

Clinical Outcomes of Preoperative Skull Traction Combined with Intraoperative Two-Step Reduction and Occipitocervical Fusion for Type A Basilar Invagination with Atlantoaxial Dislocation

Menglong Zhang

Bengbu Medical University

Mingyu Ren

Bengbu Medical University

Bowen Shen

Bengbu Medical University

Ze Zhang

Bengbu Medical University

Delong Yang

Bengbu Medical University

Xinmiao Zhu

Bengbu Medical University

Shichang Jin

The First Affiliated Hospital of Bengbu Medical University

You Li

Bengbu Medical University

Yuchen Ye

The First Affiliated Hospital of Bengbu Medical University

Changchun Zhang

zccanhui1968@126.com

The First Affiliated Hospital of Bengbu Medical University

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Abstract

Objective

To evaluate the clinical and radiological outcomes of a staged reduction strategy combining preoperative skull traction with intraoperative two-step reduction and occipitocervical fusion in patients with type A basilar invagination with atlantoaxial dislocation (BI-AAD).

Methods

A retrospective study was conducted on 27 patients with reducible type A BI-AAD who underwent posterior occipitocervical fusion with foramen magnum decompression between January 2019 and April 2025. All patients received preoperative skull traction followed by a staged two-step reduction strategy. Radiological parameters, including the atlantodental interval (ADI), the distance from the odontoid process to the Chamberlain line (DOCL), and the cervicomedullary angle (CMA), were evaluated preoperatively and at postoperative follow-up. Clinical outcomes were assessed using the Japanese Orthopaedic Association (JOA) score and visual analogue scale (VAS). Fusion status and perioperative complications were also recorded.

Results

All patients successfully underwent surgery. The mean operative time was 122.63 ± 17.59 minutes, and the mean intraoperative blood loss was 237.04 ± 89.43 mL. The mean follow-up duration was 19.93 ± 7.27 months. Significant improvements in radiological parameters were observed at the final follow-up, with ADI decreasing from 10.60 ± 0.94 mm to 1.20 ± 0.11 mm, DOCL from 11.70 ± 2.14 mm to 2.67 ± 0.27 mm, and CMA increasing from $116.96 \pm 10.54^\circ$ to $143.84 \pm 2.69^\circ$ ($P < 0.05$). Clinical outcomes also improved significantly, with the JOA score increasing from 8.56 ± 1.01 to 15.04 ± 0.71 and the VAS score decreasing from 6.59 ± 0.89 to 1.48 ± 0.51 . Solid bone fusion was achieved in all patients. Two perioperative complications occurred (one dural tear and one wound infection), both of which resolved after appropriate treatment.

Conclusion

The staged reduction strategy combining preoperative skull traction with intraoperative two-step reduction and occipitocervical fusion appears to be an effective and safe approach for the treatment of reducible type A BI-AAD. This technique may facilitate a gradual and more controllable reduction process, while achieving satisfactory radiological realignment and clinical improvement. Further prospective and comparative studies are warranted to validate these findings.

1. Introduction

Basilar invagination (BI) is a complex craniovertebral junction (CVJ) deformity characterized by upward migration of the odontoid process into the foramen magnum, which may result in compression of the medulla, upper cervical spinal cord, and associated neurovascular structures [1–3]. Among the various classification systems, Goel's widely adopted scheme distinguishes BI into type A, characterized by atlantoaxial instability with anterior displacement of the atlas, and type B, in which the atlantoaxial joint remains relatively stable [4]. Type A BI is frequently associated with more severe neurological impairment due to combined vertical and horizontal compression, and surgical intervention is often required to restore alignment and relieve neural compression [5].

Over the past decades, multiple surgical strategies have been developed for BI associated with atlantoaxial dislocation (AAD). Traditional anterior transoral decompression effectively removes ventral compressive pathology but is associated with notable risks, including infection, dysphagia, and cerebrospinal fluid leakage [6, 7]. Endoscopic transnasal approaches may reduce some of these complications; however, they remain technically demanding and are limited by a narrow operative corridor [8]. Posterior-only techniques, such as Goel's facet distraction and fixation, have gained widespread acceptance due to their ability to restore alignment while avoiding the morbidity of anterior approaches [9, 10]. Nevertheless, these techniques are not without limitations. They often require extensive facet joint exposure, may involve C2 nerve root manipulation or sacrifice, and may be less effective in patients with significant soft-tissue contracture or partially reducible deformities, where achieving controlled and sufficient reduction remains challenging [11, 12].

For reducible BI-AAD, preoperative skull traction plays an important role both as a diagnostic tool for assessing reducibility and as a therapeutic measure to gradually release soft-tissue tension [13]. However, the degree of correction achieved with traction alone is often limited and varies among patients [14, 15]. In addition, forceful or uncontrolled intraoperative reduction may increase the risk of neurological injury due to sudden traction on neural structures. Therefore, achieving a safe, gradual, and controllable reduction process remains a major challenge in the surgical management of BI-AAD. Despite previous reports on staged or stepwise reduction techniques, strategies that systematically integrate preoperative traction with intraoperative controlled mechanical reduction have not been sufficiently investigated [16].

To address these challenges, we propose a staged reduction strategy that integrates preoperative skull traction with intraoperative controlled distraction and posterior occipitocervical fusion. This approach emphasizes gradual, stepwise correction, aiming to improve the controllability and safety of reduction, reduce the risk of sudden neural traction, and facilitate stable craniovertebral realignment.

Therefore, the aim of this study was to evaluate the clinical and radiological outcomes of this staged two-step reduction strategy in patients with reducible type A BI-AAD, and to explore its potential advantages in achieving safe and controlled realignment compared with existing techniques.

2. Materials and Methods

2.1 General Information

This was a single-center retrospective study. Between January 2019 and April 2025, a total of 52 patients diagnosed with basilar invagination with atlantoaxial dislocation (BI-AAD) were admitted to our institution. Among them, 36 patients underwent surgical treatment. After applying the inclusion and exclusion criteria, 27 patients were ultimately included in the study, while 9 patients were excluded due to loss to follow-up.

The final cohort consisted of 6 males and 21 females, with an age range of 18 to 70 years (mean, 51.81 $\pm$ 7.08 years). All patients were diagnosed with type A basilar invagination combined with atlantoaxial dislocation based on radiographic evaluations. Preoperative assessments included X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) to evaluate the extent of craniovertebral junction deformity and neural compression (Table 1).

This study was approved by the institutional ethics committee, and written informed consent was obtained from all patients and clinical trial number: not applicable.

Table 1

Sl.Number	Age	Sex	Diagnosis
Case 1	56	Man	Basilar invagination with atlantoaxial dislocation and congenital fusion of the C5–C7 vertebral bodies
Case 2	31	Man	Basilar invagination with atlantoaxial dislocation, posterior displacement of the odontoid process, and syringomyelia
Case 3	69	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion
Case 4	53	Woman	Basilar invagination accompanied by atlantoaxial dislocation and syringomyelia
Case 5	50	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 6	51	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 7	53	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 8	51	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion
Case 9	53	Woman	Basilar invagination accompanied by atlantoaxial dislocation and syringomyelia
Case 10	50	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion, syringomyelia, Chiari malformation, and C2–3 vertebral fusion
Case 11	55	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion
Case 12	48	Man	Basilar invagination accompanied by atlantoaxial dislocation
Case 13	48	Man	Basilar invagination accompanied by atlantoaxial dislocation
Case 14	49	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 15	67	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 16	49	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion and Chiari malformation
Case 17	44	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion and Chiari malformation
Case 18	54	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion
Case 19	52	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 20	50	Man	Basilar invagination accompanied by atlantoaxial dislocation and syringomyelia

Sl.Number	Age	Sex	Diagnosis
Case 21	53	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion, syringomyelia, and Chiari malformation
Case 22	46	Woman	Basilar invagination accompanied by atlantoaxial dislocation
Case 23	56	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion and Chiari malformation
Case 24	58	Woman	Basilar invagination accompanied by atlantoaxial dislocation with occipito–C1 fusion, Chiari malformation, and posterior displacement of the odontoid process
Case 25	43	Man	Basilar invagination accompanied by atlantoaxial dislocation
Case 26	56	Woman	Basilar invagination accompanied by atlantoaxial dislocation with C2–C3 fusion, Chiari malformation, and syringomyelia
Case 27	54	Woman	Basilar invagination accompanied by atlantoaxial dislocation and Chiari malformation

Inclusion and Exclusion Criteria

Inclusion criteria:

- (1) Diagnosis of basilar invagination with reducible atlantoaxial dislocation (type A BI-AAD) confirmed by radiographic examinations including X-ray, CT with three-dimensional reconstruction, and MRI, accompanied by symptoms of neural compression (e.g., neck pain, limb numbness or weakness, gait instability);
- (2) All enrolled patients underwent posterior occipitocervical fusion combined with foramen magnum decompression;
- (3) Compliance with follow-up requirements: completion of at least 3 months of standardized postoperative follow-up, including clinical and radiological evaluations.

Exclusion criteria:

- (1) History of prior craniovertebral junction (CVJ) surgery;
- (2) Absence of preoperative skull traction;
- (3) Presence of severe osteoporosis or other contraindications to surgery;
- (4) Incomplete follow-up data, including loss to follow-up or missing records at key timepoints (postoperative 1 week, 3 months, or final follow-up).

2.2 Radiological Evaluation

All patients underwent X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) before surgery and during follow-up. Dynamic flexion–extension X-ray imaging was not performed postoperatively. The Wackenheim clivus line and McRae line were used to evaluate basilar invagination on pre- and postoperative CT and MRI images. Basilar invagination was diagnosed when the odontoid tip projected posterior to the Wackenheim line and above the McRae line.

Radiological measurements included: the distance between the odontoid tip and the Wackenheim line (Wackenheim value), the atlantodental interval (ADI), the distance of the odontoid to Chamberlain's line (DOCL), and the cervicomedullary angle (CMA).

Fusion was assessed based on: (1) sagittal CT reconstruction showing disappearance of the interface between the graft and bone bed, with continuous trabecular bridging;

(2) absence of abnormal motion on dynamic cervical radiographs.

Paired t-tests were used for statistical analysis, with statistical significance defined as $P \leq 0.05$.

2.3 Surgical Technique

2.3.1 Preoperative Traction

All patients underwent preoperative skull traction in the supine position to assess reducibility and gradually decrease soft-tissue tension. The initial traction weight was 2.5 kg and was increased in increments of 0.5 kg according to radiographic findings, neurological status, and patient tolerance, with a maximum traction force not exceeding one-sixth of the patient's body weight.

Reduction was monitored using serial radiographs, focusing on changes in the atlantodental interval (ADI) and the relationship between the odontoid tip and the Wackenheim and McRae lines. Neurological examinations were performed daily during traction.

The duration of traction was determined based on the degree of odontoid descent. Surgical intervention was considered when the odontoid tip descended to or below the reference lines. In cases with incomplete reduction, surgery was also performed if traction resulted in partial improvement in alignment or neurological status, suggesting the potential for further intraoperative reduction.

2.3.2 Two-Step Reduction Strategy

Step I: Release, Decompression, and Initial Reduction

The objective of the first step was to release soft-tissue constraints and achieve controlled initial reduction. Under general anesthesia, patients were positioned prone with the head secured in a Mayfield clamp. A standard posterior midline approach was used to expose the occiput, posterior arch of C1, and C2 lamina and lateral masses.

A C1 laminectomy combined with foramen magnum decompression was performed to relieve dorsal compression of the medulla and spinal cord. In patients with rigid deformities, additional facet joint release was carried out under microscopic visualization using a high-speed burr or curettes to remove contracted joint capsules and degenerated cartilage, thereby improving joint mobility.

After decompression and joint release, the head was gently positioned in slight extension to reduce anterior soft-tissue tension and facilitate reduction. Pedicle screws were inserted into C2, and an occipital plate was secured. Pre-bent titanium rods were connected to the occipital and C2 screws.

Gradual tightening of the rod–screw construct generated controlled corrective forces along the occiput–C2 axis, producing a combined upward–posterior movement of the occiput and downward–anterior traction on C2. This maneuver allowed initial descent of the odontoid process and partial realignment of the craniovertebral junction.

Step II: Final Reduction, Fixation, and Fusion

The objective of the second step was to achieve further controlled reduction and definitive stabilization. Based on the initial correction, the C2 screws were slightly loosened, and controlled distraction was applied at the rod–screw interface. This maneuver generated a downward force on the C2 vertebra, further reducing the odontoid height and improving sagittal alignment.

Intraoperative fluoroscopy was used to assess reduction, including odontoid position and the cervicomedullary angle (CMA). If necessary, minor adjustments were made by modifying rod contour or applying additional controlled distraction to optimize alignment.

Once satisfactory reduction was achieved, all screws were securely tightened to maintain the corrected position. The exposed bony surfaces, including the occiput, residual C1 posterior arch, and C2 lamina and lateral masses, were decorticated. Autologous iliac crest bone graft was then applied to promote fusion. The wound was closed in layers in a standard fashion.(Fig. 1).

2.4 Postoperative Management and Follow-up

Postoperatively, cervical immobilization was applied. Follow-up was performed at 1 week and 3 months after surgery, and then once every 1–2 years. Follow-up assessments included clinical functional scores, horizontal and vertical reduction status, position of internal fixation, and bone graft fusion, with cervical spine X-rays in anteroposterior and lateral views. When necessary, CT three-dimensional reconstruction and MRI scans were performed.

Cervical spinal cord function was evaluated using the Japanese Orthopaedic Association (JOA) score preoperatively, at 1 week, 3 months postoperatively, and at the last follow-up.

Patient pain was assessed using the Visual Analogue Scale (VAS) preoperatively, at 1 week, 3 months postoperatively, and at the last follow-up.

Preoperative symptoms and postoperative improvement were assessed using the Nurick grading system.

On mid-sagittal CT images, the following measurements were performed preoperatively, at 1 week, 3 months postoperatively, and at the last follow-up:

(1) Atlanto-dental interval (ADI), measured from the anterior arch of the atlas to the tip of the odontoid process.

(2) Distance from the odontoid tip to the Chamberlain line (DOCL) on mid-sagittal reconstructed CT images. The Chamberlain line is drawn from the posterior edge of the hard palate to the posterior margin of the foramen magnum. Odontoid tip protrusion over this line by 5 mm or more indicates basilar invagination. Values above this line are positive, and values below are negative.

(3) Cervicomedullary angle (CMA) measured on mid-sagittal cervical MRI, defined as the angle between the ventral line of the medulla and the ventral line of the cervical spinal cord. Normal values range from 139° to 175.5°, with an average of 158.46°. CMA < 130° is associated with neurological deficits and brainstem compression.

2.5 Statistical Analysis

Statistical analyses were performed using SPSS 26.0 software. Continuous variables that met the normal distribution assumption (including JOA score, VAS score, Nurick grade, ADI, DOCL, and CMA) were expressed as mean $\pm$ standard deviation ($\bar{X} \pm SD$). Comparisons between preoperative, postoperative, and follow-up data were analyzed by analysis of variance (ANOVA). Paired t-tests were used to compare each postoperative time point with preoperative values. A two-sided significance level of $\alpha = 0.05$ was adopted.

3. Results

3.1 Surgical Outcomes

All 27 patients successfully underwent surgery. The mean operative time was 122.63 ± 17.59 minutes, and the mean intraoperative blood loss was 237.04 ± 89.43 mL. The mean follow-up duration was 19.93 ± 7.27 months.

No intraoperative vertebral artery or spinal cord injury occurred. Perioperative complications were observed in 2 patients, including 1 cases of dural tear and 1 case of wound infection. All complications were managed appropriately without long-term adverse outcomes.

3.2 Radiological Outcomes

Significant improvement in radiological parameters was observed at all postoperative time points compared with preoperative values ($P < 0.05$).

The atlantodental interval (ADI) decreased from 10.60 ± 0.94 mm preoperatively to 1.20 ± 0.11 mm at the final follow-up. The distance from the odontoid process to the Chamberlain line (DOCL) decreased from 11.70 ± 2.14 mm to 2.67 ± 0.27 mm. The cervicomedullary angle (CMA) increased from $116.96 \pm 10.54^\circ$ to $143.84 \pm 2.69^\circ$ (Table 2).

After preoperative traction and the first-step reduction, partial reduction of basilar invagination and atlantoaxial dislocation was achieved in all patients. Specifically, the odontoid tip descended below the Wackenheim and McRae lines in 7 patients, reached the level of these lines in 9 patients, and approached these lines in 11 patients.

Further improvement in alignment was achieved following the second-step intraoperative reduction, with satisfactory restoration of odontoid position and craniovertebral junction alignment in all patients.

Table 2
ADI, DOCL and CMA values of the included patients

Pre-operation	ADI (mm)	DOCL (mm)	CMA (°)
	10.60 ± 0.94	11.70 ± 2.14	116.96 ± 10.54
1 week post-operation	1.64 ± 0.20	3.33 ± 0.50	143.99 ± 4.30
3 months post-operation	1.43 ± 0.16	3.02 ± 0.37	143.87 ± 3.00
Final follow-up	1.20 ± 0.11	2.67 ± 0.27	143.84 ± 2.69
Note: Compared with pre-operation, $P < 0.05$; Compared with 1 week post-operation, $P < 0.05$; Compared with 3 months post-operation, $P < 0.05$.			

3.3 Clinical Outcomes

Clinical outcomes showed significant improvement at all postoperative time points compared with preoperative values ($P < 0.05$). The visual analogue scale (VAS) score decreased from 6.59 ± 0.89 preoperatively to 1.48 ± 0.51 at the final follow-up. The Japanese Orthopaedic Association (JOA) score improved from 8.56 ± 1.01 to 15.04 ± 0.71 (Table 3).

Table 3
VAS scores and JOA scores of the included patients

Pre-operation	VAS scores(points)	JOA scores(points)
	6.59 ± 0.89	8.56 ± 1.01
1 week post-operation	2.37 ± 0.69	13.74 ± 0.90
3 months post-operation	2.00 ± 0.62	14.89 ± 0.75
Final follow-up	1.48 ± 0.51	15.04 ± 0.71
Note: ☒Compared with pre-operation, $P < 0.05$; ☒Compared with 1 week post -operation, $P < 0.05$; ☒Compared with 3 months post-operation, $P < 0.05$.		

According to the Nurick grading system, neurological function improved in most patients. At the final follow-up, 21 patients (77.8%) were classified as Grade 1 and 6 patients (22.2%) as Grade 2, with no patients remaining in Grade 3 or higher. Within 3 weeks postoperatively, 7 patients improved by 3 grades, 14 patients by 2 grades, 5 patients by 1 grade, and 1 patient showed no significant improvement. (Table 4).

Table 4
Nurick Grade of the included patients

Nurick	Pre-operation	Postoperative
Grade 1	0	21
Grade 2	4	6
Grade 3	12	0
Grade 4	11	0
Grade 5	0	0
Total	27	27

3.4 Fusion Outcomes

At the final follow-up, solid bone fusion was achieved in all patients. No implant-related complications, including screw loosening, pullout, or hardware failure, were observed. No cases of delayed neurological deterioration or reoperation were reported. (Fig. 2).

Case 3

A 69-year-old female patient. A: Preoperative MRI showing atlantoaxial dislocation and basilar invagination; B, C, D: Preoperative sagittal, coronal, and axial CT reconstructions demonstrating atlantoaxial dislocation, basilar invagination, and occipitalization of the atlas; E: Preoperative lateral X-ray showing atlantoaxial dislocation and basilar invagination; F, G: CT scan and axial view after skull traction;

H: Lateral X-ray at 7 days postoperatively indicating successful anatomical reduction; I: Follow-up X-ray at 3 months postoperatively; J: Lateral X-ray at the final follow-up showing well-positioned internal fixation.

4. Discussion

Type A basilar invagination with atlantoaxial dislocation represents a complex craniovertebral junction disorder characterized by combined vertical odontoid migration and horizontal instability, resulting in compression of the medulla and upper cervical spinal cord[12, 19, 20]. The primary goals of surgical treatment are to achieve adequate neural decompression, restore anatomical alignment, and provide stable fixation to facilitate long-term fusion[14, 21]. However, despite advances in surgical techniques, achieving a safe, gradual, and controllable reduction remains a major challenge, particularly in patients with partially reducible deformities[22, 23].

In recent years, posterior-only reduction and fixation techniques have been increasingly adopted because they avoid the morbidity associated with anterior approaches[24]. Techniques such as facet distraction with cage insertion and posterior screw-rod constructs have demonstrated favorable outcomes[13, 25, 26]. However, these approaches are often dependent on a single-stage intraoperative reduction, which may require extensive joint manipulation and can be associated with sudden mechanical forces applied to neural structures[27–29]. In addition, some techniques necessitate C2 nerve root sacrifice or complex instrumentation, which may increase surgical complexity and potential morbidity[30, 31].

The present study proposes a staged reduction strategy integrating preoperative skull traction with intraoperative stepwise mechanical reduction, which represents a conceptual refinement rather than a purely technical modification. The key feature of this approach is the redistribution of the reduction process into two sequential and controlled phases, thereby transforming a traditionally forceful intraoperative maneuver into a gradual and titrated correction process. Unlike previously reported two-step reduction techniques that primarily focus on intraoperative manipulation alone, the present strategy incorporates preoperative traction as an essential preparatory phase, thereby extending the reduction process beyond the operative setting.

Specifically, preoperative skull traction serves not only as a diagnostic tool for assessing reducibility but also as a preparatory step to progressively release soft-tissue contracture and partially reduce deformity before surgery[13]. This preconditioning effect may reduce the magnitude of intraoperative correction required. During surgery, controlled distraction following adequate joint release enables incremental realignment along the occiput–C2 axis, allowing the surgeon to adjust reduction in a stepwise manner. Compared with single-stage reduction techniques, this strategy may reduce the risk of sudden neural traction and improve the controllability and precision of deformity correction.

From a biomechanical perspective, the staged approach allows gradual redistribution of forces across the craniovertebral junction rather than abrupt loading, which may contribute to a safer reduction process. Clinically, this is supported by the absence of neurological deterioration in our cohort and the

relatively low complication rate. Radiologically, significant improvements in both vertical (DOCL) and horizontal (ADI) parameters, as well as in the cervicomedullary angle (CMA), indicate that this method can effectively restore craniovertebral alignment. These improvements are comparable to those reported in studies using posterior distraction or DCER techniques[14, 17, 18], suggesting that a staged strategy can achieve similar correction while potentially enhancing procedural safety.

Another potential advantage of this technique is that it does not routinely require sacrifice of the C2 nerve root or insertion of intra-articular cages, which may reduce surgical invasiveness and preserve anatomical structures. Compared with anterior decompression approaches, the posterior-only staged strategy avoids oropharyngeal complications while still achieving adequate reduction in appropriately selected cases[32, 33]. Therefore, this approach may be particularly suitable for patients with reducible or partially reducible BI-AAD, where controlled and progressive reduction is feasible.

Despite these advantages, it should be emphasized that this technique is not universally applicable. In patients with rigid or severely ankylosed deformities, where preoperative traction fails to achieve meaningful reduction, alternative strategies may be required[34]. In addition, the effectiveness of this method may depend on careful patient selection and surgical experience.

All patients in this study achieved solid fusion at final follow-up, with no implant-related complications or need for revision surgery, indicating that the staged reduction strategy provides reliable stabilization. However, these results should be interpreted with caution, as this study was conducted in a single center with a relatively small sample size.

Several limitations should be acknowledged. First, the retrospective design and limited sample size reduce the strength of the conclusions. Second, the absence of a control group precludes direct comparison with other established techniques. Third, variability in traction duration and reduction degree may have influenced outcomes. Future studies should include prospective, multicenter cohorts and comparative analyses with established techniques to further validate the clinical value and indications of this staged reduction strategy.

5. Conclusion

In this retrospective series, the two-step reduction method combined with posterior occipitocervical fusion appeared to achieve satisfactory radiological realignment and neurological improvement in patients with reducible type A basilar invagination with atlantoaxial dislocation. The gradual, stepwise reduction strategy may help facilitate controlled correction while maintaining acceptable perioperative safety. However, because the study is limited by its single-center retrospective design, small sample size, and lack of a comparative control group, these findings should be interpreted cautiously. Further prospective, multicenter studies with larger cohorts are needed to confirm the reproducibility, long-term stability, and clinical advantages of this technique before broader clinical recommendations can be established.

Declarations

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 was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the First Affiliated Hospital of Bengbu Medical University. For research involving human participants, informed consent was obtained from all subjects.

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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Author Contributions

Conceptualization: ZML,YYC,ZCC

Formal Analysis: YYC,ZML,

Investigation: RMY,ZZ,SBW

Methodology: YYC,ZML,ZCC,

Project Administration: JSC,LY,YDL,ZXM

Writing – Original Draft: YYC,ZML

Writing – Review & Editing: ZML,ZCC

Funding Acquisition,YYC,ZCC

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Figures

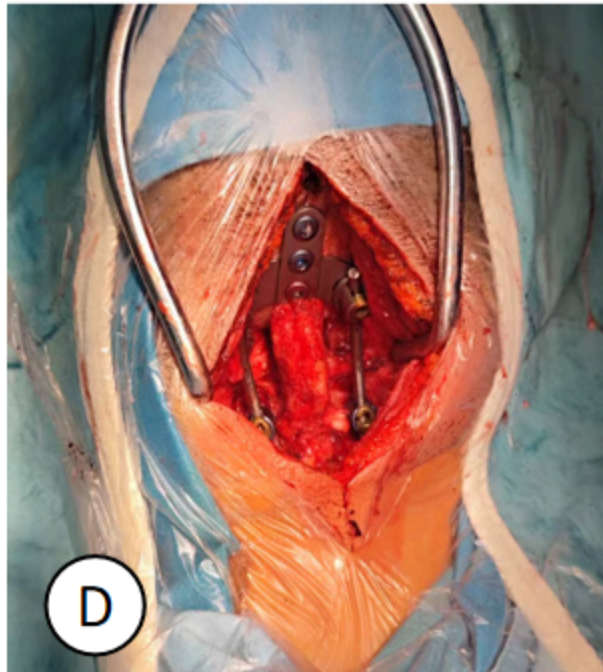
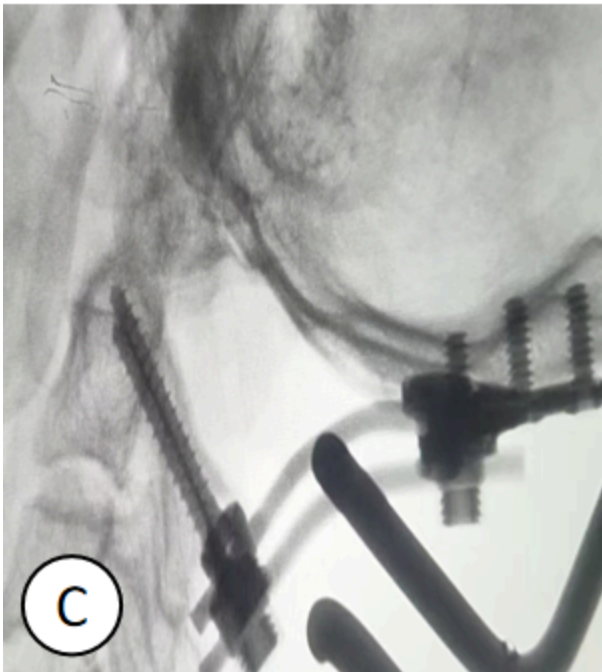
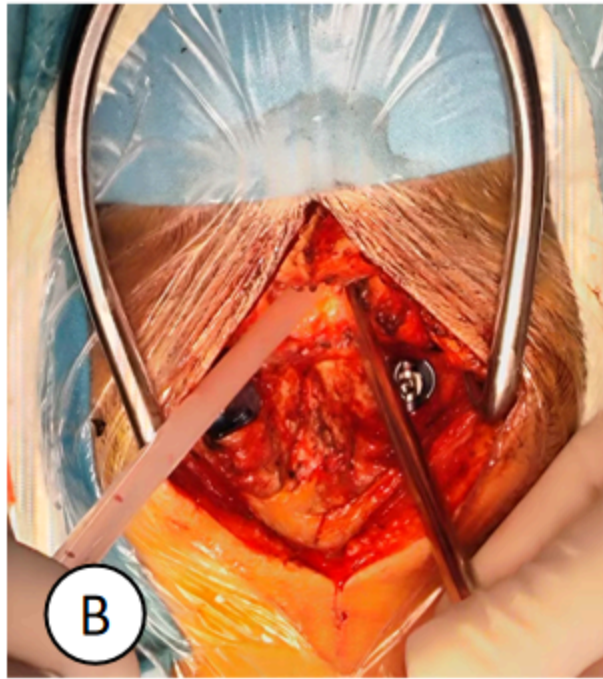
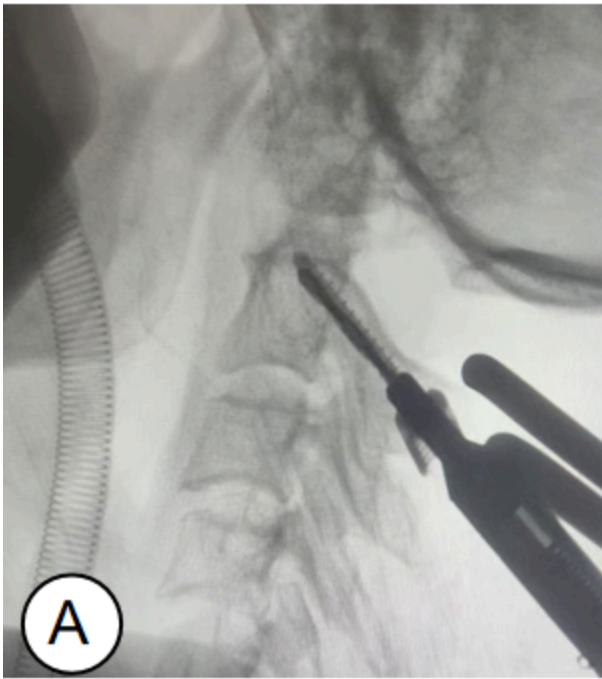


Figure 1

A. Placement of the axis vertebral screws during the first-step reduction B. Decompression of the foramen magnum during the first-step reduction C. Connection and final tightening of all occipital and axis screws to the definitive titanium rod during the second-step reduction D. Iliac bone graft harvesting and fusion

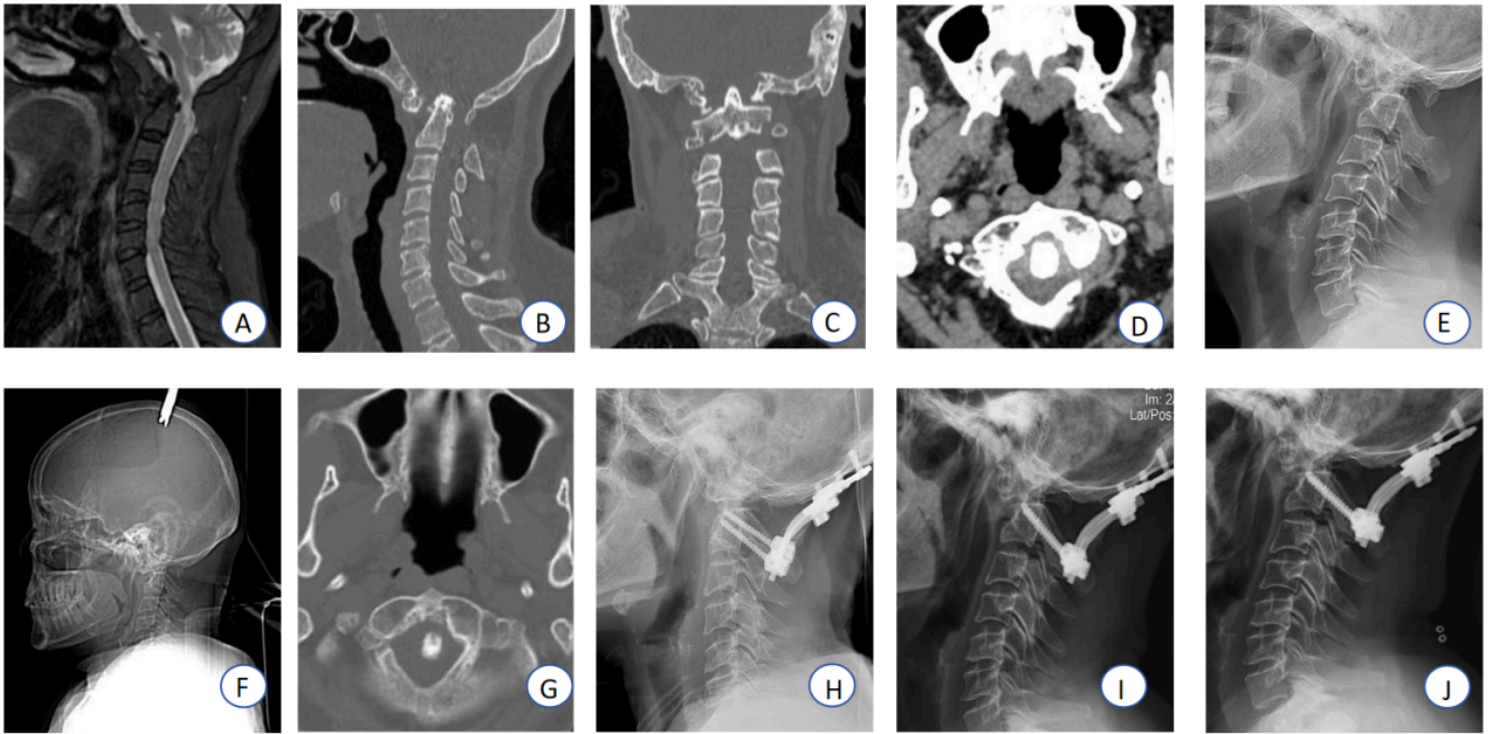


Figure 2

Case 3: A 69-year-old female patient. A: Preoperative MRI showing atlantoaxial dislocation and basilar invagination; B, C, D: Preoperative sagittal, coronal, and axial CT reconstructions demonstrating atlantoaxial dislocation, basilar invagination, and occipitalization of the atlas; E: Preoperative lateral X-ray showing atlantoaxial dislocation and basilar invagination; F, G: CT scan and axial view after skull traction; H: Lateral X-ray at 7 days postoperatively indicating successful anatomical reduction; I: Follow-up X-ray at 3 months postoperatively; J: Lateral X-ray at the final follow-up showing well-positioned internal fixation.