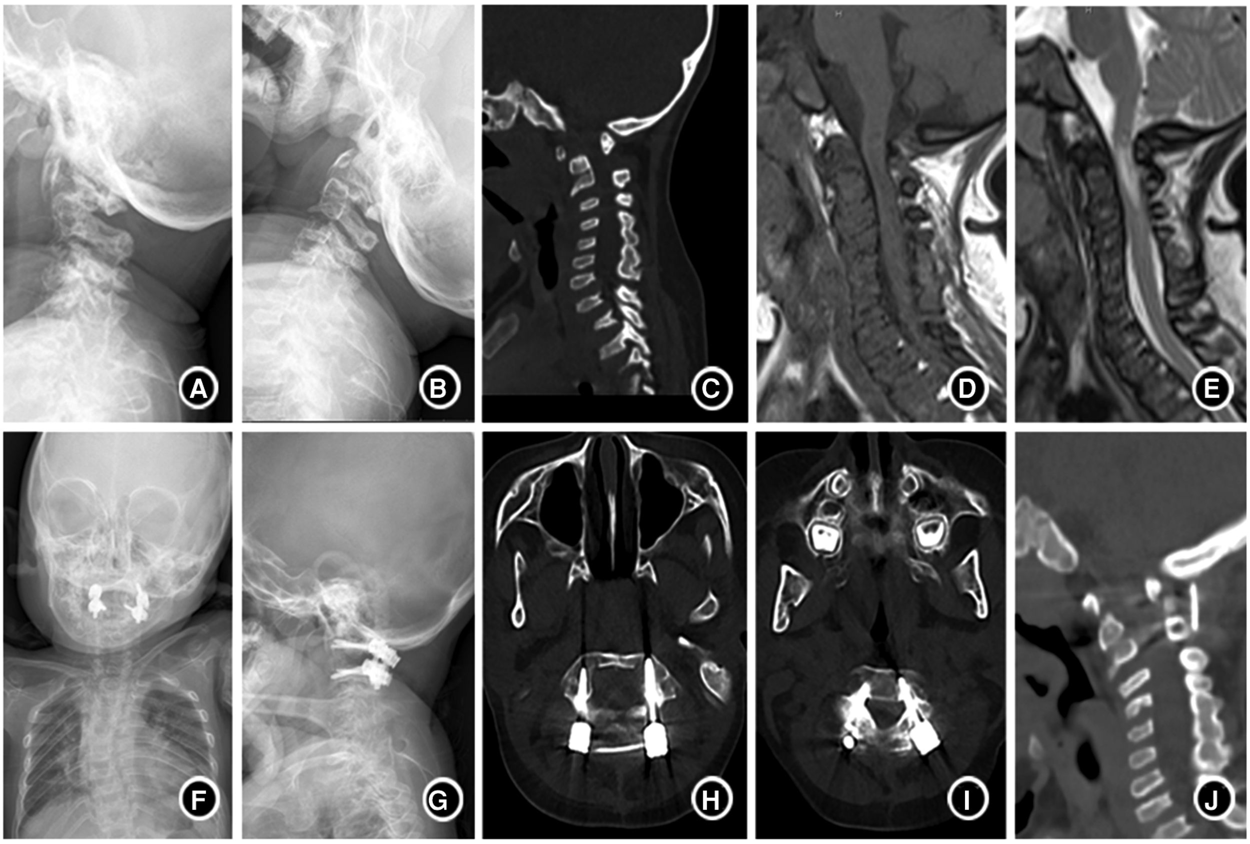


FIGURE 3
A 4-year-old boy with type IVA mucopolysaccharide disease (A,B). Lateral plain-film flexion-extension studies before the surgery showed uneven cervical bone density, flattened vertebra, atlantoaxial instability. (C) CT suggested atlantoaxial subluxation and odontoid process absence; (D,E) MRI indicated spinal canal stenosis, high cervical spinal cord compression and edema; (F,G) showed that the anatomical position of atlantoaxial returned to normal half a year after operation. (H–J). CT showed that the screw position was good, and the bone graft was fused with the atlantoaxial vertebra 6 months after operation.

2017 compared structural allograft and autograft for instrumented atlantoaxial fusions in a series of 32 pediatric patients (33). In this study, the outcomes and fusion rates were similar regardless of whether an autograft or allograft was used; fusion time was increased when using allograft technologies, but blood loss was decreased and donor-site morbidity was avoided. However, as more clinical cases were studied and further long-term follow-up were conducted, fusion failure when using allograft has been observed. As reoperation of pediatric patients with failed fusion can be challenging, we believe that autograft should be the first priority to increase the success rate as much as possible. Available autograft bones include the iliac crest, ribs, and external plate of the skull. The anatomical features of the skull make it a good site for harvesting autogenous bones, which reduces injury to other sites. For C1-C2 fusion, the external plate of the skull should be the first choice. However, the skull plate cannot be used when occipitocervical fusion is needed, as the skull cannot be nailed without the outer plate. In a young child, the iliac crest is very thin and cartilage-based, which limits its application, and harvesting of the ribs can do a lot of damage.

In addition, osteoporosis is a common condition in patients with MPS. The term “dysostosis multiplex” is used to describe the abnormalities of MPS diseases. Osteoporosis has also been described in animal models of MPS. GAGs accumulate in all cells related to bone formation and remodeling in animal models of MPS, interfering with the normal formation of mineralized cartilage septa, which is required for osteoblasts and osteoclasts in the formation of new bones. Besides, the risk of poor bone mineralization of patients with MPS increases with malnutrition and reduction of physical activities caused by pain or exercise intolerance (34, 35). The pathophysiological basis of osteoporosis in patients with MPS is not completely understood. Considering the possibility of osteoporosis and the smaller bone structure of young patients with MPS, external fixation with brace for 3 to 6 months is needed to reduce internal fixation failure and thus avoid reoperation. Anti-osteoporosis therapy may be effective for postoperative recovery.

## Conclusions

The compression of the cervical spinal cord due to various reasons is the main life-threatening factor in children with MPS. Advances in imaging technology, especially MRI, enable us to detect abnormalities of the spine and spinal cord as soon as possible and perform surgical intervention before neurological deterioration and loss of function. Although the number of cases is limited, decompression, autogenous bone fusion, and internal fixation with screws seem to be the best treatment options for children with MPS at present. With the help of various preoperative high-resolution reconstruction techniques, intraoperative 3D image-based navigation system, and 3D printing technology, C1-C2 fixation is feasible and safe in most cases, which preserves the flexion-extension capacity of the cervical spine as much as possible. In view of the high incidence of spinal diseases in children with MPS, we recommend that once MPS is diagnosed, relevant tests should be carried out as soon as possible to rule out cervical vertebra–related diseases.

## Author contributions

H-TL, Y-HZ, and F-CZ contributed to conception and design of the study. Z-HL organized the database. F-CZ performed the statistical analysis. H-TL and Q-QZ wrote the first draft of the manuscript. Y-HZ, Z-HL, JS, and JS wrote sections of the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Zhao Qinghua,
Shanghai General Hospital, China
Songyang Liu,
Aerospace Center Hospital, China

*CORRESPONDENCE
Yongming Xi
xym700118@163.com

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# The clinical validity of atlantoaxial joint inclination angle and reduction index for atlantoaxial dislocation

Yang Qu, Yukun Du, Yonghua Zhao, Jianyi Li, Hao Luo, Jiaxiang Zhou and Yongming Xi*

Department of Spinal Surgery, The Affiliated Hospital of Qingdao University, Qingdao, China

**Objective:** Atlantoaxial dislocation patients with neurological defects require surgery. Sometimes, release surgery is necessary for irreducible atlantoaxial dislocation to further achieve reduction. Whether release surgery is essential relies on the surgeon's experience and lacks objective reference criteria. To evaluate the value of atlantoaxial joint inclination angle (AAJI) in sagittal and coronal planes and reduction index (RI) in the surgical approach selection for atlantoaxial dislocation.
**Methods:** Retrospectively analyzed 87 cases (42 males and 45 females, 9–89 years) of atlantoaxial dislocation from January 2011 to November 2020. In addition, 40 individuals without atlantoaxial dislocation were selected as the control group. Imaging parameters were compared between the two groups. According to surgical methods, the experiment group was divided into two groups including Group A(release surgery group) and Group B (conventional operation group). The parameters were measured based on CT and x-ray. The relevant imaging parameters and clinical scores, including the AAJI in sagittal and coronal planes, the atlas-dens interval (ADI) before and after traction, the RI, and JOA scores were measured and analyzed.
**Results:** The sagittal and coronal atlantoaxial joint inclination angles(SAAJI and CAAJI) in the control group were 7.91 ± 0.42(L), 7.99 ± 0.39°(R), 12.92 ± 0.41°(L), 12.97 ± 0.37°(R), in A were 28.94 ± 1.46°(L), 28.57 ± 1.55°(R), 27.41 ± 1.29°(L), 27.84 ± 1.55°(R), and in B were 16.16 ± 0.95°(L), 16.80 ± 1.00°(R), 24.60 ± 0.84°(L), 24.92 ± 0.93°(R) respectively. Statistical analysis showed that there was a statistical difference in the SAAJI between the control group and the experiment group ($P < 0.01$), as well as between groups A and B ($P < 0.01$). The RI in groups A and B was 27.78 ± 1.46% and 48.60 ± 1.22% respectively, and there was also a significant difference between the two groups ($P < 0.01$). There was negative correlation between SAAJI and RI.
**Conclusions:** The SAAJI and RI can be used as objective imaging indexes to evaluate the reducibility of atlantoaxial dislocation. And these parameters could further guide the selection of surgery methods. When the RI is smaller than 48.60% and SAAJI is bigger than 28.94°, anterior release may be required.

KEYWORDS
reduction index, atlantoaxial joint angle, atlas-dens interval, operation approach, atlantoaxial dislocation

Abbreviations
AAD, atlantoaxial dislocation; IAAD, irreducible atlantoaxial dislocation; CT, computed tomography; JOA, Japanese Orthopaedic Association; AAJI, atlantoaxial joint inclination angle; SAAJI, sagittal atlantoaxial joint inclination angle; CAAJI, coronal atlantoaxial joint inclination angle; RI, reduction index; ADI, atlas-dens interval.

## Introduction

Atlantoaxial dislocation(AAD) refers to the stability loss of the atlantoaxial joint, resulting in the abnormal atlantoaxial structure (1). AAD can be caused by various reasons, including inflammation, tumor, trauma, odontoid fracture, congenital developmental deformity, and rupture of the transverse ligament. It can lead to neurological symptoms and paralysis. AAD could be divided into three types in clinical: traction reduction type, operation reduction type and irreducible type. Irreducible atlantoaxial dislocation (IAAD) is one of the types of AAD, which is difficult to reduction due to various factors, including fibrous scars, osteophyte formation, and even bony barrier. Traditionally, the diagnosis of IAAD can be made by observing the dynamic position x-ray to judge the difficulty of reduction under the dynamic position. But different opinions have been raised by some surgeons. Wang C et al. indicated that IAAD was considered if large weight (1/6 bodyweight) cranial traction after anesthesia was not able to achieve the reduction while the preoperative CT showed the absence of C1–2 lateral mass joint fusion (2). Salunke et al. believed that traction should start at 7% of body weight and gradually increase traction weight to 20% of maximum bodyweight within 48–72 h (3). It was generally believed that preoperative cranial traction was necessary for the diagnosis of IAAD.

In the treatment of AAD, decompression and maintaining regional stability of the cervical spine are the basic requirements of the operation. For some IAAD patients, posterior reduction and fixation cannot achieve complete reduction, and release sugery is necessary. The routine surgical procedures for atlantoaxial dislocation are as follows: (1) Anterior release and posterior fixation; (2) posterior reduction and fusion; (3) posterior release and fixation (4–6). At present, the management of release surgery is mainly based on the surgeon's clinical experience, lacking objective imaging reference standards (7). But there was controversial about conduction of release surgery for IAAD, which increases the blindness of treatment choice of AAD (8, 9). It has been found in clinical practice that many factors affect the reduction of AAD. Salunke et al. proposed that the angle of the atlantoaxial joint surface is of great significance in evaluating the difficulty of AAD in the sagittal plane. Based on our experience, we found that there is the correlation between atlantoaxial joint inclination angle (AAJI) and AAD. It is considered that the greater the angle and amplitude of forward tilt of atlas, the higher the relative difficulty of reduction. Therefore, it is crucial to establish an accurate and relatively objective imaging criterion for evaluating the difficulty of AAD reduction (10). Based on this, our previous study proposed a new concept named sagittal atlantoaxial joint inclination angle (SAAJI) and reduction index (RI), which can be used as an objective imaging criterion to guide the selection of surgical methods, but the study sample size was small. Aiming to further evaluate the significance of AAJI in evaluating the difficulty of atlantoaxial reduction, the CT and x-ray were conducted retrospectively to analyze the clinical value of AAJI and RI for AAD, and to provide surgeons with objective standards helping the selection of surgical procedures.

## Materials and methods

### Patients

With the approval of the ethics committee of our hospital, the patients who signed the informed consent form were included in this study. A total of 87 patients with AAD and 40 patients with normal cervical vertebra structure, from January 2011 to November 2020, were enrolled in this study. The inclusion criteria are as follows: (1) The patients with AAD received traction before the operation; (2) The patients had no oral or periodontal-related diseases; (3) Imaging examination is complete; (4) The patients were followed up for at least 12 months. The exclusion criteria are as follows: (1) The patients did not receive traction before operation; (2) Patients with coagulation system diseases or other severe comorbidities; (3) Lack of important examination; (4) The follow-up time was less than 12 months; (5) Patients with severe osteoporosis ($T \leq -2.5$). The surgery selection criteria are as follows: when the intraoperative skull traction cannot get satisfied reduction, the release and reduction operation will be performed, otherwise conventional reduction operation will be performed. The 40 patients with normal cervical vertebra structure were regarded as the control group. Based on the surgical procedure, the 87 patients were further divided into two groups: Group A (release surgery group) and Group B (conventional operation group).

### Clinical evaluation

Select reasonable statistical methods to sort out and compare the basic information of patients in groups A and B, then clarify whether there are statistical differences in the proportion of men and women and the average age of patients. All patients used the latest cervical Japanese Orthopaedic Association (JOA) scores to evaluate the degree of cervical spinal symptoms and calculated the improvement rate of cervical spinal function after treatment. The formula of JOA improvement rate (IR) was (postoperative total score-preoperative total score)/(17-preoperative total score) × 100%.

## Radiological evaluation

Atlas-dens interval (ADI) and reduction index (RI): The vertical distance from the posterior edge of the anterior arch of the atlas to the tangent line of the odontoid was measured in the anterior and lateral cervical x-ray examination, that is the ADI (**Figure 1A**). Then, according to the change of the ADI before and after traction, the RI can be calculated, and the calculation formula is (pre-traction ADI—post-traction ADI)/pre-traction ADI*100% (**Figure 2**).

Coronal Atlantoaxial joint inclination angle (CAAJI): similar to the sagittal plane, using the bone window of CT scan, the tangents of inferior articular surface of lateral mass of atlas and superior articular surface of axis were made in coronal plane, and the included angle of the two tangents was angle $\gamma$. The angle which was formed by the bisector of angle $\gamma$ and the horizontal line was the angle $\theta$ (**Figure 1B**).

Sagittal Atlantoaxial joint inclination angle (SAAJI): using the bone window of CT scan of cervical vertebra, the tangents of inferior articular surface of lateral mass of atlas and superior articular surface of axis were made in sagittal plane, and the included angle of the two tangents was angle $\alpha$. The angle was formed by the bisector of angle $\alpha$ and the horizontal line was the angle $\beta$ (**Figure 1C**).

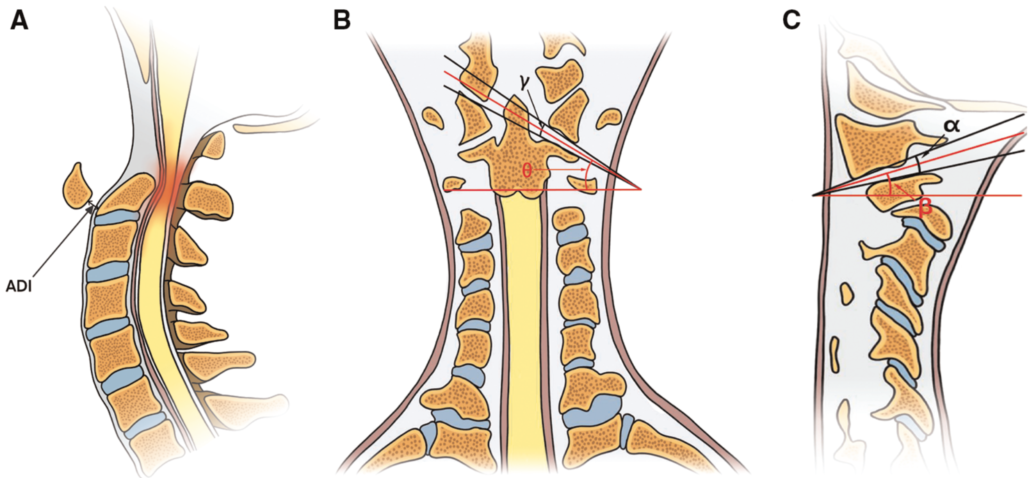


FIGURE 1
(A) The measurement of atlas-dens interval, the red section refers to the squeezed spine; (B) Angle $\gamma$ is formed by the tangents lines of the articular surface, the angle $\theta$ refers to the coronal atlantoaxial joint inclination angle; (C) angle $\alpha$ is similar to angle $\gamma$, the angle $\beta$ refers to the sagittal atlantoaxial joint inclination angle.

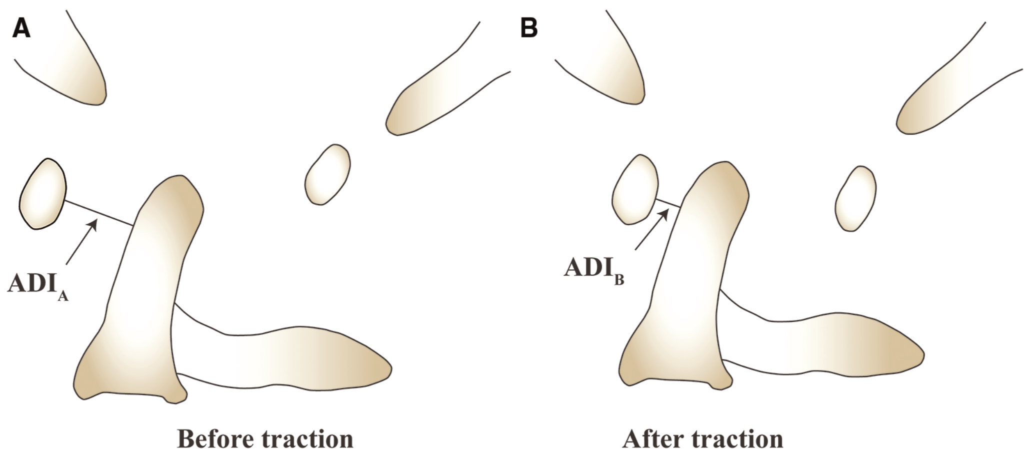


FIGURE 2
(A) The ADI measure before the traction(marked with $ADI_A$); (B) The ADI measured after traction(marked with $ADI_B$). RI can be calculated by this formulate: RI = $(ADI_A - ADI_B)/ADI_A$.

## Statistical analysis

Using SPSS 26.0 version software (SPSS Inc, Chicago, Illinois, USA.) for data analysis. The normality of the data was first tested by the Shapiro-Wilk test. All data are presented as the means and standard deviations in both chart and words. The statistical significance threshold was $P < 0.05$. In addition, Spearman correlation analysis was also conducted to get the correlation and correlation degree between parameters.

# Result

## Patient cohort

A total of 87 patients with AAD were included in the experiment group. And we statistically analyzed the information between Group A and B. The average age in group A was 57.8 ± 2.6 years (range 28–78 years), with 57.1% females and 42.9% males. While in the group B, the average age was 54.5 ± 2.1 years (range 9–89 years), with 49.2% females and 50.8% males. There were 28 patients in group A, 59 patients in group B. As we can see through the analysis, there are no statistical difference between Group A and B in both age and sex. In addition, the results of control group showed that the average age is 59.3 ± 1.9 years (range 35–76), with 45.0% females and 55.0% males (**Table 1**).

## Atlantoaxial joint inclination angle

In the control group, the AAJI in sagittal plane was 7.95 ± 0.28°, in coronal plane was 12.94 ± 0.28°. In group A, the average AAJI in coronal plane was 27.41 ± 1.29°(L) and 27.84 ± 1.55°(R), in sagittal plane is 28.94 ± 1.46°(L) and 28.57 ± 1.55°(R). In group B, the average AAJI in coronal plane was 24.60 ± 0.84°(L) and 24.92 ± 0.93°(R), in sagittal plane was 16.16 ± 0.95°(L) and 16.80 ± 1.00°(R). Statistical analysis showed that there was significant difference in AAJI between control group and experiment group ($P < 0.01$). Meanwhile, there was also significant difference in AAJI between group A and B ($P < 0.01$) (**Table 2**).

TABLE 1 The general patients information.

| Group | Case | Age | Sex (M:F) | IR |
|---|---|---|---|---|
| A | 28 | 57.75 ± 2.60 | 12:16 | 81.02 ± 2.23% |
| B | 59 | 54.54 ± 2.13 | 30:29 | 79.52 ± 1.82% |
| *P*-Value | | 0.372 | 0.486 | 0.624 |

IR, JOA improvement rate.

## ADI and reduction index

The average ADI before and after traction in group A is 6.49 ± 0.22 and 4.74 ± 0.22 respectively, reduction index is 27.78 ± 1.46%; then the average ADI before and after traction in group B is 7.06 ± 0.24 and 3.70 ± 0.18 respectively, reduction index is 48.60 ± 1.22%. Statistical analysis showed that there was no statistical difference in ADI before traction between group A and group B, but the reduction index in group A and group B were significantly different ($P < 0.01$) (**Table 2**).

## JOA score

Among the included patients with AAD, we made a comparative analysis of JOA scores between group A and group B. In group A, the preoperative JOA scores were 8.50 ± 0.35, the postoperative JOA scores was 15.21 ± 0.25, the average JOA score improvement rate was 81.02 ± 2.23%. In group B, the average preoperative JOA scores were 8.53 ± 0.21, the average postoperative JOA score was 15.15 ± 0.18, and the average improvement rate was 79.52 ± 1.82% (**Table 2**). This showed that the spinal cord function was improved, the symptoms were relieved in both groups after the operation, and there was no statistical difference in JOA improvement rates between two groups (**Table 1**).

## The correlation between ri and AAJI

The results of the correlation analysis showed that SAAJI of groups A and B were negatively correlated with the RI ($P < 0.01$), the correlation coefficient index is −0.731, indicating that the smaller the atlantoaxial inclination angle

TABLE 2 Comparison of key parameters.

| Variable/parameters | Group A | Group B | *P* Value |
|---|---|---|---|
| SAAJI (L) | 28.94 ± 1.46° | 16.16 ± 0.95° | <0.01 |
| SAAJI (R) | 28.57 ± 1.55° | 16.80 ± 1.00° | <0.01 |
| CAAJI (L) | 27.41 ± 1.29° | 24.60 ± 0.84° | <0.01 |
| CAAJI (R) | 27.84 ± 1.55° | 24.92 ± 0.93° | <0.01 |
| JOA (Pre-O) | 8.50 ± 0.35 | 8.53 ± 0.21 | 0.948 |
| JOA (Post-O) | 15.21 ± 0.25 | 15.15 ± 0.18 | 0.843 |
| ADI (Pre-T) | 6.49 ± 0.22 | 7.06 ± 0.24 | 0.142 |
| ADI (Post-T) | 4.74 ± 0.22 | 3.70 ± 0.18 | <0.01 |
| RI | 27.78 ± 1.46% | 48.60 ± 1.22% | <0.01 |

SAAJI, sagittal atlantoaxial joint inclination angle; CAAJI, coronal atlantoaxial joint inclination angle; JOA (Pre-O), preoperative JOA scores; JOA (Post-O), postoperative JOA scores; ADI(Pre-T), ADI before traction; ADI(Post-T), ADI after traction; RI, reduction index; L, left; R, right.

was, the larger the reduction index was. In contrast, CAAJI of both group A and group B were not significantly correlated with the RI. RI represents the difficulty of reduction. This showed that when the atlantoaxial inclination angle in sagittal is bigger, the difficulty of reduction is bigger.

## Case presentation

We select two typical AAD patients who were treated with the guide of our findings. Patient 1: It's a 71 years old female with AAD who suffered from progressive numbness and weakness in the limbs for more than 2 years. According to our measurement, the ADI before and after traction is 7.17 mm and 5.28 mm, SAAJI is 42.8°, RI is 26.36%, and JOA score is 6. With the guide of the standard we raised, we conducted an anterior release and posterior fixation operation for her, which resulted in a satisfied reduction and relief in symptoms (**Figure 3**). After the surgery, the JOA score is 12. Patient 2: It's a 45 years old female with AAD whose ADI before and after traction is 8.13 mm and 4.02 mm, SAAJI is 27.6°, RI is 50.55% and JOA score is 7. We conducted a posterior operation for her, which also resulted in satisfied reduction and relief in symptoms (**Figure 4**). After this surgery, the JOA score is 14.

## Discussion

Atlantoaxial dislocation is a rare and potentially fatal anatomical disorder of the occipitocervical region leading to permanent neurological defects or sagittal deformities without timely treatment (1). For AAD, the traditional operation is one-stage posterior reduction and internal fixation (11). But for IAAD, release surgery may be necessary (11, 12). At present, anterior release includes transoral approach,

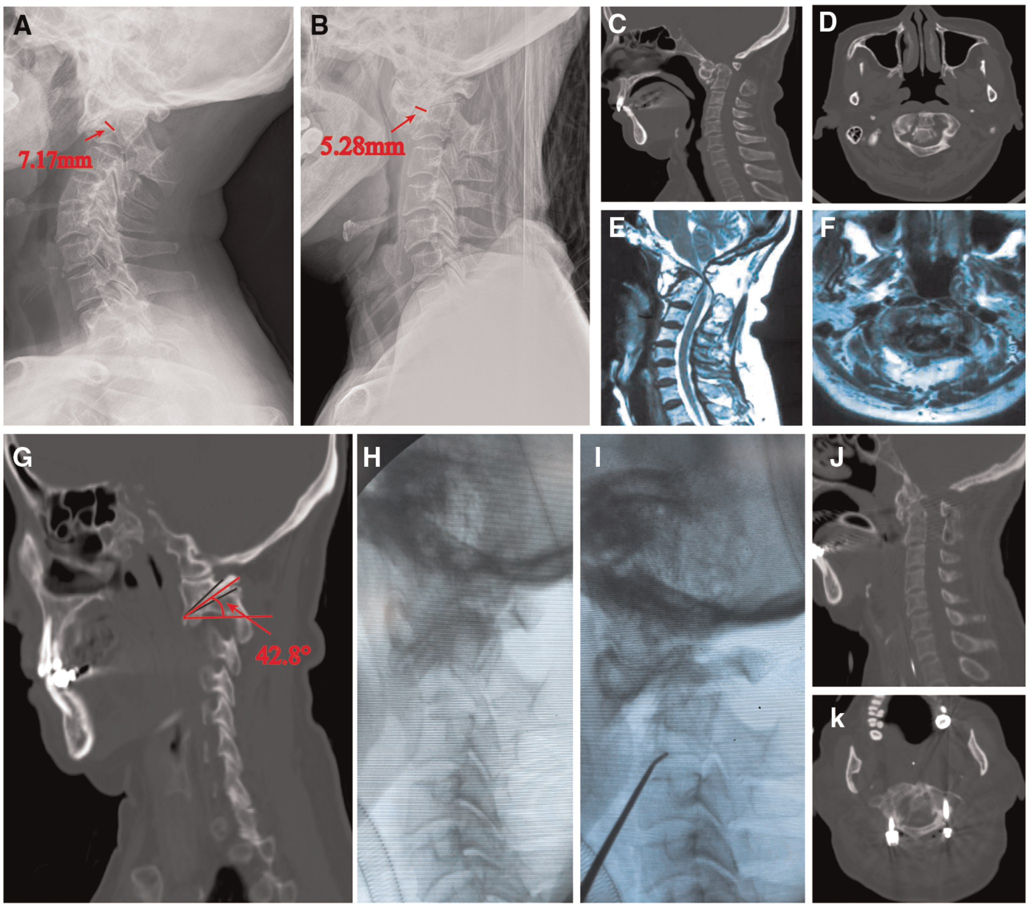


FIGURE 3
(**A,B**) A 71 years old female with AAD, the x-ray showed the results of traction: ADI before and after traction is 7.17 mm and 5.28 mm, RI is 26.36%. (**C,D**) Computed tomography (CT) was taken to show the condition of dislocation and fusion. (**E,F**) Magnetic resonance imaging (MRI) showed the compression of cervical spine. (**G**) We measured the SAAJI in the sagittal CT, and the result is 42.8°. (**H–K**) Anterior release and posterior operation was conducted for her, which get a satisfied reduction.

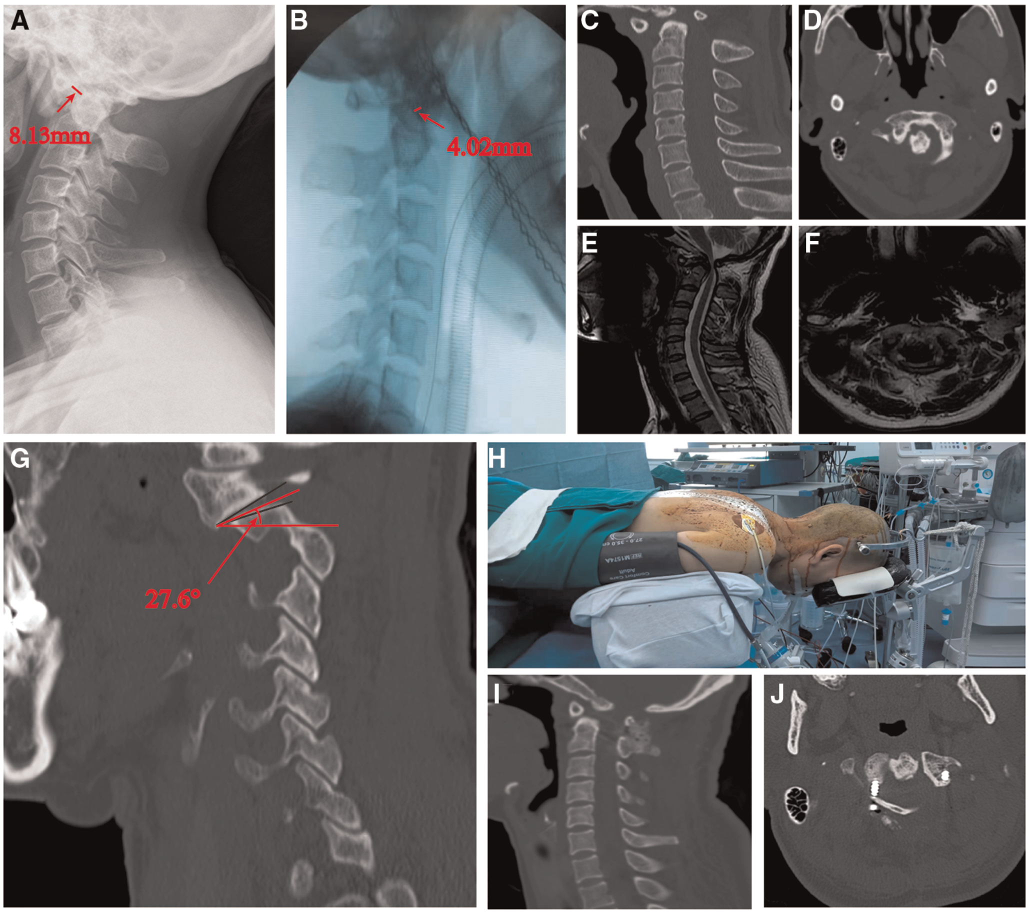


FIGURE 4
(A,B) A 42 years old female with AAD, traction was also conducted for her to evaluate the difficulty of reduction, which get the ADI before and after traction is 8.13 mm and 4.12 mm, RI is 50.55%. (C–F) CT and MRI showed that the fusion is not too much and the cervical spine is compressed severely. (H–J) The SAAJI was also measured, the result is 27.6° (G). We conducted a posterior operation with traction and get satisfied reduction.

transnasal approach and submandibular approach (2, 13–15). Yin QS et al. proposed the TARP plate system to perform decompression, reduction, internal fixation through the transoral approach (16–20). Wang et al. promoted transoral atlantoaxial release combined with posterior fixation to treat irreducible atlantoaxial dislocation (2). However, the transoral approach will increase the risk of infection during the perioperative period. Some patients with oral diseases are unable to complete transoral release surgery. Combined anterior and posterior surgery also has some limitations. It will cause long operation time, high risk, complicated situation, and higher cost (21). Moreover, posterior release surgery can also achieve good results in some cases with the development of surgical techniques. By improving Goel technique, Chen Z et al. performed one-stage posterior joint release on patients with atlantoaxial dislocation with bony fusion and reduced the dislocated atlantoaxial vertebra (22). Although a variety of surgical methods, the choice of surgical methods is mainly based on the surgeon's clinical experience (23). Meanwhile, anterior release is also controversial (15). As far as we know, there was few research on the objective criteria for the selection of surgical methods for atlantoaxial dislocation.

The atlantoaxial joint is responsible for a large part of the movement of the neck, and these movements usually occur in different planes. Salunke et al. objectively evaluated the dislocation of the first and second cervical vertebrae in multiple planes and discussed the possible mechanisms and methods for the reduction of various types of dislocation (24). Chandra et al. firstly indicated the correlation between the position of the atlantoaxial joint and the severity of the AAD. They also described the new indexes named "sagittal joint inclination" to describe the position and shape of the atlantoaxial joint (25). Baoge Liu et al. also studied the changes of related parameters of the atlantoaxial joint and atlantooccipital joint before and after anterior cervical surgery and discussed the role of related parameters of cervical spine in treatment and evaluation of curative effect (26). For spinal surgeons, it is important to understand the position and shape of atlantoaxial joints in normal people for better knowing the correction process of AAD. Therefore, it is worthy to dictate criteria for the selection of reasonable surgery methods according to the parameters.

With regard to the AAJI involving in this study, Salunke et al. proposed that an angle between the tangent lines of the atlantoaxial joint surface is of significance for the evaluation of the severity of atlantoaxial dislocation. In that study, 24 patients were included and measured. He considered that the larger angle predicted the higher severity of atlantoaxial dislocation (3). But the study lacks the further research of correlation between the angle and the difficulty of reduction. Chandra et al. have confirmed that the atlantoaxial inclination angle was related to the severity and difficulty of reduction, which was of great significance in distinguishing and judging irreducible atlantoaxial dislocation and reducible atlantoaxial dislocation. This study also confirmed that the atlantoaxial inclination angle on the coronal plane was related to the severity of basilar invagination (25). The above studies only researched the relationship between imaging parameters and the severity of the atlantoaxial dislocation without guiding the selection of surgical methods. Furthermore, the measurement of angles was merely based on the plane conversion. Another index involved in this study is the ADI, which refers to the vertical distance from the leading edge of the posterior arch of the atlas to the tangent line of the leading edge of the odontoid, which is a pivotal measurement parameter for the diagnosis of AAD. Our former study put forward the concept of RI by studying the AAD, which is calculated by the ADI before and after traction. It is used to express the degree of atlantoaxial reduction in this plane after traction (27).

In this study, based on the influence of multi-dimensional stability of atlantoaxial joint on reduction, the SAAJI was measured, and CAAJI was added to analyze the effect of coronal angle on the difficulty of reduction. The RI was used to analyze the correlation between the reduction index and the inclination angle of coronal plane and sagittal plane. Through the analysis of imaging and clinical knowledge, we found that patients in group A had larger inclination angle of sagittal plane ($28.94 \pm 1.46°$) and smaller reduction index ($27.78 \pm 1.46\%$) than patients in group B, which were respectively $16.80 \pm 1.00°$ and $48.60 \pm 1.22\%$. In other words, higher inclination angle may indicate the higher difficulty of reduction. For these patients, anterior release is necessary to ensure the reduction and the decompression of spinal cord. Compared with the previous studies, this study not only added the CAAJI as a new evaluation index but also included more patients, which further improved the accuracy and reliability of this study.

What's more, multiple regression analysis showed that the RI was negatively correlated with the SAAJI, but there was no relation with CAAJI. Through these parameters, we can judge the difficulty of reduction of AAD and guide the determination of surgery. For example, if the SAAJI is more than the average in group A ($28.94 \pm 1.46°$), RI is less than the average level of group B ($48.60 \pm 1.22\%$), release surgery may be required. Otherwise, the single-stage posterior reduction surgery is feasible. This study improved the evaluation level of SAAJI and RI for judging the difficulty of atlantoaxial dislocation reduction, and further proved that the coronal atlantoaxial inclination angle is invalid. Furthermore, we found that in group A, the SAAJI of some patients cannot meet the standard of release surgery, but the RI is small, and obvious bone fusion can be seen in CT images. For this kind of patients, the anterior release also can be conducted based on the actual clinical situation. Through the study, a more clinically valuable objective standard for the selection of surgical methods for AAD can assist doctors in deciding the management of anterior release. It also has advantages in avoiding secondary operation, reducing the cost and risk of the operation.

In this study, there are still some limitations. It is still necessary to expand the samples quantity and improve the reliability of the SAAJI and RI. According to the conclusions of this study, prospective experiments need to be carried out in the future to improve the credibility. In addition, the selection of surgery method may also have influence on the division of group. The atlantoaxial joint is a multi-dimensional structural complex, so we still need to study more parameters in order to improve the ability of the model to simulate the real situation.

## Conclusion

In this study, there is negative correlation between SAAJI and RI. The SAAJI indicated the severity of AAD, the RI indicated the difficulty of reduction. When the RI is smaller than 48.60% and SAAJI is bigger than 28.94°, anterior release may be required. The atlantoaxial joint inclination angle and reduction index can be used as objective criteria to guide the selection of surgical methods for atlantoaxial dislocation.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

YQ: took part in the whole experiment including data collection, data analysis, drawing of figures and writing of the manuscript. YX: contributed to the conception of the study. YD and JL: contributed to the drawing of the figures and data analysis. YZ and HL: contributed to the data collection. JZ: helped perform the data analysis. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Anterior cervical discectomy and fusion to treat cervical instability with vertigo and dizziness: A single center, retrospective, observational study

Huo-Liang Zheng[1†], Bo Li[1†], Shao-Kuan Song[2], Peng-Bo Chen[1], Lei-Sheng Jiang[1*] and Sheng-Dan Jiang[1*]

[1]Department of Clinic of Spine Center, Xinhua Hospital, Shanghai Jiaotong University School of Medicine, Shanghai, China, [2]Department of Clinical Medicine, Shanghai Jiaotong University School of Medicine, Shanghai, China



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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Edoardo Agosti,
University of Brescia, Italy
AB Zulkiflee,
University Malaya Medical Centre, Malaysia

*CORRESPONDENCE
Sheng-Dan Jiang
jiangshengdan@xinhuamed.com.cn
Lei-Sheng Jiang
jiangleisheng@xinhuamed.com.cn

[†]These authors have contributed equally to this work

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**Purpose:** The current study attempts to investigate the role of anterior cervical discectomy and fusion (ACDF) in alleviating symptoms in patients with cervical vertigo associated with cervical instability.

**Methods:** The patients of cervical instability with vertigo and dizziness who underwent ACDF between January 2011 and December 2019 were followed-up for more than two years. Demographic data (age, sex, follow up period and levels of instable cervical segments) were assessed; Symptoms of vertigo and dizziness before and after surgery were assessed by the 15-item version of the Vertigo Symptom Scale (VSS) and the 25-item Dizziness Handicap Inventory (DHI). The severity and frequency of other symptoms like neck and occipital pain, gastrointestinal discomfort, nausea, vomiting, tinnitus, palpitations, headache, diplopia and blurring of vision before and after surgery were also assessed.

**Results:** A total of 92 patients underwent ACDF for cervical instability with vertigo and dizziness between January 2011 and December 2019, of which 79 patients were included in the final analysis. The number of instable levels had no correlation with VSS and DHI scores before surgery ($p > 0.05$), while patients with C3/4 instability suffering a severer vertigo than other levels. Both DHI and VSS scores were significantly reduced after ACDF and this was sustained within two years after surgery ($p < 0.001$). Although there was no statistical difference in the ratio of patients with vertigo relief, patients with one-level cervical instability demonstrated a more rapid recovery than patients with multi-level cervical instability ($p = 0.048$). Also, there was improvement in other symptoms such as neck and occipital pain, gastrointestinal discomfort, nausea, vomiting, tinnitus, palpitations, headache and blurring of vision after surgery.

**Conclusions:** Vertigo caused by C3/4 instability was severer than other levels such as C4/5 and C5/6. During 2 years' follow-up the significant relief of vertigo and dizziness was observed after anterior cervical surgery. Other accompanying symptoms except hypomnesia were also extenuated in follow-up period.

KEYWORDS

cervical spine, anterior cervical discectomy and fusion, vertigo, dizziness, instability

## Introduction

Vertigo is "an illusion of movement", and it may be rotational, oscillating or tilting in nature. Dizziness can be described as light-headedness, imbalance, giddiness, or unsteadiness, and it is perhaps closest to the definition of vertigo. There are a number of different causes of vertigo including central nervous system and central or peripheral vestibular dysfunction etc. Some patients are suspected that the cause of their problem is a disorder of the cervical spine, known as cervical vertigo (1). In 1955, Ryan and Cope used the term "cervical vertigo" to refer to a combination of cervical spine problems and dizziness (2). It is defined as vertigo induced by changes of position of the neck or vertigo originating from the cervical region. A proportion of patients having cervical instability can complain about varying degrees of symptoms of vertigo and dizziness without myelopathy and/or radiculopathy, and always accompanied by tinnitus, blurred vision, headache, nausea, vomiting, palpitations, and gastrointestinal discomfort etc. The pathophysiology behind the association of these clinical symptoms with mechanical problem is not very clearly known.

Anterior cervical discectomy and fusion (ACDF) is a commonly used approach for cervical instability (3). However, the effect of ACDF on these symptoms is yet to be explored. In this retrospective study, we aimed to investigate whether ACDF is effective in improving vertigo, dizziness, and these accompanied symptoms by comparing their severity before and after surgery.

## Materials and methods

### Patients

From January 2011 to December 2019, ninety-two cervical instability patients with vertigo and dizziness underwent ACDF with PEEK cages in our institution. Of these patients, 79 were available for follow-up evaluation for more than 2 years after surgery. All patients were followed up at least three times postoperatively, at three months, one year, and two years after surgery. The mean of last follow-up was 29.6 months (range: 24 to 96 months). There were 14 males and 65 females. The ages ranged from 49 to 82 years, with a mean of 67.4 years. For patients with only one level of cervical instability, we performed single-level ACDF (**Figure 1**). For patients with two or more cervical instability, we performed ACDF on the corresponding segments (**Figure 2**). At the follow-up, patients underwent postoperative cervical spine x-ray (anteroposterior and lateral projections) and assessment

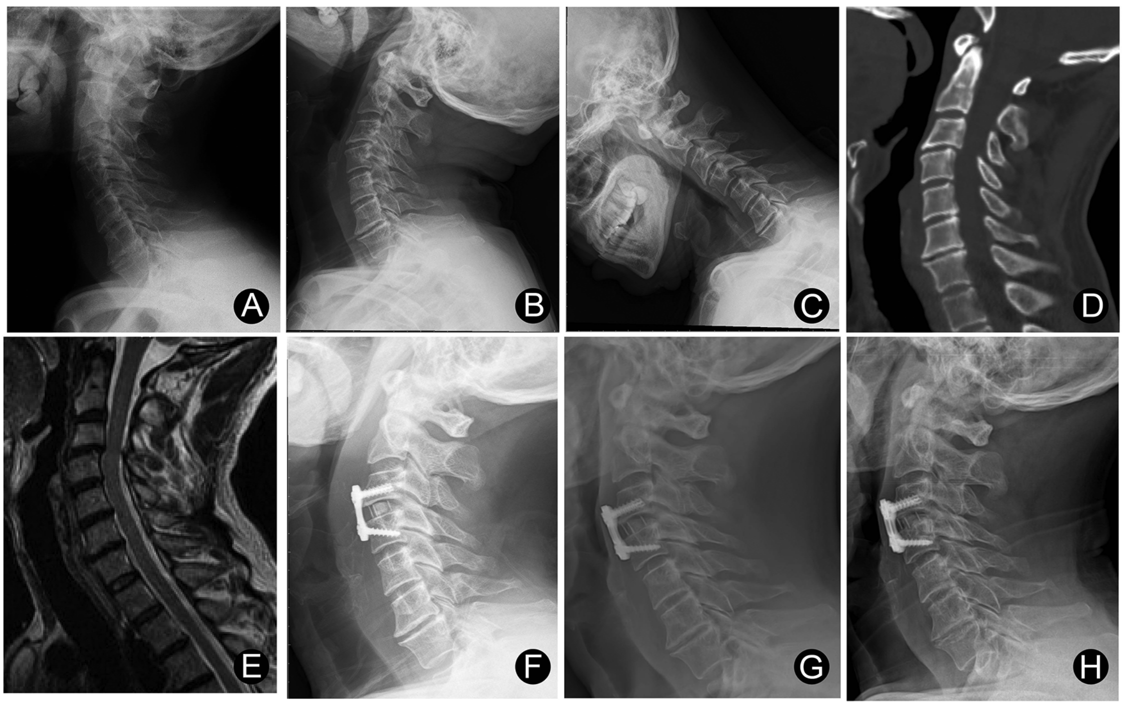


FIGURE 1
Male, 57 years old: C3/4 ACDF was experienced. (A–C) Cervical spine x-ray showing C3/4 instability. (D) Preoperative cervical CT sagittal image. (E) Magnetic resonance imaging (MRI) showing no significant compression of the spinal cord. (F) x-ray of cervical spine 3 months after surgery. (G) x-ray of cervical spine 12 months after surgery. (H) x-ray of cervical spine 24 months after surgery.

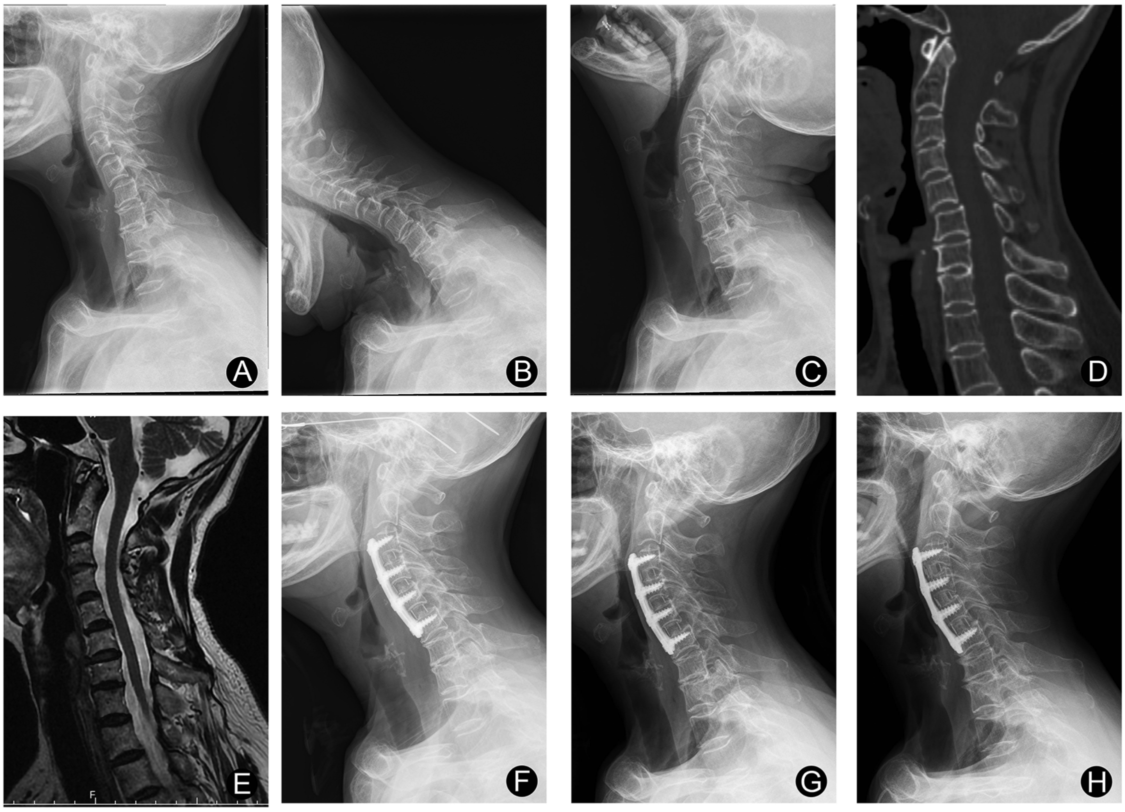


FIGURE 2
Female, 68 years old: three levels of ACDF was experienced. (A–C) Cervical spine x-ray showing C3/4, C4/5 and C5/6 instability. (D) Preoperative cervical CT sagittal image. (E) Magnetic resonance imaging (MRI) showing no significant compression of the spinal cord. (F) x-ray of cervical spine 3 months after surgery. (G) x-ray of cervical spine 12 months after surgery. (H) x-ray of cervical spine 24 months after surgery.

of clinical symptoms such as vertigo, dizziness, neck and occipital pain and so on. This study included patients who had 2 years' follow-up visit after surgery with the complete results of clinical and radiological assessments.

## Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) all patients presented vertigo and dizziness without myelopathy or radiculopathy. (2) Flexion-extension x-rays were used to assess stability of the cervical spine, and sagittal translation (>3.5 mm), or segmental angulation (>11°) was typically used to diagnose cervical instability (4). (3) Obvious cervical spinal cord compression was not demonstrated on magnetic resonance imaging (MRI). (4) Diseases relating to neurology, otolaryngology, ophthalmology, and cardiovascular diseases such as Meniere disease, cataract, lacunar infarcts, etc., were excluded. (5) The conservative treatment is ineffectual, and all the patients underwent ACDF. The exclusion criteria were as follows: (1) Alternative etiology of vertigo and dizziness revealed on consultation with neurology, otolaryngology, cardiology or ophthalmology. (2) A history of cervical spine trauma or surgery.

# Methods

All the patients underwent a clinical evaluation. A cervical spine examination was mainly performed to assess cervical mobility by standard flexion-extension x-ray imaging. A neurological assessment was completed by the brain MRI examination and evaluating of the strength of the four limbs, surface and deep sensitivity and coordination. In addition, a comprehensive ENT examination including an electronystagmogram was used in order to rule out potentially balance-altering vestibular damage. In the absence of abnormal clinical examination results, we considered that a patient's vertigo and dizziness was non-vestibular.

Perceived frequency and severity of vertigo and dizziness was assessed by the 15-item version of the Vertigo Symptom Scale (VSS) (5). The scale has 5 response categories (0–4). Total scale scores range between 0 and 60 points, severe dizziness: ≥12 points. clinically significant change: ≥3 points.

Perceived disability was assessed by the 25-item Dizziness Handicap Inventory (DHI) which has 3 response categories (0; 2; 4). Total scores range from 0 to 100 points (23), interpreted as mild 0–30; moderate 31–60; severe 61–100 (6).

To evaluate the outcome of surgery, the closest minimally clinical important difference (MCID) in terms of follow-up was used 11 for the VSS and 17 for DHI at the term of 2 years.

In addition to vertigo and dizziness, other symptoms such as neck and occipital pain, gastrointestinal discomfort, nausea, vomiting, tinnitus, palpitations, headache, hypomnesia, diplopia and blurring of vision before and after surgery were also recorded.

As there is no standardized method to assess the severity and frequency of neck and occipital pain, gastrointestinal discomfort, nausea, vomiting, tinnitus, palpitations, headache, hypomnesia and blurring of vision, we used a scale to objectively record the data. The outcomes were the intensity and frequency of these symptoms. The intensity was measured with a 100 mm visual analogue scale (VAS). Total scale scores range between 0 and 100 points, clinically significant change: ≥10 points.

## Statistical analysis

Quantitative information is presented as mean and standard deviation. The Shapiro–Wilk test was used to test the normality of continuous data. One-way repeated measures analysis of variance (ANOVA) was used to compare the indicators in the same group at different time points, while Friedman test was used for data that does not fit Gaussian distribution. Multiple comparison analysis between groups was analyzed using least significant difference (LSD). Binary and categorical indicators between groups were compared using the exact two-way Fisher criterion. The comparison of categorical variables before and after surgery was performed using the McNemar criterion. Binary logistic regression was used to investigate whether age, sex and surgery in different cervical levels influences the amelioration of vertigo and dizziness. The log-rank criterion was used to analyze the relief of vertigo after single-level and multi-levels cervical spine surgery in three weeks. Statistical significance was defined by $p < 0.05$. Data were analyzed using SPSS software version 21 for Windows 11.

# Results

## General results

A total of 79 patients underwent ACDF for cervical instability with cervical vertigo and dizziness were included in the final analysis. The main characteristics of patients are presented in Table 1. Most of the patients with cervical instability (65/79, 82.3%) were female. Among the patients, the majority had one-level cervical instability (60/79, 75.9%). The most common level of instability was C3–4 ($n = 46$, 46.0%) followed by C4–5 ($n = 40$, 40.0%) and C5–6 ($n = 14$, 14.0%). There was no significant association between the number of instability levels and symptoms of vertigo and dizziness as measured by VSS ($p = 0.724$) and DHI ($p = 0.780$) (Table 2). Vertigo and dizziness caused by the instability of C3/4 are significantly worse than those caused by C4/5 or C5/6, as evidenced by VSS and DHI scores (Table 3).

## Vertigo and dizziness

Vertigo and dizziness assessed by DHI and VSS were significantly relieved after ACDF and this was sustained at the final follow-up (Table 4). In fact, within 10 days after surgery, the relief of vertigo and dizziness was observed. Compared with single-level ACDF, two or three levels ACDF has slower symptom relief (Figure 3). About half of patients experienced significant improvement in vertigo within 4 days after single-level ACDF, while it extended to 9 days in multi-level ACDF. Although means of VSS and DHI scores decreased obviously at 12 and 24 months compared with those at 3 months, there was no statistically significant difference between scores at 12 months and 24 months after surgery.

TABLE 1 Basic data of patients (x ±, $n = 79$).

| Characteristics | No. of patients ($n = 79$) |
|---|---|
| Age at surgery | 67.4 center8.2 |
| Sex | |
| Male | 14 (17.7%) |
| Female | 65 (82.3%) |
| Levels of instability segments | |
| One-level | 60 (75.9%) |
| Two-levels | 17 (21.5%) |
| Three-levels | 2 (2.5%) |
| Numbers of surgical segments | |
| C3/4 | 46 (46.0%) |
| C4/5 | 40 (40.0%) |
| C5/6 | 14 (14.0%) |
| follow-up period, months | 29.6 ± 9.6 |

TABLE 2 Preoperative VSS and DHI scores in patients with different numbers of instability segments (x ±, $n = 79$).

| Parameters | One-level | Two-levels | Three-levels | F | *p* |
|---|---|---|---|---|---|
| VSS | 22.8 ± 4.0 | 22.2 ± 4.5 | 24.5 ± 0.7 | 0.324 | 0.724 |
| DHI | 37.8 ± 4.7 | 38.5 ± 3.4 | 39.5 ± 2.1 | 0.250 | 0.780 |

VSS, Vertigo Symptom Scale; DHI, Dizziness Handicap Inventory.

TABLE 3 Preoperative VSS and DHI scores in patients with different cervical segments (x ±, *n* = 79).

| Parameters | C3/4 ($n = 32$) | C4/5 ($n = 21$) | C5/6 ($n = 7$) | C3-5 ($n = 12$) | C4-6 ($n = 5$) | C3-6 ($n = 2$) | F | *p* |
|---|---|---|---|---|---|---|---|---|
| VSS | 24.4 ± 3.5 | 21.4 ± 4.0[a] | 19.9 ± 3.2[b] | 22.2 ± 3.7 | 22.4 ± 6.6 | 24.5 ± 0.7 | 2.63 | 0.031 |
| DHI | 39.7 ± 4.6 | 36.0 ± 4.3[a] | 34.9 ± 2.8[b] | 38.4 ± 3.7 | 38.6 ± 3.2 | 39.5 ± 2.1 | 2.91 | 0.019 |

Note: Comparison of preoperative VSS and DHI scores between C3/4 and C4/5.
[a]$p < 0.05$; Comparison of preoperative VSS and DHI scores between C3/4 and C5/6.
[b]$p < 0.05$.

TABLE 4 VSS and DHI scores before and after surgery (x ±, *n* = 79).

| Parameters | before surgery | 3 months after surgery | 12 months after surgery | 24 months after surgery | F | *p* |
|---|---|---|---|---|---|---|
| VSS | 22.7 ± 4.0 | 6.8 ± 4.0[a] | 5.8 ± 2.9[a] | 5.4 ± 2.7[a] | 140.7 | <0.001 |
| DHI | 38.0 ± 4.4 | 13.8 ± 4.7[a] | 13.0 ± 3.7[a] | 12.9 ± 3.8[a] | 640.3 | <0.001 |

Note: Comparison of VSS and DHI scores between before surgery and after surgery.
[a]$p < 0.05$.

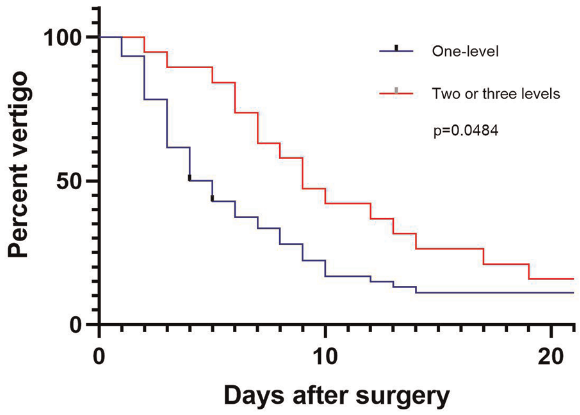


FIGURE 3
Percentage of patients with residual vertigo within three weeks after ACDF.

TABLE 5 Patient-reported outcomes during follow-up terms (*n* = 79).

| Parameter | Levels of instability segments | | *n* | *p* |
|---|---|---|---|---|
| | One-level | > One-level | | |
| VSS | | | | |
| Achieved MCID | 53 (88.3%) | 18 (94.7%) | 71 (89.9%) | 0.672 |
| Not achieved MCID | 7 (11.7%) | 1 (5.3%) | 8 (10.1%) | |
| DHI | | | | |
| Achieved MCID | 54 (90.0%) | 17 (89.5%) | 71 (89.9%) | >0.99 |
| Not achieved MCID | 6 (10.0%) | 2 (10.5%) | 8 (10.1%) | |

MCID, Minimally clinical important difference.

As an effective method of assessing the validity of scale, MCID is earning its place and recognition by patients and clinical doctors. Consequently, we evaluated the alleviating effects of ACDF on vertigo and dizziness using the MCID of VSS and DHI scales. As shown in Table 5, most patients (89.9%) achieved MCID after surgery and there is no significant difference in the ratio of achieving MCID between patients accepting one-level ACDF and multi-level ACDF. Figure 4 shows the number of patients who failed to achieve MCID at different cervical levels as measured by VSS and DHI scores.

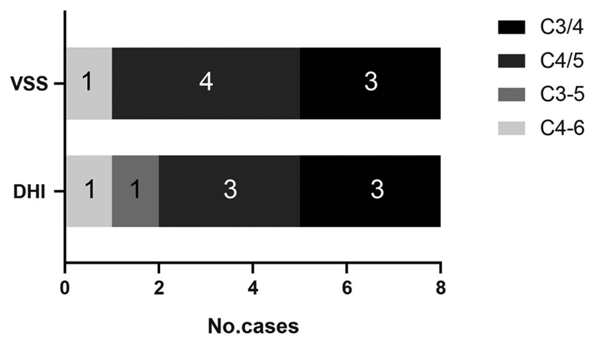


FIGURE 4
Distribution of levels of cervical spine failing to meet MCID assessed by VSS and DHI.

Furthermore, we investigated factors influencing the efficacy of ACDF on vertigo according to whether the MCID of VSS and DHI were both achieved. Although the preoperative scores of VSS and DHI varied with the levels of instable cervical segments, logistic regression showed that there was no significant correlation between postoperative amelioration of vertigo and the level of instable cervical segments such as involving C3/4 (OR = 0.386, $p = 0.338$), involving C4/5 (OR = 1.199, $p = 0.849$) and C5/6 (OR = 1.027, $p = 0.980$) (Table 6). Also, the correlation between postoperative amelioration of vertigo, age (OR = 1.046, $p = 0.339$) and sex (OR = 0.457, $p = 0.371$) was not observed.

TABLE 6 Odds ratio, 95% CI and *P* value association using multiple factors logistic regression models for vertigo meeting the MCID including cervical levels.

| Parameter | Odds ratio | 95% CI | *p* |
|---|---|---|---|
| C3/4 (involved) | 0.386 | (0.055, 2.706) | 0.338 |
| C4/5 (involved) | 1.199 | (0.185, 7.785) | 0.849 |
| C5/6 (involved) | 1.027 | (0.133, 7.930) | 0.980 |
| Age | 1.046 | (0.954, 1.148) | 0.339 |
| Sex | 0.457 | (0.082, 2.536) | 0.371 |

TABLE 7 Number and incidence of other symptoms accompanied with vertigo.

| symptoms | No. cases | Percent (%) |
|---|---|---|
| vertigo and dizziness | 79 | 100 |
| neck and occipital pain | 53 | 67.1 |
| gastrointestinal discomfort | 35 | 44.3 |
| nausea | 29 | 36.7 |
| vomiting | 17 | 21.5 |
| tinnitus | 58 | 73.4 |
| palpitations | 43 | 54.4 |
| headache | 56 | 70.9 |
| hypomnesia | 37 | 46.8 |
| diplopia | 2 | 2.5 |
| blurring of vision | 59 | 74.7 |

## Distribution of accompanying symptoms

The distribution of symptoms has been illustrated in Table 7. Besides vertigo and dizziness, out of 79 patients, blurring of vision (59/79, 74.7%) was the most common accompanying symptoms followed by tinnitus (58/79, 73.4%) and headache (56/79, 70.9%) before surgery. All accompanying symptoms were obviously extenuated 3 months after ACDF except hypomnesia (Table 8). Compared to preoperative symptoms, treatment with ACDF surgery has a significant effect on reducing the ratio of patients with neck and occipital pain ($p < 0.\ 001$), gastrointestinal discomfort ($p = 0.\ 007$), nausea ($p = 0.004$), tinnitus ($p < 0.001$), vomiting ($p = 0.003$), palpitation ($p < 0.001$), headache ($p < 0.001$) and blurred vision ($p < 0.001$). Diplopia in two patients disappeared after surgery. Although most patients experienced symptom relief after surgery, there was no significant effect on the relief of hypomnesia ($p = 0.302$) in patients experiencing ACDF (Tables 9–11).

## Discussion

To date, the etiology and mechanisms of cervical vertigo are still unknown, conservative therapy has been the main treatment which has been unsatisfactory. Some studies (7–9) manifested that ACDF improved the sympathetic symptoms like vertigo, headache, nausea, vomiting and gastrointestinal discomfort in patients with cervical radiculopathy and/or myelopathy. This doesn't mean that all patients who have cervical spondylosis with concomitant vertigo and dizziness should be treated with anterior cervical surgery. Treatment of cervical vertigo is complicated in patients who have chronic neck pain and concomitant vertigo and dizziness but without cervical disc herniation or compression of nerve root and spinal cord.

In 1928, Pearce and Barré–Liéou (10) suggested that cervicogenic dizziness was due to an abnormal input from the cervical sympathetic nerves. They proposed that the posterior

TABLE 8 Severity of symptoms accompanied with vertigo before and after surgery (x ±).

| Parameter | Before surgery | 3 months after surgery | 12 months after surgery | 24 months after surgery | F | *p* |
|---|---|---|---|---|---|---|
| Neck and occipital pain ($n = 53$) | 38.0 ± 7.7 | 13.9 ± 6.7[a] | 10.8 ± 5.5[b] | 9.3 ± 4.6 | 303.1 | <0.001 |
| Gastrointestinal discomfort ($n = 35$) | 38.9 ± 6.5 | 11.0 ± 4.7[a] | 10.7 ± 4.6 | 10.3 ± 5.1 | 337.9 | <0.001 |
| Nausea ($n = 29$) | 31.4 ± 6.1 | 11.2 ± 4.3[a] | 9.9 ± 4.1 | 10.0 ± 4.3 | 162.1 | <0.001 |
| Vomiting ($n = 17$) | 36.7 ± 5.6 | 6.6 ± 3.7[a] | 5.7 ± 3.3 | 5.0 ± 2.6 | 306.9 | <0.001 |
| Tinnitus ($n = 58$) | 29.4 ± 4.4 | 11.9 ± 4.6[a] | 10.7 ± 4.4 | 9.6 ± 4.6 | 339.4 | <0.001 |
| Headache ($n = 56$) | 42.4 ± 7.3 | 11.8 ± 5.6[a] | 10.4 ± 5.7 | 10.0 ± 5.3 | 461.7 | <0.001 |
| Blurring of vision ($n = 59$) | 46.8 ± 8.3 | 16.2 ± 7.3[a] | 14.9 ± 7.5 | 14.0 ± 7.3 | 341.6 | <0.001 |
| Hypomnesia ($n = 37$) | 12.3 ± 2.1 | 11.9 ± 3.8 | 10.9 ± 4.8 | 11.4 ± 4.7 | 1.69[FD] | 0.6386 |
| Palpitations ($n = 43$) | 36.8 ± 6.3 | 13.4 ± 5.0[a] | 12.1 ± 5.3 | 10.1 ± 5.2[c] | 323.2 | <0.001 |

Note: Comparison of symptoms accompanied with vertigo between before surgery and 3 months after surgery.
[a]$p < 0.05$; Comparison of symptoms accompanied with vertigo between 3 months after surgery and 12 months after surgery.
[b]$p < 0.05$; Comparison of symptoms accompanied with vertigo between 12 months after surgery and 24 months after surgery.
[c]$p < 0.05$; FD, Friedman test.

TABLE 9 Number of patients with neck and occipital pain, gastrointestinal discomfort or blurring of vision before and after surgery. (x ±, *n* = 79).

| Symptom | Neck and occipital pain (After surgery) | | Gastrointestinal discomfort (After surgery) | | Blurring of vision (After surgery) | |
|---|---|---|---|---|---|---|
| | Symptomatic | Symptomless | Symptomatic | Symptomless | Symptomatic | Symptomless |
| Symptomatic (Before surgery) | 28 | 25 | 22 | 13 | 41 | 18 |
| Symptomless (Before surgery) | 1 | 25 | 2 | 42 | 2 | 18 |
| *P* | <0.001 | | 0.007 | | <0.001 | |

Note: Comparison of neck and occipital pain, gastrointestinal discomfort and blurring of vision before and after surgery.

TABLE 10 Number of patients with nausea, vomiting or tinnitus before and after surgery. (x ±, *n* = 79).

| Symptom | Nausea (After surgery) | | Vomiting (After surgery) | | Tinnitus (After surgery) | |
|---|---|---|---|---|---|---|
| | Symptomatic | Symptomless | Symptomatic | Symptomless | Symptomatic | Symptomless |
| Symptomatic (Before surgery) | 15 | 14 | 0 | 17 | 28 | 30 |
| Symptomless (Before surgery) | 3 | 47 | 3 | 59 | 1 | 20 |
| *P* | 0.004 | | 0.003 | | <0.001 | |

Note: Comparison of nausea, vomiting or tinnitus before and after surgery.

TABLE 11 Number of patients with hypomnesia, headache or palpitations before and after surgery. (x ±, *n* = 79).

| Symptom | Hypomnesia (After surgery) | | Headache (After surgery) | | Palpitations (After surgery) | |
|---|---|---|---|---|---|---|
| | Symptomatic | Symptomless | Symptomatic | Symptomless | Symptomatic | Symptomless |
| Symptomatic (Before surgery) | 27 | 10 | 29 | 27 | 18 | 25 |
| Symptomless (Before surgery) | 5 | 37 | 3 | 20 | 2 | 34 |
| *P* | 0.302 | | <0.001 | | <0.001 | |

Note: Comparison of hypomnesia, headache or palpitations before and after surgery.

sympathetic plexus could be mechanically irritated by degenerative arthritis and induce reflex vertebrobasilar vasoconstriction and symptoms of vertigo and dizziness. It is well known that cervical spinal tissues are rich in sympathetic fibers. The cervical dura mater and the posterior longitudinal ligament have different sympathetic innervation patterns (11). In addition, the cervical sympathetic trunk consists of a main trunk and two to four ganglia which are located anterior to the transverse processes (12, 13). We speculated that abnormal motion of the cervical segment may stimulate the sympathetic nervous system other than the vertebral artery which induces symptoms such as vertigo, dizziness, tinnitus, nausea, vomiting, palpitations, headache, hypomnesia, and gastrointestinal discomfort.

Some authors have attributed cervical vertigo to the dynamic vertebrobasilar insufficiency (14, 15). In other words, at least in a subset of dizzy patients with degenerative cervical spine disorders, the cause of dizziness on turning the neck could be due to the reduced vertebral blood flow. The complementary tests used to diagnose vertebrobasilar insufficiency are still controversial. As a consequence of the fact that vertebral artery stenosis is transitory, the use of these tests in asymptomatic patients is usually negative. Vertebrobasilar insufficiency secondary to cervical instability may be a mechanism in patients with vertigo and dizziness in our study.

ACDF surgery contributing to segmental cervical vertebrae fixation and fusion seems to be an effective surgical treatment modality for alleviating vertigo, dizziness and other sympathetic symptoms caused by cervical instability. We included patients who have cervical instability with vertigo and dizziness, and the main symptoms are vertigo and dizziness but not neck pain in study. And our study revealed that symptoms of vertigo and dizziness relieved after anterior cervical surgery and the surgical results were encouraging.

MCID indicates minimum clinically important differences and is an important metric in evaluating resolution of symptoms (16, 17). However, there is no consensus on the MCID value for VSS and DHI. Emasithi A has reported 17 as the MCID of DHI-TH (Thai version of the Dizziness Handicap Inventory) (18). The MCID of VSS and DHI used in this study were obtained numerically by using anchor-based method. To better assess the effectiveness of ACDF surgery on vertigo and dizziness resolution, we divided patients into two groups depending on whether the MCID of VSS and DHI was achieved. About 90% patients get a satisfactory improvement in vertigo and dizziness while the number of surgical levels didn't influence the symptom relief.

Also, there was improvement in severity and frequency of other symptoms such as neck and occipital pain, gastrointestinal discomfort, nausea, vomiting, tinnitus, palpitations, headache, diplopia and blurring of vision after surgery. Though the specific mechanism of ACDF in improving these symptoms are not clearcut, the anterior cervical surgery might be useful to reduce abnormal motion of the cervical segment which lead to the aberrant stimulation of sympathetic nerves.

Although our preliminary results are encouraging, long-term follow-up of the surgically treated cases are still needed. Moreover, randomized controlled studies are warranted to further investigate the surgical outcome of cervical vertigo.

In summary, the diagnosis and treatment of cervical vertigo still remain controversial. Patients with cervical instability may have symptoms of vertigo and dizziness, and successful clinical results in terms of symptom improvement can be obtained in such patients with anterior cervical surgery. Relief of vertigo and dizziness following anterior surgery can be attributed to stabilization of the cervical segment, the elimination of irritation of sympathetic plexus and vertebrobasilar insufficiency. With other causes of the symptoms dismissed, anterior cervical surgery becomes an option when conservative treatment fails.

## Limitations

Our present study has limitation. Few patients underwent three-level cervical surgery, these patients were included in the two-level group in partial analysis.

## Conclusion

The most severe symptoms of vertigo are caused by C3/4 instability and the number of levels of instability segments are not significantly influenced. The present study indicated that ACDF can relieve vertigo and dizziness caused by cervical instability and most of the accompanying symptoms could also be greatly extenuated.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by This study was approved by the Ethics Committee of Xinhua Hospital Affiliated to Shanghai Jiaotong University School of Medicine. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

HZ and BL wrote the article. SS and PC were responsible for data collection and analysis. SJ was responsible for reviewing the data. LJ and SJ were responsible for reviewing and revising the article. All authors contributed to the article and approved the submitted version.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Edvin Zekaj,
Galeazzi Orthopedic Institute (IRCCS), Italy
Bo Han,
Capital Medical University, China

*CORRESPONDENCE
Huilin Yang
suzhouspine@163.com
Junjie Niu
jjnewzzzx@sina.com

†These authors have contributed equally to this work and share first authorship

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# The clinical efficacy of anterior cervical discectomy and fusion with ROI-C device vs. plate-cage in managing traumatic central cord syndrome

Dawei Song†, Zicheng Deng†, Tao Feng, Jinning Wang, Yijie Liu, Heng Wang, Huilin Yang* and Junjie Niu*

Department of Orthopaedics, The First Affiliated Hospital of Soochow University, Suzhou, China

**Purpose:** To assess the efficacy and complications of anterior cervical discectomy and fusion (ACDF) with ROI-C device vs. conventional anterior plate and cage system (APCS) in managing traumatic central cord syndrome (TCCS).

**Methods:** A total of 37 patients diagnosed with TCCS who underwent ACDF with ROI-C implant and APCS were recruited in this retrospective study from June 2012 to February 2020. Radiological parameters and clinical results were recorded and compared through follow-up time. Characteristics of patients and complications were also recorded.

**Results:** All patients tolerated the procedure well. The average follow-up time was 25.00 ± 7.99 months in the ROI-C group, and 21.29 ± 7.41 months in the APCS group. The blood loss and operation time were significantly lower in the ROI-C group than in the APCS group. Radiological parameters and clinical results were all improved postoperatively and maintained at the final follow-up. Fusion was achieved in all patients. ROI-C group had a lower incidence of postoperative dysphagia than the APCS group. Only 1 case of ALD was observed at the final follow-up in the APCS group.

**Conclusions:** Both ROI-C device and APCS demonstrated satisfactory clinical effects and safety in managing symptomatic single-level traumatic central cord syndrome with underlying instability. Both techniques could improve and maintain cervical lordosis and disc height. ROI-C device was related to a lower incidence of postoperative dysphagia, shorter operation time, and less blood loss.

KEYWORDS

traumatic central cord syndrome, anterior cervical discectomy and fusion, ROI-C device, plate-cage system, ASIA impairment scale, dysphagia

## Introduction

Regarding the most common type of incomplete spinal cord injury (SCI), traumatic central cord syndrome (TCCS) is often associated with hyperextension trauma, leading to disproportionately more damage to the upper than in the lower extremities, bladder dysfunction, and variable sensory loss below the level of injury (1). After first proposed by Schneider et al. in 1954 (2), conservative treatment was regarded as a reliable method in managing TCCS for mild TCCS with slight neurological impairment (3). However, for patients with TCCS, there is a great probability of a combination of preexisted cervical spinal cord compression due to degeneration, leading to correlated symptoms and further segmental instability. With the development of cervical spinal surgery and the recognition of the injury mechanism, operation is becoming an effective and secure way of treating TCCS, especially with symptomatic spinal compression and segmental instability.

Determined by angular displacement and vertebral body translation, cervical spinal instability is the key indication for surgery, which needs reconstruction of both alignment and stability (4). Nevertheless, dynamic x-ray was not suitable for patients with trauma in case of aggravation of symptoms. Besides, prevertebral edema signals from magnetic resonance (MR) and lesions from intervertebral space found during operation are potential factors of spinal instability (5).

For patients with instability from the anterior column, anterior cervical discectomy and fusion (ACDF) can achieve direct decompression of protrusions, restore intervertebral height, correct cervical alignment, and attain solid fusion. A stand-alone cage has less stability to obtain solid fusion (6). Anterior plating and cage system (APCS) was introduced thereafter to further stabilize the cervical spine in ACDF (7). However, relative complications were recognized as plate and screw fracture, malposition, loosening, dysphagia and future degeneration of adjacent levels (8–12).

The ROI-C peek cage device, a type of zero-profile anchored cage (ZPAC) implant without using anterior plating, has been developed as it can further increase cervical stability through 2 integrated self-locking clips compared with stand-alone cages (9, 10, 13). Currently, there is only few clinical research about the ROI-C device, and few studies concentrated on its application in TCCS. In the present study, we perform this retrospective clinical research to assess the efficacy of ACDF with ROI-C device vs. APCS in managing single-level symptomatic TCCS with potential instability.

# Materials and methods

## Characteristics of patients

This study was approved by the Institutional Ethics Committee of our institution. Informed consent was obtained from all individual participants included in the study. A total of 37 patients diagnosed with TCCS with potential instability underwent single-level ACDF with ROI-C implant (LDR, Troyes, France) and APCS (Medtronic, USA) were recruited in this retrospective study from June 2012 to February 2020. Patients' characteristics were summarized in Table 1. Data were collected and analyzed at admission preoperatively, postoperative at discharge, 3 months postoperatively, and at final follow-up time.

TABLE 1 Characteristics of patients.

| Characteristics | ROI-C | APCS |
|---|---|---|
| Number | 20 | 17 |
| Age (years) | 51.90 ± 9.64 | 50.00 ± 9.37 |
| Gender (male/female) | 17/3 | 13/4 |
| Follow-up time (months) | 25.00 ± 7.99 | 21.29 ± 7.41 |
| Inpatient days | 13.10 ± 4.18 | 13.24 ± 2.80 |
| Time before surgery (days) | 5.35 ± 2.52 | 5.59 ± 2.12 |
| Causes for trauma | | |
| Falling | 11 | 8 |
| Traffic accident | 6 | 7 |
| Sports | 3 | 2 |
| Levels operated | 20 | 17 |
| C3–4 | 8 (40.0%) | 2 (11.8%) |
| C4–5 | 6 (30.0%) | 5 (29.4%) |
| C5–6 | 6 (30.0%) | 8 (47.1%) |
| C6–7 | 0 (0.0%) | 2 (11.7%) |
| Operation time (minutes) | 89.40 ± 14.03* | 110.29 ± 12.31* |
| Intraoperative blood loss (ml) | 58.50 ± 7.72* | 93.53 ± 15.18* |

APCS, Anterior plating and cage system.
*Statistical significance achieved compared between groups ($P < 0.05$).

The inclusion criteria were: (1) incomplete single-level spinal cord damage symptom due to related trauma; (2) identified spinal cord compression sign, prevertebral edema signal from magnetic resonance, image (MRI) or lesion from intervertebral space found during operation; (3) no cervical vertebral fracture or dislocation. Exclusion criteria were: (1) severe brain damage, pre-traumatic neurological paralysis symptoms, and complete spinal cord injury; (2) history of cervical spine surgery; (3) multi-level spinal cord injury, cervical bony fracture, evident dislocation, subluxation, ossification of the posterior longitudinal ligament, infection, tumor, and severe osteoporosis; (4) severe spinal canal stenosis.

## Surgical procedure

After general anesthesia, patients were placed in supine position. An anterior Smith–Robinson approach was applied for exposure and distraction of intervertebral space. Intervertebral discs and endplate cartilage was removed without excessive scraping of the subchondral bone for preparation of arthrodesis and prevention of cage subsidence. The posterior longitudinal ligament was excised for further decompression of protrusions. For the ROI-C group, an appropriate-sized ROI-C implant was inserted into the intervertebral space monitored by fluoroscopy. After removal of the Caspar distracter, 2 anchoring clips were then installed in the up and lower vertebral body to achieve solid stabilization. For the plate and cage group, a suitable-sized cage and plate were placed, and self-tapping screws were fixed through the plate to the vertebrae.

## Radiological evaluation

All patients included underwent anteroposterior and lateral x-rays (**Figures 1**, **2**). Cobb's method was applied to measure cervical angle (CA)which was the angle between the lower vertebral endplate of C2 and the upper endplate of C7. The intervertebral height was calculated as the mean value of the anterior, midline, and posterior distance between the inferior endplate of the cephalad vertebral body to the superior endplate of the caudal vertebral body of the operated segment. Fusion was considered as the absence of a radiolucent gap between the graft and the endplate, and evidence of continuous bridging trabecular bone at the fusion interface. Computed tomography (CT) would be performed if there was any controversy in the determination of fusion. Subsidence was assessed according to the criteria of device penetration into the endplates for more than 3 mm (14, 15). Adjacent level degeneration (ALD) was detected based on narrowing of intervertebral space and new osteophyte formation at adjacent interspace (9).

## Clinical outcome assessment

Patients' operative time and intraoperative blood loss were recorded. ASIA (American Spinal Injury Association) Impairment Scale was applied to assess neurological status, which consists of 5 grades each (From A to E). Furthermore, ASIA Impairment Scale was evaluated through motor scores and sensory scores. Japanese Orthopaedic Association (JOA) score and the neck disability index (NDI) score were also evaluated. Recovery rate (RR) of JOA was calculated as (postoperative JOA scores- preoperative JOA scores)/(17-preoperative JOA scores) × 100%. RR of JOA was interpreted as ≥75% (excellent), 50% to 74% (good), 25% to 49% (fair),

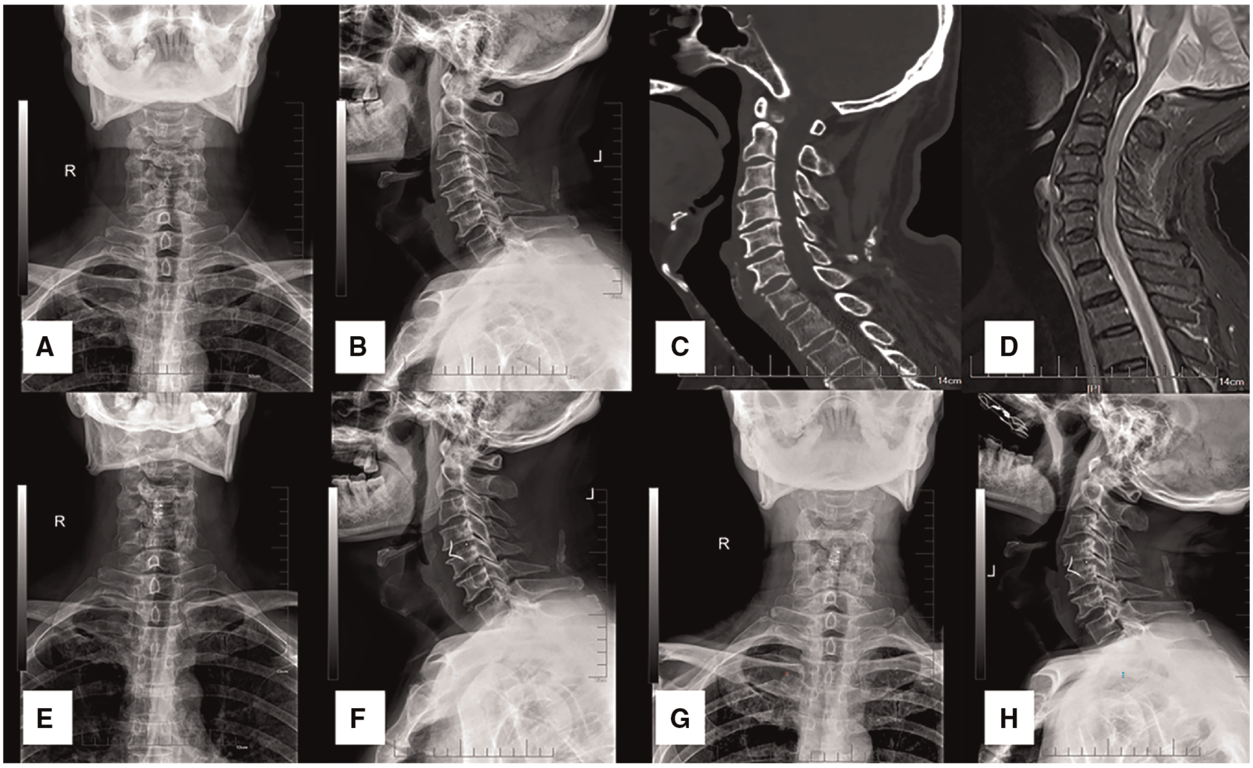


FIGURE 1
A 60-year-old male patient diagnosed with TCCS. (A,B) preoperative A-P and lateral x-ray showing the slight degenerative change of cervical spine with relative normal curvature, and conspicuous anterior osteophyte formation. (C) preoperative CT scan demonstrated no fracture or dislocation of the cervical spine. (D) preoperative MRI from short time inversion recovery (STIR) illustrated significant cervical spinal cord compression at C4–5 with spinal cord signal change at the same level, while evident prevertebral hyperintense and slight elevation of the ligament was also detected. (E,F) postoperative A-P and lateral x-ray at discharge indicate well positioned ROI-C device with normal CA and disc height. (G,H) the CA and disc height remained at final follow-up, and solid fusion was achieved.

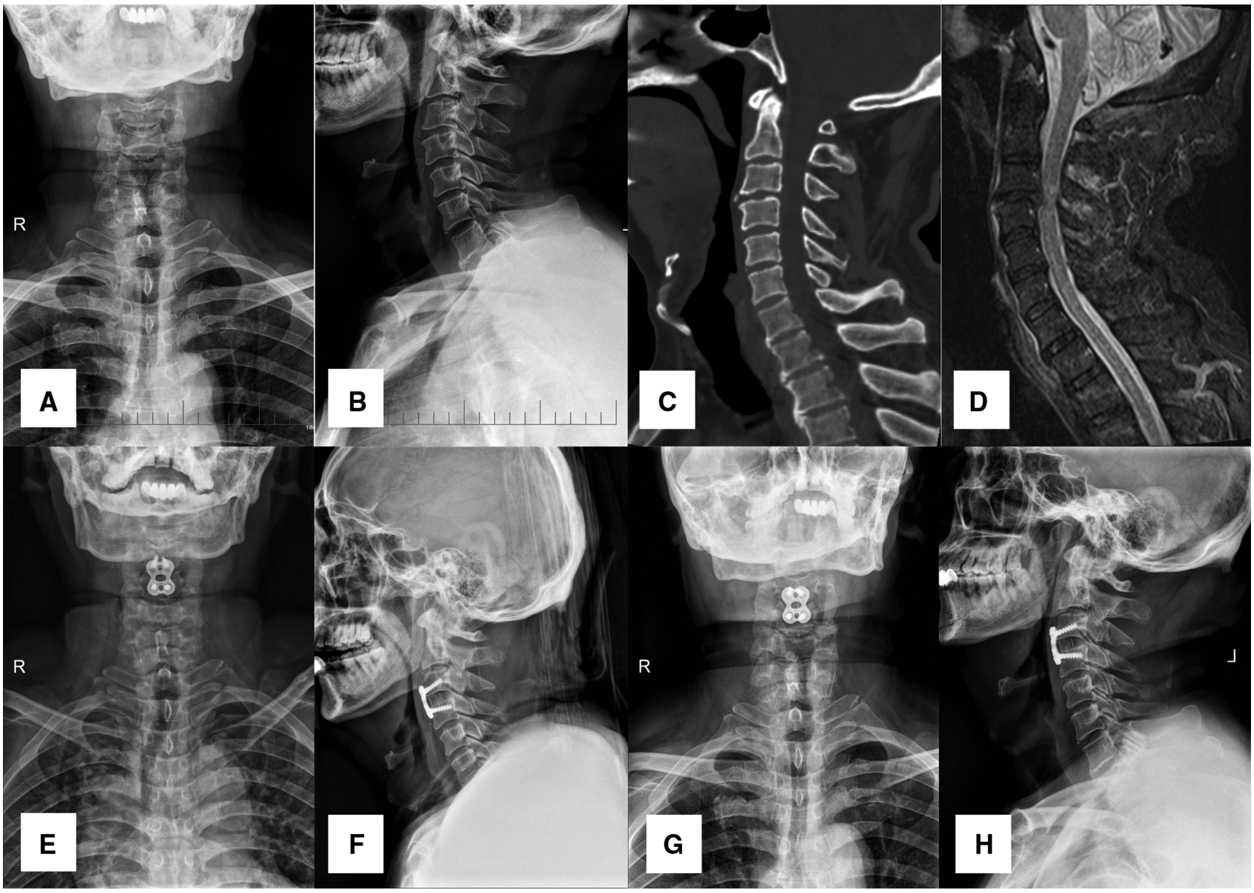


FIGURE 2
A 56-year-old male patient diagnosed with TCCS. (A,B) preoperative A-P and lateral X-ray images showing the slight degenerative change of cervical spine with relative normal curvature, and slight anterior osteophyte formation. (C) preoperative CT scan presented no fracture or dislocation of the cervical spine. (D) preoperative MRI from STIR displayed significant cervical spinal cord compression at C3-4 with spinal cord signal change at the same level, while distinct prevertebral hyperintense was also detected. (E,F) postoperative A-P and lateral X-ray images at discharge indicated APCS was in the appropriate site, and disc height was restored to a normal degree. (G,H) both CA and disc height were maintained at final follow-up.

and <25% (poor). Recovery rate of NDI was calculated as (preoperative NDI scores- postoperative NDI scores)/(preoperative NDI scores) × 100%. Similarly, recovery rate of ASIA scores was calculated as (postoperative ASIA scores- preoperative ASIA scores)/ (full scores- preoperative ASIA scores) × 100%. Dysphagia-related symptoms were identified according to the system defined by Bazaz (12).

## Statistical analysis

Continuous variables were presented as mean ± standard deviation. The normal distribution of the continuous variable was tested by Kolmogorov-Smirnov test. Unpaired Student's *t*-test was used to analyze the 2 procedures. A paired sample *t*-test was applied to test data between preoperative and postoperative status. Chi-square test was used to assess categorical variables. A *P*-value less than 0.05 was considered to be statistically significant. SPSS 19.0 (SPSS Inc, Illinois, USA) was used for statistical analysis.

# Results

The demographic data were revealed in **Table 1**. A total of 37 patients (30 males and7 females) with 37 levels achieved final follow-up. Twenty patients underwent 1-level ACDF with ROI-C device, and 17 patients received 1-level ACDF with APCS. The distribution of operated levels was presented in **Figure 3**. The mean age in the ROI-C group was 51.90 ± 9.64, and 50.00 ± 9.37 in the APCS group. The average follow-up time was 25.00 ± 7.99 months in the ROI-C group, and 21.29 ± 7.41 months in the APCS group. All devices were successfully implanted and anchored. ROI-C group had less operative time and less blood

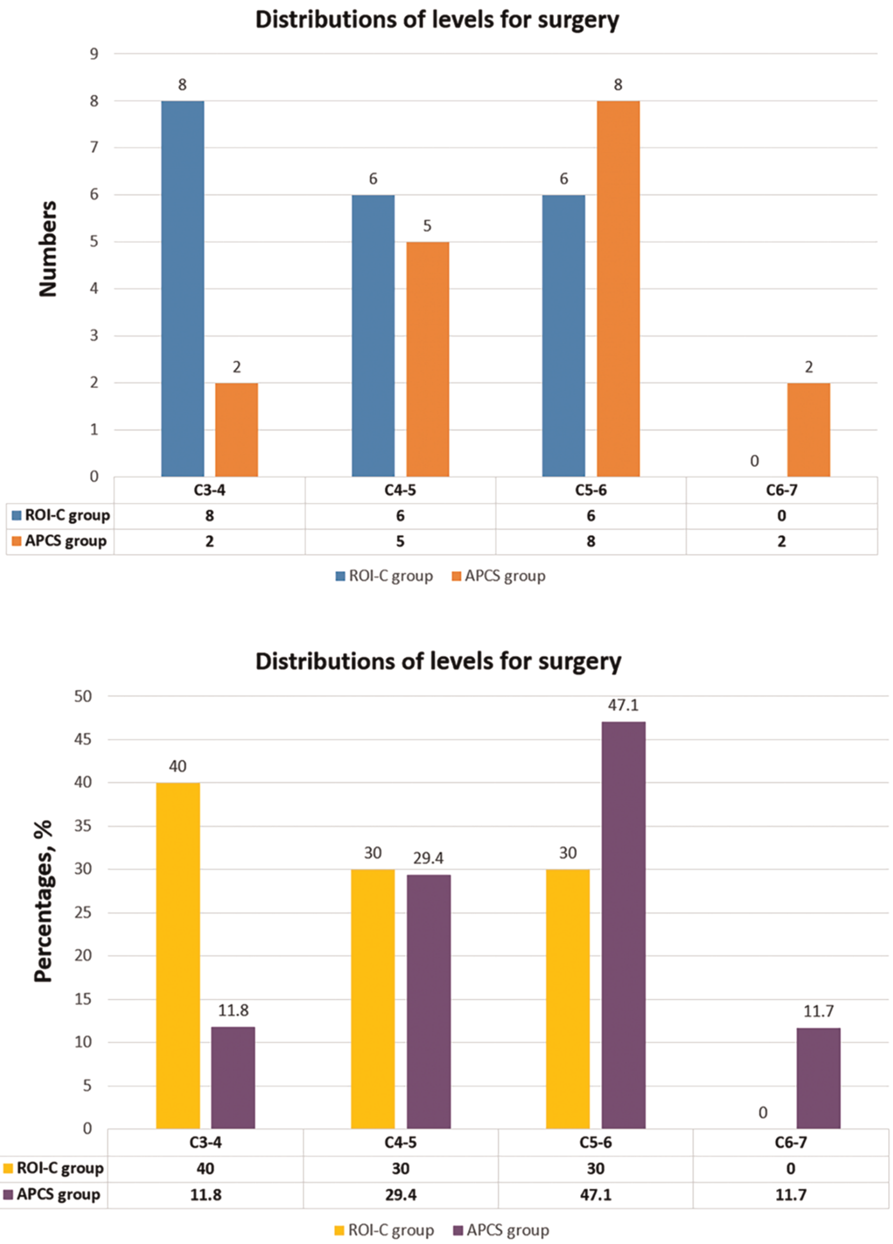


FIGURE 3
The distributions of levels for surgery in the ROI-C group and APCS group, exhibited as numbers and percentages.

loss than the APCS group (89.40 ± 14.03 min vs. 110.29 ± 12.31 min, $P < 0.05$; 58.50 ± 7.72 ml vs. 93.53 ± 15.18 ml, $P < 0.05$).

## Clinical evaluation

The preoperative JOA and NDI scores did not significantly differ between the ROI-C and APCS groups. Meanwhile, no statistical difference between each postoperative time point and final follow-up. However, the JOA scores and NDI improved significantly from preoperative to postoperative time points ($P < 0.05$) and were maintained at final follow-up in each group. There was no statistical difference between the 2 groups regarding RR of JOA, NDI, total motor scores and sensory scores at final follow-up ($P > 0.05$) (Table 2).

ASIA Impairment Scale and grading results were demonstrated in Tables 2, 3. All patients included ranged from C to D at admission. The upper and lower extremities motor scores were analyzed separately, and the preoperative difference value was >10. Significant improvement was detected postoperatively and maintained at 3 months postoperatively and final follow-up time compared with

TABLE 2 Clinical assessment of JOA, NDI, ASIA scores and radiographic measurement.

| | ROI-C | APCS |
|---|---|---|
| JOA scores | | |
| Admission | 8.85 ± 0.81 | 8.82 ± 0.95 |
| Discharge | 13.55 ± 1.47* | 13.35 ± 1.12* |
| Postoperative 3 months | 14.45 ± 1.19* | 14.35 ± 0.93* |
| Final follow-up | 14.95 ± 0.99* | 14.88 ± 0.78* |
| Recovery rate | 75.14 ± 11.29 | 73.42 ± 8.15 |
| NDI scores | | |
| Admission | 34.25 ± 4.28 | 33.82 ± 4.45 |
| Discharge | 14.65 ± 3.36* | 15.65 ± 3.99* |
| Postoperative 3 months | 12.90 ± 2.63* | 13.65 ± 3.28* |
| Final follow-up | 11.15 ± 1.95* | 11.88 ± 2.57* |
| Recovery rate | 67.48 ± 3.52 | 65.19 ± 3.83 |
| ASIA scores | | |
| Upper extremities motor scores | | |
| Admission | 21.05 ± 3.24 | 20.76 ± 3.17 |
| Discharge | 30.45 ± 3.39* | 30.07 ± 4.07* |
| Postoperative 3 months | 34.10 ± 3.21* | 34.47 ± 4.09* |
| Final follow-up | 38.10 ± 3.42* | 37.65 ± 3.67* |
| Recovery rate | 58.96 ± 10.99 | 57.25 ± 12.79 |
| Lower extremities motor scores | | |
| Admission | 37.15 ± 2.09 | 36.59 ± 3.28 |
| Discharge | 41.10 ± 1.94* | 39.94 ± 3.15* |
| Postoperative 3 months | 42.80 ± 1.96* | 41.94 ± 2.66* |
| Final follow-up | 45.05 ± 1.82* | 43.94 ± 2.01* |
| Recovery rate | 61.97 ± 10.82* | 54.75 ± 9.18* |
| Total motor scores | | |
| Admission | 58.20 ± 4.73 | 57.35 ± 5.50 |
| Discharge | 71.55 ± 4.49* | 70.65 ± 5.97* |
| Postoperative 3 months | 76.90 ± 4.29* | 76.41 ± 5.21* |
| Final follow-up | 83.15 ± 3.84* | 81.58 ± 4.46* |
| Recovery rate | 59.74 ± 7.87 | 56.23 ± 9.05 |
| Difference of upper and lower extremities motor score | | |
| Admission | 16.10 ± 2.69 | 15.82 ± 3.38 |
| Discharge | 10.65 ± 3.23* | 9.23 ± 4.18* |
| Postoperative 3 months | 8.70 ± 3.15* | 7.47 ± 4.53* |
| Final follow-up | 6.95 ± 3.90* | 6.29 ± 3.90* |
| Sensory scores | | |
| Admission | 79.15 ± 9.48 | 78.59 ± 7.90 |
| Discharge | 103.95 ± 14.26* | 102.29 ± 12.49* |
| Postoperative 3 months | 144.20 ± 14.78* | 141.35 ± 12.44* |
| Final follow-up | 147.65 ± 15.02* | 144.88 ± 12.26* |
| Recovery rate | 47.60 ± 7.72 | 45.74 ± 7.04 |
| CA (degree, °) | | |
| Admission | 13.82 ± 2.58 | 13.86 ± 3.38 |
| Discharge | 17.57 ± 2.26* | 17.71 ± 2.91* |
| Postoperative 3 months | 17.16 ± 2.11* | 17.46 ± 2.94* |
| Final follow-up | 16.97 ± 2.07* | 17.35 ± 2.93* |

(continued)

TABLE 2 Continued

| | ROI-C | APCS |
|---|---|---|
| Disc height (mm) | | |
| Admission | 4.63 ± 0.50 | 4.43 ± 0.40 |
| Discharge | 6.16 ± 0.45* | 6.24 ± 0.63* |
| Postoperative 3 months | 5.96 ± 0.50* | 6.13 ± 0.64* |
| Final follow-up | 5.81 ± 0.50* | 6.06 ± 0.61* |

JOA, Japanese Orthopaedic Association; NDI, neck disability index; ASIA, American Spinal Injury Association; CA, cervical angle.
*Statistical significance achieved compared to preoperative value ($P < 0.05$).

preoperative values. No significant differences were detected between the two groups at each follow-up time.

## Radiological assessment

The radiological outcomes were illustrated in Table 2. The preoperative CA and disc height of operated level did not

TABLE 3 ASIA grading for neurological status.

| | ROI-C ($n = 20$) | APCS ($n = 17$) |
|---|---|---|
| Admission | | |
| A | 0 | 0 |
| B | 0 | 0 |
| C | 5 | 4 |
| D | 15 | 13 |
| E | 0 | 0 |
| Discharge | | |
| A | 0 | 0 |
| B | 0 | 0 |
| C | 2 | 2 |
| D | 12 | 13 |
| E | 4*,** | 2*,** |
| Postoperative 3 months | | |
| A | 0 | 0 |
| B | 0 | 0 |
| C | 0 | 0 |
| D | 4 | 3 |
| E | 16*,** | 14*,** |
| Final follow-up | | |
| A | 0 | 0 |
| B | 0 | 0 |
| C | 0 | 0 |
| D | 1 | 1 |
| E | 19*,** | 16*,** |

*Significant difference compared with the previous time point ($\chi^2$ test), $P < 0.05$.
**Significant difference compared with preoperative time point at admission ($\chi^2$ test), $P < 0.05$.

vary between the 2 groups ($P > 0.05$). In both groups, the CA and disc height of operated level significantly increased postoperatively ($P < 0.05$) and maintained at 3 months postoperatively and in the final follow-up, respectively.

## Complications

Fusion was achieved in all patients. No deep infections, hematomas, bolt loosening, or breakage of anchoring clips, screws, or titanium plates were observed in both groups during the follow-up period. There were 2 patients complained of postoperative mild dysphagia (2/20, 10.0%) in the ROI-C group and 8/17 (47.1%) in the APCS group at discharge, which all recovered within 3 weeks. There was a statistical difference between the 2 groups as the ROI-C group had a lower incidence of dysphagia than the APCS group postoperatively ($P < 0.05$). Only 1 case of ALD was observed at final follow-up in the APCS group with no significant difference ($P < 0.05$). No subsidence was detected in both groups.

# Discussion

The distinctive clinical characteristic of TCCS distinguished from other types of SCIs is exhibited as disproportionate impairment of the upper limbs compared with the lower limbs in motor function damage. MH Pouw et al. (16) stratified TCCS through a quantitative and reproducible diagnostic criterion. Moreover, the subsequent study demonstrated a minimal difference of 10 ASIA motor score points between the upper and lower extremities, in favor of the lower extremities in TCCS patients (17, 18). This quantified criterion is consistent with the result of our study as all patients in both groups had great than 10 points differences between upper and lower extremities motor scores at admission, which made the selection of the targeted population more accurate. However, for injury at the lower cervical level (C7- T1), this difference was regarded to be too high. In addition, there was no patient included with spinal impairment below the level of C6–7 in our study, which is similar to the previous research (18).

Segment instability is an explicit indication for surgery, as increased range of motion at injured level of the cervical spine may lead to further compression of spinal cord. Assessment of discoligamentous complex is important in determining spinal stability. However, in patients with TCCS without cervical vertebral fracture or dislocation, the conventional radiographic assessment of stability has limited ability, because lateral radiographs in maximum extension are not recommended to avoid further spinal cord impairment (19). Although MRI findings cannot match all signs intraoperatively, it still has an acceptable sensitivity in detecting segment instability by inspecting anterior longitudinal ligament (ALL) disruption manifested as discontinuity of the hypointense band with prevertebral hyperintense or elevation of the ligament from adjacent structures. In the present study, all patients had prevertebral hyperintense signal preoperatively, and all confirmed appearing ALL rupture intraoperatively, indicating spinal instability.

ACDF can achieve direct decompression of spinal cord or nerve roots, reconstruction of cervical lordotic alignment, improvement of intervertebral height, solid fusion with smaller trauma, and less blood loss. Anterior decompression and intervertebral autologous bone grafting without fixation have been demonstrated to have an ideal incidence of fusion (20). However, it can result in graft displacement, subsidence, further damage to the nerve, kyphotic deformity change, and donor site complications (7). APCS can provide extra stability. However, it is connected with the following complications: plate and screw displacement, loosening, patient dysphagia, and future degeneration of adjacent discs (8, 9, 11, 21). Integrated with characters of both, ZPAC implant was invented with various designs. With no prevertebral occupation, ZPAC has been demonstrated with a relatively lower incidence of dysphagia than APCS, while similar fusion rate, JOA score improvement, and cervical lordosis were observed for single or multiple levels uses in contrast with APCS (8, 9, 14, 22). This was consistent with our findings as ROI-C device was related to a lower incidence of postoperative dysphagia, shorter operation time and less blood loss.

Several *in vitro* biomechanical studies were conducted with different versions of ZPAC. Scholz et al. (23) compared the locked version of ZPAC with APCS in 1-level ACDF, while Clavenna et al. (24) later compared the variable-angle version of ZPAC with APCS in 2 and 3-level ACDF. Their results were similar as no significant difference was detected in ROM during flexion-extension, lateral bending or axial rotation, although APCS displayed slightly better stability in flexion-extension, deducing equivalent stability of the 2 devices. Paik et al. (25) demonstrated that no difference was achieved in ROM between another sort of variable-angle screw version of ZPAC and APCS in 1-level application, but less stability was observed in ZPAC when operated in 2–3 levels. Their explanation was different designs of devices as screws of ZPAC did not provide lag compression or solid locking. The ROI-C device, integrated with 2 anchoring locking clips, enhances the stability of stand-alone cages (9, 10, 13). ROI-C has been proven to be an effective method for 1–2 level ACDF or even treating Hangman fracture (9, 10, 13). Interestingly, it remains obscure how much stability or ROM reduction is required for solid interbody fusion (26) as the weakness in flexion-extension of ZPAC did not influence the clinical results. In our study, all patients who underwent single-level ACDF with ROI-C showed significant improvement in JOA, NDI and ASIA scores, and fusion was achieved in all cases. These may be attributed to our cautious management: (1) optimal preparation of fusion surface without excessive damage to the bony endplate; (2) neck brace was used routinely postoperatively; (3) few osteoporotic patients were operated in this study, while it was usually encountered in cadaveric biomechanical researches.

Both CA and disc height significantly increased in ROI-C group in our study, which was consistent with previous studies treating cervical spondylotic myelopathy, indicating its good efficacy in restoring cervical alignment. However, during the postoperative 3 months of follow-up and later final follow-up, a slight loss of CA and disc height were observed without statistical significance. No subsidence was detected. Nevertheless, no clip breakage, displacement or loosening happened during each follow-up time. Apart from the advantages of the device, it may partly be due to the relatively young age and good bone quality of patients.

Plate thickness of APCS device is considered a primary factor that results in postoperative dysphagia as it may cause impingement or irritation to the ventral esophagus (21). ROI-C device is embedded in intervertebral space without protrusion at prevertebral space, which can reduce the incidence of dysphagia (8–10, 14, 27). However, intraoperative traction and mechanical stimulation of prevertebral tissues, postoperative local edema, hematoma and operation time also play roles in causing dysphagia after ACDF (27). ROI-C retrenches the operation time while ACPS has to consume more in preparing for plate installation, measurement and adjustment. Furthermore, different from the previous Zero-*P* device, no screw is applied in ROI-C devices (9, 10), which avoided various problems during screw insertion and further loosening. Fortunately, the dysphagia after ACDF is usually temporary, and most of them are relieved within 3 months postoperatively (8, 12, 27).

There exists a long-standing controversy about the optimal timing for surgery in patients with TCCS. Urgent surgery (≤24 h of injury) is recommended for acute instability of dislocation and progressive neurologic deficit, and it was associated with better recovery than delayed surgery or conservative treatment. However, the definition of early decompression is fuzzy as various studies set 24 h or 72 h as the time limit (3). Lenehan et al. (28) suggested that it is reasonable and safe to consider early surgical decompression in patients with a profound neurologic deficit (ASIA = C) and persistent spinal cord compression due to developmental cervical spinal canal stenosis without fracture or instability, while patients with a slight deficit (ASIA = D) could be treated with initial observation with surgery potentially at a later date depending on the extent and temporal profile of the patients' neurologic recovery. In our study, the average time before operation is beyond 72 h in both groups. The plausible explanations are indicated as follows: (1) a majority of patients included in the study are ASIA D, which opportunities could be given for observation before surgery according to the above viewpoint; (2) some patients were accompanied with underlying diseases such as associated slight injuries in brain and chest, which need careful consideration before surgery. Although relative late surgery time was observed in the current study, significant neurologic improvement was achieved at subsequent follow-up time.

The following limitations of this study were noted: (1) the retrospective character and small sample size; (2) MRI was not performed routinely in detecting ALD, which early degeneration may be neglected. Further large sample size, well-designed prospective randomized trials could be conducted comparing ROI-C and APCS devices in multilevel applications.

## Conclusion

Both ROI-C device and APCS demonstrated satisfactory clinical effects and safety in managing symptomatic single-level TCCS with underlying instability. Both techniques could improve and maintain cervical lordosis and disc height. ROI-C device was related to a lower incidence of postoperative dysphagia, shorter operation time, and less blood loss.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

## Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

DS Conceptualization, Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization; ZD Methodology, Writing - Original Draft, Software, Formal analysis, Resources; TF Visualization, Supervision, Data Curation, Validation; JW Methodology, Software, Formal analysis, Resources; YL Software, Formal analysis, Resources, Data Curation; HW Software, Formal analysis, Resources, Data Curation; HY Visualization, Supervision, Project administration, Writing - Review & Editing, Validation; JN Conceptualization, Methodology, Writing - Original Draft, Writing - Review &

Editing, Visualization, Supervision. All authors contributed to the article and approved the submitted version.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

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Plauto Christopher A. Watanabe,
University of São Paulo, Brazil
Zhonghai Li,
First Affiliated Hospital of Dalian Medical University, China
Xiaoji Luo,
Chongqing Medical University, China

*CORRESPONDENCE
Hao Liu
liuhaospine@163.com

†These authors share first authorship

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# The predictive value of Hounsfield units for titanium mesh cage subsidence after anterior cervical corpectomy and fusion

Haimiti Abudouaini[†], Tingkui Wu[†], Hao Liu*, Beiyu Wang and Hua Chen

Department of Orthopedic Surgery, West China Hospital, Sichuan University, Chengdu, China

**Objective:** To investigate whether bone mineral density (BMD) measured in Hounsfield units (HUs) correlates with titanium mesh cage (TMC) subsidence after anterior cervical corpectomy and fusion (ACCF).
**Methods:** A total of 64 patients who underwent one or two levels of ACCF with TMC with a mean follow-up of 19.34 ± 7.86 months were analysed. HU values were measured three times in 3 different planes in the upper and lower vertebrae according to published methods. Subsidence was defined as segmental height loss of more than 3 mm. Pearson correlation analysis was performed. Receiver operating characteristic (ROC) curve analysis was used to obtain optimal thresholds. A multivariate logistic regression analysis was also conducted.
**Results:** Twenty-two patients (34.38%) had evidence of TMC subsidence on follow-up x-ray. The mean HU values in the subsidence group (317.34 ± 32.32, $n = 22$) were significantly lower than those in the nonsubsidence group (363.07 ± 25.23 $n = 42$, $p < 0.001$, *t* test). At last follow-up, mean disc height loss was 4.80 ± 1.16 mm in the subsidence group and 1.85 ± 1.14 mm in the nonsubsidence group ($p < 0.001$). There was a negative correlation between HU values and disc height loss (Pearson's coefficient −0.494, $p < 0.001$). HU values decreased gradually from the C3 vertebra to the C7 vertebra, and the HU values of the C5, C6, and C7 vertebrae in the nonsubsidence group were significantly higher than those in the subsidence group ($p < 0.05$). Furthermore, there were significant differences between the groups in the segmental angle at the last follow-up and the mean changes in segmental angle ($p < 0.05$). The area under the ROC curve was 0.859, and the most appropriate threshold of the HU value was 330.5 (sensitivity 100%, specificity 72.7%). The multivariate logistic regression analysis showed that older age ($p = 0.033$, OR = 0.879), lower LIV HU value ($p < 0.001$, OR = 1.053) and a greater segmental angle change ($p = 0.002$, OR 6.442) were significantly associated with a higher incidence of TMC subsidence after ACCF.
**Conclusion:** There are strong correlations between a lower HU value and TMC subsidence after ACCF. More accurate assessment of bone quality may be obtained if HU measurement can be used as a routine preoperative screening method together with DXA. For patients with HU values <330.5, a more comprehensive and cautious preoperative plan should be implemented to reduce TMC subsidence.

KEYWORDS

anterior cervical corpectomy and fusion, ACCF, Hounsfield units, subsidence, bone mineral density

## Introduction

Reconstruction of the cervical spine with titanium mesh cages (TMCs) has been widely used in anterior cervical corpectomy and fusion (ACCF) (1, 2). Although many previous studies report satisfactory decompression, rapid stabilization and a relatively high fusion rate (ranging from 95% to 100%) (3), subsidence of the TMC is a major concern before implementing ACCF. Indeed, cage subsidence after ACCF may lead to ligamentum flavum wrinkles and neural foramen stenosis, segmental instability, non-union, or postoperative kyphosis, with some patients even requiring revision surgery (4, 5).

Several papers have reported a close relationship between bone mineral density (BMD) and postoperative cage subsidence in both the lumbar and cervical spines (6–8). The DXA (dual-energy x-ray absorptiometry) technique is widely used to evaluate preoperative bone quality before spinal surgery. DXA assesses BMD by measuring the T-score of both hips and waist 1–4 to represent the whole-body bone quality. However, previous literature shows that measurement error may occur when evaluating the bone mass of spine vertebra using DXA examination (9–11). Moreover, there is still insufficient evidence to prove the accuracy of assessing the bone mass of the cervical vertebrae with T-score measured in the hip bone and lumbar spine. Although local trabecular BMD can be accurately obtained through quantitative CT (QCT) (12), the popularity of QCT remains very low in China and is also costly.

Several studies have found that Hounsfield units (HU) measured by CT are associated with cage subsidence after lumbar surgery (13–15). To the best of our knowledge, there are few reports on the relationship between TMC subsidence and HU values in ACCF (16). Therefore, in this study, we sought to determine associations between preoperative CT HU and post-ACCF TMC subsidence and to identify patients who are at high risk for severe subsidence.

## Materials and methods

### Study population and criteria

Patients who underwent single- and two-level ACCF using a titanium mesh cage (Medtronic Sofamor Danek) from March 2011 to December 2019 were included. All surgeries were performed by one surgeon. The study's indication for ACCF included posterior osteophytes of the vertebrae, ossified posterior longitudinal ligament (OPLL) and prolapse of the free nucleus pulposus between the C3/4 and C6/7 levels that did not respond to conservative treatment for at least 6 weeks or resulted in progressive symptoms of nerve root/spinal cord compression. All patients were followed up clinically and radiographically for a minimum of 12 months. Patients undergoing anterior cervical discectomy and fusion (ACDF), revision surgery and history of surgery, trauma or tumor at the C1–C7 level, and severe osteoporosis (T-score ≤−2.5), Patients with endplate injury were excluded. Besides, patients with lack of clinical and radiological data or lost follow-up were also excluded and patients only with complete clinical, radiological, and follow-up data were included.

### Surgical procedure

After general anesthesia, the patient was maintained in the supine position with the neck slightly extended. The Smith-Robinson approach was used in all cases. After the intervertebral space was expanded, discectomy and removal of vertebral bodies were performed, and autologous bone was applied as bone graft material. Then, the osteophytes and posterior longitudinal ligament were removed, and the endplate was carefully prepared. After adequate decompression, a TMC with an appropriate size was selected and filled with autologous bone fragments. The TMC was then inserted into the corpectomy defect, and fluoroscopy was used to confirm the cage location. Last, a suitably sized anterior cervical locking plate system was used in all cases for further stabilization. After surgery, all patients were advised to wear a soft neck collar for 6 weeks.

### Radiographic evaluation

HU was measured at vertebrae above and below the titanium mesh cage placement (e.g., C4 ACCF had C3 and C5 vertebral bodies measured for HU). The measurement method proposed by Schreiber et al. (17) was used to evaluate the vertebral body HU values. The HU value was measured three times in the upper and lower vertebrae by selecting the elliptical region of interest (ROI) on sagittal, mid-coronal and mid-axial plane CT image reconstruction, and the average value was defined as the final HU (**Figure 1A**). The connecting line between the midpoint of the upper endplate of the upper vertebra and the midpoint of the lower endplate of the lower vertebra was defined as the disc height (Figure 1B). Disc height measurements were recorded before surgery, at the initial postoperative radiograph (within 7 days after surgery) and at the final follow-up; the difference between the last follow-up and initial postoperative disc height was defined as the loss in disc height. Subsidence was defined as a disc height loss >3 mm or TMC migration (angular deviation >3 degrees in lateral and AP plane) into the endplate at the final follow-up (4). The $C_{2-7}$ angle was the angle between the caudal margin of $C_2$ and the caudal margin of $C_7$ at the neutral position. The segmental angle was the angle formed by lines drawn at the cranial margin of the superior vertebral body and at the caudal margin of the inferior body (Figure 2). Solid bone fusion was defined as the establishment of a solid bone bridge between fusion segments on the last follow up reconstructed CT scans.

To reduce measurement errors, an independent panel of radiologists was established in our study. The panel consisted of three study-blinded radiologists. Among them, two radiologists were responsible for data collection while the remaining one was responsible for data analysis. In case differences between the first two collected sets of data were relatively large (e.g., more than 10 HU value, 2 degrees or 2 mm), the third radiologist was responsible for confirmative remeasuring.

## Statistical methods

All statistical analyses were performed using SPSS 25.0 software (SPSS Inc., Chicago, IL, USA). Continuous data are presented as the mean ± standard deviation. Independent t tests were used to detect differences, including HU values and disc height, between patients with and without TMC subsidence. Chi-square analysis and Fisher's exact test were applied to assess differences between groups for categorical variables. Correlations were analysed using Pearson

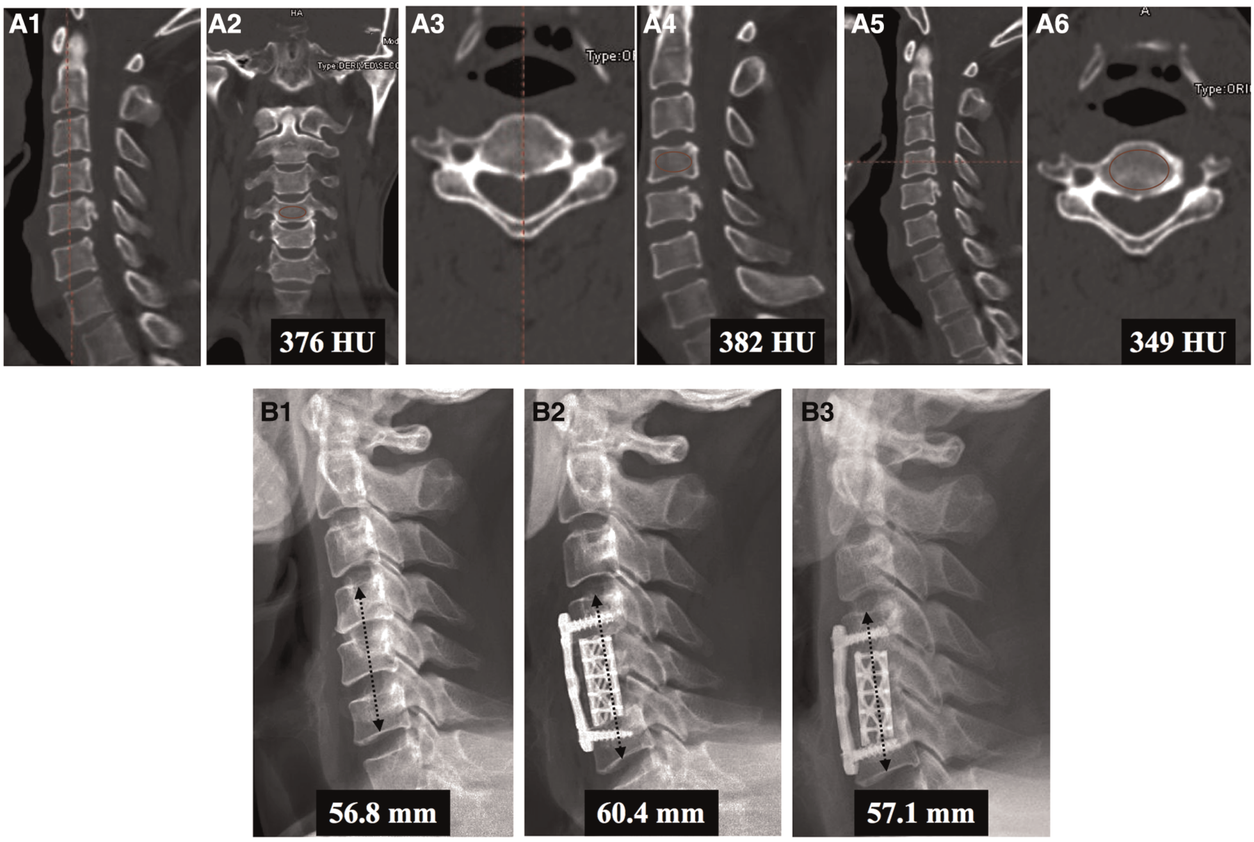


FIGURE 1
Measurement method of the HU value in C5 ACCF. (A) First, HU values of the C4 vertebral body were calculated. The HU values of the mid-sagittal (A1,A2), mid-coronal (A3,A4), and mid-axial (A5,A6) planes were measured. The same method was used to calculate the HU values of the C6 vertebral body. (B) Illustration of the method for measuring disc height. Disc height was defined as the straight line between the midpoint of the lower endplate of the upper vertebra and the midpoint of the upper endplate of the lower vertebra. Disc height was measured before surgery (B1) and within 3 days after surgery (B2) and at the final follow-up (B3). This patient was assessed to have subsidence due to height loss greater than 3 mm at the final follow-up (1.5 years after surgery).

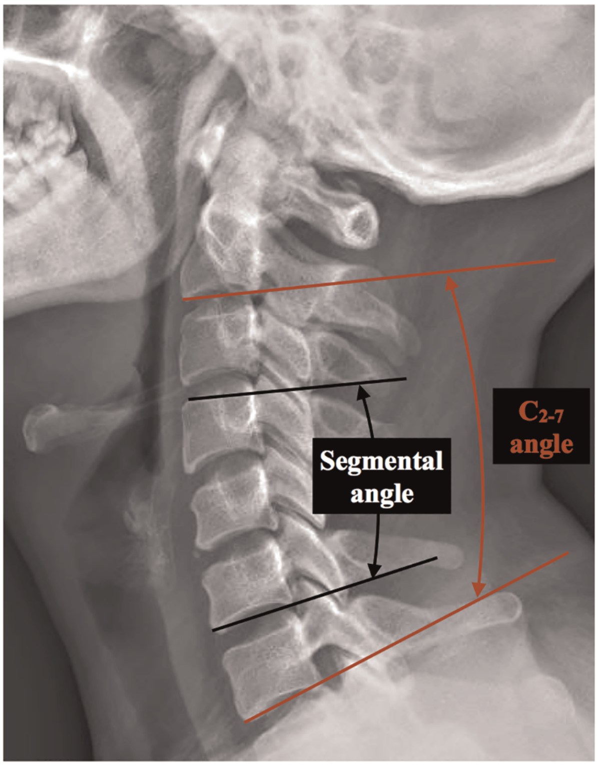


FIGURE 2
Measurement method of the global and segmental cervical curvature. The C2–7 angle was defined as the angle between the caudal margin of C2 and the caudal margin of C7 in a neutral position. The segmental angle was defined as the angle formed by lines drawn at the cranial margin of the upper instrumented vertebral body and the caudal margin of the lower instrumented vertebral body.

TABLE 1 Preoperative information and disc height of the patients.

| Variable | Value |
|---|---|
| Number of patients | 64 |
| Age (years) | 51.29 ± 9.98 |
| BMI (kg/m$^2$) | 23.16 ± 3.68 |
| Sex (*n*) | |
| Male | 37 |
| Female | 27 |
| Follow-up (months) | 19.34 ± 7.86 |
| Level number and distribution (*n*) | |
| One level | |
| C4 | 10 |
| C5 | 36 |
| C6 | 13 |
| Two level | |
| C4 + 5 | 1 |
| C5 + 6 | 4 |
| T-score | −0.24 ± 1.30 |
| Disc height (mm) | |
| Preoperative | 49.10 ± 5.26 |
| 1 week | 64.80 ± 4.32 |
| Final follow-up | 59.02 ± 4.83 |
| Mean change | 2.86 ± 1.82 |

Change of disc height, disc height at 1 week after surgery—disc height at last follow-up.

correlation. The optimal cut-offs of the HU value were established using a receiver operating characteristic (ROC) curve, and the area under the curve (AUC) was calculated. The maximum Youden index was used to determine the optimal cut-off value of Hounsfield units. Patients were classified according to the HU threshold value, as determined by ROC curve analysis. A multivariate logistic regression analysis was also conducted. For all statistical analyses, 95% confidence intervals were obtained; $p < 0.05$ (two-sided) was the criterion for statistical significance.

## Results

A total of 64 patients met the inclusion criteria (Table 1). All patients were followed up for at least 1 year (mean 19.34 ± 7.86 months). Of the 64 patients, 22 (34.38%) developed TMC subsidence, and 42 were classified into the nonsubsidence group. There were no significant differences in sex, BMI, level number or distribution, T-score between the subsidence and nonsubsidence groups (Table 2). The average age in the subsidence group was 55.85 ± 9.43 and 48.95 ± 9.54 years in nonsubsidence group. The average age in subsidence group was significantly higher than the average age in nonsubsidence group ($p = 0.017$). The mean HU value in the subsidence group was 317.34 ± 32.32, which was significantly lower than the mean HU value of the nonsubsidence group, at 363.07 ± 25.23 ($p < 0.001$; Table 2). The mean height loss in the nonsubsidence and subsidence groups was 1.85 ± 1.14 and 4.80 ± 1.16 mm, respectively ($p < 0.001$; Table 2).

Pearson correlation analysis revealed a significant negative correlation between preoperative HU values and postoperative disc height loss ($r = -0.494$, $p < 0.001$; Figure 3). HU values decreased gradually from the C3 vertebra to the C7 vertebra, and the HU values of the C5, C6, and C7 vertebrae in the nonsubsidence group were significantly higher than those in the subsidence group ($p < 0.05$, Table 3). Furthermore, there were no significant differences in global cervical curvature between the 2 groups ($p > 0.05$, Table 4). In the nonsubsidence group, the segmental angle was improved from 1.63 ± 2.01° before surgery to 3.26 ± 2.03° at the last follow-up, with a mean change value of −0.15 ± 0.60°. In the subsidence group, it decreased from 1.67 ± 2.78° before surgery to −1.19 ± 4.10 at the last follow-up, and the mean change value

TABLE 2 Preoperative information and HU between patients with and patients without subsidence.

| Variable | Subsidence group ($n = 22$) | Control group ($n = 42$) | $p$ value |
|---|---|---|---|
| Age (years) | 55.85 ± 9.43 | 48.95 ± 9.54 | **0.017** |
| BMI (kg/m$^2$) | 23.02 ± 3.46 | 23.23 ± 3.82 | 0.737 |
| Sex ($n$) | | | 0.274 |
| Male | 14 | 23 | |
| Female | 8 | 19 | |
| Follow-up (months) | 19.09 ± 6.58 | 19.48 ± 8.52 | 0.915 |
| One/Two level | 21/1 | 38/4 | 0.371 |
| T-score | −0.46 ± 1.21 | −0.13 ± 1.34 | 0.334 |
| Mean HU value | 317.34 ± 32.32 | 363.07 ± 25.23 | **<0.001**[a] |
| No. >330.5 HU | 6 | 42 | **0.001**[b] |
| No. <330.5 HU | 16 | 0 | |
| Mean height loss (mm) | 4.80 ± 1.16 | 1.85 ± 1.14 | **<0.001**[a] |

Bold values represents that the results have statistical significance.
[a]Independent *t*-test.
[b]Fisher's exact test.

was −3.73 ± 3.53. There were significant differences between the groups in the segmental angle at the last follow-up and the mean changes in segmental angle ($p < 0.001$) (**Table 4**).

The AUC of the ROC curve was 0.859 (95% CI: 0.748–0.971; **Figure 4**), and the optimal cut-off was 330.5, with a sensitivity of 100% and a specificity of 72.7%. Fisher's exact test showed that patients with <330.5 HU were more prone towards TMC subsidence ($p = 0.001$, **Table 2**).

The age, gender, surgical level, HU value of upper instrumented vertebra (UIV) and lower instrumented vertebra (LIV), T-score, segmental angle change and preoperative disc height were elected to undergo multiple logistic regression analysis. The results showed that older age ($p = 0.033$, OR = 0.879), lower LIV HU value ($p < 0.001$, OR = 1.053) and a greater segmental angle change ($p = 0.002$, OR 6.442) were significantly associated with a higher incidence of TMC subsidence after ACCF (**Table 5**).

## Discussion

In this study, imaging data of 64 patients undergoing anterior cervical corpectomy with TMC fusion were retrospectively reviewed. TMC subsidence was observed in 22 (34.38%) patients in our study, which is roughly consistent with previous studies (3, 16). However, the subsidence standard varies among studies. Majority of previous articles have used the disc height loss >3mm (4, 16–19) to define the TMC subsidence, whereas others have used 4 mm (20) or 2 mm (21) as a threshold. If subsidence is defined as a definite disc height loss >3 mm, then the subsidence rate of ACCF with TMC fluctuates between 12% and 80% in previous studies (3–5, 17, 22). To the best of our knowledge, there is no consensus in the literature regarding an accurate relationship between TMC subsidence and clinical outcomes. For example, Chen et al. (4) reported that 7% of single-level and 12% of two-level patients with corpectomy developed TMC subsidence, which might have led to poor clinical

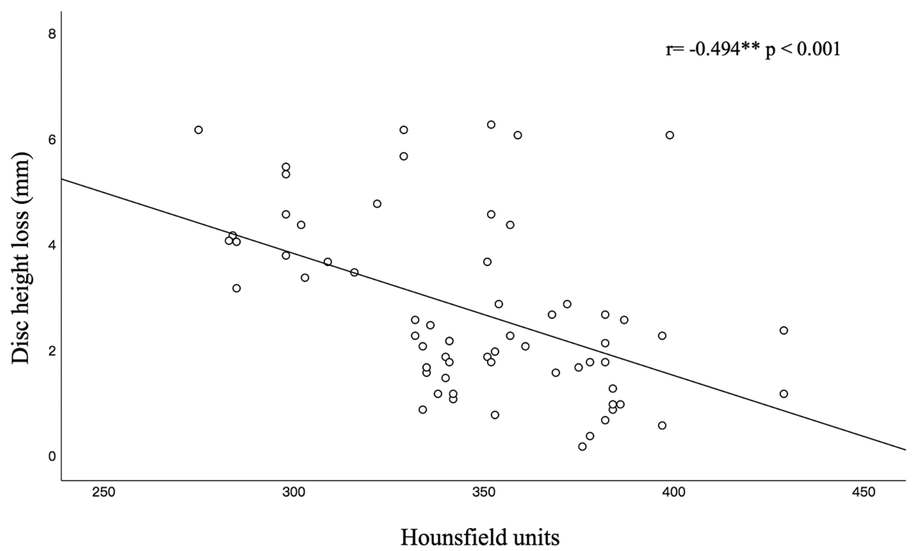


FIGURE 3
Linear correlation (black line) between HU and the TMC subsidence correlation coefficient ($r$) at the overall cervical vertebrae. Significant correlation coefficients are indicated by asterisks.

TABLE 3 Mean HU values of different subaxial cervical vertebrae in patients.

| Level | Total ($n = 64$) | Mean vertebral HU | | $p$ value |
|---|---|---|---|---|
| | | Subsidence ($n = 22$) | Non-subsidence ($n = 42$) | |
| C3 | 397.18 ± 42.54 | 398.67 ± 64.08 | 397.03 ± 41.40 | 0.951 |
| C4 | 383.09 ± 57.13 | 378.52 ± 55.30 | 385.55 ± 58.30 | 0.523 |
| C5 | 354.57 ± 62.15 | 311.63 ± 52.26 | 376.04 ± 55.67 | **<0.001** |
| C6 | 312.04 ± 54.29 | 276.12 ± 40.08 | 332.20 ± 50.47 | **<0.001** |
| C7 | 297.10 ± 42.95 | 272.38 ± 30.23 | 319.07 ± 40.91 | **<0.001** |

Bold values represents that the results have statistical significance.

TABLE 4 Comparison of the global and segmental cervical curvature between the groups.

| | Subsidence group ($n = 22$) | Control group ($n = 42$) | $p$ value |
|---|---|---|---|
| $C_{2-7}$ A (°) | | | |
| Preoperative | 13.18 ± 5.01 | 12.19 ± 7.35 | 0.334 |
| 1 week | 14.52 ± 3.71 | 13.94 ± 6.76 | 0.471 |
| Last FU | 12.57 ± 2.86 | 13.35 ± 5.60 | 0.530 |
| d$C_{2-7}$ A | −1.94 ± 2.57 | −0.59 ± 6.73 | 0.185 |
| Segmental A (°) | | | |
| Preoperative | 1.67 ± 2.78 | 1.63 ± 2.01 | 0.824 |
| 1 week | 2.53 ± 4.05 | 3.41 ± 2.00 | 0.296 |
| Last FU | −1.19 ± 4.10 | 3.26 ± 2.03 | **<0.001** |
| dSegmental A | −3.73 ± 3.53 | −0.15 ± 0.60 | **<0.001** |
| Fusion rate (%) | 90.91% (20/22) | 97.62% (41/42) | 0.270 |

Bold values represents that the results have statistical significance.
$C_{2-7}$ A, $C_2$–$C_7$ angle; Segmental A, Segmental angle; d, last follow-up value—postoperative 1 week value; Independent $t$-test was used to compare the $C_{2-7}$ A and Segmental A between the groups; *Chi-square test* was used to compare the fusion rate between the groups.

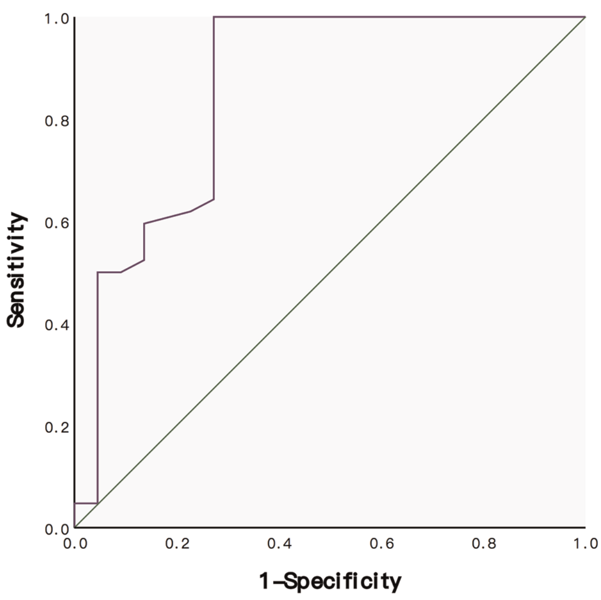


FIGURE 4
ROC curve for the sensitivity and specificity of HU values in predicting subsidence after ACCF. The AUC was 0.859.

TABLE 5 Results of multivariate logistic regression.

| Covariates | $B$ | $p$ | OR | 95% CI | |
|---|---|---|---|---|---|
| | | | | Lower bound | Upper bound |
| Age (years) | −0.129 | **0.033** | 0.879 | 0.781 | 0.989 |
| Gender (male/female) | −0.816 | 0.507 | 0.442 | 0.040 | 4.937 |
| C6 corpectomy (yes/no) | 1.091 | 0.092 | 2.978 | 0.838 | 10.582 |
| C5 corpectomy (yes/no) | −0.720 | 0.634 | 0.487 | 0.025 | 9.471 |
| UIV HU value | 0.013 | 0.207 | 1.014 | 0.993 | 1.035 |
| LIV HU value | 0.052 | **<0.001** | 1.053 | 1.024 | 1.082 |
| T-score | 0.763 | 0.135 | 2.146 | 0.789 | 5.834 |
| dSegmental A (°) | 1.863 | **0.002** | 6.442 | 1.953 | 21.253 |
| Preoperative disc height (mm) | −0.224 | 0.071 | 0.799 | 0.627 | 1.019 |

Bold values represents that the results have statistical significance.
UIV, upper instrumented vertebra; LIV, lower instrumented vertebra; dSegmental A, change value of segmental angle.

results and related complications. However, Ji et al. (16) reported that TMC subsidence does not negatively affect the clinical outcomes after ACCF. Nevertheless, nearly all authors agree that low BMD or osteoporosis is an important element causing TMC subsidence. Hence, accurate evaluation of bone quality at the upper and lower adjacent segments seems to be very important to reduce the TMC subsidence rate after ACCF.

In most situations, DXA has been used to assess bone quality prior to performing ACCF. Although DXA is a valid and time-tested method to estimate overall bone quality, it is still unclear whether each cervical vertebra can be accurately assessed. It has been reported that some T-scores obtained by DXA are higher than the actual BMD in patients with severely degenerative spines (9–11). Therefore, HU has received increasing attention during the last few years, with the hope of providing more accurate information on local bone strength. Recent studies have revealed a strong correlation between HU and BMD and T-scores (23–25) and between HUs and graft subsidence (26–28) after spine surgery. However, most of the studies focused on lumbar surgery. To our knowledge, only one article has reported the relationship between the HU value and TMC subsidence after ACCF (16). In that study, the global cervical HU value was significantly lower in the subsidence group (315 ± 73) than in the nonsubsidence group (388 ± 64), and a global cervical HU value <333 was independently associated with TMC subsidence. Nonetheless, the HU value was measured only in axial images: just inferior to the superior endplate, mid-body, and just superior to the inferior endplate. To maximally reduce bias, we measured the HU value 3 times in three different plane; we found that a cut-off value of 330.5 was associated with subsidence and that the HU value decreased gradually from C3–C7. Wang et al. (13) also measured HU values of different subaxial cervical vertebrae before ACDF using the technique described by Schreiber et al. (the same technique was used in our study), and the HU values ranged from 326.9 ± 40.7 to 426.3 ± 61.8 in their study. They also found that a threshold of 343.7 for the HU value had a sensitivity of 77.1% and specificity of 87.5% for predicting cage subsidence after ACDF. In our study, the threshold of 330.5 had a sensitivity of 100% and specificity of 72.7% in predicting cage subsidence for predicting TMC subsidence after ACCF.

Although HU measurement had useful predictive value for both the lumbar and cervical spines, one important limitation of HU measurement in assessing bone quality is that it does not consider various endplate conditions. In fact, several studies have reported that changes in the endplate are associated with cage subsidence (29, 30), and others have reported that CT can evaluate and predict lumbar vertebral endplate mechanical properties, including osteoporosis and osteopaenia (31–33). Therefore, we believe that if appropriate methods that provide more information about the strength of the endplate area in direct contact with the TMC can be added to HU measurements, the predictive value of HU may be further increased.

Lee et al. (8) also analyzed the cervical alignment and segmental angle after ACCF and found that patients with cage subsidence seemed to have significantly greater kyphotic changes than those in patients without subsidence. One different finding from our study, the both cervical alignment and segmental angle were significantly different in their study. However, in our study, a significant difference was only found in segmental angle between the groups. One possible reason is a decrease in segmental height loss during subsidence induces kyphotic changes in the segmental angle, but such changes failed to impact the global cervical curve.

Many factors affecting TMC subsidence after ACCF have been reported in the previous studies. These factors including an older patient age, more corpectomy levels, severe osteoporosis, excessive endplate removal and intraoperative over distraction (20, 29). In addition, the diameter, metal attributes of TMC and the shape of the graft also are important factors that can affect the TMC subsidence after ACCF (34). At present, researchers constantly exploring ways to prevent the subsidence of TMC from many aspects, such as the design of titanium mesh, the exploration of new materials, and surgical methods. Ren et al. (35) have found that middle part of the endplate is mostly a cystic cavity, and the edge of the endplate has the maximum strength. Therefore, endplate should not be scraping too much during the operation, and preserving the integrity of the endplate as possible for preventing postoperative TMC subsidence. Besides, due to cervical spine endplate has a certain inclination, if the TMC cannot be fully contacted to the endplate may lead to stress concentrations and TMC subsidence. Therefore, in order to increase stress dispersion, when inserting TMC during the operation, we should note that both ends of the TMC are as consistent as possible with the inclination of the surface of the endplate. Hasegawa et al. (36) have reported that a TMC with larger diameter and/or augmentation of internal end ring produces a significant increase of the interface strength between the cage and the vertebra, and their result also implies that in severe osteoporotic spine the stability of the cage is declined, and suggested that other instrumentation should be combined with TMC in severe osteoporosis. Based on your suggestion, these contents have been added to the discussion section in the revised manuscript.

## Study limitations

There are some limitations of this study that should be considered. First, this was a retrospective study, and a prospective study is required to confirm the sensitivity and specificity of <330.5 HU in predicting TMC subsidence after ACCF. Second, we did not investigate clinical efficacy because many larger-sample studies have reported the relationship between TMC subsidence and clinical efficacy, which we think may be more representative (4, 16, 5, 17, 22). We did not measured the hardness of endplate in this study. One major reason is that there is currently no standardized methods of evaluate the endplate bone quality directly through Hounsfield units measured on CT. Another limitation of the study is that radiological parameters such as the position and contact area of the TMC were not discussed. This is mainly because we sought to explore the relationship between the bone quality measured by HU values and TMC subsidence, which have some differences from studies that discuss several risk factors at the same time. Besides, even though we measured these radiological parameters based on previous reports, we acknowledge that measurement error may still persists.

Another limitation is the relatively small number of patients. Although we selected patients from March 2011 to December 2019, we limited the sample to only operations performed by the same doctor, and ACCF with TMC is not the type of surgery most performed by our team. Similar patients may have more opportunities to undergo multilevel ACDF, cervical disc replacement (CDR) or hybrid surgery (ACDF + CDR) by our team.

## Conclusion

There are strong correlations between a lower HU value and TMC subsidence after ACCF. More accurate assessment of bone quality may be obtained if HU measurement can be used as a routine preoperative screening method together with DXA. For patients with HU values <330.5, a more comprehensive and cautious preoperative plan should be implemented to reduce TMC subsidence.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

All methods were performed in accordance with the relevant guidelines and regulations. The study was conducted after ethical approval was obtained from the West China Hospital of Sichuan University College Ethical Committee, and all the participants provided written informed consent.

## Author contributions

HA and HL contributed to the design of the study. TW and BW contributed significantly to the analysis and manuscript preparation. HC helped perform the analysis with constructive discussions. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Xinghuo Wu,
Tongji Medical College, Huazhong University of Science and Technology, China

REVIEWED BY
Bahram Biglari,
BG-Trauma Center Ludwigshafen, Germany
Xiaodong Guo,
Huazhong University of Science and Technology, China

*CORRESPONDENCE
Mei-hua Li
limeihua2000@sina.com

[†]These authors have contributed equally to this work and share first authorship

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# Epidemiological characteristics of 1,806 patients with traumatic spinal cord injury: A retrospective study

Zhihua Wang[†], Wu Zhou[†] and Meihua Li*

Department of Neurosurgery, The First Affiliated Hospital of Nanchang University, Nanchang, China

**Background:** Traumatic spinal cord injury (TSCI) is a type of highly disabling central nervous system trauma. In this study, we investigated the epidemiological characteristics of 1,806 TSCI patients and compared the characteristics of patients with traumatic cervical spinal cord injury (TCSCI) caused by cervical fracture/dislocation and disc herniation/bulging.

**Methods:** We retrospectively reviewed the hospital records of 1,806 TSCI patients. The detailed information included gender, marital status, occupation, age, neurological level of injury, etiology, American Spinal Injury Association (ASIA) grade, combined injuries, complications, treatment, the interval between admission and surgery, intubation/tracheostomy requirement, and the length of hospital stay.

**Results:** Cervical spinal cord injury (CSCI) was the most common injury. Compared to non-CSCI cases, patients with TCSCI were older, and more likely to suffer from tetraplegia and require intubation/tracheostomy, but had fewer other injuries or complications and a shorter length of hospital stay. Compared to patients with cervical fracture/dislocation, those with TCSCI caused by disc herniation/bulging were older and more likely to suffer from paraplegia, but required intubation/tracheostomy less frequently, exhibited fewer other injuries and complications, and required shorter hospitalization.

**Conclusions:** Men, married individuals, manual laborers, and individuals aged 31–75 years had the highest risk of TSCI. Patients with TCSCI tended to have a shorter length of hospital stay than patients with non-CSCI. More attention should be paid to the other injuries and complications of non-CSCI patients, which may increase the length of hospital stay and delay rehabilitation. Compared to patients with cervical disc herniation, the patients with fracture/dislocation tended to be younger, but prognosis was severely compromised by tetraplegia, a greater need for intubation/tracheostomy, additional injuries, and complications.

KEYWORDS

traumatic spinal cord injury, cervical fracture/dislocation, cervical disc herniation/bulging, prevention, epidemiology

Abbreviations
SCI, spinal cord injury; TSCI, traumatic spinal cord injury; TCSCI, traumatic cervical spinal cord injury; CSCI, cervical spinal cord injury; ASIA, American Spinal Injury Association; TCSF, traumatic cervical spinal fracture; IQR, interquartile range; CT, computed tomography; MRI, magnetic resonance imaging.

## Introduction

Central nervous system trauma can cause varying degrees of sensory and motor dysfunction, which seriously affect quality of life and increase the economic burden on the family and society. Traumatic brain injury is common but can occasionally be prevented by wearing a safety helmet to reduce injuries. However, traumatic spinal cord injury (TSCI) sometimes occurs in the absence of effective preventive measures. The life expectancy of spinal cord injury (SCI) patients in the USA has not improved in the past three decades; the overall age-standardized mortality rate from 2010 to 2017 was threefold greater for individuals with SCI than for members of the general population (1). Compared with the 2008 TSCI population profile, Americans living with TSCI during 2015–2019 (mean years since injury: 18 years, 79.4% men, and 62.5% Caucasian) were older (51.6 vs. 45.0 years) and had a higher percentage of C1–C4 (21.9% vs. 17.0%) and American Spinal Injury Association (ASIA) D injuries (31.5% vs. 26.0%) than did individuals in other group (2). In Korea, the mean age (standard deviation) at the time of injury increased from 32.4 (12.4) years in the 1990s to 47.1 (16.2) years in the 2010s. Land transport and falls were the most common causes of TSCI. Tetraplegia was more common than paraplegia; incomplete tetraplegia was highest in the 2010s (3).

TSCI is often caused by falls and traffic accidents, and can induce severe and irreversible dysfunction of both the motor and sensory systems, as well as tetraplegia or paraplegia, and an inability to live unassisted (4, 5). Thus, TSCI impose a major burden on individuals, families, and society, because of the high costs of treatment and rehabilitation and lost productivity (6, 7). Traumatic cervical spinal cord injury (TCSCI) can cause tetraplegia and death. In the acute stage of TCSCI, 84% of patients with C1–4 injuries and 60% with C5–8 injuries experience respiratory complications (8). Timely intubation and tracheostomy are essential (9, 10).

A traumatic cervical spinal fracture (TCSF) is typically caused by severe violence; if this is combined with a dislocation, the risk of CSCI is greatly increased. The mean annual incidence of TCSF is 65 cases per 100,000 hospital admissions; risk factors include an age of 31–45 years, male sex, fall from a height, and traumatic [C5, C6] vertebral fractures (11). The intervertebral discs separate the vertebral bodies and evenly spread the loads among them. These discs degenerate with age and become more susceptible to injury (12). TCSF/dislocation has received a great deal of attention worldwide (13–15). However, cervical disc herniation and bulging have not been well-studied. The posterior ligamentous complex includes the intervertebral disc, ligamentum flavum, and interspinous and nuchal ligaments; this complex plays a critical role in cervical spine stability (16, 17). This retrospective and descriptive study examined the epidemiological data of 1,806 TSCI patients who were admitted from 1 January 2012 to 31 December 2020. We also retrospectively analyzed the epidemiology of TCSCI and non-CSCI, and compared the clinical characteristics of patients with TCSCI caused by cervical fracture/dislocation and disc herniation/bulging.

## Patients and methods

Two researchers separately reviewed the data of all hospitalized patients diagnosed with SCI. Detailed information were recorded, including gender, marital status, occupation, age, neurological level of injury, etiology, American Spinal Injury Association (ASIA) grade, combined injuries, complications, treatment, the interval between admission and surgery, intubation/tracheostomy requirement, and the length of hospital stay. The inclusion criteria were spinal cord or cauda equina injury, confirmed by clinical symptoms and an imaging examination or surgery; injury resulting from trauma; and reasonable and detailed patient records. The exclusion criteria were: non-traumatic spinal cord or cauda equina injury; treatment in departments other than orthopedics or neurosurgery; and unreasonable or incomplete patient records.

In this study, the TCSCI group included only patients with simple cervical injuries. The non-CSCI group included patients with injuries in the thoracic, lumbar, cervical and thoracic; thoracic and lumbar; cervical and lumbar; and cervical, thoracic and lumbar regions. The fracture/dislocation group included patients with at least one cervical vertebral fracture/dislocation other than disc herniation/bulging. Patients in the disc herniation/bulging group exhibited herniation/bulging of at least one cervical disc without any fracture/dislocation. SPSS software version 25.0 and GraphPad Prism software version 8.0 were used for the data analysis. The data are presented as numbers, percentages and medians with interquartile range (IQR). The Mann-Whitney U test and chi-squared ($\chi^2$) test were used to compare the two groups; the level of statistical significance was set to $p < 0.05$.

## Results

The flow chart for patient selection is displayed in **Figure 1**. In total, 4,185 patients were diagnosed with SCI; of these, 1,806 were diagnosed with TSCI, 2,379 were excluded for some reasons. 1,922 cases were excluded because they involved treatment in departments other than orthopedics or neurosurgery. 380 were excluded because of unreasonable or incomplete medical records. 77 cases were excluded because of non-traumatic factors.

### Gender and age

The ratio of men to women was 3.8:1. The patients were divided into six age groups: ≤ 15, 16–30, 31–45, 46–60, 61–75, and ≥ 76 years. The median age (IQR) of the 1,806 patients was

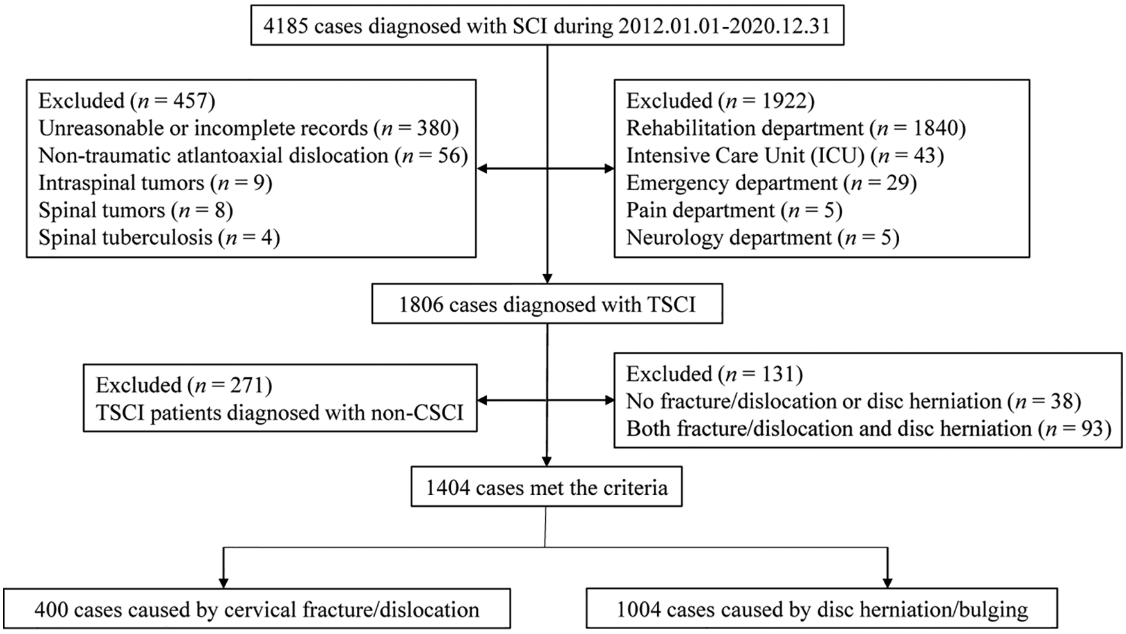


FIGURE 1
Flow chart of patient selection.

53 (IQR = 45–61) years [men: 53 (IQR = 44–61), women: 53 years (IQR = 46–62)]. The three age groups with the largest numbers of patients were 46–60, 61–75, and 31–45 years (Table 1). Patients in these groups constituted 90.9% of all included patients. The high-risk age group was similar for men and women (Figure 2). The 46–60 years age group was the largest, followed by the 61–75 years and 31–45 years age groups.

## Marital Status, occupation, and etiology

As shown in Table 1, 92.0% of patients were married. Manual laborers (peasant and worker, 89.0%) were the main group of TSCI patients. Falls (51.2%) and traffic accidents (28.1%) were the two most common causes of TSCI. Patients with impact-related injuries included 72 who were struck by objects falling from a high altitude, 6 who received lateral impacts because of operating errors during work, and 4 who received cattle impacts. Other patients experienced knife wounds ($n = 5$), fighting injuries ($n = 7$), and unclassified trauma ($n = 280$). The high-risk age group experienced similar rates of the two most common causes (Figure 3). The data had a unimodal distribution and both peaks were in the 46–60 years age group.

## Level of injury and ASIA grade

The SCI segment was determined on the basis of clinical symptoms, computed tomography and magnetic resonance imaging findings, or postoperative records. The cervical spinal cord was more often injured than the thoracic or lumbar segments, with a total operation rate of 73.4% (1227/1740). Few cases were encountered involving combined (i.e., simultaneous) injuries of two or three segments, but their operation rate was higher (93.9%; 62/66). ASIA grades D and C constituted 70.8% of the total cases (Table 1).

## Combined injuries, complications and treatment

Approximately 44% of the TSCI patients had at least one combined injury upon admission to the hospital (Table 1). As shown in Table 2, the percentage of trunk injuries was higher than the percentages of traumatic brain injury or limb injuries. Pulmonary contusion, hydropneumothorax, and rib fracture were the three most common trunk injuries. The most common traumatic brain injury was a cerebral contusion and laceration, while tibiofibular fracture was the most common limb injury. In total, 21.3% of patients had at least one complication during their hospitalization (Table 1). The percentage of complications is shown in Table 3. The three most common complications were pulmonary infection, pleural effusion, and respiratory failure. Among the 1,806 TSCI patients treated in our hospital, the operation rate was 83.2% (Table 1). In total, 303 patients were not treated because they discontinued treatment ($n = 156$), were transferred to a specialized rehabilitation department or

TABLE 1 Characteristics of 1,806 TSCI patients.

| Variables | | No. | Pct. (%) |
|---|---|---|---|
| Gender | Male | 1428 | 79.1 |
| | Female | 378 | 20.9 |
| Marital status | Married | 1661 | 92.0 |
| | Unmarried | 89 | 4.9 |
| | Others | 56 | 3.1 |
| Occupation | Peasant | 1488 | 82.4 |
| | Worker | 119 | 6.6 |
| | Civil servant | 5 | 0.3 |
| | Student | 85 | 4.7 |
| | Others | 109 | 6.0 |
| Age | ≤ 15 | 21 | 1.1 |
| | 16–30 | 90 | 5.0 |
| | 31–45 | 386 | 21.4 |
| | 46–60 | 808 | 44.7 |
| | 61–75 | 447 | 24.8 |
| | ≥ 76 | 54 | 3.0 |
| Level of injury | Cervical | 1535 | 85.0 |
| | Thoracic | 122 | 6.8 |
| | Lumbar | 83 | 4.6 |
| | Cervival + Thoracic | 37 | 2.0 |
| | Thoracic + Lumbar | 19 | 1.1 |
| | Cervival + Lumbar | 8 | 0.4 |
| | Cervical + Thoracic + Lumbar | 2 | 0.1 |
| Etiology | Fall | 924 | 51.2 |
| | Traffic accident | 508 | 28.1 |
| | Struck by object | 82 | 4.6 |
| | Others | 292 | 16.1 |
| ASIA grade | A | 357 | 19.8 |
| | B | 113 | 6.3 |
| | C | 631 | 34.9 |
| | D | 649 | 35.9 |
| | E | 56 | 3.1 |
| Combined injury | Yes | 787 | 43.6 |
| | No | 1019 | 56.4 |
| Complication | Yes | 385 | 21.3 |
| | No | 1421 | 78.7 |
| Treatment | Conservation | 303 | 16.8 |
| | Surgery | 1503 | 83.2 |

hospital ($n = 142$), or were transferred to another large hospital ($n = 5$).

## Characteristics of the 1,806 patients with different ASIA grades

As shown in Table 4, the 46–60 years age group had the greatest proportion of different ASIA grades. CSCI was much more frequent than SCI involving other segments. The proportion of patients who underwent surgery within 24 h after admission was low; most patients underwent surgery within 4–7 days after admission. Nearly 90% of patients in each grade underwent surgery within 7 days of admission. The artificial airway management status and the mean in-hospital stay findings were consistent with injury severity. Patients with a worse ASIA grade were more likely to receive tracheostomy or intubation and have a longer mean in-hospital stay.

## Characteristics of TSCI and TCSCI

Figure 1 shows that 1,806 patients were diagnosed with TSCI, some of whom had multi-segment or multi-site injuries (Figure 4). All injury sites were detected *via* computed tomography (CT) or magnetic resonance imaging (MRI), or postoperatively; and the most common injuries were CSCI (Figure 5). There were 1,535 patients in the TCSCI group and 271 in the non-CSCI group. We focused on 400 TCSCI patients (526 sites of injury) who suffered cervical fracture/dislocation and 1,004 patients (1,537 sites of injury) with cervical disc herniation/bulging (Figure 6).

## Characteristics of the 1,806 patients with TCSCI and non-CSCI

Table 5 compares the medical characteristics of the 1,535 TCSCI patients to those of the 271 non-CSCI patients. In the TCSCI group, the male: female ratio was 4.0:1, the age group with the highest risk was the 46–60 years group (followed by the 61–75 and 31–45 years groups), the tetraplegia rate was 90.6% and most patients were of ASIA grade D or C (in that order). In the non-CSCI group, the male: female ratio was 2.7:1, the age group with the highest risk was the 46–60 years group (followed by the 31–45 and 61–75 years groups), the paraplegia rate was 80.1% and most patients were of ASIA grade A or C (in that order). Patients with TCSCI (median age, 54 years; IQR = 46–62 years) tended to be older than those with non-CSCI (median age, 48 years; IQR = 37–57 years) ($p < 0.001$). Significant differences between the TCSCI and non-CSCI patients were seen for gender, age, neurological injury level, ASIA grade, interval between admission and surgery, other injuries, complications, and the length of hospital stay, but not in treatment or the intubation/tracheostomy requirement.

## Characteristics of the 1,404 patients with cervical fracture/dislocation and disc herniation/bulging

Table 6 summarizes the medical characteristics of the 1,404 TCSCI patients with cervical fracture/dislocation and disc herniation/bulging. In the cervical fracture/dislocation group, the male: female ratio was higher than in the other group (5.5:1 vs. 3.5:1). Patients with cervical disc herniation/bulging were older (median age, 54 years; IQR = 47–62.75 years)

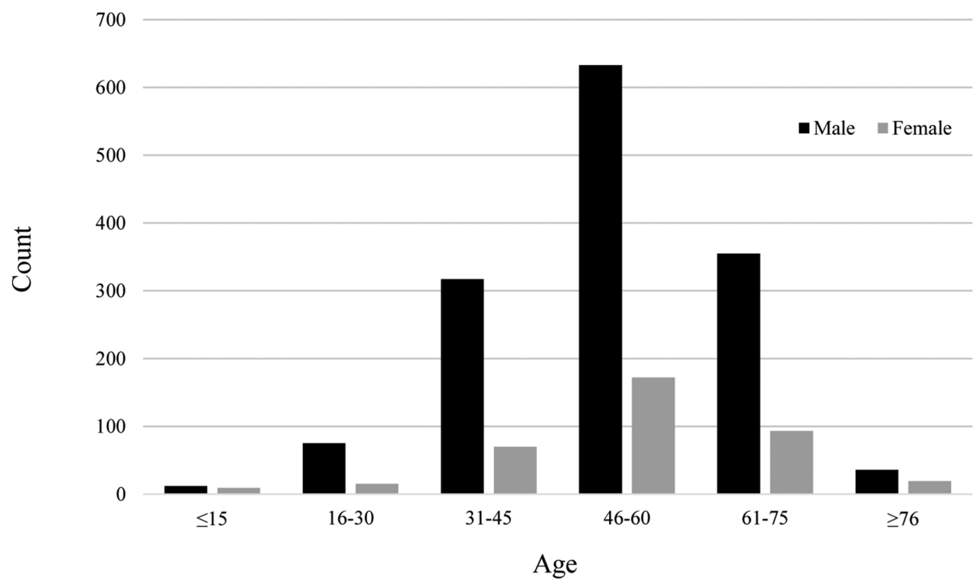


FIGURE 2
High-risk age group of different genders.

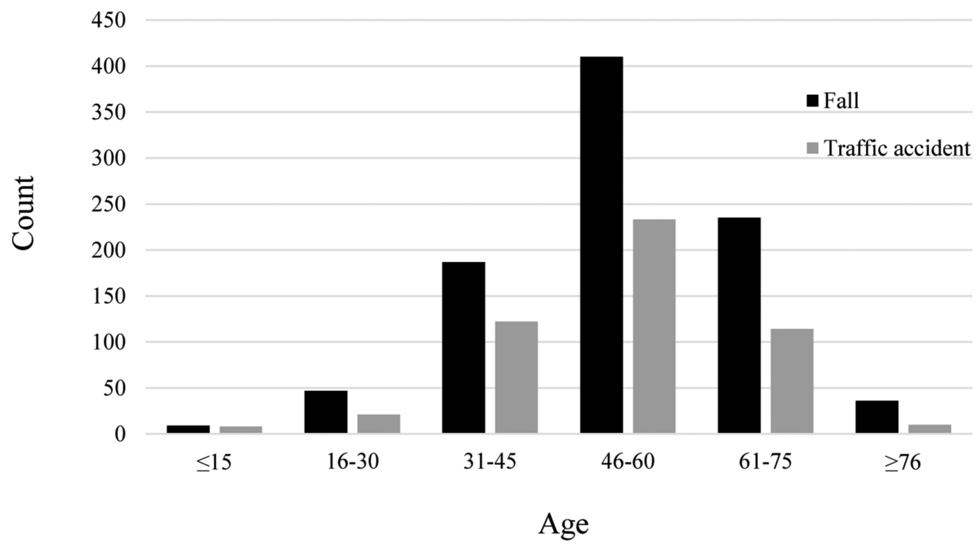


FIGURE 3
High-risk age group of the top two causes.

compared to the other patients (median age, 51 years; IQR = 42.25–61 years) ($p < 0.001$). In the fracture/dislocation group, the rate of tetraplegia was higher than in the other group (93.5% vs. 89.2%) and most patients were of ASIA grade C. In the disc herniation/bulging group, the rate of paraplegia was higher than in the other group (10.8% vs. 6.5%) and most patients were of ASIA grade D. With the exception of treatment, there were significant group differences in all other parameters.

## Discussion

After careful selection, we identified 1,806 cases; the ratio of men to women in this study was 3.8:1, which was similar to the ratios in several previous studies in China (18–22). In other regions, the male: female ratios have been 2.4:1 in Russia, 2.6:1 in Finland, 3.0:1 in Japan, 3.6:1 in Mexico, 6.1:1 in India, and 7.3:1 in Saudi Arabia (23–28). China is the largest developing country in the world. The agricultural population

TABLE 2 Combined injuries of 787 TSCI patients.

| Combined injuries | | No. | Pct. (%) |
|---|---|---|---|
| Trunk injuries (Chest, abdomen and pelvis) | Pulmonary contusion | 302 | 38.4 |
| | Hydropneumothorax | 268 | 34.1 |
| | Rib fracture | 129 | 16.4 |
| Traumatic brain injuries | Cerebral contusion and laceration | 274 | 34.8 |
| | Traumatic subarachnoid hemorrhage | 203 | 25.8 |
| | Skull fracture | 115 | 14.6 |
| Limb injuries | Tibiofibula fracture | 84 | 10.7 |
| | Ulna radial fracture | 57 | 7.2 |
| | Ankle injury | 21 | 2.7 |

TABLE 3 Clinical complications of 385 TSCI patients.

| Complications | | No. | Pct. (%) |
|---|---|---|---|
| 1 | Pulmonary infection | 306 | 79.5 |
| 2 | Pleural effusion | 123 | 31.9 |
| 3 | Respiratory failure | 100 | 26.0 |
| 4 | Urinary tract infection | 31 | 8.1 |
| 5 | Bedsore | 16 | 4.2 |
| 6 | Septic shock | 14 | 3.6 |
| 7 | Deep venous thrombosis | 12 | 3.1 |
| 8 | Death | 9 | 2.3 |
| 9 | Intracranial infection | 5 | 1.2 |
| 10 | Pulmonary embolism | 2 | 0.5 |
| 11 | Paralytic ileus | 2 | 0.5 |

of China has an absolute numerical advantage. Middle-aged and elderly people are always the "backbone of the family"; they engage in manual labor. In this study, married individuals, manual laborers, and individuals aged 31–75 years (especially 46–60 years) had the highest risk of TSCI. A previous comparative study indicated that TSCI caused by low and high falls has distinct epidemiological characteristics (29). In our study, some medical records were marked "fall" without a specific height or marked "traffic accident" without a specific vehicle type; they could not be further stratified into other subtypes. However, the results were consistent with previous findings; fall and traffic accidents were the two most common causes of TSCI (11, 18, 20, 22, 30–32).

CSCI is recognized as the most frequent type of TSCI. In this study, we examined the types and occurrence of combined injuries and complications to provide more clinically useful insights. Although surgical decompression should be performed as soon as possible (with the ideal surgical timing of 8 h post-injury) for both complete and incomplete lesions), many patients in this study underwent surgery within 4–7 days after admission (33–35). Possible reasons for such delay were as follows. First, many patients needed to maintain their physical status and stabilize their condition to reduce the risk of death after hospital admission.

TABLE 4 Characteristics of 1,806 patients with different ASIA grade.

| Variables | No. & Pct. (%) | ASIA grade A | B | C | D | E |
|---|---|---|---|---|---|---|
| Age | ≤ 15 | 6 (1.7) | 4 (3.5) | 6 (0.9) | 4 (0.6) | 1 (1.8) |
| | 16–30 | 30 (8.4) | 5 (4.4) | 26 (4.1) | 26 (4.0) | 3 (5.4) |
| | 31–45 | 79 (22.1) | 17 (15.0) | 134 (21.2) | 140 (21.6) | 16 (28.6) |
| | 46–60 | 156 (43.7) | 48 (42.5) | 266 (42.2) | 309 (47.6) | 29 (51.8) |
| | 61–75 | 81 (22.7) | 37 (32.7) | 171 (27.1) | 152 (23.4) | 6 (10.7) |
| | ≥ 76 | 5 (1.4) | 2 (1.9) | 28 (4.4) | 18 (2.8) | 1 (1.7) |
| | Total | 357 (100) | 113 (100) | 631 (100) | 649 (100) | 56 (100) |
| Level of injury | Cervical | 257 (72.0) | 90 (79.6) | 560 (88.7) | 591 (91.1) | 37 (66.1) |
| | Thoracic | 63 (17.6) | 16 (14.2) | 22 (3.5) | 15 (2.2) | 6 (10.7) |
| | Lumbar | 14 (3.9) | 5 (4.4) | 28 (4.4) | 30 (4.5) | 6 (10.7) |
| | Cervival + Thoracic | 15 (4.2) | 1 (0.9) | 12 (1.9) | 7 (1.1) | 2 (3.6) |
| | Cervival + Lumbar | 2 (0.6) | 0 | 3 (0.5) | 3 (0.5) | 0 |
| | Thoracic + Lumbar | 5 (1.4) | 1 (0.9) | 6 (1.0) | 2 (0.4) | 5 (8.9) |
| | Cervical + Thoracic + Lumbar | 1 (0.3) | 0 | 0 | 1 (0.2) | 0 |
| | Total | 357 (100) | 113 (100) | 631 (100) | 649 (100) | 56 (100) |
| Time from admission to surgery | ≤ 24 h | 91 (29.6) | 14 (14.4) | 65 (11.8) | 34 (6.7) | 5 (13.5) |
| | 2day-3day | 96 (31.3) | 29 (29.9) | 194 (35.2) | 191 (37.4) | 10 (27.0) |
| | 4day-7day | 88 (28.7) | 45 (46.4) | 237 (43.0) | 228 (44.6) | 18 (48.6) |
| | >7day | 32 (10.4) | 9 (9.3) | 55 (10.0) | 58 (11.3) | 4 (10.9) |
| | Total | 307 (100) | 97 (100) | 551 (100) | 511 (100) | 37 (100) |
| Intubation or tracheostomy | Yes | 90 (25.2) | 13 (11.5) | 45 (7.1) | 11 (1.7) | 0 |
| | No | 267 (74.8) | 100 (88.5) | 586 (92.9) | 638 (98.3) | 56 (100) |
| | Total | 357 (100) | 113 (100) | 631 (100) | 649 (100) | 56 (100) |
| Mean in-hospiyal day | | 23.9 | 19.2 | 17.8 | 13.8 | 13.7 |

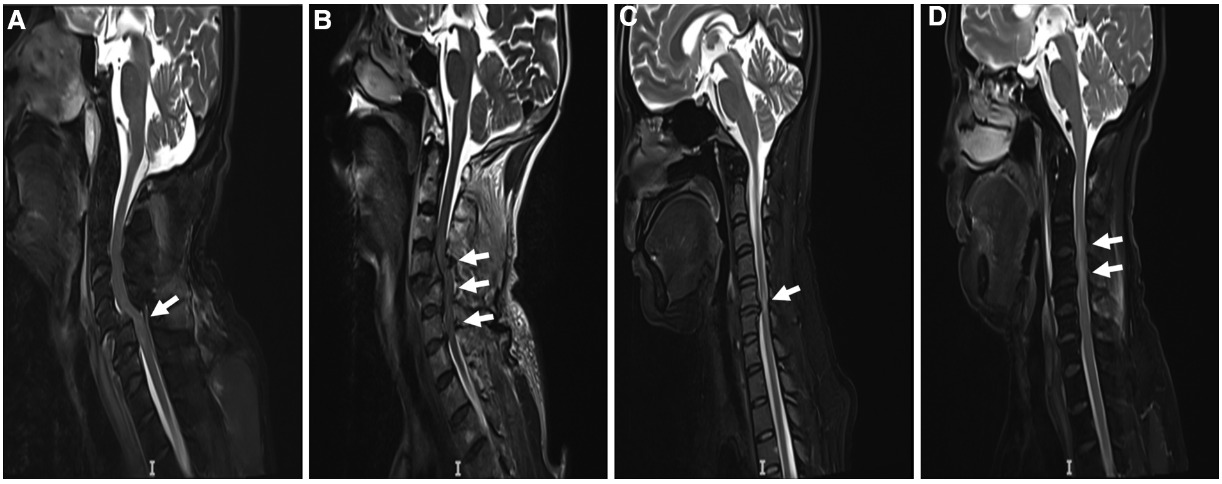


FIGURE 4
Two typical MRI scans of TCSCI patients. MRI scans of TCSCI patients with fracture/dislocation and disc herniation/bulging. (A) The C5 vertebral body slipped forward to the III° position; the spinal canal was narrowed and the cervical spinal cord was severely compressed. (B) The C4 vertebral body slipped forward to the II° position and a TCSCI is evident at the C4 -6 level. (C) The C5/6 intervertebral disc herniated backward and a TCSCI is apparent at the C5/6 level, especially C5. (D) The C3/4, C4/5, C5/6, and C6/7 intervertebral discs herniated posteriorly and a TCSCI is apparent at the C3/C4 level.

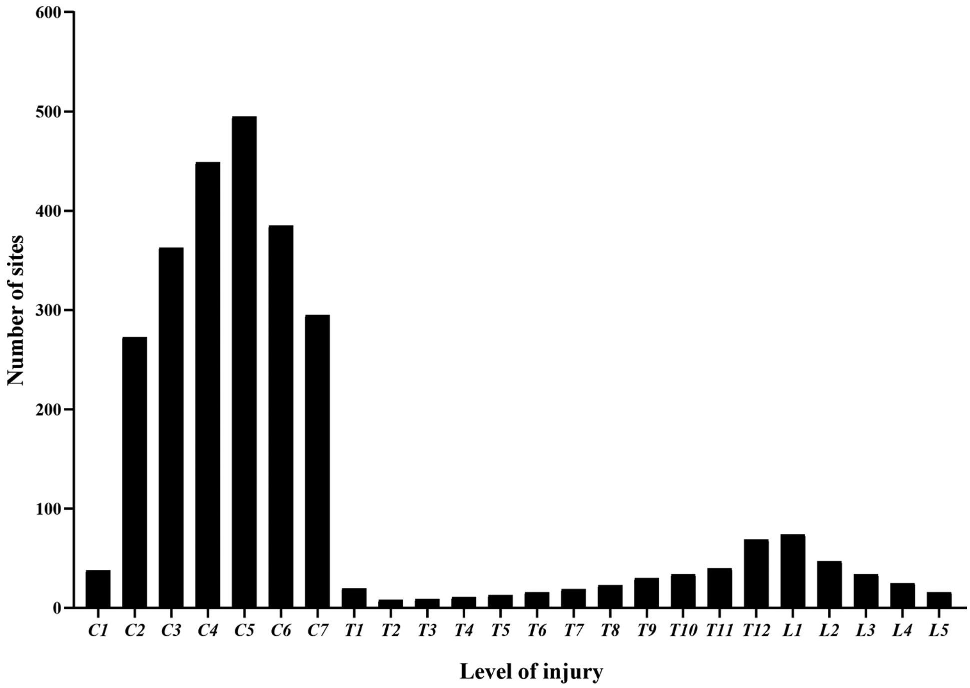


FIGURE 5
Distributions of sites of injury (C1–L5).

Second, imaging examinations and preoperative examinations (i.e., magnetic resonance imaging) could not be performed immediately. Third, specialists explained the need for surgery, but the family members required several days of consideration prior to consent for surgery. Our results also indicate that patients with a worse ASIA grade were more likely to undergo airway management with a longer mean in-hospital stay.

To the best of our knowledge, this is the first study to classify and compare the clinical characteristics of patients with TCSCI caused by fracture/dislocation and disc

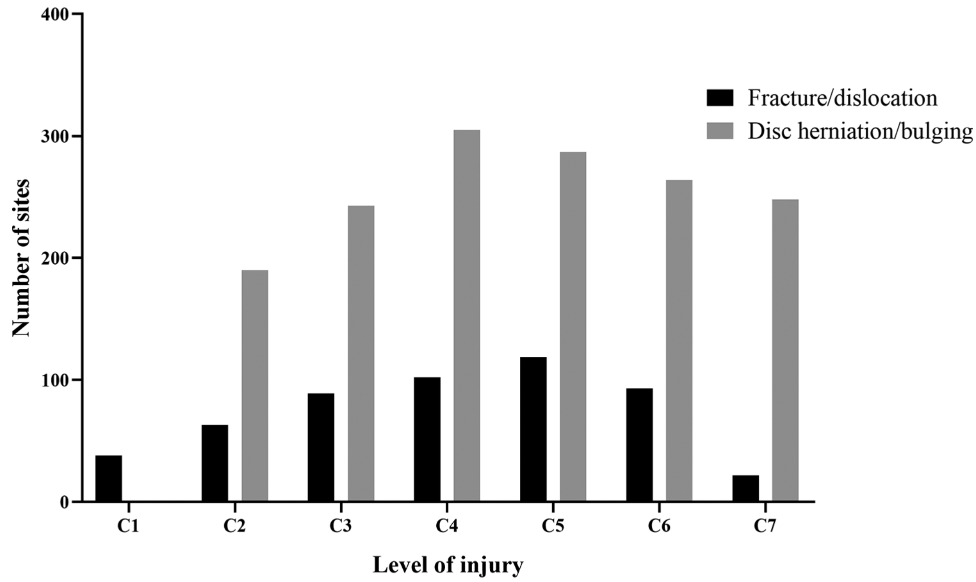


FIGURE 6
Distributions of all sites of injury (C1–C7) caused by fracture/dislocation and disc herniation/bulging.

TABLE 5 Characteristics of 1,806 patients resulted from TCSCI and Non-CSCI.

| Variables | | TCSCI group *n* (%) | Non-CSCI *n* (%) | *p* value |
|---|---|---|---|---|
| Gender | Male | 1,231 (80.2) | 197 (72.7) | $\chi^2 = 7.832$, $P = 0.005$ |
| | Female | 304 (19.8) | 74 (27.3) | |
| Age | ≤ 15 | 11 (0.7) | 10 (3.7) | $\chi^2 = 67.125$, $P < 0.001^{\#}$ |
| | 16–30 | 55 (3.6) | 35 (12.9) | |
| | 31–45 | 312 (20.3) | 74 (27.3) | |
| | 46–60 | 703 (45.8) | 105 (35.1) | |
| | 61–75 | 402 (26.2) | 45 (16.6) | |
| | ≥ 76 | 52 (3.4) | 2 (4.4) | |
| Neurological level of injury | Tetraplegia | 1,390 (90.6) | 54 (19.9) | $\chi^2 = 716.915$, $P < 0.001$ |
| | Paraplegia | 145 (9.4) | 217 (80.1) | |
| ASIA grade | A | 256 (16.7) | 101 (37.3) | $\chi^2 = 93.978$, $P < 0.001$ |
| | B | 90 (5.9) | 23 (8.5) | |
| | C | 561 (36.5) | 70 (25.8) | |
| | D | 591 (38.5) | 58 (21.4) | |
| | E | 37 (2.4) | 19 (7.0) | |
| Time from admission to surgery | ≤ 24 h | 155 (12.1) | 54 (23.9) | $\chi^2 = 24.449$, $P < 0.001$ |
| | 2day-3day | 442 (34.6) | 78 (34.5) | |
| | 4day-7day | 539 (42.2) | 77 (34.1) | |
| | >7day | 141 (11.1) | 17 (7.5) | |
| Combined injury | Yes | 600 (39.1) | 187 (69.0) | $\chi^2 = 83.839$, $P < 0.001$ |
| | No | 935 (60.9) | 84 (31.0) | |
| Complication | Yes | 310 (20.2) | 75 (27.7) | $\chi^2 = 7.683$, $p = 0.006$ |
| | No | 1,225 (79.8) | 196 (72.3) | |
| Treatment | Surgery | 1,277 (83.2) | 226 (83.4) | $\chi^2 = 0.007$, $p = 0.934$ |
| | Conservation | 258 (16.8) | 45 (16.6) | |
| Intubation or tracheostomy | Yes | 140 (9.1) | 19 (7.0) | $\chi^2 = 1.277$, $p = 0.259$ |
| | No | 1,395 (90.9) | 252 (93.0) | |
| Length of stay (IQR) | | 13 (10, 20) | 18 (12, 26) | $p < 0.001$* |

IQR, interquartile range.
*Mann-Whitney *U* test.
[#]Fisher's exact test.

TABLE 6 Characteristics of 1,404 patients caused by fracture/dislocation and disc herniation/bulging.

| Variables | | Fracture/dislocation group *n* (%) | Disc herniation/bulging group *n* (%) | *p* value |
|---|---|---|---|---|
| Gender | Male | 338 (84.5) | 779 (77.6) | $\chi^2 = 8.399$, $p = 0.004$ |
| | Female | 62 (15.5) | 225 (22.4) | |
| Age | ≤ 15 | 7 (1.8) | 3 (0.3) | $\chi^2 = 66.414$, $P < 0.001^{\#}$ |
| | 16–30 | 37 (9.3) | 13 (1.3) | |
| | 31–45 | 99 (24.7) | 187 (18.6) | |
| | 46–60 | 152 (38.0) | 489 (48.7) | |
| | 61–75 | 93 (23.2) | 276 (27.5) | |
| | ≥ 76 | 12 (3.0) | 36 (3.6) | |
| Neurological level of injury | Tetraplegia | 374 (93.5) | 896 (89.2) | $\chi^2 = 6.004$, $p = 0.014$ |
| | Paraplegia | 26 (6.5) | 108 (10.8) | |
| ASIA grade | A | 116 (29.0) | 110 (11.0) | $\chi^2 = 76.866$, $p < 0.001$ |
| | B | 15 (3.8) | 56 (5.6) | |
| | C | 142 (35.5) | 380 (37.8) | |
| | D | 114 (28.5) | 434 (43.2) | |
| | E | 13 (3.2) | 24 (2.4) | |
| Time from admission to surgery | ≤ 24 h | 58 (17.9) | 81 (9.6) | $\chi^2 = 18.430$, $p < 0.001$ |
| | 2day-3day | 99 (30.6) | 298 (35.4) | |
| | 4day-7day | 124 (38.3) | 373 (44.3) | |
| | >7day | 43 (13.2) | 90 (10.7) | |
| Combined injury | Yes | 173 (43.3) | 354 (35.3) | $\chi^2 = 7.790$, $p = 0.005$ |
| | No | 227 (56.7) | 650 (64.7) | |
| Complication | Yes | 122 (30.5) | 164 (16.3) | $\chi^2 = 35.384$, $p < 0.001$ |
| | No | 278 (69.5) | 840 (83.7) | |
| Treatment | Surgery | 324 (81.0) | 842 (83.9) | $\chi^2 = 1.667$, $p = 0.197$ |
| | Conservation | 76 (19.0) | 162 (16.1) | |
| Intubation or tracheostomy | Yes | 53 (13.3) | 83 (8.3) | $\chi^2 = 8.119$, $p = 0.004$ |
| | No | 347 (86.7) | 921 (91.7) | |
| Length of stay (IQR) | | 15 (10, 24) | 13 (9, 19) | $p < 0.001$* |

IQR: interquartile range.
*Mann-Whitney U test
#Fisher's exact test

herniation/bulging. We first compared the clinical features of TCSCI and non-CSCI patients. The treatments and intubation/tracheostomy requirements did not differ between the two groups. A comparison of two subgroups of TCSCI patients indicated that those with fracture/dislocation were more likely to require intubation/tracheostomy. Treatment did not show a group difference, perhaps because all patients underwent careful initial evaluation followed by surgery if necessary.

A study conducted in Chongqing (China) reviewed 643 patients with TCSI; the mean age was 42.5 ± 13.8 years (range: 18–86 years), the male: female ratio was 4.3:1 and the most common site of injury was C5 (22.7% of cases) (11). A study conducted in Maryland (USA) evaluated 1,420 patients with TCSCI; 78.3% were male, with a mean age of 51.5 years. Complete TCSCI were noted in 29.6% of cases, and fracture dislocations were apparent in 44.7% (36). The incidence of traumatic disc herniation was 32% (37). In the present study, we screened more TCSCI patients with cervical disc herniations than fractures [71.5% (1,004/1,404) vs. 28.5% (400/1,404)]. The former patients were older (median age, 54 years; IQR = 47–62.75 years vs. 51 years; IQR = 42.25–61 years), as reflected in the higher proportion of patients aged 46–60 years (48.7% vs. 38.0%), and accounted for 71.5% (1,004/1,404) of all TCSCI cases. In general, the injuries were not as serious as those of patients with traumatic cervical fracture/dislocation. Thus, the rates of tetraplegia and operation within 24 h were lower in the former group, as were the intubation/tracheostomy rates and those of other injuries and complications. This may explain the short hospitalization period. These patients are quickly transferred for rehabilitation. Shorter hospitalization and rapid rehabilitation reduce the incidence of complications. Thus, in daily practice, patients with severe cervical fracture/dislocation require particular attention in terms of active treatment, including of other injuries, and prevention of complications. For patients with TCSCI caused by cervical disc herniation/bulging, early surgery, recovery, and rehabilitation are possible.

Notably, this study did not include data regarding TSCI patients from other affiliated hospitals or large grade A tertiary hospitals in Jiangxi Province. We only examined the epidemiological characteristics of some TSCI patients; thus, these findings are limited to the current status of diagnosis and treatment of TSCI patients in our hospital.

## Data availability statement

All data generated or analysed are included in this article and are available from the corresponding author on reasonable request.

## Ethics statement

Hospitalization information of TSCI patients was considered exempt by the Human Investigation Ethical Committee of the first affiliated hospital of Nanchang University.

## Author contributions

ZW: study design and concept; data collection, analysis and visualization; article writing and revising. WZ: data collection, analysis and visualization; article revising and reviewing. ML: study design and concept; article reviewing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Takashi Kaito,
Osaka University, Japan

REVIEWED BY
Jinhai Xu,
Shanghai University of Traditional Chinese Medicine, China
Jingchi Li,
Sichuan University, China

*CORRESPONDENCE
Xiaolong Shen
✉ spine_shen@163.com
Wen Yuan
✉ Yuanwenspine@smmu.edu.cn

[†]These authors have contributed equally to this work

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# Anterior cervical discectomy and fusion, open-door laminoplasty, or laminectomy with fusion: Which is the better treatment for four-level cervical spondylotic myelopathy?

Huajian Zhong[†], Chen Xu[†], Ruizhe Wang[†], Xiaodong Wu, Huiqiao Wu, Baifeng Sun, Xinwei Wang, Huajiang Chen, Xiaolong Shen* and Wen Yuan*

Department of Orthopaedic Surgery, Changzheng Hospital, Naval Medical University, Shanghai, China

Four-level cervical spondylotic myelopathy (CSM) is a common disease affecting a large number of people, with the optimal surgical strategy remaining controversial. This study compared the clinical outcomes, radiological parameters, and postoperative complications of primarily performed surgical procedures such as anterior cervical discectomy and fusion (ACDF), open-door laminoplasty (LAMP), and laminectomy with fusion (LF) in treating four-level CSM. A total of 116 patients who received ACDF (38 cases), LAMP (45 cases), and LF (33 cases) were followed up for a minimum of 24 months were enrolled in this study and retrospectively analyzed. Clinical outcomes were evaluated using the Japanese Orthopedic Association (JOA) scoring system, the Neck Disability Index (NDI), and the Visual Analogue Scale (VAS). Changes in the curvature of the cervical spine were determined using the cervical curvature index (CCI) and the C2–C7 Cobb angle. Cervical mobility was evaluated using the C2–C7 range of motion (ROM) and active cervical ROM (aROM). Complications were recorded and compared among the three groups. All patients achieved significant improvement in JOA, NDI, and VAS scores at the final follow-up ($P < 0.05$), whereas no remarkable difference was found among the groups ($P > 0.05$). In addition, both C2–7 ROM and aROM were significantly reduced in the three groups and LAMP showed the least reduction relatively. As for complications, LAMP showed the lowest overall incidence of postoperative complications, and patients in the ACDF group were more susceptible to dysphagia, pseudoarthrosis than LAMP and LF. Considering improvements in clinical symptoms and neurological function, no remarkable difference was found among the groups. Nevertheless, LAMP had advantages over the other two surgical procedures in terms of preserving cervical mobility and reducing postoperative complications.

KEYWORDS

anterior cervical discectomy and fusion, open-door laminoplasty, laminectomy with fusion, cervical spondylotic myelopathy, cervical surgery

# 1. Introduction

Cervical spondylotic myelopathy (CSM) is a progressive, degenerative disease that ranks as the leading cause of spinal cord dysfunction in the adult population (1). The pathogenesis of CSM is characterized by a degeneration of various elements of the cervical spine, such as the cervical vertebral body, intervertebral disc, surrounding ligaments, and accessory structures, which leads to spinal cord or nerve root compression and corresponding neurological symptoms (2). Although conservative treatment shows promising effects for patients with mild symptoms, surgical intervention remains a better option for those with moderate to severe neurological symptoms.

Surgical management of CSM could be achieved through anterior, posterior, or a combined procedure if necessary. The anterior surgical procedure mainly includes anterior cervical discectomy and fusion (ACDF) (3), anterior cervical corpectomy and fusion (ACCF) (4), and cervical disk arthroplasty (CDA) (5); In contrast, laminectomy with or without instrumented fusion and open-door or French-door laminoplasty represent popular posterior surgical procedures (6–8). Due to concerns involved in multilevel surgical management, such as postoperative cervical deformity and segmental instability, ACDF and laminectomy with fusion (LF) are the commonly performed fusion surgeries for multilevel CSM, which are complemented by non-fusion open-door laminoplasty (LAMP), because certain reports indicate that LAMP results in a higher magnitude of function recovery and symptomatic alleviation than French-door laminoplasty (FDL) (9). Up to now, ACDF, LAMP, and LF have been the most commonly performed spinal surgical procedures for multilevel CSM because of their relatively low complication rates and fair neurological outcomes, whereas which among these three is the optimal procedure remains controversial. Although studies comparing the clinical outcomes of these surgical procedures in three-level CSM have been undertaken, there are few reports on four-level CSM. Thus, in the present study, we compare the clinical outcomes of ACDF, LAMP, and LF in treating four-level CSM.

# 2. Materials and methods

## 2.1. Patients

All study procedures were approved by the institute chancellor's Human Research Committee in accordance with the institute's protocol. Ethical approval of this retrospective study was given by the Naval Medical University ethics committee review board. The design and reporting were performed in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) statement. This research was conducted in accordance with the Declaration of Helsinki. This study retrospectively reviewed patients who were diagnosed with CSM between February 2008 and January 2014 in our institute, and all patients presented with symptoms of cervical myelopathy with/without radiculopathy. The inclusion criteria were as follows: (1) magnetic resonance imaging and x-ray radiography showing signs of intervertebral disc degeneration or herniation of four consecutive levels; (2) patients diagnosed and suffering from CSM symptoms requiring surgical treatment; and (3) patients treated with either ACDF, LAMP, or LF. The exclusion criteria were as follows: (1) ossification of the posterior longitudinal ligament (OPLL), (2) severe kyphosis, (3) motor neuron disease (MND), (4) previous cervical surgery, (5) history of rheumatoid arthritis, (6) cerebral palsy, (7) thoracic spondylotic myelopathy, (8) lumbar spinal canal stenosis, (9) congenital deformities, and (10) tumors, and trauma. After selection, we included 158 patients and grouped them as ACDF, LAMP, and LF according to the surgical procedure that they underwent. Of the 158 patients, 116 who were followed up for more than 24 months were enrolled (follow-up rate, 73.4%), the remaining 42 patients lost contact during follow-up, and the final sample comprised 60 male and 56 female patients (with a mean age of 56 years; and range of 47–49 years) who were followed up for an average period of 39.4 months (range 24–72 months).

## 2.2. Surgical technique

All operations were performed routinely by two senior surgeons, and the operative procedure was performed as follows (**Figure 1**).

### 2.2.1. ACDF (ACDF group)

The ACDF procedure was performed under general anesthesia, with the patients placed in the supine position, the surgical site was exposed through the standard Smith–Robinson approach (10), and ventral compressors of the spinal cord including the intervertebral disc and posterior longitude ligament were removed for direct decompression. The interbody cage (DePuy Spine, USA), combined with the anterior cervical plate (Slim-Loc or SKYLINE, DePuy Spine, USA), was used for anterior fusion (the ACDF group, 38 patients).

### 2.2.2. Open-door laminoplasty (LAMP group)

After general anesthesia, the patients were placed in the prone position with the head fixed using the Mayfield head holder. Through a posterior midline approach, the lamina and spinous processes were exposed, and the side with relatively severe clinical symptoms and/or radiographic compression

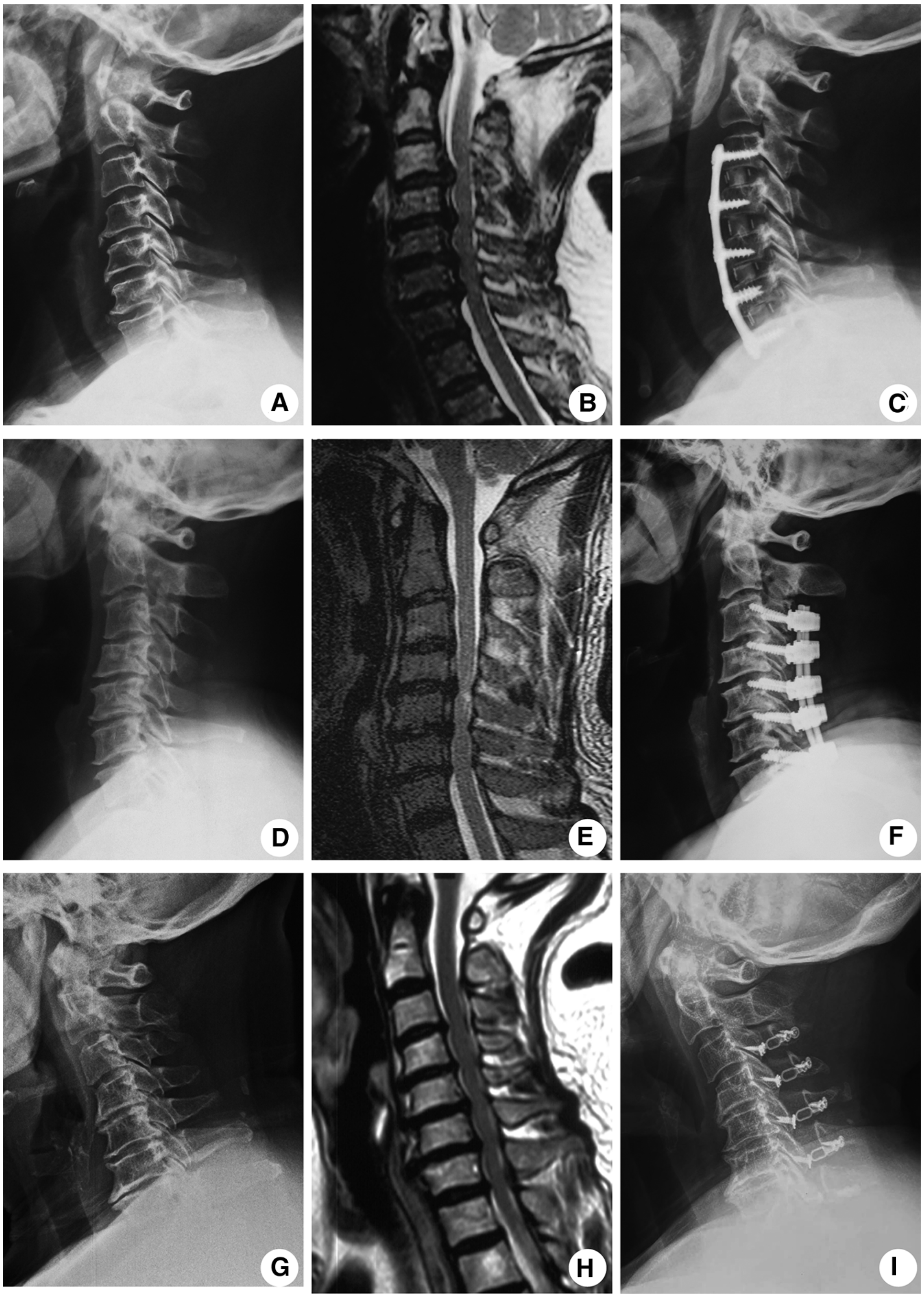


FIGURE 1
Typical radiological images showing four-level CSM patients treated with either ACDF, LAMP, or the LF approach. Representative preoperative lateral position x-ray radiograph (A), preoperative MRI image (B), and x-ray radiographs at a 2-year follow-up (C) of ACDF-treated patients. Representative preoperative lateral position x-ray radiograph (D), preoperative MRI image (E), and x-ray radiographs at a 2-year follow-up (F) of LF-treated patients. Representative preoperative lateral position x-ray radiograph (G), preoperative MRI image (H), and x-ray radiographs at a 2-year follow-up (I) of LAMP-treated patients.

was selected as the open side, whose outer and inner cortical margins were both drilled using a high-speed drill. The inner cortical margin of the hinge side was preserved, and the lamina was lifted from the open side toward the hinge side and fixed in an expanded position with 8–12 mm miniplates (LAMP group, 45 patients).

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### 2.2.3. Laminectomy with fusion (LF group)

After general anesthesia, the spinous processes, laminae, facet joints, and transverse processes were exposed through a posterior midline approach that was similar to laminoplasty, and then, lateral mass screws and prebending titanium rods were placed at the planned segment, followed by a resection of the lamina and ligamentum flavum. Autologous bone grafts from the lamina were placed adjacent to bilateral joints to facilitate fusion (LF group, 33 patients).

## 2.3. Clinical evaluation

Baseline data such as demographic information and symptomatology were collected, and operation data on the operation time, blood loss, and hospitalization time were recorded. The Japanese Orthopedic Association scale (JOA), the Neck Disability Index (NDI) scoring system, and the visual analog scale (VAS) scoring system (scores 0–10) evaluating neurological outcomes, neck function, and axial symptoms, respectively, were used for clinical assessment.

## 2.4. Radiological evaluation

For radiographic assessment, anteroposterior, lateral, and flexion–extension x-ray images of the standing cervical spine were obtained before surgery and during the follow-up period. The cervical curvature index (CCI) and C2–7 Cobb angle evaluating the cervical alignment (**Figure 2**) and the cervical range of motion (ROM) and active cervical ROM (aROM) evaluating cervical mobility were measured. The aROM was measured using a cervical Range of Motion (ROM) device (Performance Attainment Associates, Roseville, MN, USA). The measurement of the six conventional motions of the cervical spine was performed (flexion, extension, left lateral flexion, right lateral flexion, left rotation and right rotation).

## 2.5. Statistical analysis

Statistical analysis was performed with SPSS version 25.0 (SPSS Inc., Chicago, IL, USA), continuous variables were presented as mean ± standard deviation (SD), and frequencies with percentages were used to summarize categorical variables. The $\chi^2$ test was used for determining categorical variables in demographic data. Fisher's exact test was used for determining categorical variables in postoperative complications. One-way ANOVA, followed by Tukey's multiple comparison test, was used for determining continuous variables in demographic data as well as clinical and radiographic outcomes. A two-tailed $P < 0.05$ was considered statistically significant.

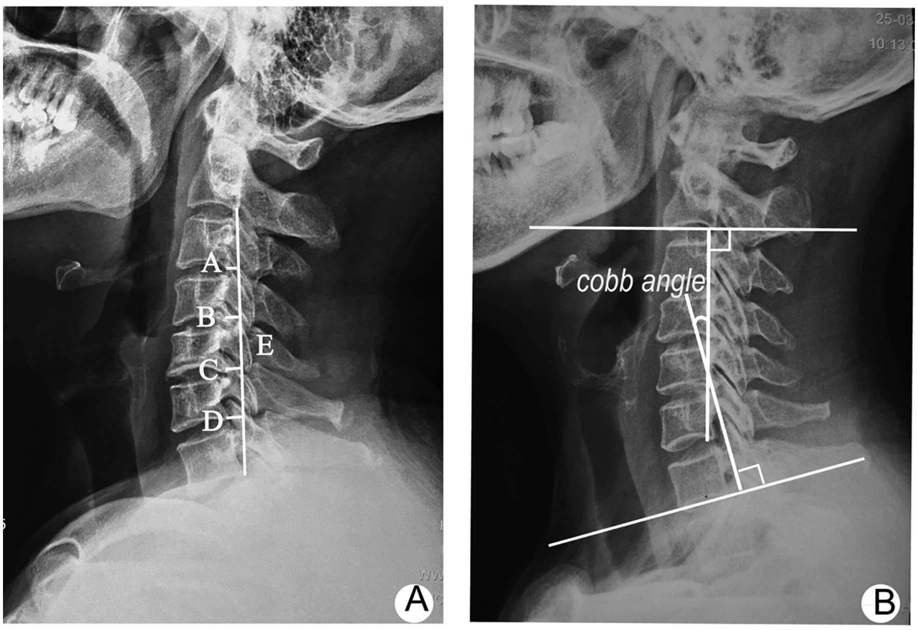


FIGURE 2
Radiological parameters of the cervical spine. (A) CCI measures cervical curvature based on the distance from the posteroinferior edge of the C3–C6 vertebral body to a straight line drawn from the posteroinferior edge of C2–C7 [CI = (A + B + C + D)/E × 100]; (B) Cobb angle measures the cervical lordotic angle formed by two lines perpendicular to inferior endplates of the C2 and C7 vertebral bodies, respectively. Cervical range of motion (ROM) was calculated as the difference between the Cobb angles at maximal flexion and extension on anteroposterior (AP) radiographs.

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# 3. Results

## 3.1. Study population

Our cohort consisted of 116 patients (60 males and 56 females) who were followed up for a mean period of 39.4 months (24–72 months) postoperatively. The demographics of the patients are shown in **Table 1**. No significant differences in age ($P = 0.098$), gender ($P = 0.625$), smoking ($P = 0.936$), diabetes ($P = 0.974$), symptom duration ($P = 0.472$), or follow-up period ($P = 0.321$) were detected among the three groups. The ACDF group had the least bleeding loss, which was in contrast to the LF group, which had the maximum bleeding loss, and the operation time in the LF group was the longest among the three groups, which showed no significant differences between the ACDF and the LAMP groups.

## 3.2. Clinical outcomes

**Table 2** summarizes the clinical outcomes of surgery. By assessing the JOA, NDI, and VAS scores before surgery and at the final follow-up, we found no remarkable differences regarding the preoperative clinical symptoms and neurological functions among the three groups (JOA $P = 0.310$, NDI $P = 0.429$, VAS $P = 0.975$). At the final follow-up, all patients achieved significant improvement in JOA, NDI, and VAS scores ($P < 0.05$) (**Table 2**), However, no differences were detected among the three groups in these scores (ΔJOA $P = 0.474$, ΔNDI $P = 0.300$, and ΔVAS $P = 0.715$).

## 3.3. Radiographic outcomes

The radiographic outcomes were evaluated by analyzing the CCI, C2–C7 Cobb angle, and C2–7 ROM, which are summarized in **Table 3**. Before surgery, all patients showed no differences in cervical alignment and mobility (CCI $P = 0.728$, C2–C7 Cobb angle $P = 0.863$, C2–7 ROM $P = 0.448$ **Table 3**). At the final follow-up, only patients in the ACDF group achieved significant improvement in the C2–C7 Cobb angle ranging from (10.0 ± 8.6)° to (17.4 ± 7.9)°, ($P < 0.05$). Simultaneously, the ROM significantly reduced in the ACDF group, which showed identical results in the LAMP and LF groups. Noteworthily, although the ROM decreased in all three groups, LAMP showed a smaller reduction in the ROM; in other words, there was greater preservation of the ROM compared with ACDF and LF.

## 3.4. Active cervical ROM

The active cervical ROM of all patients in flexion–extension, lateral flexion (left and right), and rotation (left and right) are summarized in **Table 4**, and the range of flexion–extension, lateral flexion, and total rotation reduced after surgery in the three groups. Comparatively, the LAMP group showed a less reduction of the flexion–extension range (preoperation 102.8 ± 10.9; final follow-up 88.7 ± 11.1) than the ACDF group (preoperation 102.2 ± 10.2; final follow-up 55.1 ± 9.7) and the LF group (preoperation 101.4 ± 11.3; final follow-up 50.6 ± 7.9). Similarly, the preservation of the lateral flexion range in the LAMP group (preoperation 79.4 ± 11.1; final follow-up 66.0 ± 9.8) was greater than that in the ACDF group (preoperation 79.2 ±

TABLE 1 Demographic and surgical data of patients.

| Variables | ACDF group ($n = 38$) | LAMP group ($n = 45$) | LF group ($n = 33$) | *P*-value |
|---|---|---|---|---|
| Mean age (years) | 53.5 ± 10.2 | 59.4 ± 14.7 | 58.8 ± 13.9 | 0.098 |
| Gender (male) (%) | 21 (55.26) | 25 (55.56) | 15 (45.45) | 0.625 |
| Current smoker (%) | 9 (23.68) | 11 (24.44) | 9 (27.27) | 0.936 |
| Patient with diabetes (%) | 7 (18.42) | 9 (20.00) | 6 (18.18) | 0.974 |
| Symptom duration (months) | 29.1 ± 11.3 | 25.7 ± 13.9 | 26.8 ± 12.4 | 0.472 |
| Follow-up period (months) | 42 ± 20.4 | 34.8 ± 15.6 | 38.4 ± 28.8 | 0.321 |
| Bleeding loss (ml) | 102.3 ± 35.8[§¶] | 209.3 ± 41.6[†] | 343.2 ± 50.5 | <0.001 |
| Operation time (min) | 95.1 ± 20.6[¶] | 102.6 ± 33.4[†] | 135.1 ± 37.4 | <0.001 |

The *p*-value was calculated by comparing all groups using one-way ANOVA. ACDF, anterior cervical discectomy and fusion; LAMP, posterior open-door laminoplasty; LF, posterior laminectomy and fusion.
[§]Statistically significant difference between ACDF and LAMP ($P < 0.05$).
[¶]Statistically significant difference between ACDF and LF ($P < 0.05$).
[†]Statistically significant difference between LAMP and LF ($P < 0.05$).

TABLE 2 Clinical outcomes in each group.

| Variables | | ACDF group ($n$ = 38) | LAMP group ($n$ = 45) | LF group ($n$ = 33) | $P$-value |
|---|---|---|---|---|---|
| JOA | Preoperation | 9.26 ± 0.93 | 9.13 ± 1.26 | 8.85 ± 1.18 | 0.310 |
| | Final follow-up | 14.22 ± 1.74* | 14.85 ± 2.13* | 13.97 ± 2.82* | 0.198 |
| | ΔJOA | 5.12 ± 1.01 | 5.52 ± 1.57 | 5.28 ± 1.83 | 0.474 |
| NDI | Preoperation | 36.61 ± 3.52 | 37.54 ± 4.16 | 37.77 ± 4.45 | 0.429 |
| | Final follow-up | 14.18 ± 2.25* | 13.73 ± 2.57* | 14.42 ± 3.74* | 0.555 |
| | ΔNDI | −23.14 ± 1.96 | −24.08 ± 3.68 | −23.79 ± 2.01 | 0.300 |
| VAS | Preoperation | 7.48 ± 3.02 | 7.54 ± 2.65 | 7.63 ± 2.70 | 0.975 |
| | Final follow-up | 1.87 ± 1.30* | 2.08 ± 1.63* | 2.47 ± 1.85* | 0.285 |
| | ΔVAS | −5.53 ± 1.97 | −5.21 ± 1.35 | −5.38 ± 2.04 | 0.715 |

The $p$-value was calculated by comparing all groups using one-way ANOVA. ACDF, anterior cervical discectomy and fusion; LAMP, posterior open-door laminoplasty; LF, posterior laminectomy and fusion; JOA, the Japanese orthopedic association scale; NDI, the neck disability index; VAS, the visual analog scale.
*Statistically significant difference between the last follow-up and the preoperative period ($P < 0.05$).
ΔIndicates the change of parameter at the last follow-up compared with the preoperative period.

TABLE 3 Radiographic outcomes in each group.

| Variables | | ACDF group ($n$ = 38) | LAMP group ($n$ = 45) | LF group ($n$ = 33) | $P$-value |
|---|---|---|---|---|---|
| CCI (%) | Preoperation | 13.6 ± 7.8 | 14.8 ± 6.6 | 14.6 ± 7.1 | 0.728 |
| | Final follow-up | 15.5 ± 7.2 | 14.3 ± 6.1 | 14.0 ± 7.3 | 0.607 |
| | ΔCCI | 1.78 ± 6.9 | 0.98 ± 6.5 | 1.16 ± 7.0 | 0.859 |
| C2–C7 Cobb angle (°) | Preoperation | 10.0 ± 8.6 | 9.5 ± 5.9 | 10.4 ± 7.4 | 0.863 |
| | Final follow-up | 17.4 ± 7.9* | 10.1 ± 5.8 | 10.8 ± 7.0 | <0.001 |
| | ΔC2–C7 Cobb angle | 7.5 ± 7.7[§¶] | 1.1 ± 5.7 | 0.8 ± 7.1 | <0.001 |
| C2–7 ROM (°) | Preoperation | 40.4 ± 7.7 | 38.3 ± 7.6 | 39.8 ± 8.1 | 0.448 |
| | Final follow-up | 12.8 ± 5.1* | 31.6 ± 6.2* | 11.5 ± 5.4* | <0.001 |
| | ΔC2–7 ROM | −29.5 ± 6.1[§] | −7.1 ± 6.5[†] | −28.9 ± 7.3 | <0.001 |

The $p$-value was calculated by comparing all groups using one-way ANOVA. ACDF, anterior cervical discectomy and fusion; LAMP, posterior open-door laminoplasty; LF, posterior laminectomy and fusion; CCI, cervical curvature index; ROM, range of motion.
*Statistically significant difference between the last follow-up and the preoperative period ($P < 0.05$).
[§]Statistically significant difference between ACDF and LAMP ($P < 0.05$).
[¶]Statistically significant difference between ACDF and LF ($P < 0.05$).
[†]Statistically significant difference between LAMP and LF ($P < 0.05$).
Δ Indicates the change of parameter at the last follow-up compared with the preoperative period.

11.3; final follow-up 55.7 ± 9.5) and LP group (preoperation 81.7 ± 10.0; final follow-up 54.0 ± 7.4). Furthermore, the total rotation range in the LAMP group (preoperation 123.8 ± 13.2; final follow-up 105.4 ± 10.1) declined to a minimal extent compared with that in the ACDF group (preoperation 127.1 ± 12.6; final follow-up 99.6 ± 10.4) and the LP group (preoperation 121.6 ± 12.8; final follow-up 96.2 ± 9.1) (**Table 5**). All these results indicate that LAMP was more effective in preserving active cervical ROM than ACDF and LF.

## 3.5. Complications

The postoperative complications showed significant differences among the three groups ($P = 0.003$), with LAMP having a lower total incidence compared with ACDF and LF. As for individual complications, the rates of hematoma, axial pain, cerebrospinal fluid leakage, C5 paralysis, infection, or deterioration in neurologic deficits were comparable among groups. Notably, dysphagia occurred in 15.79% of patients from the ACDF group, which was not observed in the LAMP

TABLE 4 Active cervical ROM measurement in each group.

| Variables | | ACDF group ($n = 38$) | LAMP group ($n = 45$) | LF group ($n = 33$) | $P$-value |
|---|---|---|---|---|---|
| Flexion–extension | Preoperation | 102.2 ± 10.2 | 102.8 ± 10.9 | 101.4 ± 11.3 | 0.852 |
| | Final follow-up | 55.1 ± 9.7* | 88.7 ± 11.1* | 50.6 ± 7.9* | <0.001 |
| | Δ Flexion–extension | −50.8 ± 9.9$^{§}$ | −15.1 ± 10.9$^{†}$ | −51.6 ± 8.7 | <0.001 |
| Lateral flexion | Preoperation | 79.2 ± 11.3 | 79.4 ± 11.1 | 81.7 ± 10.0 | 0.545 |
| | Final follow-up | 55.7 ± 9.5* | 66.0 ± 9.8* | 54.0 ± 7.4* | <0.001 |
| | Δ Lateral flexion | −25.3 ± 10.2$^{§}$ | −13.6 ± 10.1$^{†}$ | −25.9 ± 10.0 | <0.001 |
| Total rotation | Preoperation | 127.1 ± 12.6 | 123.8 ± 13.2 | 121.6 ± 12.8 | 0.196 |
| | Final follow-up | 99.6 ± 10.4* | 105.4 ± 10.1* | 96.2 ± 9.1* | <0.001 |
| | Δ Total rotation | −27.4 ± 10.5$^{§}$ | −17.7 ± 10.8$^{†}$ | −25.9 ± 11.2 | <0.001 |

The $p$-value was calculated by comparing all groups using one-way ANOVA. ACDF, anterior cervical discectomy and fusion; LAMP, posterior open-door laminoplasty; LF, posterior laminectomy and fusion; ROM, range of motion.
*Statistically significant difference between the last follow-up and the preoperative period ($P < 0.05$).
§Statistically significant difference between ACDF and LAMP ($P < 0.05$).
†Statistically significant difference between LAMP and LF ($P < 0.05$).
Δ Indicates the change of parameter at the last follow-up compared with the preoperative period.

TABLE 5 Postoperative complications.

| Complication | ACDF group ($n = 38$) | LAMP group ($n = 45$) | LF group ($n = 33$) | $P$-value |
|---|---|---|---|---|
| Dysphagia | 6 (15.79%)$^{§¶}$ | 0 (0.00%) | 0 (0.00%) | 0.001 |
| Pseudoarthrosis | 10 (26.32%)$^{§¶}$ | 0 (0.00%)$^{†}$ | 8 (24.24%) | 0.001 |
| Hematoma | 1 (2.63%) | 0 (0.00%) | 0 (0.00%) | 0.612 |
| Axial pain | 3 (7.89%) | 4 (8.89%) | 8 (24.24%) | 0.104 |
| Cerebral fluid leakage | 1 (2.63%) | 2 (4.45%) | 2 (6.06%) | 0.857 |
| C5 paralysis | 1 (2.63%) | 3 (6.67%) | 5 (15.15%) | 0.163 |
| Infection | 0 (0.00%) | 0 (0.00%) | 1 (3.03%) | 0.285 |
| Deterioration in neurologic deficit | 1 (2.63%) | 1 (2.22%) | 0 (0.00%) | >0.999 |
| Revision surgery | 7 (18.42%)$^{§}$ | 1 (2.22%) | 4 (12.12%) | 0.044 |
| Total$^{\#}$ | 23 (60.53%)$^{§}$ | 11 (24.44%)$^{†}$ | 16 (48.49%) | 0.003 |

The $p$-value was calculated by comparing all groups using one-way ANOVA. ACDF, anterior cervical discectomy and fusion; LAMP, posterior open-door laminoplasty; LF, posterior laminectomy and fusion.
§Statistically significant difference between ACDF and LAMP ($P < 0.05$).
¶Statistically significant difference between ACDF and LF ($P < 0.05$).
†Statistically significant difference between LAMP and LF ($P < 0.05$).
#Patients may have had more than one complication, so the total may be less than the sum of categories.

and LP groups, and the occurrence of pseudoarthrosis showed significant differences in the three groups, with ACDF having the highest rate compared with LAMP, which had no case. In addition, the revision surgery rate in ACDF was remarkably higher than that in LAMP. Taken together, these results indicate that patients who undergo ACDF are more likely to experience dysphagia, pseudoarthrosis, and reoperation than those who are subjected to LAMP, which showed the lowest incidence of postoperative complications.

## 4. Discussion

For surgical management of CSM, it is critical to select the optimal procedure preoperatively, and surgeons should seek adequate nerve decompression, restoring the physiological curvature of the cervical spine, preserving cervical mobility, and reducing postoperative complications as soon as possible.

In the present study, we compared the clinical efficacy of three routinely performed surgical procedures, ACDF, LAMP, and LF, on patients with four-level CSM. By using the JOA, NDI, and VAS score systems, we found that all patients achieved gratifying improvements in clinical symptoms and neurological functions, which showed no significant differences among the three groups. This result indicates that ACDF, LAMP, and LF could offer equal outcomes of nerve decompression. In addition, our operation data showed that ACDF had the least bleeding loss, which was in contrast to LF, which had the maximum bleeding loss. What is more, the operation time in the LF group was the longest among the three groups. This suggests that LF was more invasive and time-consuming but could not exert better nerve decompression than LAMP and ACDF.

The physiological curvature of a healthy cervical spine is characterized as lordosis (11), a large number of patients with CSM, especially four-level CSM, show more or less magnitude of lordosis loss, and the recovery of cervical lordosis affects the long-term clinical outcomes of surgery. In this study, only ACDF rather than LAMP or LF showed improvement on the C2–C7 Cobb angle, whereas this advantage failed to translate into better clinical results at the final follow-up. In addition, CCI, another parameter displaying cervical alignment, showed no difference in all patients between the preoperative period and the final follow-up. These results indicate that, although ACDF had the advantage of restoring the C2–C7 Cobb angle, neither ACDF, LAMP, nor LF affected the cervical curvature in our study. Given that subjects with severe kyphosis were excluded in advance, we attribute this phenomenon to the comparable and relatively mild to moderate change in preoperative cervical alignment.

The cervical spine is a hypermobile structure that allows for flexion, extension, lateral flexion, and rotation (12), and mobility, displayed as the range of motion (ROM), represents the critical physiological function of the cervical spine. Noteworthily, owing to solid fusion or loss of the relevant muscle attachment site, cervical spine surgery often leads to a reduced ROM. Thus, a surgical procedure that carries with it a ROM-preserving advantage seems more likely to bring better long-term outcomes (13). In this study, all patients showed a significant reduction in their cervical ROM at the final follow-up; nevertheless, comparatively, LAMP caused a slighter decrease in cervical mobility. Although no differences were observed in clinical outcomes in this study, we supposed that, with a longer follow-up, the superiority of mobility preservation of LAMP would produce a greater improvement in clinical symptoms and neurological function.

Due to the complex anatomical structures of the cervical spine, whose motion involves multiple vertebral joints simultaneously, it is hard to precisely assess that cervical spine movements rely solely on ROM measurement. Thus, we adopt an active cervical ROM (aROM) using a ROM goniometer, which has been validated as a noninvasive, quick, and reproducible method (14)., The aROM is an important indicator while assessing the recovery of patients with cervical disturbances. Surgical intervention predisposes to a decreased aROM, whereas the degree of reduction varies substantially among different surgical procedures (15, 16). Our previous study reported a decreased aROM after multilevel ACDF (17). In the present study, we measured the aROM in six movement directions for a reliable assessment of cervical mobility (18). We found a significant reduction in all patients at the final follow-up compared with the preoperative period. In addition, the aROM showed similar results to the ROM, which revealed less LAMP reduction than ACDF and LF. Taken together, we can conclude that LAMP is superior to ACDF and LF in terms of cervical mobility preservation.

Postoperative complications are an important indicator for surgical evaluation, which should be considered when selecting surgical procedures. With the development of cervical spine surgery, various relevant complications such as dysphagia, pseudoarthrosis, hematoma, axial pain, cerebrospinal fluid leakage, kyphosis, C5 paralysis, infection, and deterioration in neurologic deficit (19), have been widely reported. The occurrence of complications of cervical spine surgery usually depends on the surgical procedure, segments of operation, and severity of compression on the spinal cord or nerve root (20). For example, dysphagia is a common complication of ACDF, while axial pain is prone to occur after the performance of posterior surgical procedures such as LAMP and LF (21, 22). In the present study, we found a significantly higher incidence of complications in patients who underwent ACDF compared with those who underwent LAMP and LF, especially for dysphagia and pseudoarthrosis. Transient dysphagia was one of the most common postoperative complications following the ACDF procedure (23), a part of which was self-healing, whereas the others may suffer for a long time, severely impacting patients' living quality. Because the site of operation and fixation with plate and graft were adjacent to the esophagus, patients who underwent the anterior cervical procedure were predisposed to suffer from dysphagia postoperatively, and this tendency was more evident as the operative segments increased (21). Thus, spinal surgeons need to consider this complication when deciding on their surgical procedures. Pseudoarthrosis, by definition, is an undesirable condition in which the intended arthrodesis does not lead to valid fusion, causing local instability (24). Pseudoarthrosis has been widely reported in cervical spine surgery that involves fusion such as ACDF, with roughly approximate occurrences in 30%–50% of cases for three or more levels of ACDF (24). As for LF, most studies indicate higher fusion rates in posterior procedures than in anterior procedures, indicating less occurrence of pseudoarthrosis in posterior procedures (25). Eeric Truumees et al. (26) reported 21.2% of pseudoarthrosis incidence in patients who underwent three or more levels of posterior fusion surgery, which was consistent with our data. As pseudoarthrosis always leads to an instability of cervical biomechanics, a substantial proportion of patients in this study needed revision surgery for further fusion, although some of them were asymptomatic. Noteworthily, LAMP, which does not involve the fusion procedure, showed the least incidence of pseudoarthrosis and revision rates. In this respect, we tend to regard LAMP as the optimal procedure for four-level CSM.

There were some limitations in this present study. Firstly, as a retrospective study with a little sample, our conclusion might be affected by sample selection bias. Secondly, only the efficacy of ACDF, LAMP, and LF on four-level CAM were compared because the number of patients receiving other surgical procedures was too small, which does not necessarily mean that spinal surgeons have to select only one of the three procedures for patients.

## 5. Conclusion

This study systematically compared the efficacy of three routinely performed surgical procedures, ACDF, LAMP, and LF, on patients with four-level CSM, exploring nerve decompression, the restoration of cervical alignment, cervical spine mobility preservation, and postoperative complications. By consulting two-year follow-up data, we observed an equivalent efficacy of ACDF, LAMP, and LF in nerve decompression and symptomatic recovery. Importantly, although ACDF resulted in less bleeding loss and better restoration of the C2–C7 Cobb angle than LAMP or LF, a higher incidence of complications such as dysphagia, pseudoarthrosis, and revision surgery severely limited its application in four-level CSM. In contrast, LAMP showed superiority in terms of preserving cervical mobility and controlling complications compared with ACDF or LF; thus, we prefer recommending LAMP as the optimal surgical procedure for four-level CSM.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

All study procedures were approved by the institute chancellor's Human Research Committee in accordance with the institute's protocol. Written informed consent for participation was obtained by the patients.

## Author contributions

Study conception and design were done by HZ, XS, and WY. Acquisition of data was done by HZ, CX, and RW. Analysis and interpretation of data were performed by HZ, XW, HW, BS, XW, and HC. All authors made substantial contributions to revising this manuscript for intellectual content and approved the final published version. XS and WY had full access to all data in the study and took responsibility for ensuring the integrity of data and the accuracy of data analysis. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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EDITED BY
Feifei Zhou,
Peking University Third Hospital, China

REVIEWED BY
Kong Chao,
Capital Medical University, China
Hao Liu,
Sichuan University, China
Chao Chen,
Huazhong University of Science and Technology, China

*CORRESPONDENCE
Xiangyang Wang
xiangyangwang@126.com

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# Osteophyte formation causes neurological symptoms after anterior cervical discectomy and fusion (ACDF): A case report

Haiming Jin[1,2], Jiangtao Luo[3], Yuhan Jiang[3], Jinghao Lin[3], Junchen Jiang[3], Rufeng Ren[3], Weiyuan Fang[3], Yaosen Wu[1,2] and Xiangyang Wang[1,2]*

[1]Division of Spine Surgery, Department of Orthopaedics, The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, Wenzhou, China, [2]Key Laboratory of Orthopaedics of Zhejiang Province, The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, Wenzhou, China, [3]School of the Second Clinical Medical Sciences, Wenzhou Medical University, Wenzhou, China

Spinal surgeons have been drawn to the incidence of osteophytes following intervertebral disc degeneration in clinical practice. However, the production of osteophytes, particularly in the spinal canal, after anterior cervical discectomy and fusion (ACDF) is uncommon. We described a 42-year-old male patient who underwent C4–6 ACDF due to cervical stenosis two years prior in another public hospital in the province. His primary symptoms were significantly relieved, but he developed new pain and weakness in his right leg six months after surgery. The imaging results revealed a large posterior osteophyte at C5/6, compressing the spinal cord anteriorly. Accordingly, we performed cervical open-door laminoplasty to decompress the spinal cord. The patient's clinical symptoms had significantly improved at the one-year follow-up. This case seeks to inform surgeons that cautious, routine follow-ups are necessary for the event that a severe intracanal osteophyte develops at the operated level following ACDF. The comprehensive osteophyte removal and strong fixation at the operative level during ACDF warrant more consideration as these procedures may lower the incidence of new osteophytes. Additionally, surgical procedures may be required.

KEYWORDS

osteophyte, ACDF = anterior cervical discectomy and fusion, myelopathy, cervical open-door laminoplasty, strong fixation

## Introduction

An osteophyte is a fibrocartilage-capped bony protrusion that is a characteristic of osteoarthritis; it is unusual for vertebral osteophytes to form following disc degeneration (1, 2). Theoretically, the fusion of the vertebrae in the spine will increase stress loads and strains at the adjacent segments, which could result in the development of osteophytes in the segments adjacent to the fused vertebrae (3). Anterior cervical discectomy and fusion (ACDF) is a routinely performed spinal fusion procedure for decompressing the cervical cord (4), and having undergone this procedure is a potential risk factor for developing osteophytes in the adjacent segments (5). However, in our assessment of the English scientific literature, we found that the production of symptomatic osteophytes at the operative level is highly unusual after ACDF as only two cases of osteophytes in the posterior region of the operated disc were described (6, 7). In the current work, we present a unique case of a large osteophyte that developed after ACDF. Osteophyte growth within the spinal canal generated clinical symptoms of neural compression. A posterior one-sided open-door laminoplasty was performed to decompress the spinal cord to relieve the patient's myelopathic symptoms.

## Case report

A 42-year-old male patient was diagnosed with cervical stenosis three years ago, with limb numbness for two weeks and aggravation for one week. Imaging results demonstrated spinal stenosis at the C4/5 and C5/6 levels secondary to central disc herniation (**Figures 1A–C**). He received treatment at the time in another public hospital in the province with standard ACDF at both levels (C4/5, C5/6) utilizing the right-sided approach (**Figures 1D–F**). A steel plate was screwed to the C4 and C6 vertebral bodies, with both two screws attached to the C4 and C6 and another screw attached to the C5. The patient experienced significant improvement from his initial symptoms following surgery, but he developed new pain and weakness in his right leg six months later. Symptoms persisted despite a 2-year course of nonsurgical treatments that included physical therapy, nonsteroidal anti-inflammatory, and neurotrophic medication. The symptoms worsened one month before admission to our hospital, and the patient developed new symptoms of limb numbness and weakness accompanied by unstable walking, limiting his ability to perform regular tasks and ambulate. Physical examination revealed decreased sensations in both the upper and lower limbs, whereas the symptoms were more severe on the right side than on the left. His muscle strength was grade 4 for the upper limbs, grade 3 for the left leg, and grade 2 for the right leg. Hoffman's and Babinski's signs were positive on both sides.

The x-ray images revealed a large posterior cervical osteophyte at the level of C5/6 (**Figures 2A,B**), which did not exist at the time of the initial procedure. The C4–6 Cobb angle was 12.8°. The computed tomography (CT) scan provided more information about the osteophyte. The preoperative sagittal CT images revealed a large heterotopic bone that stretched from the posterior side of the C5 inferior end plate to the posterior side of the C6 superior end plate (**Figure 2C**). It also demonstrated the segmental fusion status following ACDF, revealing bridging trabeculae at the C4/C5 level, which was considered fused, and a bony gap at the C5/C6 level, which was termed fused poor. Transversal CT imaging revealed evident cervical stenosis, and ossification compressed the spinal cord anteriorly, resulting in a narrow space laterally for the spinal cord, dura mater, and cerebrospinal fluid (**Figure 2D**). The preoperative MR images also revealed a narrow spinal canal space and a T2-weighted hyperintense intramedullary signal at the C5/6 level (**Figures 2E,F**).

The symptoms failed to improve with nonoperative management; as such, the patient was advised to undergo surgical decompression and posterior stabilization *via* laminoplasty under general anesthesia. We performed cervical open-door laminoplasty at C3–7 to widen the space of the cervical vertebral canal, particularly at the C5/6 level, to assure the postoperative effect of decompression surgery. A cervical midline skin incision was made from C2 spinous processes to C7. The C3–C7 laminae were exposed following the installation of the automatic retractor. Open-door laminoplasty was performed by constructing bilateral gutters at the intersection of the laminae and the medial aspect of the lateral mass. The left side was opened, while the right-side gutter served as a hinge. The laminae from C3 to C7 were fully opened and held in place with mini plates placed between the laminae and lateral mass. The wound was then extensively irrigated and closed in layers after homeostasis was achieved. The postoperative course went smoothly, and the patient felt considerably better and presented no symptoms.

The x-ray and CT scans during the one-year follow-up revealed that all the plates had adhered directly to the host bone, widening the canal space (**Figures 3A–D**). The MRI scan at the one-year follow-up showed decompression at the C4/5 level (**Figures 3E,F**). The muscle strength grades of the left upper limb, right upper limb, left lower limb, and right lower limb improved to 5, 5, 4, and 3, respectively, after the operation.

## Discussion

A vertebral osteophyte is a typical osteoarthritic characteristic that is defined as an aberrant bony growth or bone spur that occurs along intervertebral joints (8). Emerging evidence indicates that age, acute injury, endplate sclerosis, and intervertebral disc degeneration are potential risk factors for the formation of vertebral osteophytes (8, 9). The fusion of spine segments may also result in osteophyte formation at adjacent segments (3). In contrast, no osteophytes were found at the adjacent segments in our case, and a severe intracanal osteophyte grew at the operative level without the application of bone morphogenetic proteins. The intracanal osteophyte triggered severe neurological symptoms. This is, to the best of our knowledge, the first time such a case has been reported.

The precise cause of osteophytes appears intricate and elusive. In successful fusion cases of cervical surgery, the vertebral range of motion (ROM) at the operative level is severely limited. At the same time, any persisting ROM and an abnormal instantaneous axis of rotation (IAR) at the operative level may trigger osteophyte formation in cases of cervical instability by loosening the instrumentation used for internal fixation. Osteophyte formation may be a self-regulatory mechanism as it increases the contact surface and restricts excessive motion. In this view, applying appropriate internal fixation devices such as an anterior plate and screws, as well as appropriate postoperative management, can help to avoid screw loosening and enhance the spine stability at the operative level. In this case, we strongly believe the first operation caused cervical instability. The surgeon managed to secure one screw fixation at C4 and C5 levels during the first surgery, however, the second screw at the C4 level violated the endplate. Poor C4 and C5 fixations generated a lever arm on the solid C6 fixation. The lever arm resulted in a mobile segment with unusual ROM and an abnormal IAR, which could explain the formation of an osteophyte. The inconspicuous remnant osteophyte following ACDF could be another major cause of osteophyte in the present case. We noted that osteophyte formation was primarily on the left side, which corresponded to the location of the marginal remnant posterior osteophyte detected in postoperative CT images following ACDF. Progenitor cells derived from muscle and bone are thought

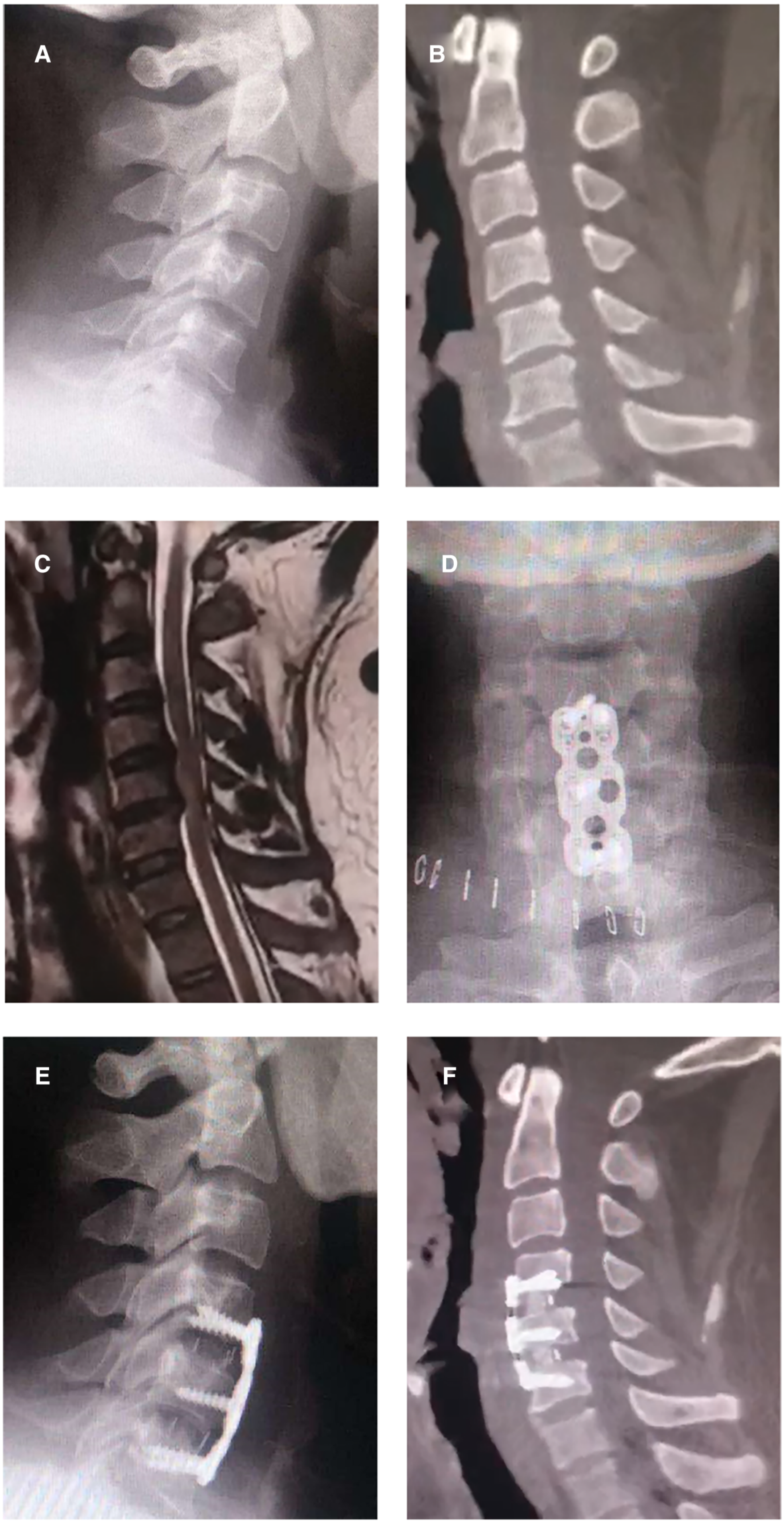


FIGURE 1
Preoperative and postoperative images of anterior cervical discectomy and fusion. (A) A preoperative lateral x-ray image of the patient; (B) A preoperative sagittal CT image of the patient; (C) A preoperative sagittal MR image, revealing spinal stenosis at the C4/5 and C5/6 levels secondary to central disc herniation; (D–F) Postoperative x-ray and CT images, revealing accurate placement of the plates, screws, and cages.

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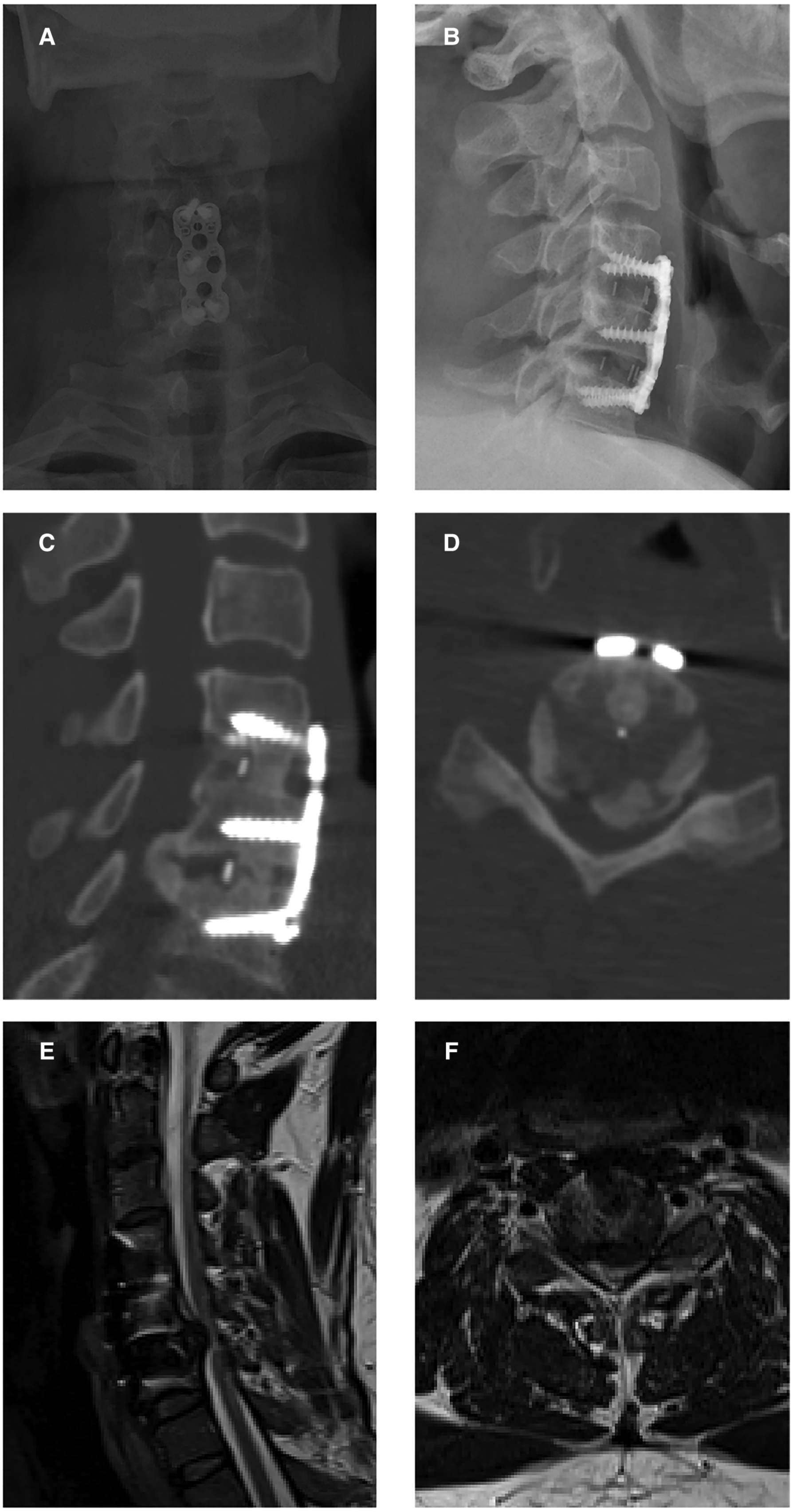


FIGURE 2
Preoperative images before open-door laminoplasty. (A,B) Preoperative x-ray images showing a large posterior cervical osteophyte at the level of C5/6. (C) A preoperative sagittal CT image showing a large heterotopic bone achieved from the posterior side of the C4 inferior end plate to the posterior side of the C5 superior end plate. (D) A transverse CT image revealing evident cervical stenosis and anterior spinal cord compression due to ossification. (E,F) Preoperative MR images showing the narrow space of the spinal canal and a T2-weighted hyperintense intramedullary signal at the C5/6 level.

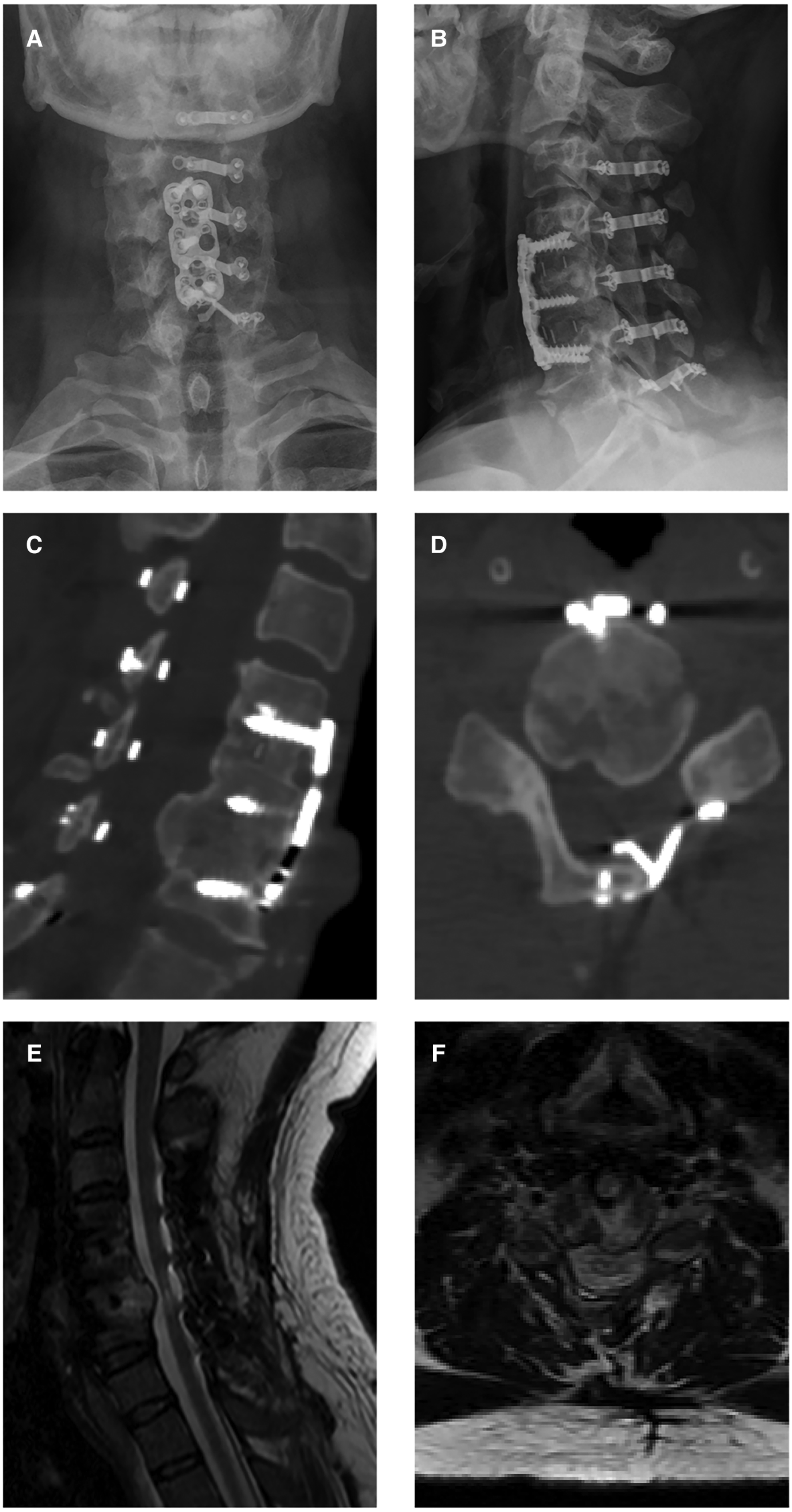


FIGURE 3
One-year follow-up images after open-door laminoplasty. (A,B) Postoperative x-ray images showing the accurate positions into which the plates and screws were installed. (C,D) Postoperative CT images showing direct adherence of all plates to the host bone, creating a new, wide canal space. (E,F) Postoperative MRI images showing decompression of the spinal cord at the C5/6 level.

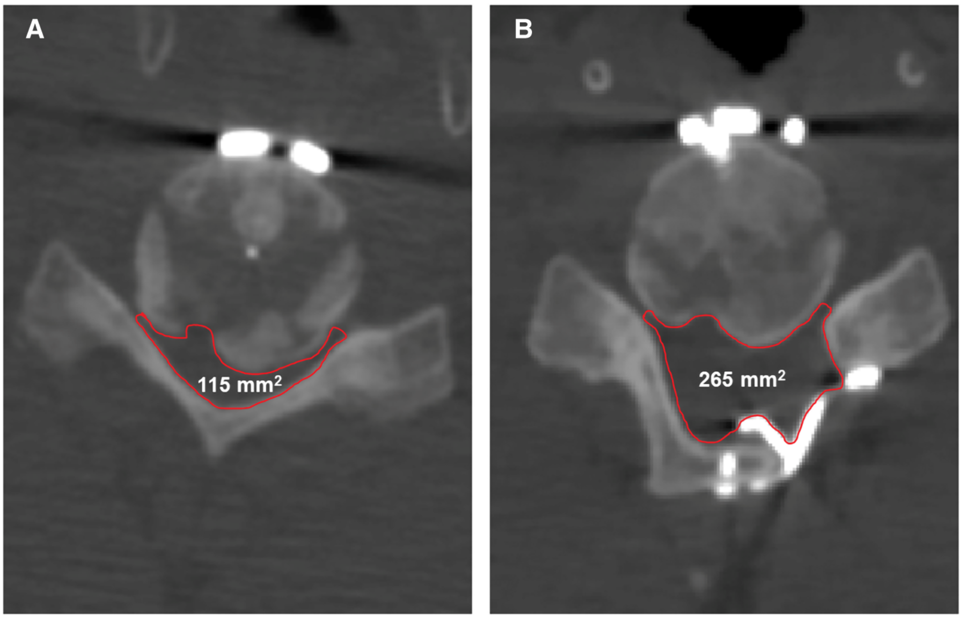


FIGURE 4
The changes in the space in the spinal canal from preoperative to postoperative. (**A**) The preoperative space in the spinal canal at the C5/6 level is 115 $mm^2$. (**B**) The postoperative space of the spinal canal at the C5/6 level is 265 $mm^2$.

to potentially differentiate into osteoprogenitor cells, supplying osteoblast precursors in the formation of new bone (10, 11). The manipulation of bone and muscle during surgery may allow progenitor cells to spread into nearby well-vascularized soft tissue. Choosing the appropriate operative technique, honing one's operative skills, and keeping the surgical field free might, therefore, assist lowering the rate of osteophytes. In addition, post-surgery inflammatory responses may be a factor in the progression of osteophyte formation (12). Studies have demonstrated that NSAIDs significantly lower the incidence of heterotopic ossification after cervical arthroplasty (13). This "heterotopic ossification" after cervical arthroplasty does not occur within soft tissue, and the mechanism is presumed to be related to the aggravation of preoperative osteophytes with aseptic inflammatory hyperplasia and dynamic loading stimulation (14, 15), which is highly comparable to the formation of vertebral osteophyte in the present case. Bone fusion and heterotopic ossification are both regarded as indicators of individual osteogenic capacity in patients (16), and we speculate that accessible NSAIDs may inhibit osteophyte formation through a similar mechanism. Furthermore, low-dose NSAIDs are frequently used for postoperative analgesia and have been shown not to influence the fusion rate after the lumbar fusion procedure (17). It is critical to note that an infection, postoperative hematoma, or persistent abnormal motion at the surgical site may aggravate inflammation. Patients with potential infections should take NSAIDs to manage them. Moreover, treatment with bisphosphonate and alendronate could slow osteophyte progression (18, 19). The recombinant human bone morphogenetic protein-2 (rhBMP-2) has been identified as a potential accelerating factor for osteophyte formation 6, while the application of barriers to prevent BMP exposure to soft tissue and neural elements may minimize its effects (20).

The present work observed bone development at the posterior region of the C5/6 level (**Figure 2**). While research into the fate of the posterior osteophyte following anterior cervical fusion surgery is scarce and contradictory, recent studies have shown that spontaneous diminution of the posterior osteophyte is extremely unusual. As a result, suitable surgical procedures are useful in improving the prognosis. All surgical attempts to resect this heterotopic bone run the risk of further spinal cord compression and may cause cerebrospinal leakage owing to tight adhesion or ossification of the dura. Moreover, dissecting scar adhesion between the plate and surrounding tissues to remove the fixation devices may result in several complications. This is why we first performed posterior decompression; which saw a gradual improvement in the patient's symptoms after surgery. Postoperative CT scan revealed that the space in the spinal canal expanded from 115 $mm^2$ to 265 $mm^2$ at the C5/6 level (**Figure 4**), whereas the postoperative MRI scan showed complete decompression of the spinal cord (**Figures 3E,F**). Given the patient's clinical improvement, we recommended that he receive rehabilitation therapy and proceed with follow-ups to detect any progression of osteophytes or the emergence of new symptoms.

## Conclusion

Patients who receive ACDF occasionally develop osteophytes. The massive intracanal heterotopic bone and poor clinical symptoms found in the present case distinguish it from others. Nonetheless, we performed a successful surgical posterior decompression by open-door laminoplasty. The case report aims to raise awareness among surgeons that a severe intracanal osteophyte may develop after ACDF, and that cautious, regular follow-ups are warranted. Furthermore, to reduce the rate of postoperative osteophytes, surgeons should focus more on the comprehensive removal of osteophytes, strong fixation at the operative level, and a clear surgical field during ACDF. Surgical interventions may also be required.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Research Ethics Committee of the Second Affiliated Hospital of Wenzhou Medical University and Yuying Children's Hospital of Wenzhou Medical University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

HJ, JTL and YJ: were contributed equally to this article and mainly responsible for article writing. YW and XW: were mainly responsible for the surgical design, and implementation. JHL, JJ and RR: were mainly responsible for image acquisition and data collection. WF: was mainly responsible for article revising and improvement. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Lifeng Lao,
Shanghai Jiao Tong University, China
Mengchen Yin,
Shanghai University of Traditional Chinese Medicine, China

*CORRESPONDENCE
Tiantong Xu
✉ xtt114@sina.com

[†]These authors have contributed equally to this work

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# Evaluation of enlarged laminectomy with lateral mass screw fixation in relieving nerve root symptoms and correcting kyphosis for cervical myelopathy and radiculopathy

Zhao Fang[1†], Yuqiao Li[1,2†], Zongyu Huang[1,2], Gan Luo[1,2], Houzhi Yang[1,2], Haiyang Cheng[1,2] and Tiantong Xu[1*]

[1]Department of Spine Surgery, Tianjin Union Medical Center, Tianjin, China, [2]Graduate School, Tianjin Medical University, Tianjin, China

**Purpose:** This study aimed to compare the surgical efficacy of enlarged laminectomy with lateral mass screw fixation (EL-LMSF) and anterior cervical decompression and fusion (ACDF) for multilevel cervical myelopathy and radiculopathy (CMR) related to kyphosis.

**Methods:** 75 patients were retrospectively reviewed and divided into ACDF and EL-LMSF group. Clinical results including operative time, blood loss, and postoperative complications were compared. The JOA scoring system was used to evaluate spinal cord function and the VAS score evaluate nerve root pain severity. Cervical alignment a C2–C7 was measured with Cobb method and compared to confirm the reconstruction effect.

**Results:** Data on 75 patients (M/F: 41:34; EL-LMSF/ACDF:42/33) with the mean age of 57.5 years (range 43–72 year old) were reviewed retrospectively. Discectomy and/or sub-toal corpectomy in ACDF group was performed with a mean of 3.24 levels (range, 3–4). Enlarged laminectomy in EL-LMSF group was performed with a mean of 3.89 enlarged levels (range, 3–5). The procedure of ACDF group showed a shorter operation time (103 ± 22 min vs. 125 ± 37 min, $P = 0.000$) and less blood loss (78 ± 15 ml vs. 226 ± 31 ml, $P = 0.000$) compared than that of the EL-LMSF group. Patients treated with EL-LMSF indicated lower VAS for upper extremity (1.3 ± 1.7 vs. 3.3 ± 1.3, $P = 0.003$) and better curvature corrected (10.7 ± 4.2° vs. 8.5 ± 3.5°, $P = 0.013$). The difference were of statistical significance. No statistical difference was found after surgery in the JOA score (14.1 ± 1.7 vs. 13.5 ± 2.1, $P = 0.222$). During the follow-up period, 15.2% of patients in the ACDF group had complications including 2 cases with transient dysphagia, 1 case with C5 palsy, 1 case with axial pain, and 1 case with screw pullout 3 month after surgery. However, only 9.5% of cases in the EL-LMSF group experienced complications, including 3 cases of axial pain and 1 case of epidural hematoma.

**Conclusion:** The EL-LMSF procedure requires a longer operation time and more blood loss because of the incision of the stenosed foramen. However, the procedure has obvious advantages in relieving nerve root symptoms and correcting cervical curvature with fewer postoperative complications.

KEYWORDS

cervical myelopathy and radiculopathy, enlarged laminectomy, lateral mass screw fixation, kyphosis, anterior cervical corpectomy decompression and fusion

Abbreviations
EL-LMSF, enlarged laminectomy with lateral mass screw fixation; ACDF, anterior cervical decompression and fusion; CMR, cervical myelopathy and radiculopathy; JOA, Japanese Orthopedic Association; VAS, Visual Analog Scale; CT, computed tomography; MRI, magnetic resonance imaging

# 1. Background

Coexisting cervical myelopathy and Radiculopathy (CMR) is a disabling and prevalent disease. The progression of inter-vertebral disc degeneration and cervical malalignment lead to spinal cord and nerve compression, and disruption of spine kinematics.

Surgical management for patients with multilevel CMR associated with kyphosis aims to decompress the spinal cord and nerve root and improve the sagittal alignment using either an anterior approach or a posterior approach. However, the optimal surgical procedure remains controversial. The procedure of anterior cervical decompression and fusion (ACDF) may be accompanied by a high incidence of fusion failure and adjacent segment degeneration especially for multilevel CMR associated with kyphosis (1). The traditional posterior Laminoplasty/laminectomy cannot relieve nerve root compression, and even causes stretching of the nerve root due to backward shifting of the spinal cord. Enlarged laminectomy with lateral mass screw fixation (EL-LMSF) seemed to be an alternative procedure (2). Enlarged laminectomy allows adequate decompression of the spinal cord and nerve root by widening the spinal canal dimensions and removing the posterior wall of the the stenosed inter-vertebral foramen (3). Posterior plating with lateral mass screws is in favor of correcting cervical curvature and providing stability.

This is a retrospective comparative study of two surgical procedures between EL-LMSF and ACDF procedure in the management of multilevel CMR with cervical kyphosis. The study is designed to investigate the surgical efficacy in decompressing nerve root and correcting cervical kyphosis.

# 2. Materials and methods

## 2.1. Ethics statement

Informed written consent was obtained from each patient. The study protocol was approved by the Ethics Committee of Tianjin Union Medical Center.

## 2.2. Patient population

All patients with multilevel CMR associated with kyphosis were consecutively screened at Tianjin Union Medical Center between 2017 and 2019. Inclusion criteria: (1) degeneration cervical spine disease; (2) more than 3 levels of compression of the spinal cord; (3) bilateral nerve root compression symptoms; (4) overall and/or segmental cervical kyphosis); (5) more than 1 year follow-up. Exclusion criteria: (1) previous history of cervical surgery, cervical tumor or trauma; (2) unilateral nerve root compression symptom; and (3) continuous ossification of the posterior longitudinal ligament.

A total 75 patients with complete dates were finally retrospectively reviewed and divided into ACDF and EL-LMSF group. Surgical choice to use corpectomy, discectomy, or hybrid decompression was depending on local compressive pathology and level. In EL-LMSF group, level of laminectomy and foraminotomy was confirmed according to the imaging study and clinical symptom.

## 2.3. Operative technique

### 2.3.1. Enlarged laminectomy with lateral mass screw fixation (EL-LMSF)

The procedure was performed mainly in three steps as follows: lateral mass screw fixation, laminectomy and cutting the posterior wall of the intervertebral foramen. Posterior plating with lateral mass screw fixation were placed bilaterally in the modified Magerl's technique (4). Rods of appropriate size were selected and bent to match the contour of the lateral masses and secured to the lateral masses by screws, and then laminectomy were performed based on the preoperative surgical planning. While cutting the posterior wall of the inter-vertebral foramen, medial edge of the upper and lower facet resection should be ≤50%. This resection removed the posterior part of foramen thus making nerve root decompressed (**Figure 1**).

### 2.3.2. Anterior cervical decompression and fusion with titanium plate and screw fixation (ACDF)

For the ACDF procedure, the removed discs and/or sub-total vertebrae were replaced by an appropriate-size cage or titanium mesh combined with small pieces of the bone allograft. The vertebrae above and the below fusion level were fixed with the

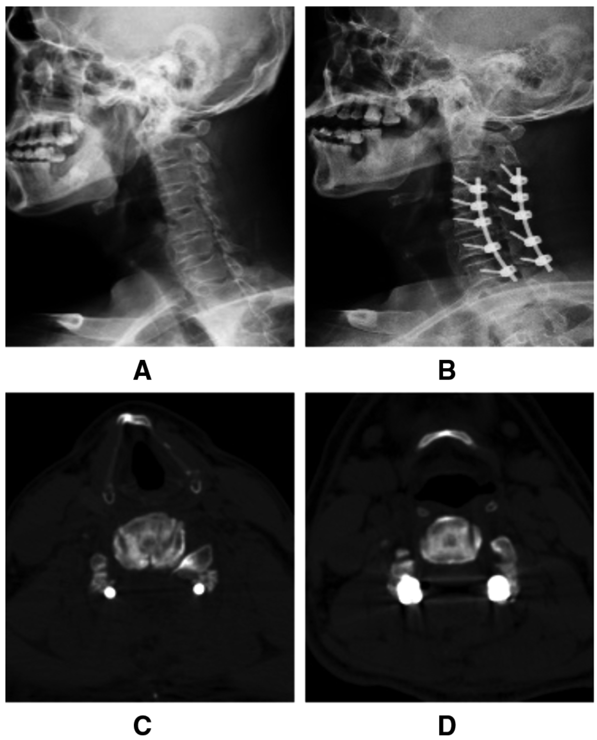


FIGURE 1
C3–C7 Enlarged laminectomy and lateral mass screw fixation with foraminotomy at the Lt. C4/5 and Rt. C4/5 and C5/6 levels. (A,B) Cervical curvature correction and foramen expanding at Rt. C4/5 and C5/6 levels. (C,D) Postoperative bilateral C4/5 and Lt. C5/6 foraminotomy.

appropriate-sized titanium plate and screw. The positions of cage, plate and screws were confirmed with C-arm (Figure 2).

## 2.4. Postoperative rehabilitation

Postoperative care was similar between the two groups. All patients wore a hard neck collar after surgery for 4–6 weeks. Pain management and some adjunctive therapy were emphasized equally. The wound drain tube was removed within 3 days after surgery. Patients were discharged from the hospital on the 7th postoperative day.

## 2.5. Clinical evaluation

The JOA (Japanese Orthopedic Association) scoring system was used to evaluate the severity of myelopathy based on the degree of dysfunction in each category. The VAS (Visual Analog Scale) score was used to evaluate upper extremity pain caused by nerve root compression. The JOA and VAS score was investigated before surgery and on the postoperative 7th day, 3th month and 1st year.

Symptoms mentioned above consist of three categories: myelopathy (extremity weakness/numbness, gait instability, and bladder dysfunction), radiculopathy (upper extremity pain), and postoperative axial pain.

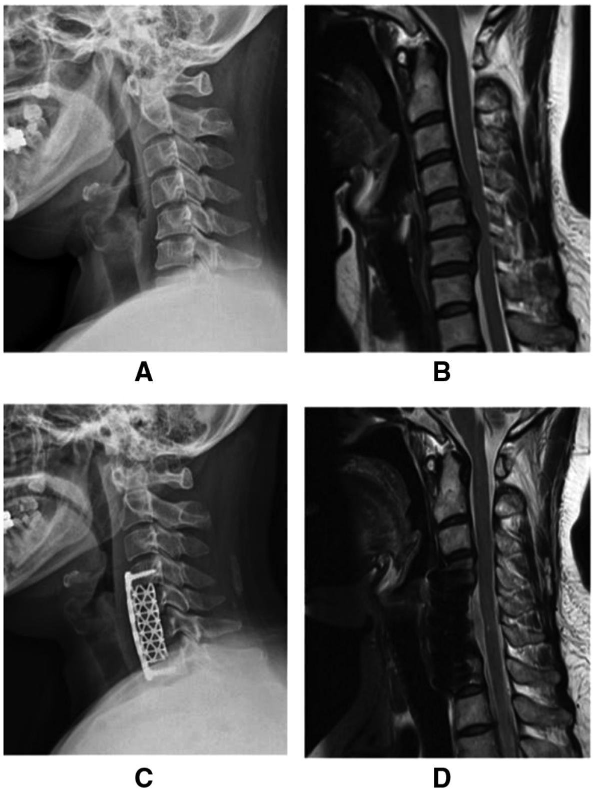


FIGURE 2
Anterior cervical subtotal corpectomy with titanium plate and screw fixation. (A) Lateral radiograph showing cervical kyphosis. (B) Posterior compressing of the spinal cord at the C4/5–C6/7 level. (C) Postoperative improved cervical alignment. (D) Postoperative MRI showing the decompressed spinal cord.

## 2.6. Radiographic measurements

Cervical alignments at C2–C7 was measured with Cobb method on lateral cervical radiograph (5). MR images were used to confirm the degree of spinal cord compression and postoperative extent, and CT scans to judge the placement of screw fixation. The radiographic measurements were performed by two independent surgeons before surgery and at the postoperative 1st year follow-up.

## 2.7. Statistical analysis

Unpaired *t*-tests or Mann–Whitney *U* tests were used to detect differences between the two groups. Statistical analyses were performed with SPSS 22.0 (SPSS, Inc., Chicago, IL, USA). $P < 0.05$ was considered to indicate statistical significance.

# 3. Results

## 3.1. Patients demographics

Data on 75 patients (M/F: 41:34; EL-LMSF/ACDF:42/33) with the mean age of 57.5 years (range 43–72 year old) were reviewed retrospectively. The average follow-up was from 14.8 to 55.2 months, and all of the follow-up dates were recorded completely at least within 1 year. The follow-up period between the two group was of no statistical difference. Discectomy and/or sub-toal corpectomy in ACDF group was performed with a mean of 3.24 levels (range, 3–4). Enlarged laminectomy in EL-LMSF group was performed with a mean of 3.89 enlarged levels (range, 3–5). The difference was no statistically significant. The level and side of foraminotomy include: C4/5 in 12 cases, C5/6 in 16 cases, C6/7 in 1 case, C4/5 and C5/6 in 9 cases, C5/6 and C6/7 in 4 cases. There was no statistical difference between the two groups for the preoperative JOA score, VAS for upper extremity and C2-C7 alignment (Table 1).

TABLE 1 Clinical characteristics of the patients before operation.

| | ACDF group | EL-LMSF group | *P* value |
|---|---|---|---|
| Age | 54.8 ± 11.7 | 57.2 ± 12.9 | - |
| Male (%) | 54.4% | 56.2% | - |
| BMI (kg/m$^2$) | 23.1 ± 4.5 | 27.1 ± 5.1 | 0.078 |
| JOA score | 8.3 ± 2.0 | 7.9 ± 1.9 | 0.290 |
| VAS score | 7.2 ± 1.2 | 6.9 ± 1.3 | 2.084 |
| C2–C7 angle | 1.3 ± 9.3 | 0.7 ± 8.6 | 0.765 |

Mean ± SD; NS, not statistically significant; -, no statistical calculation; BMI, body mass index; JOA: Japanese Orthopedic Association; VAS, Visual Analog Scale.

### 3.2. Clinical results, radiographic results and postoperative complications

No statistical difference was found at 1 year-follow-up after surgery in the JOA score (14.1 ± 1.7 vs. 13.5 ± 2.1, $P = 0.222$) between the two procedures. The procedure of the ACDF group showed a shorter operation time (103 ± 22 min vs. 125 ± 37 min, $P = 0.000$) and less blood loss (78 ± 15 ml vs. 226 ± 31 ml, $P = 0.000$) compared to that of the EL-LMSF group. Patients treated with EL-LMSF indicated lower VAS for the upper extremity (1.3 ± 1.7 vs. 3.3 ± 1.3, $P = 0.003$) and better curvature corrected (10.7 ± 4.2° vs. 8.5 ± 3.5°, $P = 0.013$). The difference was of statistical significance.

In the EL-LMSF group, CT scans after surgery did not show any error in screw location, trajectory or length. While in the ACDF group, a patient was found with screw pullout 3 months after surgery, but the patient remains asymptomatic and the titanium mesh fuses solidly.

During the follow-up period, 15.2% of patients in the ACDF group had complications including 2 cases with transient dysphagia, 1 case with C5 palsy, and 1 case with axial pain. However, only 9.5% of cases in the EL-LMSF group experienced complications, including 3 cases of axial pain and 1 case of epidural hematoma (**Table 2**).

## 4. Discussion

### 4.1. Radiologic comparison in correcting cervical kyphosis

For patients with multilevel CMR with kyphosis, the aims of surgical treatment were not only decompressing the spinal cord and nerve root but also improving cervical alignment.

TABLE 2 Surgical results, radiology assessment and complications.

| | ACDF group | EL-LMSF group | *P* value |
|---|---|---|---|
| **Clinical assessments** | | | |
| Operation time (min) | 103 ± 22 | 125 ± 37 | 0.000 |
| Blood loss (ml) | 78 ± 15 | 226 ± 31 | 0.000 |
| JOA score | 14.1 ± 1.7 | 13.5 ± 2.1 | 0.222 |
| VAS score | 3.3 ± 1.3 | 1.3 ± 1.7 | 0.003 |
| **Radiologic assessments** | | | |
| C2–C7 angle (°) | 8.5 ± 3.5 | 10.7 ± 4.2 | 0.013 |
| **Postoperative complications** | | | |
| Transient dysphagia | 2 | 0 | - |
| C5 palsy | 1 | 0 | - |
| Axial pain | 1 | 3 | - |
| Epidural hematoma | 0 | 1 | - |
| Screw pullout | 1 | 0 | - |

Mean ± SD; $P < 0.05$: statistically significant difference; -, no statistical calculation; JOA: Japanese Orthopedic Association; VAS: Visual Analog Scale.

Reconstruction of cervical alignment is essential in treating cervical radiculomyelopathy related to kyphotic deformity (6, 7). Poor reconstruction maybe offset the effect of decompression. Restoring alignment in conjunction with decompression has been purported to improve long-term patient-reported symptoms (8). Uchida et al. (9) confirmed adequate correction of sagittal alignment may help to maximize the chance of neurological improvement. For the anterior approach, the height and longitudinal diameter of the inter-vertebra can be increased with the help of implants like a cage or mesh (10). ACDF seems to be the mainstay procedure but at a limited number of levels. Multilevel anterior cervical corpectomy and fusion seem to be a radical surgical option because of the high incidence of fusion failure, titanium mesh subsidence, and adjacent segmental degeneration (1, 11). Duan et al. pointed out that posterior fixations could provide immediate stability to the cervical spine after laminectomy, correct cervical kyphosis and promote early neurological recovery (12). Up to date, there is seldom report about a comparison of radiographic results between EL-LMSF and ACDF procedures in the management of multilevel CMR with kyphosis.

At the last postoperative follow-up, the EL-LMSF group provided better cervical alignment than that of the ACDF group (10.7 ± 4.2° vs. 8.5 ± 3.5°, $P = 0.013$). The difference was of statistical significance. EL-LMSF procedure had an obvious advantage in correcting cervical curvature. During the follow-up period, there was no screw loose or curvature loss in EL-LMSF group, while a patient in ACDF group was found with screw pullout 3 months after surgery, but the patient remained asymptomatic and accepted regular follow-up.

### 4.2. Clinical comparison and postoperative complications

There was no statistical difference in the JOA score at the last postoperative follow-up between the two procedures (14.1 ± 1.7 vs. 13.5 ± 2.1, $P = 0.222$). While postoperative patients in the EL-LMSF group reported lower VAS scores for upper extremity pain than that of the ACDF group (1.3 ± 1.7 vs. 3.3 ± 1.3, $P = 0.003$), which indicated patients with EL-LMSF procedure received better treatment effect in relieving nerve root symptoms. During the follow-up period, 15.2% of patients developed postoperative complications in the ACDF group, while 9.5% of patients were in the EL-LMSF group. We still believe EL-LMSF procedure is more safe than ACDF especially for more than 4-level stenosis lesion, Although axial pain was an unavoidable complication after posterior surgery.

As we know, the longitudinal diameter of inter-vertebral foramen was increased with the help of implants. While anteroposterior diameter was widen in the way of excision of uncovertebral joint or facet joint (13). The Choice of surgical procedure for radiculopathy should be based on the foraminal stenosis mechanism. The neural foramen is a funnel-shaped structure where the nerve root extending from the spinal cord is the widest and the root localization is the narrowest. This anatomical characteristic provides evidence for enlarged laminectomy (14). The technique of foraminotomy has been continually developed since the 1990s with a satisfying result of decompressing the nerve root and preventing nerve root paralysis (15). The reported incidence of postoperative C5 palsy was 4.6% (range from 0% to 30%) (16). In this study, the ACDF group had a patient with C5 palsy, whereas none of the patients in the EL-LMSF group experienced this condition. This result demonstrates that an enlarged laminectomy can prevent postoperative C5 palsy, and many other studies have reported similar findings (17, 18).

Axial pain has been defined as pain from the nuchal to the periscapular or shoulder region (19). Such a complication has been reported mainly after posterior cervical surgery. The underlying mechanisms of axial pain are still not fully understood. Potential sources of axial pain include posterior muscle atrophy, the muscles detaching from C2 or C7, and sinking or nonunion of the expanded laminae (20, 21). The decrease in cervical lordosis or increase in cervical kyphosis would produce more axial pain. It is reported that reconstruction of the posterior tension band decreased the incidence of axial pain (22). The incidence of axial symptoms after laminectomy or laminoplasty can be as high as 30%. In this study, 7.1% of patients complained of postoperative axial pain which occurred mainly in patients with obvious cervical kyphosis. The decreasing incidence of axial symptoms may correlate with the reconstruction of posterior tension band and restoration of cervical curvature. This finding is consistent with the findings of previous reports (23, 24). However, few high-quality clinical trials have reported this association.

In conclusion, the EL-LMSF procedure requires a longer operation time and more blood loss because of the incision of the stenosed foramen. However, the procedure has obvious advantages in relieving nerve root symptoms and correcting cervical curvature with fewer postoperative complications. However, Large scale clinical trials with long-term follow-up are urgently warranted. We expect a further correlation analysis between the reconstruction of alignment and neurological function.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

This study protocol was approved by the Institutional Review Board and Ethics Committee of Tianjin Union Medical Center.

## Author contributions

ZF, TX, and YL designed the study. GL and HY collected the data. TX, GL, HY, and ZH analyzed the data and drafted the manuscript. ZF, HC and YL revised and approved the final version of the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Xinghuo Wu,
Huazhong University of Science and Technology, China

REVIEWED BY
Konstantinos Margetis,
Icahn School of Medicine at Mount Sinai, United States
Weibin Sheng,
Xinjiang Medical University, China

*CORRESPONDENCE
Huafeng Zhang
✉ fcczhanghf@zzu.edu.cn

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# Impact of the K-line in patients with ossification of the posterior longitudinal ligament: Analysis of sagittal cervical curvature changes and surgical outcomes

Zhongxin Tang, Tailong Chen, Jun Tan and Huafeng Zhang*

Department of Orthopaedic Surgery, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China

**Objective:** This study aimed to investigate the relationship of the K-line with sagittal cervical curvature changes and surgical outcomes in patients with cervical ossification of the posterior longitudinal ligament (OPLL).
**Methods:** We retrospectively reviewed 84 patients with OPLL who underwent posterior cervical single-door laminoplasty. The patients were divided into a K-line-positive (+) group and a K-line-negative (–) group. Perioperative data, radiographic parameters, and clinical outcomes were compared between the two groups.
**Results:** Of 84 total patients, 50 patients were in the K (+) group and 29 patients were in the K (–) group. Neurological function improved in both groups after laminoplasty. The C2–7 Cobb angle, T1 slope, and C2–7 sagittal vertical axis were significantly changed in the K(–) group compared with those in the K (+) group before the operation and at the 3-month and final follow-ups.
**Conclusion:** Neurological function was recovered in both groups, and the clinical effect on the K (+) group was better than that on the K (–) group. The cervical curvature in patients with OPLL tends to be anteverted and kyphotic after laminoplasty and is an important factor in reducing the clinical effect.

KEYWORDS
cervical, OPLL, surgical outcomes, laminoplasty, K-line

## Introduction

Ossification of the posterior longitudinal ligament (OPLL) is one of the main causes of cervical myelopathy (1), which not only causes the spinal cord and nerve root disease in patients but also increases the risk of spinal cord injury after minor trauma (2, 3). Its pathogenesis is unclear, as many factors are at play. These include endocrine factors (4, 5), genetic factors (6, 7), mechanical stress stimuli, and biomechanical factors (8). Continued ossification often results in cervical spinal stenosis and progressive compression of the nervous system, so patients with OPLL often require surgical treatment. Laminoplasty is a commonly used surgical method. However, many factors may lead to poor symptom relief or even aggravation after posterior laminoplasty (9).

Fujiyoshi et al. (10) proposed the K-line theory to make an appropriate prognosis evaluation for OPLL patients. The K-line is a virtual line that connects the midpoints of the anteroposterior diameter of the spinal canal at C2 and C7 in a plain lateral radiogram. If the peak of the OPLL ossification focus does not exceed this line, it is K-line-positive; otherwise, it is K-line-negative. This single parameter can be used to explain the poor surgical outcomes after laminoplasty due to cervical kyphosis and the high occupancy rate of OPLL to the spinal canal. Some researchers (11, 12) have suggested that patients who are K-line-negative usually have poor outcomes after laminoplasty due to limited spinal cord retromobility. However, the K-line classification does not include dynamic factors, and there is controversy regarding whether sagittal cervical curvature will affect the efficacy of laminoplasty in OPLL patients.

Therefore, we designed the present study to (1) analyze the correlation between the clinical efficacy of laminoplasty and the change in cervical curvature in patients with OPLL and (2) analyze how the K-line is related to changes in the sagittal cervical curvature and kyphosis after laminoplasty.

# Materials and methods

## Patients

The study design was approved by the ethics committee of our institution. We retrospectively reviewed the medical records of patients who underwent posterior cervical single-door laminoplasty for cervical myelopathy caused by OPLL at our institution between January 2015 and December 2019. Altogether, 84 patients were ultimately included in this study. The inclusion criteria are as follows: (1) diagnosis of cervical compressive myelopathy due to OPLL; (2) increased signal intensity of the spinal cord on MRI; and (3) OPLL involving two or more vertebrae. The exclusion criteria are as follows: (1) cervical trauma and tumor; (2) a history of cervical surgery; (3) a history of neuromuscular diseases or the presence of other complex concomitant diseases; and (4) follow-up of less than 2 years.

## Operative procedure

For each patient, we performed single-open-door laminoplasty. A midline incision was made on the posterior neck skin to expose the laminae and articular processes of the decompression segment. Determined by the severity of the symptoms, the more severe side of the laminae was selected as the open-door side, with the other side used as the hinged side. The grooves along the junction of the lamina and facet articular process on both sides were cut by a high-speed grinding drill or an ultrasonic bone knife. After the laminae had been elevated, anchor sutures were used and fixed. After postoperative day 1, the patients were permitted to ambulate using their neck bracket.

## Data collection

The mean follow-up period was 36 months (ranging from 24 to 84 months). All patients were re-examined 3 months after the operation and at the last follow-up appointment. Based on the K-line (10) (**Figure 1**), the patients were retrospectively classified into the K-line-positive [K (+)] group and the K-line-negative [K (−)] group. The basic data of each patient included age, sex, and body mass index (BMI). The sagittal cervical radiographic measures included x-ray radiography, CT, and MRI. The C2–7 sagittal vertical axis (SVA), C2–7 Cobb angle, T1 slope, and spinal canal occupation rate of the ossified mass were measured (**Figure 1**). The Japanese Orthopedic Association (JOA) score (17-point method) (13) was used to evaluate the clinical outcomes before the operation, 3 months after the operation, and at the last

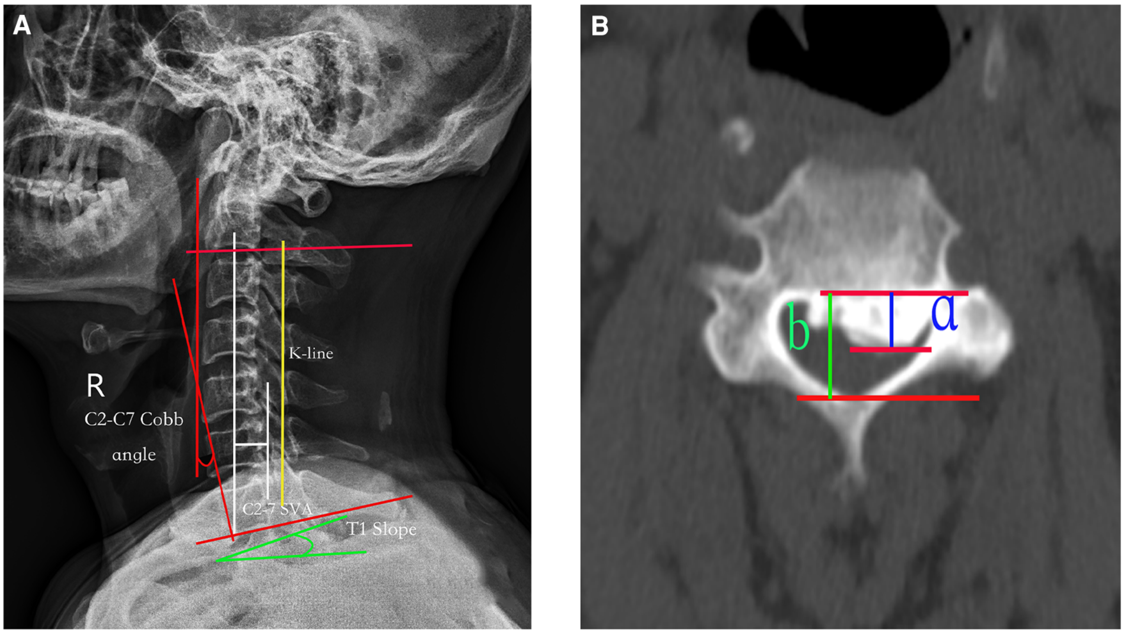


FIGURE 1
(A) Radiographic measurements: (1) the K-line is a straight line joining the midpoints of the spinal canal at C2 and C7 on a lateral radiograph; (2) C2−C7 SVA: the distance between the C2 plumb line and the superoposterior endplate of C7; (3) C2−C7 Cobb angle: the angle formed by the C2 and C7 lower endplates; and (4) T1 slope: the angle between the horizontal line and the T1 upper endplate. (B) Percentage of spinal canal occupation by ossified mass. The thickness of the ossification block (a, green line) and the anteroposterior diameter of the spinal canal (b, yellow line) were measured on the axial CT section of the highest point of the ossification block. The percentage of spinal canal occupation by the ossification block = a/b × 100%. SVA, sagittal vertical axis.

follow-up. The improvement rate of the JOA score 3 months after the operation and at the last follow-up was also calculated. Recovery rate (%) = (postoperative JOA score − preoperative JOA score/17 − preoperative JOA score) × 100.

## Statistical analysis

SPSS 22.0 statistical software (IBM Corp, Armonk, New York, United States) was used for the statistical analysis of the data. The data are expressed as the mean ± SD. The analyses of the continuous variables were performed using unpaired Student's *t*-test or Welch's test for two-group comparisons, and the clinical and radiological measurements were analyzed using Wilcoxon's test. Differences with a *P*-value of <0.05 were considered statistically significant.

# Results

A total of 84 patients were reviewed, and the duration of follow-up ranged from 24 to 84 months. There were 51 men and 33 women, with an average age of 55.60 ± 8.94 years (range 35–7 76 years). According to the position in relation to the K-line, 59 patients were in the K (+) group (36 men, 23 women) and 25 patients were in the K (−) group (15 men, 10 women). There were no significant differences in the characteristics of the data between the groups ($P > 0.05$; **Table 1**).

There were significant differences in C2–7 SVA, C2–7 Cobb angle, and T1 slope between the two groups before the operation ($P < 0.001$). In the K (+) group, the T1 slope and the Cobb angle were both larger than those in the K (−) group, and the C2–7 SVA was smaller than that in the K (−) group. After the operation, the T1 slope and the Cobb angle decreased in both groups, and the change was greater in the K (−) group ($P < 0.05$). However, the C2–7 SVA increased more in the K (+) group than in the K (−) group ($P < 0.05$). Meanwhile, there were no significant differences in the JOA scores between the groups before and after the operation ($P > 0.05$), and there were significant differences in the JOA improvement rate ($P < 0.05$; **Table 2** and **Figure 2**).

# Discussion

OPLL often causes abnormal paranesthesia and motor dysfunction due to spinal stenosis with compression of the spinal cord and nerve roots. There are commonly two surgical approaches for removing cervical OPLL: anterior and posterior. The anterior approach is riskier and more prone to spinal cord injury (14, 15), so posterior spinal cord decompression is widely performed to treat patients with OPLL (12, 16, 17). Single-open-door laminoplasty can achieve decompression and preserve spine stability to a certain extent. It has yielded favorable clinical outcomes when used for treating OPLL (18–20). However, there are many disadvantages of posterior laminoplasty (11): decompression is achieved through spinal cord retreat to the dorsal side rather than direct decompression. As the dentate ligament connects the spinal cord to the front of the spinal canal, and the nerve roots from the dura and the front of the spinal cord also limit the movement of the spinal cord to the back. Therefore, if the spinal cord does not move backward enough, the compression of the ossification focus in front of the spinal cord will persist, and the postoperative outcomes will be poor.

Iwasaki et al. (21) concluded that laminoplasty is effective and safe for most patients with an occupying ratio of OPLL of less than 60% but is poor or fair in patients with an occupying ratio greater than 60%. Koda et al. (22) found that laminoplasty should not be used for K-line (−) cervical OPLL. In the present study, the

TABLE 1 Comparison of patient characteristics between the groups.

| Variable | K (+) group (59 patients) | K (−) group (25 patients) | *P*-value |
|---|---|---|---|
| Age (years) | 55.78 ± 9.41 | 55.15 ± 7.89 | 0.769 |
| Gender (female/male; numbers) | 23/36 | 10/15 | 0.559 |
| BMI (kg/m$^2$) | 25.48 ± 3.87 | 23.87 ± 1.88 | 0.052 |
| Canal occup. ratio | 46.60 ± 12.11 | 54.16 ± 10.44 | 0.662 |

TABLE 2 Comparison of surgical results between the groups.

| | K (+) group (59 patients) | K (−) group (25 patients) | *P*-value |
|---|---|---|---|
| **C2–7 Cobb angle (°)** | | | |
| Preoperative | 18.77 ± 6.70 | 11.28 ± 6.67 | 0.010 |
| Postoperative 3 months | 17.04 ± 6.77 | 8.88 ± 6.48 | 0.003 |
| Postoperative change | 1.73 ± 0.68 | 2.39 ± 0.82 | <0.001 |
| At last follow-up | 15.59 ± 4.98 | 7.08 ± 3.80 | <0.001 |
| **C2–7 SVA (mm)** | | | |
| Preoperative | 17.51 ± 5.67 | 20.51 ± 5.88 | 0.020 |
| Postoperative 3 months | 20.09 ± 6.55 | 23.72 ± 6.21 | <0.001 |
| Postoperative change | 2.58 ± 1.88 | 3.21 ± 1.52 | 0.010 |
| At last follow-up | 21.89 ± 7.61 | 26.70 ± 7.11 | 0.050 |
| **T1 slope (°)** | | | |
| Preoperative | 23.34 ± 5.58 | 21.58 ± 5.66 | 0.192 |
| Postoperative 3 months | 21.64 ± 5.7 | 18.94 ± 5.52 | 0.048 |
| Postoperative change | 1.70 ± 0.54 | 2.64 ± 1.01 | <0.001 |
| At last follow-up | 19.46 ± 6.86 | 17.29 ± 5.38 | 0.436 |
| **JOA score** | | | |
| Preoperative | 11.41 ± 2.11 | 9.6 ± 2.16 | 0.562 |
| Postoperative 3 months | 14.43 ± 2.32 | 12.60 ± 2.27 | 0.763 |
| Improvement rate of the JOA score (%) | 62.499 ± 26.66 | 44.37 ± 15.22 | 0.002 |
| At last follow-up | 15.21 ± 2.21 | 13.61 ± 2.16 | 0.030 |

SVA, sagittal vertical axis; JOA, Japanese Orthopedic Association.

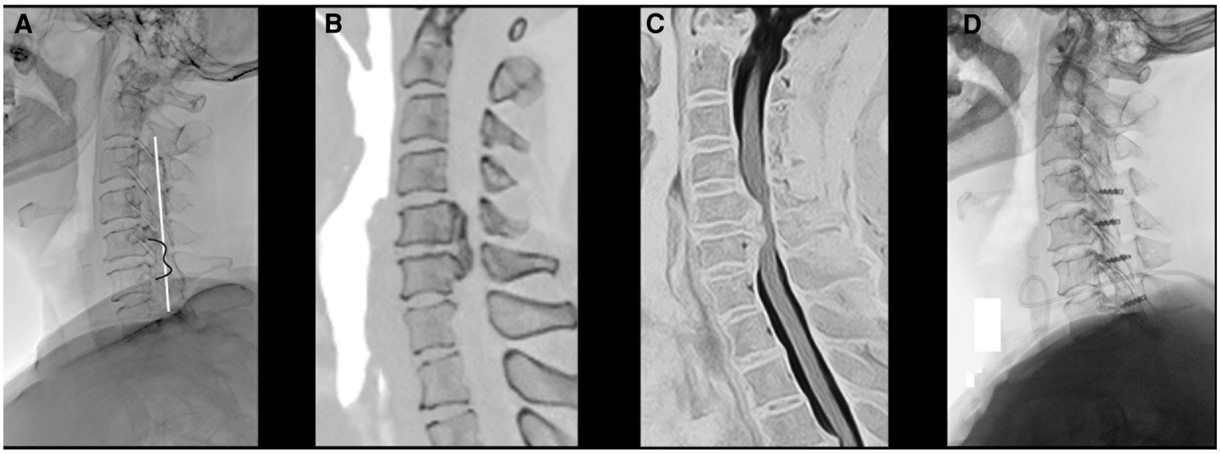


FIGURE 2
(A) A 60-year-old woman with OPLL and negative K-line. (A) A preoperative x-ray film of the cervical spine showing that the peak of ossification foci is beyond the K-line; (B) preoperative sagittal CT showing that the range of ossification of the posterior longitudinal ligament is C5–C6; (C) preoperative MRI showing obvious compression in front of the cervical spinal cord; and (D) postoperative x-ray showing good internal fixation position and lordosis reduced.

JOA improvement rate was significantly better in the K (+) group than in the K (−) group at the last follow-up ($P < 0.05$). This shows that the efficacy of laminoplasty in the K (+) group is significantly better than that in the K (–) group. The possible reason is that the spinal cord did not give way to the back after laminoplasty in the K (−) group, and the improvement in neurological symptoms was not noticeable. Therefore, it is inappropriate for such patients to choose posterior laminoplasty, and anterior surgery should be the first choice.

The destruction of cervical muscles and ligaments after posterior laminoplasty may lead to changes in cervical curvature, which accelerates the change in cervical curvature, leading to increased cervical anteversion and reduced cervical lordosis. In patients with cervical spondylosis, the center of gravity of the cervical vertebra must be moved backward to achieve sagittal balance. In our research, the patients in the K (−) group of the present study showed a significant change in cervical spine curvature after posterior laminoplasty (the T1 slope decreased, the C2–7 Cobb angle decreased, and the C2–7 SVA increased). Miyazaki et al. (23) and Cho et al. (24) concluded that their clinical outcomes demonstrated overall improvement after cervical laminoplasty with cervical OPLL, regardless of the preoperative T1 slope. Kim et al. (25) showed that preoperative cervical lordosis is not related to the clinical effect after laminoplasty. In contrast, Suk et al. (26) found that preoperative lordosis of the cervical spine is a prerequisite for laminoplasty, and maintaining postoperative lordosis is also important for decompression of the spinal cord. Masaki et al. (11) stated that the sagittal position of the cervical spine often showed kyphosis after laminoplasty but that cervical sagittal alignment and clinical outcomes were still unclear.

We found that the clinical effect was connected to the change in sagittal curvature of the cervical spine. Compared to the K (+) group, there were significant changes in the cervical spine curvature in the K (–) group, and the clinical effect was also poor at the last follow-up ($P < 0.05$). We also found that the change in the cervical curvature after posterior laminoplasty tended toward anteversion and kyphosis in both groups. However, the preoperative cervical lordosis of the patients in the K (+) group was greater than that in the K (–) group, thus buffering the changes in cervical lordosis after surgery. Based on the bowstring effect, the K (+) group had a better clinical effect after surgery. In contrast, for patients in the K (–) group, the preoperative cervical curvature was not sufficient to resist the postoperative curvature change, and patients were more affected by the cervical curvature, leading to a worse clinical effect. Therefore, we believe that the change in cervical curvature after laminoplasty may influence the clinical effect in patients with OPLL.

In the present study, we still have several limitations. (1) There were a limited number of eligible patients, as this was a single-center study. (2) We only included patients who underwent single-open-door laminoplasty. Larger studies with long-term follow-ups are needed.

## Conclusion

Neurological function was improved after posterior laminoplasty in both K-line groups. The clinical effect in the K (+) group was better than that in the K (−) group. In addition, the cervical curvature changed little in the K (+) group compared with the K (–) group. The important factor reducing the clinical effect of laminoplasty is that cervical curvature in patients with OPLL tends toward anteversion and kyphosis.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by The First Affiliated Hospital of Zhengzhou University

Ethics Committee. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

ZT: data curation and writing—original draft preparation. TC: formal analysis and investigation. JT: supervision. HZ: writing—review and editing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Nanfang Xu,
Peking University Third Hospital, China
Kai Cao,
The First Affiliated Hospital of Nanchang University, Nanchang University, China

*CORRESPONDENCE
Yue-Hui Zhang
✉ zyhandy8030@126.com
Jiang Shao
✉ shaojiang@xinhuamed.com.cn

†These authors have contributed equally to this work

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# Comparison of structural occipital and iliac bone grafts for instrumented atlantoaxial fusions in pediatric patients: Radiologic research and clinical outcomes

Zhi-Hui Liang†, Yue-Hui Zhang*, Hai-Tao Liu, Qiu-Qi Zhang, Jia Song† and Jiang Shao*

Spine Center, Xin Hua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine, Shanghai, China

**Background:** Structural autografts harvested from the iliac bone have been used in atlantoaxial fusion; they have been the gold standard for years. However, emerging occipital bone grafts have the advantage of avoiding donor-site morbidity and complications. Thus, we compared the clinical outcomes of structural autografts from the occipital bone or iliac crest and discussed the clinical significance of occipital bone grafts in pediatric patients.

**Methods:** Pediatric patients who underwent posterior fusion using occipital bone grafts (OBG) or iliac bone grafts (IBG) between 2017 and 2021 were included in this study. Data on clinical outcomes, including operation time, estimated blood loss, length of hospitalization, complications, fusion rate, and fusion time, were collected and analyzed. Additionally, 300 pediatric patients who underwent cranial computed tomography scans were included in the bone thickness evaluation procedure. The central and edge thicknesses of the harvested areas were recorded and analyzed.

**Results:** Thirty-nine patients were included in this study. There were no significant differences in patient characteristics between the OBG and IBG groups. Patients in both groups achieved a 100% fusion rate; however, the fusion time in the OBG group was significantly longer than that in the IBG group. Estimated blood loss, operation time, and length of hospitalization were significantly lower in the OBG group than those in the IBG group. The surgery-related complication rate was lower, but not significantly, in the OBG group than that in the IBG group. For occipital bone thickness evaluation, a significant difference in the central part of the harvesting area was found between the young and old groups, with no significant sex differences.

**Conclusion:** The use of OBG for atlantoaxial fusion is acceptable for pediatric patients with atlantoaxial dislocation, avoiding donor-site morbidity and complications.

KEYWORDS
atlantoaxial fusion, iliac bone graft, occipital bone graft, structural autograft, atlantoaxial dislocation

Abbreviations
IBG, Iliac bone grafts; OBG, Occipital bone grafts; CT, Computed tomography; PRC, People's Republic of China.

## 1. Introduction

Atlantoaxial dislocation is defined as a loss of normal articulation and instability of the atlantoaxial joint, often resulting from trauma and congenital and inflammatory factors (1, 2). The surgical treatment of atlantoaxial dislocation is focused on decompressing the spinal cord and reconstructing a stable atlantoaxial joint (3–5). Atlantoaxial fusion can regenerate stable joint constructs and promote solid arthrodesis, and a bone graft is a key factor in the fusion process (6). Recently, cadaveric allografts for pediatric atlantoaxial fusion showed their competence with lower blood loss, shorter operative time, and no donor-site morbidity (7); however, they have the risk of infectious transmission and a relatively low fusion rate (5, 8). Furthermore, in pediatric upper cervical spine fusion, the use of iliac bone grafts (IBG) was considered the gold standard due to their high fusion rate. However, the potential donor-site complications, prolonged operation time, and increased estimated blood loss resulting from the second incision need to be seriously considered (8).

An occipital bone graft (OBG) is an ideal material for spine fusion consisting of bicortical elements and a diploe, ensuring a rich blood supply and biomechanical strength for the graft. It has the advantages of IBG and allografts, with a relatively high fusion rate and no requirement for an extra incision (9). Previous studies found that an OBG, as a membranous bone, has the advantage of less resorption than an IBG or rib, which are endochondral bones (10, 11). Several studies have reported the use of OBG for atlantoaxial fusion in adult and pediatric patients (9, 12–14); however, no research has compared the clinical outcomes of OBG and IBG with the use of the screw/rod fixation technique in pediatric patients and evaluated the thickness of the occipital bone donor site for safety concerns. Therefore, the main purpose of this study was to evaluate the clinical outcomes of OBG and IBG with the use of rigid screw/rod fixation techniques in pediatric patients.

## 2. Methods

The study protocol was approved by the Ethics Committee of Xinhua Hospital (XHEC-D-2022-193). This study followed the principles of the Declaration of Helsinki and the laws and regulations of the People's Republic of China, and all patients provided written informed consent.

The small population of pediatric patients with atlantoaxial dislocation provided limited information to evaluate the thickness of the occipital bone donor site. Hence, we included 300 pediatric patients aged 2–12 years who underwent computed tomography (CT) scanning for concussion or brain damage and the scanning area included the occipital bone. The center of the occipital donor site was defined as the external occipital protuberance. Additionally, the thickness of the four corners in the 1.5 cm × 2 cm donor site was measured, and the average thickness of the four corners was considered the edge thickness (**Figure 1**).

For atlantoaxial fusion evaluation, 39 pediatric patients who underwent atlantoaxial fusion for atlantoaxial dislocation with OBG and IBG in the authors' hospital between 2017 and 2021 were retrospectively evaluated and analyzed. Age, sex, body weight, diagnosis, graft type, operation time, estimated blood loss, approach, type of instrumentation, length of hospitalization, postoperative follow-up period, fusion time, intra-and perioperative complications, and donor-site morbidities were examined. Patients diagnosed with tumors or serious infections were excluded. Surgical indications included neurological deficits, neck pain or occipital headache, and limitation of neck motion, with or without severe spinal cord compression.

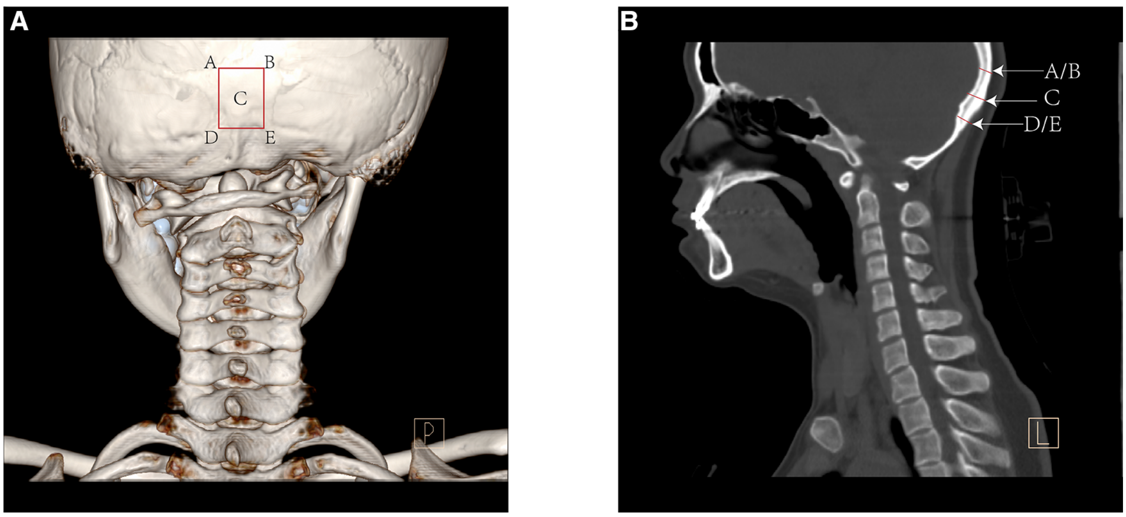


FIGURE 1
The posterior view of computed tomography (CT) 3D reconstruction (A) and the sagittal reconstruction (B) showed the method to measure the bone thickness of the occipital donor-site.

## 2.1. Surgical procedure and clinical follow-up

The patients were placed under general anesthesia, and cranial skeletal traction was applied. Irreducibility was determined if the patient did not show a satisfactory reduction under skeletal traction. For irreducible atlantoaxial dislocation, anterior release through the retropharyngeal approach described in a previous study was performed (15).

After satisfactory reduction was achieved, the patient was placed in the prone position for posterior instrumentation and fusion. After exposure of the posterior side of C1–C2, C1 pedicle screws were inserted as previously described (16–18). Briefly, the vertebral artery was cranially dissected away from the posterior arch of the atlas, while the C2 root was caudally dissected away. The vertebral artery and C2 root were protected using two Penfield dissectors. The pilot hole was drilled and deepened as previously described (5). The C1 polyaxial screws were inserted through the pilot holes, and C2 pedicle screws were placed as described by Harms et al. (19); after satisfactory reduction was confirmed using fluoroscopy, titanium fixation rods were placed.

The midline incision was extended over the external occipital protuberance for the OBG harvesting procedure. A 1.5 cm × 2 cm split-thickness OBG was obtained using piezosurgery or an osteotome. For iliac crest bone harvesting, we used the strategy of harvesting a 1.5 cm × 2 cm bone graft under the ilium edge to avoid growth plate injury and preserve the integrity of the ilium in pediatric patients. Briefly, a rectangular bone graft was harvested by piezosurgery or osteotome under the edge of the posterior superior iliac spine, bone wax was used to control bleeding. The posterior arch of the atlas and the spinous process of the axis were decorticated using a high-speed bur, and all bone fragments were collected and planted between the bone graft and transplantation bed. The bone graft was trimmed to adapt to the shape of the transplantation bed and then placed and fixed by using wire, as previously described (5, 20). For clinical follow-up, the Philadelphia collar would be placed for 3 months, and CT scans were conducted 6 months postoperatively, and the interval between CT scans was 3 months until osseous fusion was achieved. A three-dimensional reconstructive CT scan was used to identify complete fusion.

## 2.2. Statistical analysis

Statistical analysis was conducted in R, version 4.0.3 (Boston, MA). Values are expressed as mean ± standard deviation. Estimated blood loss, operative time, length of hospitalization, and fusion time of the two groups were assessed using the student's *t*-test or Mann–Whitney test. Fisher's exact test was used to compare fusion and complication rates between the two groups. A *P* value <0.05 was considered statistically significant.

# 3. Results

The occipital bone thickness was measured in 300 pediatric patients, divided into 2–6 and 7–12-year age groups. The results are shown in **Table 1**. The central thickness of the harvesting area in the male groups of 2–6 and 7–12-year categories was 7.9 ± 1.1 mm and 11.0 ± 1.9 mm, respectively; and in females, the values were 7.3 ± 0.7 mm and 10.0 ± 2.3 mm, respectively. Furthermore, the edge thickness of the OBG in the male groups of 2–6 and 7–12-year categories were 4.8 ± 1.9 mm and 5.1 ± 1.0 mm, respectively, and those in the female group were 4.5 ± 1.0 mm and 5.5 ± 1.9 mm, respectively.

Fusion surgery with OBG or IBG was performed in 19 and 20 patients, and a summary of patient characteristics is shown in **Table 2**. No significant differences were observed in sex, age, height, weight, atlan-dens interval (ADI), or primary diagnosis between the two groups. The operative and postoperative data are shown in **Table 3**; both groups achieved a 100% bone fusion rate (**Figures 2, 3**). In the IBG group, the fusion time was 6.1 ± 0.7 months, significantly shorter than that in the OBG group (7.4 ± 2.1 months). Estimated blood loss was significantly lower and the length of hospitalization was significantly shorter in the OBG group than in the IBG group.

There was a higher, but not significant, complication rate in the IBG group than in the OBG group. In the OBG group, a cerebrospinal fluid leak was found in one patient during surgery.

TABLE 2 Summary of patients' characteristics.

| | Occipital bone graft group | Iliac bone graft group | *P* value |
|---|---|---|---|
| Sex (male : female) | 10 : 9 | 13 : 7 | 0.5231 |
| Age (years) | 7.1 ± 4.6 | 8.9 ± 3.5 | 0.2609 |
| Height (cm) | 116.3 ± 31.3 | 114.7 ± 23.9 | 0.8791 |
| Weight (kg) | 28.7 ± 17.6 | 24.2 ± 12.2 | 0.7870 |
| ADI (mm) | 5.6 ± 1.6 | 6.0 ± 1.0 | 0.4898 |
| **Primary diagnosis** | | | |
| Os odontoideum | 11 | 12 | 0.7168 |
| Hypoplasia of the dens | 6 | 6 | |
| Atlantoaxial rotatory displacement | 2 | 1 | |
| Relaxation of the transverse ligament | 0 | 1 | |

TABLE 1 Occipital bone donor site thickness (mm).

| | 2–6 years/male | 7–12 years/male | *P* value | 2–6 years/female | 7–12 years/female | *P* value |
|---|---|---|---|---|---|---|
| central | 7.9 ± 1.1 | 11.0 ± 1.9 | 0.0001 | 7.3 ± 0.7 | 10.0 ± 2.3 | 0.0001 |
| edge | 4.8 ± 0.9 | 5.1 ± 1.0 | 0.2002 | 4.5 ± 1.0 | 5.5 ± 0.9 | 0.0001 |

There were two cases of seroma formation, two of chronic donor-site pain, and one of donor-site infection in the IBG group. All patients with preoperative neurological deficits achieved significant relief at 6-month follow-ups.

TABLE 3 Comparison of operative and postoperative data.

| | Occipital bone graft group | Iliac bone graft group | *P* value |
|---|---|---|---|
| Operation time (min) | 99.5 ± 24.8 | 145.5 ± 58.5 | 0.0004 |
| Estimated blood loss (ml) | 73.7 ± 25.7 | 127.5 ± 44.4 | 0.0001 |
| Length of hospitalization (days) | 7.5 ± 1.7 | 9.5 ± 2.1 | 0.0077 |
| Sugery-related complication | 1 (Cerebrospinal fluid leak) | 5 (Seroma formation, Infection, Donor-site pain) | 0.1818 |
| Fusion rate (%) | 100 | 100 | 0.9999 |
| Average fusion time (months) | 7.7 ± 2.1 | 6.1 ± 1.0 | 0.0067 |
| **Fusion time after surgery** | | | |
| ≤6 months | 9 | 17 | 0.0296 |
| 7–9 moths | 7 | 3 | |
| 10–12 months | 3 | 0 | |

## 4. Discussion

For atlantoaxial dislocation, the primary goal of surgery is to achieve bone fusion; however, decompressing neural elements and restoring the stability and structure of the atlantoaxial joint are also important. With the application of the C1–C2 screw/rod construct technique, which provides effective biomechanical stability, patients who underwent rigid fixation showed higher fusion rates and lower complication rates than those who underwent the wire fixation technique (21–23); however, rigid fixation alone without solid bony fusion could not provide long-term stability of the atlantoaxial joint. Thus, rigid fixation and bony fusion are required for satisfactory long-term clinical outcomes. Bone graft materials are key factors for achieving solid bony fusion. Autografts and allografts are two major bone graft materials used in clinical practice. Although the use of allografts has eliminated donor-site morbidity with a relatively high fusion rate, autologous bone grafts have always been the gold standard for posterior cervical fusion because of their osteogenic and osteoinductive advantages (24). Autografts can be harvested from the iliac crest, posterior superior iliac spine, rib, or occipital bone. For structural autografts, IBG have been widely accepted as the reference standard bone material for atlantoaxial fusion. However, iliac bone harvesting is often associated with donor-site

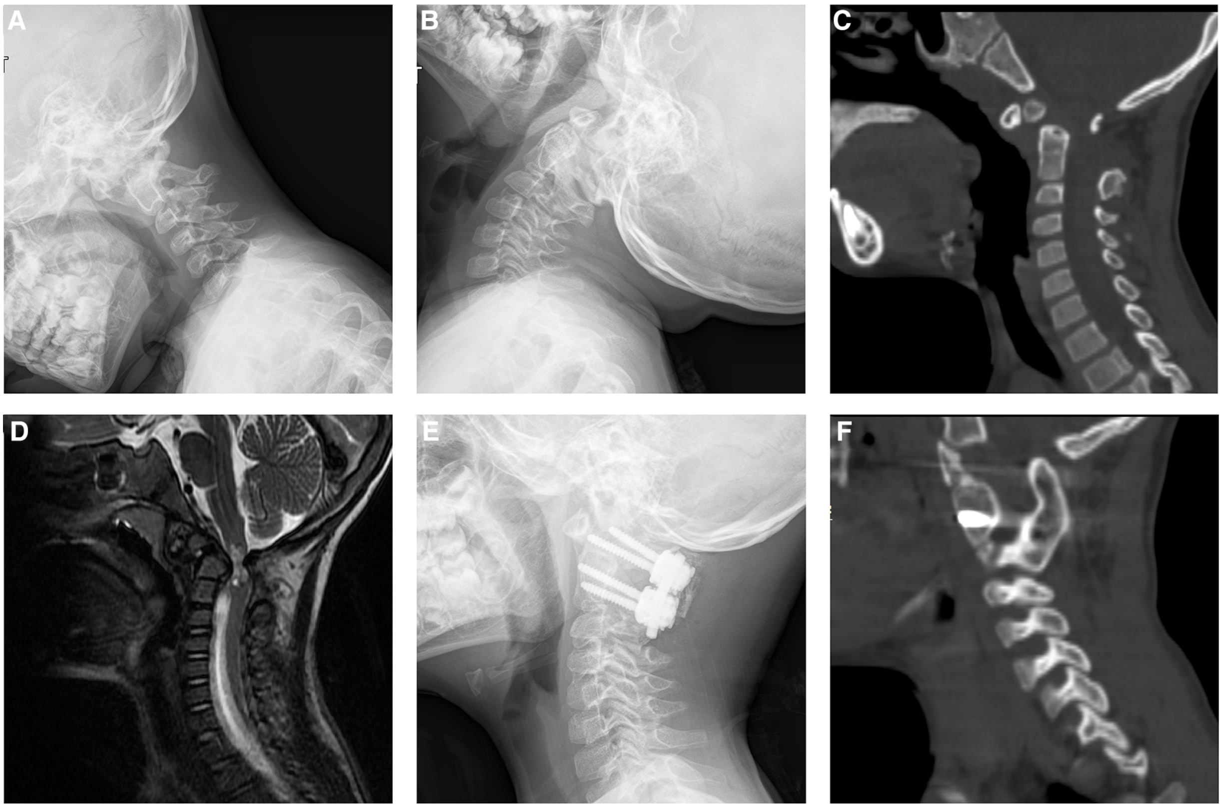


FIGURE 2
Images of a 5-year-old boy diagnosed of os odontoideum and underwent atlantoaxial fusion with the use of IBG. Preoperative plain radiograph of flexion (A) extension (B) showed atlantoaxial dislocation. Preoperative CT showed os odontoideum (C). Preoperative magnetic resonance imaging (MRI) showed spinal cord compression (D). Postoperative plain radiograph (E) showed the rigid screw/rod fixation. CT sagittal reconstruction showed solid bony fusion 6 months after surgery (F).

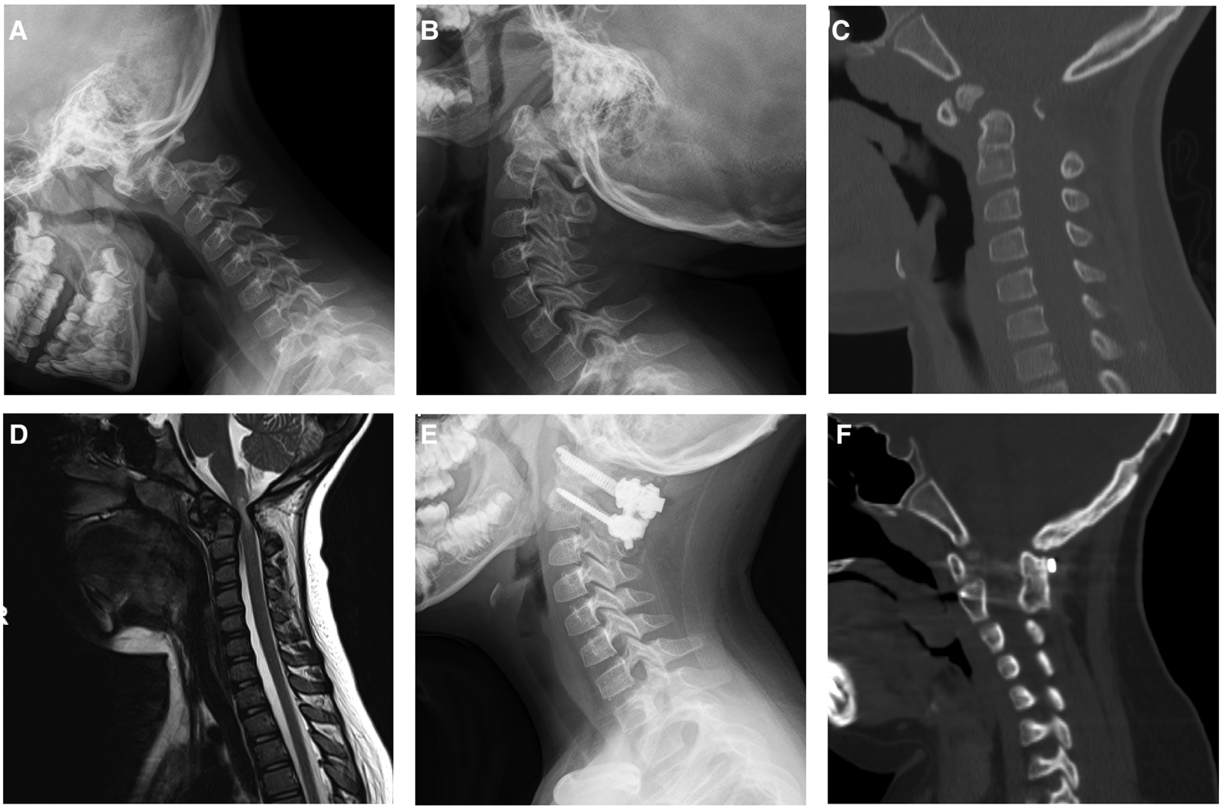


FIGURE 3
Images of a 8-year-old boy with atlantoaxial dislocation due to os odontoideum. This patient underwent atlantoaxial fusion with the use of OBG. Preoperative plain radiograph in flexion (A), extension (B) showed atlantoaxial dislocation. CT showed os odontoideum (C). MRI showed neural element compression (D). Postoperative plain radiograph in neutral (E) showed rigid fixation. Computed tomography sagittal reconstruction showed solid bony fusion 12 months after surgery, white arrow showed occipital bone donor-site (F).

pain, prolonged operation time, increased blood loss, and pelvic fracture (25, 26). In pediatric patients, iliac bone harvesting has the potential risk of injuring the growth plate and further affecting the growth of the iliac bone. The type of bone grafting technique also affects the bone fusion process. Morselized bone grafts have optimal osteoconductive properties for the porosity of bone grafts but provide limited structural strength and integrity (27). Structural bone grafts provide excellent mechanical strength and structural integrity. This technique has a relatively low excessive bony fusion rate and can avoid venous plexus injury. Considering the advantages of the structural bone grafting technique, we used the occipital bone as an autologous structural bone graft material to treat pediatric patients diagnosed with atlantoaxial dislocation and compared the clinical outcomes of OBG and IBG.

To harvest the OBG, the bone harvesting area was 1.5 cm × 2 cm, and the external occipital protuberance was the center of the bone harvesting area. However, pediatric patients have a thinner occipital bone than adult patients, which raises a serious safety concern for harvesting this bone from them. During the occipital bone harvesting procedure, the risk of penetrating the full thickness of the occipital bone, dural laceration, and cerebrospinal fluid leakage resulting from a thinner bone harvesting area, deserves serious consideration. To address this safety issue, we evaluated the thickness of the occipital bone harvesting area from the CT scans of 300 pediatric patients. The results showed that male and female pediatric patients aged 2–6 years had a significantly thinner occipital bone than those aged 7–12 years; the average edge thickness of the bone harvesting area was $4.5 \pm 1.0$ mm in the younger group. Previous studies have described the techniques of harvesting full- and split-thickness grafts from the occipital or calvarial bone (12–14, 28), one recommended that the calvarial bone grafting technique should be applied in patients aged >1.5 years; however, no study has assessed the relationship between the safety of occipital bone harvesting and the thickness of the occipital donor site. We considered that an edge thickness of the occipital donor site >4 mm was relatively safe according to our clinical experience. Consequently, we selected pediatric patients who met the criteria for occipital bone grafting, and the results showed a relatively low incidence of complications related to donor site thickness.

With the application of the rigid internal fixation technique, both groups achieved a 100% fusion rate at 12 months of follow-up. However, the fusion time in the OBG group was significantly longer than that in the IBG group. Two patients who underwent occipital bone grafting did not achieve bony fusion until 12 months postoperatively, possible reason explaining the prolonged fusion time of these patients was that most of bone grafts harvested from occipital bone were cortical. Most patients in the iliac bone graft group achieved bony fusion 6 months postoperatively. The IBG mainly consist of cancellous bone, whereas most OBGs are cortical. A cancellous IBG, containing osteoblasts and osteoinductive factors, has properties of osteogenesis, osteoconduction, and osteoinduction (27, 29). A cortical OBG possesses osteoconductive properties and provides limited osteoinductive properties (29). Furthermore, the success of bony fusion is not merely due to the function of the bone graft; the decorticated transplantation bed and morselized bone harvested from the transplantation bed are also involved in the osteogenic process. Hence, the nature of the cancellous bone graft explains the significantly shorter fusion time in the IBG group. Sheehan et al. reported an 81% overall fusion rate with the use of IBG in patients who underwent atlantoaxial fusion surgery; however, the evaluation period of fusion was 6–12 weeks, which is relatively short. The wire loop was used as the fixation method, providing less stability than the screw/rod construct (9). Casey et al. demonstrated a 100% fusion rate using OBG for posterior cervical fusion over a one-year follow-up period. However, in the patients included in that study, the wire fixation technique was applied with less stability and halo bracing. However, they used a reverse hockey-stick graft shape and the full-thickness graft to compensate for the weakness of wire fixation (14). Bauman et al. applied rigid screw/rod fixation and halo bracing for pediatric patients with occipital bone grafting, and all patients achieved bony fusion during the clinical follow-up period. Structural bone grafts were placed bilaterally between C1 and C2, which was different from that in our surgical method. Compared with the bilateral grafts, our transplantation technique using one piece of a bone graft created a more stable structure (13). In our present study, comparable fusion rates in both groups showed that the occipital bone grafting technique provided guaranteed results combined with the use of rigid internal fixation.

Compared with the OBG group, the IBG group had a significantly longer operation time, increased estimated blood loss, and prolonged length of hospitalization. The prolonged length of hospitalization in the IBG group may have resulted from the second incision and the subsequent slow recovery. Harvesting IBG resulted in injury to the cancellous bone of the ilium, followed by an increase in the estimated blood loss.

Furthermore, harvesting the iliac bone requires a second incision during surgery, whereas occipital bone grafting requires no additional incision. Previous studies have reported that donor-site morbidity ranged from 10% to 24% in pediatric patients who underwent iliac bone harvesting (30, 31). The most common donor-site complication is donor-site pain. In IBG group, two patients reported chronic donor-site pain. One patient in the IBG group experienced donor-site infection, and two had seroma postoperatively. None of the patients experienced life-threatening or severe surgery-related complications. Cerebrospinal fluid leakage was observed in one 3-year-old patient who underwent occipital bone grafting. The cause of the cerebrospinal fluid leak was an accidental breakage of the inner table of the occipital bone by the osteotome. We speculated that the child had a relatively thin occipital bone, and the subsequent CT scan confirmed our speculation. The results of the occipital thickness evaluation revealed that children aged between 2 and 6 years had a significantly thinner occipital bone than children aged between 6 and 12 years, with only 4.5 mm thickness at the edge of the donor site—the occipital donor-site defect redeveloped at the last follow-up in 13 of 20 patients. In seven patients, the outer table of the occipital donor site was not regrown at the last follow-up. The defect of the occipital donor site was treated using bone wax for bleeding control. We did not use a morselized or structural bone to repair the occipital defect. The long-lasting occipital outer table defect possibly resulted from the excessive use of bone wax or over-harvesting the diploe. As for methods of managing occipital osteotomy complications, patient diagnosed of cerebrospinal fluid leakage was first accept conservative treatment including bed rest with head elevated and the prophylactic use of antibiotics. For the defect of donor-site, limiting the use of bone wax is recommended.

Our study has some limitations. First, this was a retrospective study with a small sample size. Second, to protect pediatric patients, the starting point of routine CT scanning was 6 months postoperatively, which was insufficient to assess the fusion time accurately. According to our previous experience, some adult patients achieved bony fusion in less than 3 months postoperatively using IBG. Pediatric patients have a greater potential for osteogenesis; thus, they can achieve bony fusion within 3 months or less.

## 5. Conclusion

The greatest strength of OBG is a fusion rate comparable to that of IBG. Thus, OBG are acceptable bone grafting materials for pediatric patients with atlantoaxial dislocation and they avoids donor-site morbidity and complications.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

## Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

ZH-L: data collection and analysis, writing original-draft; YH-Z: methodology and editing; HT-L and QQ-Z: visualization; J-Song and J-Shao: conceptualization and supervision. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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EDITED BY
Fuxin Wei,
Sun Yat-sen University, China

REVIEWED BY
Shuo Duan,
Capital Medical University, China
Nanfang Xu,
Peking University Third Hospital, China

*CORRESPONDENCE
Shuai Xu
✉ xushuairmyy@pku.edu.cn
Xianguo Bao
✉ liuchenjun1131@sina.com
Yingjun Chen
✉ 670790359@qq.com

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# Comparison of anterior and posterior approaches in Treating odontoid fractures: a meta-analysis and systematic review

Xianguo Bao[1]*, Yingjun Chen[1]*, Chen Guo[2] and Shuai Xu[2]*

[1]Spinal Surgery, Nanjing Lishui People's Hospital, Nanjing, China, [2]Spinal Surgery, Peking University People's Hospital, Beijing, China

**Background:** Odontoid fractures account for 15%–20% of cervical injuries. Although the operation methods vary in different types, the superiority of overall outcomes of the anterior approach (AA) and posterior approach (PA) in treating odontoid fractures still remains controversial. Thus, a meta-analysis was performed comparing AA and PA for these fractures.

**Methods:** The relevant studies were searched in PubMed/MEDLINE, Cochrane Library, EMBASE, China Biological Medicine (CBM), and Wanfang Database from the onset of conception to June 2022. Prospective or retrospective comparative studies on AA and PA for odontoid fractures were screened, referring to fusion rates (primary outcomes), complications, and postoperative mortality rates. A meta-analysis of the primary outcomes and a systematic review of other outcomes were performed; the procedure was conducted with Review Manager 5.3.

**Results:** Twelve articles comrising 452 patients were included, and all publications were retrospective cohort studies. The average postoperative fusion rate was 77.5 ± 17.9% and 91.4 ± 13.5% in AA and PA, respectively, with statistical significance [OR = 0.42 (0.22, 0.80), *P* = 0.009]. Subgroup analysis showed a difference in fusion rates between AA and PA in the elderly group [OR = 0.16 (0.05, 0.49), *P* = 0.001]. Five articles referred to postoperative mortality, and the mortality rates of AA (5.0%) and PA (2.3%) showed no statistical difference (*P* = 0.148). Nine studies referred to complications, with a rate of 9.7%. The incidence of complications in AA and PA groups was comparable (*P* = 0.338), and the incidence of nonfusion and complications was irrelevant. The prevalent cause of death was myocardial infarction. The time and segmental movement retention of AA were possibly superior to those of PA.

**Conclusion:** AA may be superior in regard to operation time and motion retention. There was no difference in complications and mortality rates between the two approaches. The posterior approach would be preferred in consideration of the fusion rate.

KEYWORDS

odontoid fracture, anterior approach, posterior approach, fusion rate, complications, meta-analysis

## 1. Introduction

An odontoid fracture is the most common acute injury of the axis, accounting for 15%–20% of the cervical spine injury and showing an upward tendency in nearly 20 years (1). Odontoid fractures were categorized into three types by Anderson and D'Alonzo in 1974, among which type II fractures were the majority, with a proportion from 65% to 74% (2).

According to the point by Yoganandan and Osti, the main causes of odontoid fractures were traumatic injury and osteoporosis (3, 4), where type II and type III fractures were commonly treated with surgeries due to poor blood supplementation. Generally, surgical indications include fracture displacements longer than 5 mm, angulation deformities larger than 10°, and the combination with neurological dysfunction. Shilpakar et al. believed that this kind of injury is more inclined to receive operation (5) and the symoptoms might be relaxed unless patients are fit for general anesthesia, or else the conservative treatment would lead to higher potential mortality. Surgical approaches are usually divided into an anterior approach (AA) and a posterior approach (PA). However, based on perspective advantages, the current evidence on the selection of AA and PA remains controversial. Experts who supported AA suggested that it was directly exposed to the fracture site for fixation and retained the motion of the C1–2 unit (6), while others confirmed that PA could be applied for various fracture types, with wider application and better stability (7). Based on the superiority defects reported on both procedures, the overall efficacy was still undetermined.

It was believed that the fusion rate, to a great extent, reflects the stability and potential risk of spinal cord injury. Some publications reported a nonfusion rate ranging from 0% to 27% (8), and the fusion rate of PA was higher than that of anterior selection (7), but the constriction of the number and quality of literature weakened the conviction. For decades, there have been publicized systematic reviews on comparing the fusion rates of odontoid fractures (9), but a few literature works account for the overall efficacy by pooling data from both procedures. Therefore, based on previous studies, we aimed to perform a meta-analysis and systematic review to identify the overall efficacy of AA and PA.

## 2. Materials and methods

The studies were mainly retrospective therapeutic studies. Patients with odontoid fractures, mainly diagnosed as type II and type III fractures with surgical indications, were reviewed, and the intervention was AA and PA for odontoid fractures.

The studies were searched in PubMed/MEDLINE, Cochrane Library, EMBASE, China Biological Medicine (CBM), and Wanfang Database from January 1988 to June 2022. The keywords were odontoid fracture OR odontoid process fracture OR dens fracture AND odontoid screw OR anterior screw OR dens osteosynthesis AND C1–C2 fusion OR transarticular OR wiring OR posterior cervical arthrodesis OR atlantoaxial arthrodesis.

The inclusion criteria were the following: (1) the article was a prospective or retrospective therapeutic study; (2) the article was a comparative study referring to AA and PA; (3) the outcomes were about postoperative fusion rates or other parameters such as the incidence of complications, postoperative mortality rate, and so on; and (4) the number of samples in each group was at least 3. The exclusion criteria were the following: (1) the studies were case reports, reviews, or meta-analyses; (2) the literature merely referred to odontoid fractures with no surgery; and (3) the comparisons were not performed between AA and PA.

Two reviewers screened and evaluated the literature per the inclusion criteria, and the discrepancy was uniformed by a third person. Two individuals extracted data independently. Data extraction included the outcomes mainly containing surgery time, fusion rates, intra- and postoperative complications, mortality, and cervical activity.

Two reviewers independently evaluated the quality with the Newcastle–Ottawa quality assessment scale (NOS), which was used on nonrandomized controlled literature in meta-analysis. NOS refers to the literature selection, comparability, and outcome with a total score of nine. The 0–3, 4–6, and 7–9 scores represent low quality, middle quality, and high quality, respectively, where the articles with scores above 5 could be included in the study.

The meta-analysis was performed to assess the postoperative fusion rate, and the subgroup analysis was performed to assess the postoperative fusion rate in terms of age. The heterogeneity was measured by $I^2$, where a value of $I^2$ lower than 50% suggested a small heterogeneity, which could be addressed with fixed-effects models. The results of dichotomous variables were shown as odds ratios (ORs) and 95% confidence intervals (CIs) by the Mantel–Haenszel method, and *P*-values <0.05 showed a statistical difference. The meta-analysis was performed using Review Manager software, version 5.3 (The Cochrane Collaboration, Oxford, UK). The $\chi^2$ test was used for comparing mortality and complication rates between groups, which was analyzed by IBM SPSS Statistics 22.0 (International Business Machines Corporation, Armonk, NY, USA).

## 3. Results

### 3.1. Characteristics of included studies

A total of 1,468 studies were searched and screened. Finally, 12 articles (10–21) with a total of 452 patients (266 men and 186 women) were included in the study (**Figure 1**).

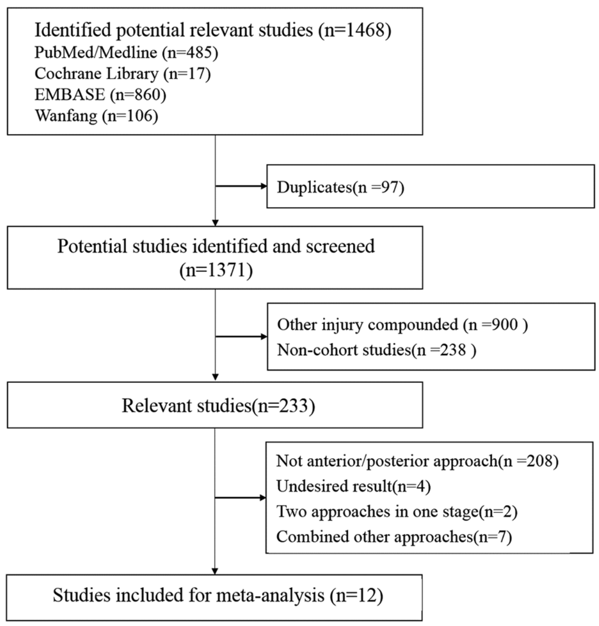


FIGURE 1
Selection process for meta-analysis of the studies.

The relevant information is given in Table 1. Included articles were all retrospective therapeutic studies, among which seven studies were with a mean age over 60 years. The majority of fractures were type II odontoid fractures (89.6%), and the fresh fractures accounted for 81.4%. The common causes of odontoid fractures were traffic accidents (44.6%) and falling trauma (43.0%), followed by hitting injuries (6.0%) and others. A total of 278 patients underwent surgery through AA; the majority of procedures were performed by a conventional approach (93.2%), while 19 cases were operated via an oral route (12, 18, 20). PA was performed in 174 cases, and most procedures were C1–C2 arthrodesis (95.4%). Among these, pedicle or lateral mass screw fixation (54.8%), cable with bone graft fixation (24.1%) (14, 16, 20), articular screw fixation (16.9%), and splint with bone graft (1.8%) (14, 15) were orderly performed, while one article (21) did not involved the fusion rate but provided other results.

The NOS score for each included study is listed in Table 2. All 12 studies had a score of more than 6, of which eight studies were of high quality. A funnel plot was constructed to evaluate publication bias (Figure 2), which, on the whole, suggested a little bias.

## 3.2. Meta-analysis of the fusion rate

The fusion rates involved in 11 studies were analyzed, where the average fusion rates were 77.5 ± 17.9% in AA and 91.4 ± 13.5% in PA. The meta-analysis for the fusion rate (Figure 3) revealed a statistical difference between the two approaches [OR = 0.42 (0.22, 0.80), $P = 0.009$, $I^2 = 23\%$].

## 3.3. Subgroup analysis of the fusion rate

According to stratification by age, the fusion rate in the elderly group (mean age >60 years) showed a statistical difference between AA and PA [OR = 0.16 (0.05, 0.49), $P = 0.001$, $I^2 = 0\%$], while it was indifferent between the two procedures in the adult group [OR = 0.90 (0.38, 2.13), $P = 0.81$, $I^2 = 36\%$] (Figure 4). A total of 224 patients (7 studies) (10, 11, 16, 17, 19–21) were in the elderly group, consisting of 127 people via AA and 97 cases via PA. Table 1 shows that the proportion of AA ranged from 34.2% to 68.2% in the elderly group and from 32.6% to 81.8% in the adult group. The surgery approach selection between the two age groups showed a statistical difference by a nonparametric test ($Z = 2.08$, $P = 0.038$), and it was considered that elderly might be more likely to choose PA.

## 3.4. Comparison of postoperative mortality

Five articles referred to postoperative mortality (11, 13, 16, 19, 20), and the mortality rates of AA (5.0%) and PA (2.3%) showed no statistical difference ($\chi^2 = 1.442$, $P = 0.230$).

Omeis et al. (11) reported three cases of death during an 18-month follow-up in 29 patients (16 cases in AA and 13 in PA), consisting of two cases with AA and one with PA, of which one died of acute myocardial infarction and the others died of medically unrelated issues. Ziai and Hurlbert (13) described three cases of death (one case in AA), of which two cases died of spinal cord injury, and one died of a medically unrelated event. Platzer et al. (16) reviewed 56 cases, where three died cases were from the AA group and one was from the PA group, who were all related to the operation, with one died of cardiac arrest, two died of severe respiratory failure, and one died of pulmonary embolism. Scheyerer et al. (19) reported four died cases out of 33 patients (17 cases in AA) immediately died after discharge, all in the AA group. Steltzlen et al. (20) reported four died cases out of 15 patients in the AA group, but the specific causes were unidentified.

## 3.5. Analysis of complications

Nine studies referred to complications, with a rate of 9.7%, where the rates in AA and PA groups were comparable ($\chi^2 = 0.918$, $P = 0.338$) (Table 3).

TABLE 1 Characteristics of the 12 included studies.

| Study and publication year | Mean age (y) | Gender | | Fracture type | | FU (m) | Anterior approach | | Posterior approach | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | M | F | II | III | | Usual screw + oral way | No. of F | C1–2 + OC fusion | No. of F |
| Andersson 2000 (10) | 78.0 | 7 | 11 | 15 | 3 | 24.0 | 11 | 9 | 7 | 7 |
| Omeis 2009 (11) | 79.9 | 11 | 18 | 29 | 0 | 18.0 | 16 | 15 | 11 + 2 | 13 |
| Fujii 1988 (12) | 34.0 | 21 | 7 | 22 | 6 | Unknown | 11 + 9 | 16 | 8 | 8 |
| Ziai 2000 (13) | 57.0 | 12 | 8 | 14 | 6 | 3.0 | 13 | 5 | 7 | 4 |
| Mashhadinezhad 2012 (14) | 33.0 | 33 | 13 | 46 | 0 | 9.0 | 15 | 13 | 31 | 28 |
| Pointillart 1994 (15) | 54.0 | 45 | 23 | 68 | 0 | 6.0 | 49 | 47 | 19 | 15 |
| Platzer 2007 (16) | 71.4 | 25 | 31 | 48 | 8 | 1.5 | 37 | 33 | 19 | 19 |
| Konieczny 2012 (17) | 64.5 | 22 | 16 | 32 | 6 | 6.0 | 13 | 10 | 25 | 25 |
| Chiba 1996 (18) | 35.0 | 50 | 16 | 52 | 14 | 12.0 | 45 + 9 | 49 | 12 | 12 |
| Scheyerer 2013 (19) | 81.7 | 14 | 19 | 33 | 0 | 31.1 | 17 | 10 | 16 | 15 |
| Steltzlen 2013 (20) | 60.1 | 15 | 7 | 19 | 3 | 6.0 | 14 + 1 | 9 | 4 + 3 | 6 |
| Ardeshiri 2013 (21) | 81.1 | 11 | 17 | 27 | 1 | 41.4 | 18 | Unknown | 7 + 3 | Unknown |

M, male; F, female; FU, follow-up time; No. of F, number of fusions; OC, occipitocervical fusion.

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TABLE 2 NOS for quality evaluation of included studies.

| Studies | Selection of AA and PA | | | | Comparability | | Outcome | | | Total score |
|---|---|---|---|---|---|---|---|---|---|---|
| | Representativeness of the exposed cohort | Selection of the nonexposed cohort | Ascertainment of exposure | Demonstration that the outcome of interest was not present at the start of the study | Study controls for age | Study controls for any additional factor | Assessment of outcomes | Follow-up long enough | Adequacy of follow-up | |
| Andersson et al. (10) | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| Omeis et al. (11) | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| Fujii et al. (12) | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| Ziai and Hurlbert (13) | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7 |
| Mashhadinezhad et al. (14) | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| Pointillart et al. (15) | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| Platzer et al. (16) | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| Konieczny et al. (17) | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7 |
| Chiba et al. (18) | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7 |
| Scheyerer et al. (19) | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| Steltzlen et al. (20) | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| Ardeshiri et al. (21) | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |

NOS, Newcastle–Ottawa quality assessment scale; AA, anterior approach; PA, posterior approach.

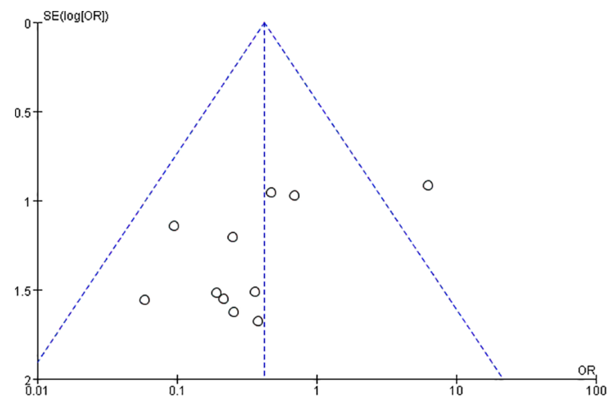


FIGURE 2
Funnel plot of the postoperative fusion rates of included studies.

The majority of adverse events were intraoperative screw repositioning or loosening (48.7%), venous plexus bleeding (12.8%), and wound infection (7.7%), where screw displacement (64.0%) was the prevalent complication in the AA group, while venous plexus injury (28.4%), wound infection (21.4%), and screw repositioning (21.4%) were prevalent complications in PA. Five cases of plexus hemorrhage were all reported by Scheyerer et al. (19). Ziai et al. (13) reported two cases of spinal cord injuries in AA and PA groups and one case of urinary tract infection in the AA group.

## 3.6. Quality of life after AA and PA

Here, only one study (14) involved surgery time, which reported a mean operated time of 65 min in the AA group, less than the 118 min in the PA group. One study (21) that referred to the neurological function score was performed by Ardeshiri et al., who assessed it by the ASIA grade. Platzer et al. (16) assessed the postoperative efficacy with the "excellent–good–fair–poor" grade, where 37 cases were with the 27–8–2–0 number in the AA group and 19 cases were with the 5–4–8–2 number in the PA group. As to the operated segmental motion, Platzer et al. (16) reported that 11 cases were facing range-of-motion limitation in the AA group and all cases (19 cases) suffered from it in the PA group; a similar viewpoint was addressed by Scheyerer (19).

# 4. Discussion

The nonunion of an odontoid fracture and the consequent pseudoarthrosis possibly led to compression of the spinal cord and a high incidence of morbidity (22). Bohler et al. advocated that surgical intervention can improve the fusion rate by 26%–80% compared to conservative treatment due to the traumatic instability of type II and type III fractures (23). Some authors believed that PA was a stable strategy with a reliable fusion rate, while Dailey et al. considered that AA could also provide an

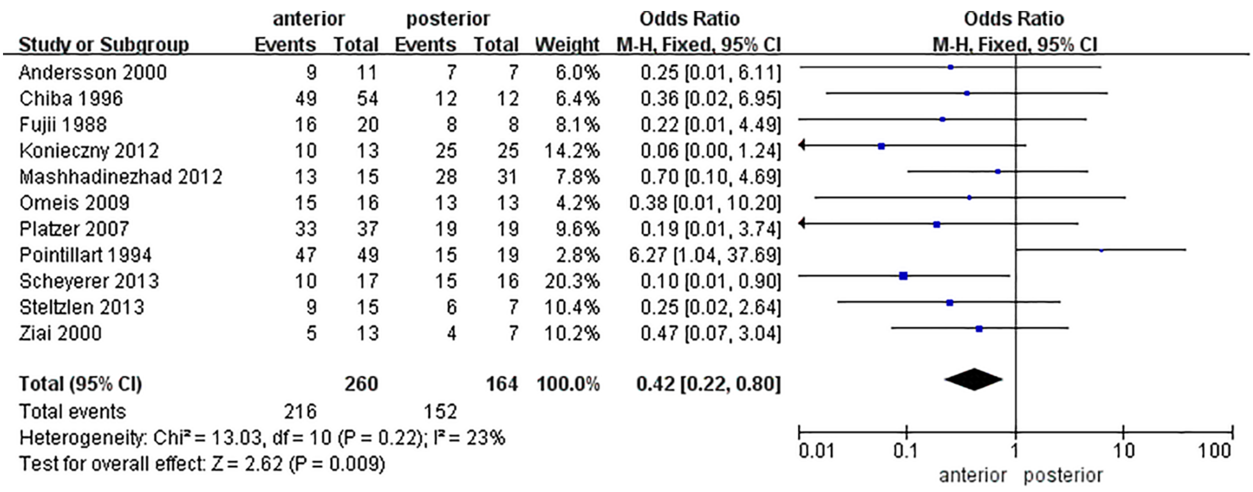


FIGURE 3
Forest plot of the meta-analysis of fusion rates of AA and PA.

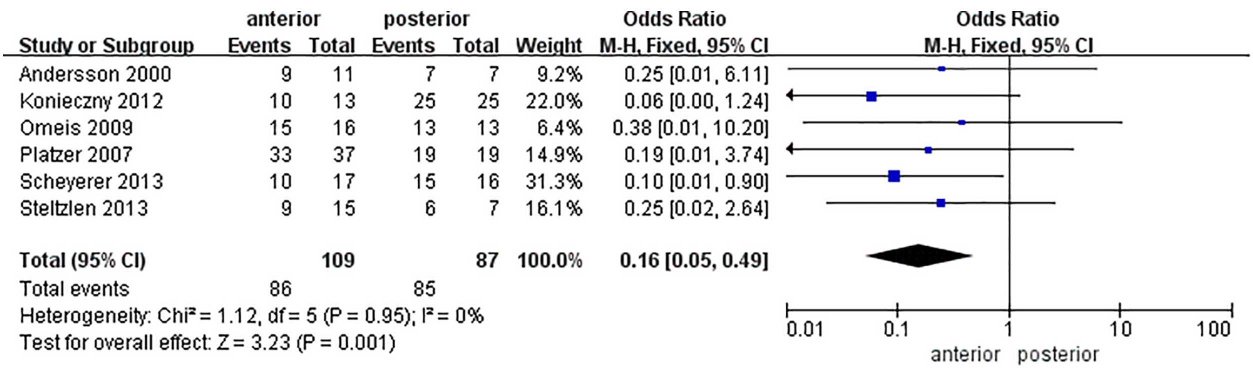


FIGURE 4
Forest plot of the meta-analysis of postoperative fusion rates in the elderly group.

TABLE 3 Ttypes and numbers of complications in AA and PA.

| Complications | AA | PA | Total |
|---|---|---|---|
| Screw replantation and dislocation | 16 | 3 | 19 |
| CSF leakage | 0 | 1 | 1 |
| Spinal cord injury | 1 | 1 | 2 |
| Superior laryngeal nerve injury | 4 | 0 | 4 |
| Pharyngalgia | 2 | 0 | 2 |
| Wound infection | 0 | 3 | 3 |
| Urinary infection | 1 | 0 | 1 |
| Liquidizing | 1 | 0 | 1 |
| Redisplacement | 2 | 0 | 2 |
| Venous plexus bleeding | 0 | 5 | 5 |
| Respiratory failure | 2 | 0 | 2 |
| Cardiac arrest/infarction | 1 | 1 | 2 |
| Total | 30 | 14 | 44 |

AA, anterior approach; PA, posterior approach; CSF, cerebrospinal fluid.

acceptable fusion rate, with the superiority of less range of motion loss, minimal muscle stripping, and reduction of hospitalization time (24).

In our data, both type II and type III fractures were included, most of which were type II (83.8%). In contrast, few analytical studies on type I fractures have been published because of the absence of significant surgical indications. Radiology was the most intuitive method for postoperative fusion (25), and the evaluation of its outcomes was dependent on its measurements. In this study, by consolidating a large number of articles through meta-analysis, it was confirmed that the fusion rates were higher through PA than AA, which was consistent with previous publications (7, 16).

It was believed age might be the critical factor affecting the outcomes of surgery (9). The study conducted by Nourbakhsh et al. confirmed that the fusion rate did not differ between AA and PA in patients younger than 55 years (26). Biomechanically, PA provides a stable basis through joint fusion and cervical-motion restriction. In contrast, the anterior technique was performed through odontoid screw fixation without bone implantation, causing, to a certain extent, damage to the vessels of the fracture segment. In the older population, osteoporosis and poor blood supplementation further resulted in a lower healing rate (25). Therefore, the difference in fusion rates between AA and PA in the elderly indicated that the latter was a better selection for them.

Ardeshiri et al. (21) reported that the incidence of postoperative complications was 7% in the elderly, with a mortality rate of 0%–57%. Montesano and Osti publicized that the incidence of dysphagia caused by anterior screw fixation was 17%–35% and that of pneumonia was 14%–19% (4, 27), while the incidence of PA-related infection was 33% and that of pneumonia was 17%. In this study, we proved that there was no statistical difference in the number of adverse events between AA and PA but with disparities in the kinds of complications. Platzer et al. believed the incidence of complications was higher in the elderly group (16). The nonparametric test in this study also showed that elderly might suffer from a higher complication rate ($P < 0.001$), both in AA and PA, which was consistent with previous publications, suggesting that elderly should pay more attention to this issue.

Mortality was analyzed in five studies, with rates of 0%–26.7%, which was associated with myocardial infarction, pulmonary embolism, respiratory failure, and spinal cord injury. Therefore, close monitoring of the physiological state and cardiopulmonary function should be emphasized during the perioperative period. The mean age of more than 60 years old was tabulated here in four out of the five articles (11, 16, 19, 20), which predicted that the incidence of postoperative mortality in the elderly was possibly higher than that in adults. However, with the few positive results in this study, the correlation between nonfusion and death was hard to be addressed. Given that there were no death event cases in the other seven studies at the end of follow-up, a statistical difference in the mortality rates between AA and PA could not be considered.

There has always been a controversy between postoperative complications and nonunion. Schatzker et al. suggested that nonfusion would lead to a series of adverse events such as spinal cord injury (28), whereas others reported that no obvious symptoms were found, although with as high as 33% nonfusion rate postoperatively. The follow-up study (mean of 5.6 years) on five older patients conducted by Hart et al. showed there was no case trapped in spinal cord lesions with adverse nonfusion, although with the suspicion of paralysis (29). This article believed that age was related to the rate of fusion and complications, while it failed to draw a correlation between nonfusion and complications because of the low incidence of complications, which may be consistent with the previous reports.

Despite limited literature referring to the operative time and segmental range of motion, it was thought that the anterior technique involved less invasion and short operation time, together with more preservation of segmental motion. Commonly, the consumable material of AA was simpler than PA on internal fixation, which reflected that AA might be an inexpensive alternative with potentially shorter hospitalization time. Consequently, this surgical approach is likely to reduce the overall charge (24), while a further cost–benefit analysis must be performed individually.

Some limitations should be noted in this study. The specific types of fractures may affect the rate of fusion and complications (6), but the included studies failed to extract the information on the proportion of type II or type III fractures, which led to a heterogeneity in subgroup analysis. Then, it was the mean age instead of the individual data that differed between the elderly and adult groups; as a result, the probability of abnormal distribution or crossover between the two age groups would bring reporting bias. The inconsistency and large span of follow-up among enrolled studies would also affect the evaluation of the postoperative fusion rate. Finally, the reports on outcomes of odontoid fractures in low-level quality would generate inevitable bias.

## 5. Conclusion

By performing the meta-analysis based on 12 studies, we found that PA acquired a higher fusion rate of odontoid fractures, while AA may be superior in the operation time and segmental motion retention. The older population preferred to select PA, although the fusion rate was of no statistical difference between adults and the elderly. Most adverse events were screw repositioning or loosening in the AA group, while venous plexus injuries and wound infections were more common in the PA group. There was no statistical difference in the incidence of complications and the rate of mortality between the two approaches. The correlation between nonfusion and complications remained unidentified. In sum, when the fusion rate was focused on first, the posterior approach would be preferred and more reliable.

## Data availability statement

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

## Author contributions

XB and YC: contributed equally to the conception of the study, searching and screening articles, processing study data, and drafting and reviewing the manuscript. XB and CG: contributed to manuscript editing. SX: helped review the manuscript. SX: supervised the whole procession and solved discrepancies. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer, NX, declared a shared parent affiliation with authors SX and CG to the handling editor at the time of review.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2023.1125665/full#supplementary-material

SUPPLEMENTARY TABLE S1
Supplemental Digital Content, which was relevant data about this study.

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