



# Posterior two-step distraction and reduction for basilar invagination with atlantoaxial dislocation: a novel technique for precise control of reduction degree without traction

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## Abstract

**Purpose** The pathological changes of basilar invagination (BI) and atlantoaxial dislocation (AAD) include vertical and horizontal dislocations. Current surgical techniques have difficulty in accurately controlling the degree of reduction in these two directions and often require preoperative traction, which increases patients' pain, hospital stay, and medical cost. This study aimed to introduce a novel technique for accurately reducing horizontal and vertical dislocation without preoperative traction and report the radiological and clinical outcomes.

**Methods** From 2010 to 2020, patients with BI and AAD underwent posterior two-step distraction and reduction (TSDR) and occipitocervical fixation. Radiological examination was used to evaluate the reduction degree (RD) and compression. Japanese Orthopedic Association (JOA) score was used to evaluate clinical outcome.

**Results** A total of 55 patients with BI and AAD underwent TSDR and occipitocervical fusion. The clinical symptoms of 98.2% of them improved. JOA score increased significantly after the operation. Appropriate ( $50\% \leq RD < 80\%$ ) or satisfactory ( $RD \geq 80\%$ ) horizontal reduction was achieved in 92.7% of patients, and 90.9% obtained appropriate or satisfactory vertical reduction. Thirty-one patients did not undergo preoperative skull traction. There was no significant difference in radiological outcomes or JOA scores between the traction and non-traction groups. However, the length of hospital stay in the traction group was longer than that in the non-traction group.

**Conclusion** TSDR enables horizontal and vertical reduction. It is a safe, simple, and effective technique for patients with BI and AAD. Despite the absence of preoperative skull traction, the degree of reduction and clinical outcomes were satisfactory.

**Keywords** Basilar invagination · Atlantoaxial dislocation · Two-step distraction and reduction · Occipitocervical fusion · Traction · Reduction

## Introduction

Basilar invagination (BI) is an occipitocervical deformity caused by abnormal development and is often associated with atlantoaxial dislocation (AAD), occipitalization of the atlas (OA), Klippel–Feil syndrome, and other deformities

[1–3]. BI usually results in cervical spinal cord compression and requires surgery [4]. For BI with AAD, vertical and horizontal dislocation are added to the pathological characteristics. Vertical dislocation means that the skull base is flat and inverted, and the odontoid process protrudes upward into the foramen magnum and compresses the cervical cord and medulla oblongata. Horizontal dislocation means that the atlanto-dental interval (ADI) increases, and the odontoid process compresses the upper spinal cord backward. As a result, patients often show obvious compression of the medulla oblongata and neurological symptoms, possibly leading to paralysis in severe cases. Therefore, correction of vertical and horizontal dislocation and release of compression of the medulla oblongata are key to the surgical treatment of BI with AAD.

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There are many classification methods for basilar depression combined with AAD. Wang et al. [5] classified AAD into four types: type I (dynamically reducible in flexion and extension radiographs), type II (dynamic reduction cannot be performed, but it can be reset through skeletal traction under general anesthesia), type III (irreducible through traction but without C1–C2 bony fusion), and type IV (C1–C2 has bony fusion and needs anterior approach decompression before fixation).

Anterior atlantoaxial decompression or odontoidectomy combined with posterior fixation constitutes the traditional correction procedure for BI and AAD. Although it can effectively achieve decompression, it has disadvantages such as large surgical trauma, long postoperative endotracheal intubation time, high risk of infection and cerebrospinal fluid leakage, difficulties in postoperative nursing, and difficulties in the operation [6, 7]. Goel et al. [8, 9] introduced an atlantoaxial fixation technique using posterior lateral mass screws and supported bone graft. However, with that technique, the ability to correct the horizontal dislocation is weak, the degree of reduction of the vertical dislocation is difficult to precisely control, and the C2 nerve root needs to be removed. The transoral atlantoaxial reduction-plate (TARP) technique has a reliable reduction capability [10, 11]. However, it fails in performing horizontal reduction appropriately, and patients have a long fasting time, a high probability of postoperative infection, pharyngeal discomfort, and respiratory obstruction. Jian et al. [12] and Peng et al. [13] used posterior direct distraction reduction occipitocervical fusion fixation, which avoids the anteroposterior combined approach, and reduces the operation trauma and surgical complication. However, it was difficult to reduce horizontal and vertical dislocation, respectively, with their technique, and the degree of reduction could not be precisely controlled. Precise control of this degree is important in achieving sufficient reduction and improving neurological symptoms [12]. Also, precise control of the degree of reduction can avoid over distraction and spinal cord injury, which commonly cause catastrophic complications such as respiratory and cardiac arrest [14].

This study aimed to describe in detail a novel posterior “two-step” distraction and reduction (TSDR) technique for treating BI with nonbony fusion AAD. The degree of reduction is precise, simple, and safely controlled, without preoperative or intraoperative traction or needing to cut C2 nerve roots.

## Methods

### Patients' data

The study was approved by the institutional ethics committee, and we obtained written consent from the participants.

We retrospectively reviewed a prospectively designed database of occipitocervical fixation from April 2010 to September 2020 in a single center. We identified consecutive patients who had BI and nonbony fusion AAD, had undergone TSDR during surgery, completed preoperative and postoperative radiological outcomes, and obtained patient-reported outcome measures (PROMs).

## Radiological and patient-reported outcome measurement

Preoperative dynamic and static X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) were performed on all patients to confirm their diagnoses. Dynamic radiographs were used to evaluate whether the AAD could be dynamically reduced. This technique is unsuitable for patients with a bony fusion between C1 and C2. O-C2 angle (O-C2A) was measured on X-ray to evaluate occipitocervical position. The degree of horizontal dislocation was assessed by measuring the atlantodens interval (ADI) on sagittal reconstructed CT scans. The distances of the odontoid process beyond the Chamberlain line (CL), Wackenheim's line (WL), and McRae line (ML) were measured on sagittal reconstructed CT scans to assess the degree of vertical dislocation (Fig. 1). For patients undergoing foramen magnum decompression, we used the measurement method of Jian et al. [12] since postoperative ML and CL measurements were difficult. The reduction degrees (RD) were calculated as follows [15].

$$RD = \left( 1 - \frac{\text{cut off value} - \text{postoperative value}}{\text{cut off value} - \text{preoperative value}} \right) \times 100\%.$$

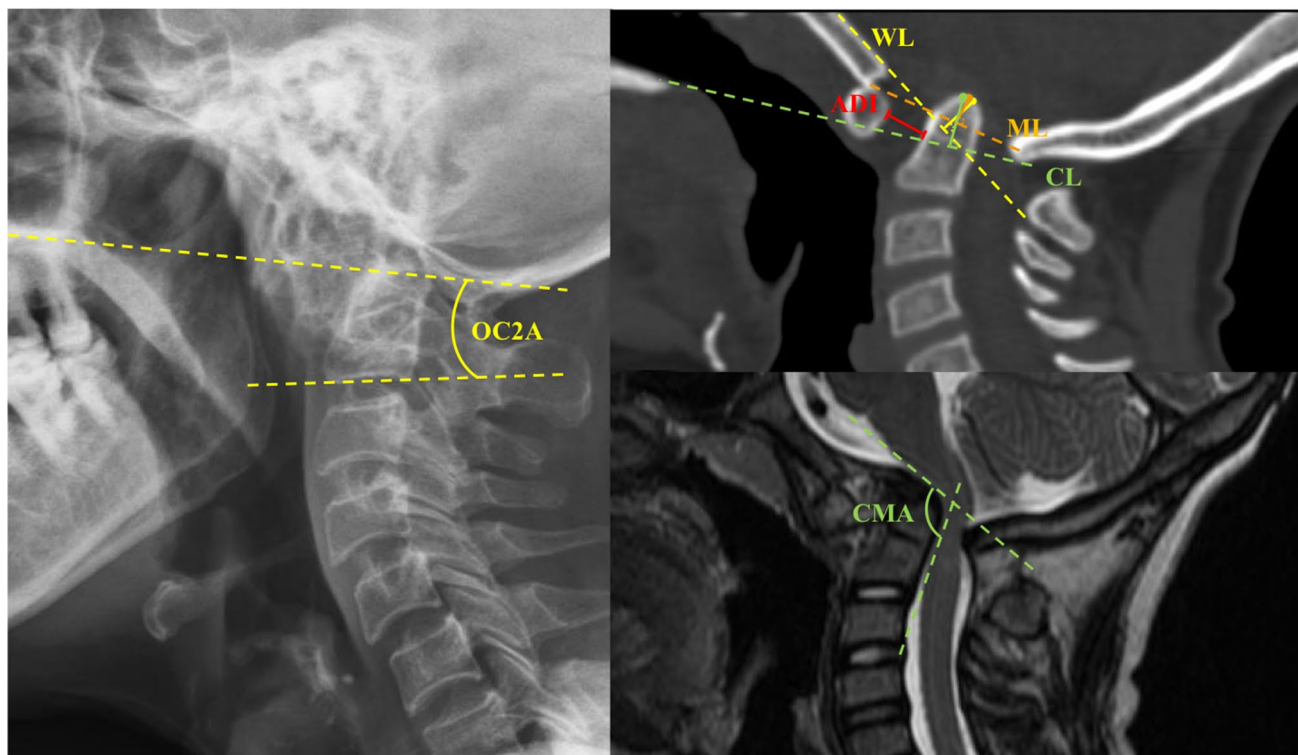
Cutoff values for ADI, ML, CL, and WL were 3 mm, 0 mm, 3 mm, and 0 mm, respectively. When postoperative value  $\leq$  cutoff value, the RD was set to 100%.

Cervicomedullary angle (CMA) was measured on sagittal reconstructed MRI scans to assess superior spinal cord and medulla oblongata compression. Imaging parameters were measured by two authors separately and averaged. Japanese Orthopedic Association (JOA) score was used to assess neurological function.

## Surgical technique

### Patient position and incision

The patient was placed in the prone position, and a Mayfield head holder was used to fix the head after general anesthesia. The head was placed in a slightly flexed position to tighten



**Fig. 1** Measurement of imaging parameters. The distance of the tip of the odontoid process beyond CL, ML, and WL was measured. CL is a line drawn from the posterior margin of the hard palate to the posterior aspect of the foramen magnum; ML is the line drawn from the anterior inferior margin to the posterior superior margin of the foramen magnum. WL is the extension line of clivus. O-C2A is the angle between C2 inferior endplate extended line and McGregor line. McGregor line is the line from the posterior margin of the hard pal-

ate to the inferior margin of the occipital scales. ADI is the distance between the posterior cortex of the atlas anterior arch and the anterior cortex of the odontoid process. CMA is the angle between the ventral extension of the cervical medulla and the ventral extension of the medulla oblongata CL, Chamberlain line; ML, McRae line; WL, Wackenheim's line; ADI, atlantodens interval; CMA, cervicomedullary angle

the skin and subcutaneous tissue (Fig. 2A, D, and G) for better exposure of the craniovertebral junction. A natural position was recommended if the patient had severe cervical cord compression. Motor-evoked potential monitoring with transcranial electrical stimulation was conducted during operation. Through a midline incision, the external occipital protuberance, posterior arch of the occipitalized C1, the lamina, and spinous process of C2–C3 were exposed.

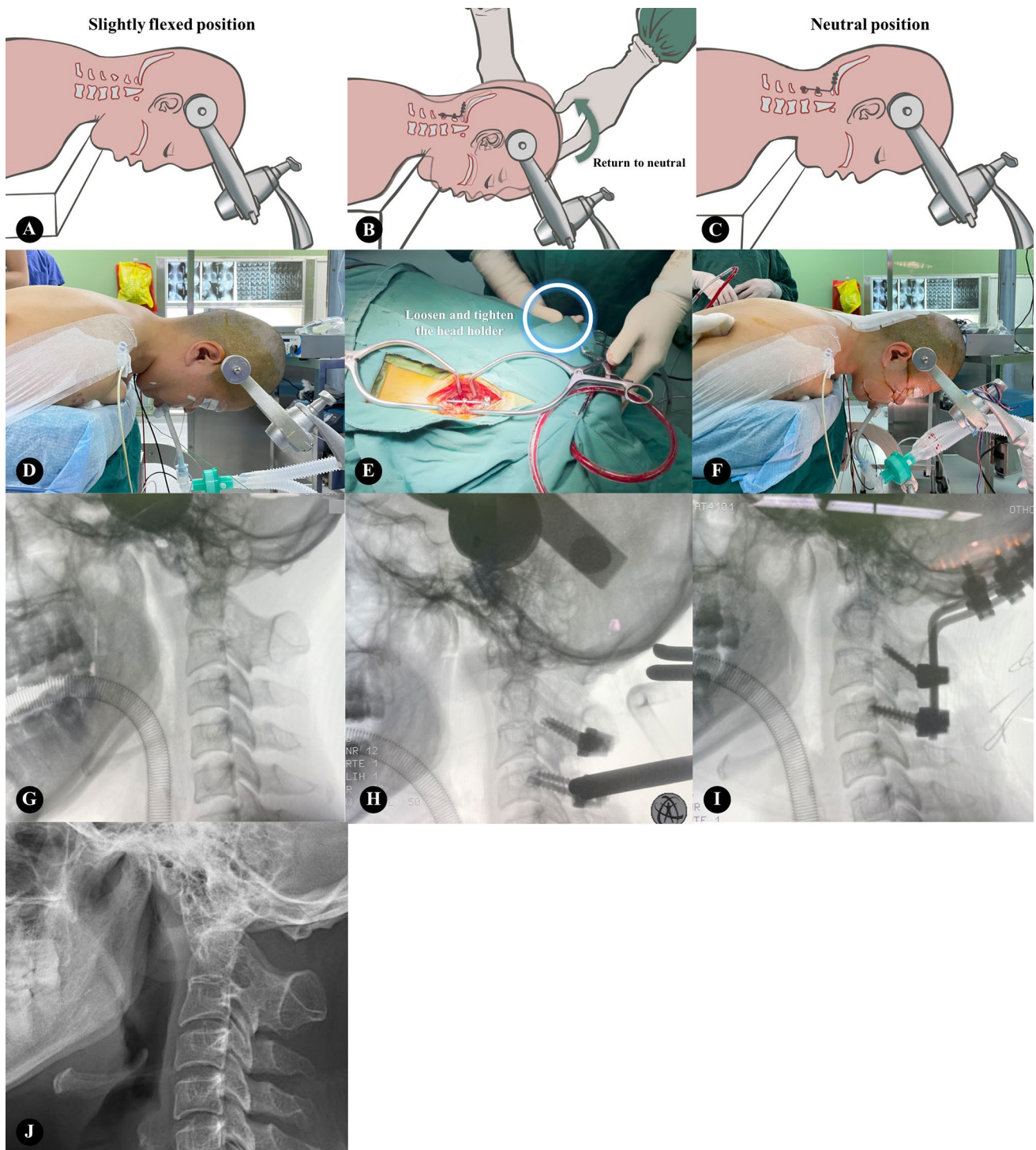
### Installing the screw-rod system

If the patient had posterior compression at the foramen magnum, the posterior arch of the occipitalized C1 and posterior margin of the foramen magnum were removed. Lateral mass screws were inserted bilaterally in C2 and C3. For patients with C2 and C3 fusion, lateral mass screws were inserted at C3 and C4. Two titanium rods were bent to  $100^{\circ}$ – $110^{\circ}$ , an angle similar to the typical posterior occipitocervical angle in the neutral position in most people [16], since it may lead to more beneficial clinical results [17]. Three cranial screw connectors were placed at the cranial end of each rod. The

caudal end of rod was fixed to the lateral mass screw. Then, the Mayfield head holder was adjusted to the physiological neutral position. Pay attention to the process of adjusting the head holder to make good contact between the cranial screw connector and the occipital bone (Fig. 2B, E, and H). Then three pairs of occipital screws were inserted into the thick central part of the occipital bone through the rod connector. After installing the rods, C-arm fluoroscopy was used to ensure that the screw-rod system was in proper position and that the O-C2A was larger than before surgery to prevent the occurrence of postoperative dysphagia (Fig. 2C, F, I, and J).

### Two-step distraction reduction (TSDR)

The reduction of BI with AAD was conducted in two steps. In step one, cervical lateral mass screws were tightly fastened, while occipital screws were loosened moderately. Distraction between the occipitocervical junction of the rod (OCJR) and occipital screws was performed, and the occipital screws were subsequently tightened. Therefore, the skull and the occipitalized C1 moved backward and upward,



**Fig. 2** Process of adjusting O-C2 angle. **A, D, G** A slight flexion position was taken at the beginning of surgery to facilitate exposure. **B, E, H** The Mayfield head holder was adjusted to the physiological neutral position. During the process, pay attention to make good

contact between the cranial screw connector and the occipital bone. **C, F, I** The position of the head after the operation; the O-C2A was improved compared with **J** the preoperative state

bringing horizontal and partial vertical reduction (Fig. 3A and C). In step two, the lateral mass screws were partially loosened. Distraction between OCJR and the C2 screws was

performed to bring C2 downward, which completed vertical reduction (Fig. 3D–F), locking the nuts afterward (**Video 1 Surgical Animation, Supplementary Material**). In these

two steps, the distraction distance depended on the degree of dislocation measured on CT film preoperatively. After reduction, intraoperative C-arm fluoroscopy was used to evaluate whether the reduction degree was adequate. Decorticated massive and cancellous bone were harvested from the iliac bone and implanted between the C3 spinous process and the decorticated occiput. Finally, the wound was closed in layers, and drainage was placed. Patients wore cervical collars for  $\geq 3$  months.

### Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, New York). Paired *t* test was used to evaluate the difference in variables pre- and postoperatively; *p* value  $< 0.05$  was considered statistically significant. All data are presented as mean  $\pm$  standard deviation (SD).

### Results

A total of 55 patients met the criteria, and we obtained at least 1 year of complete follow-up data for each patient (Fig. 4). The average age was 50 years (21–72 years), and 36% were men. The mean follow-up time was 24.2 months

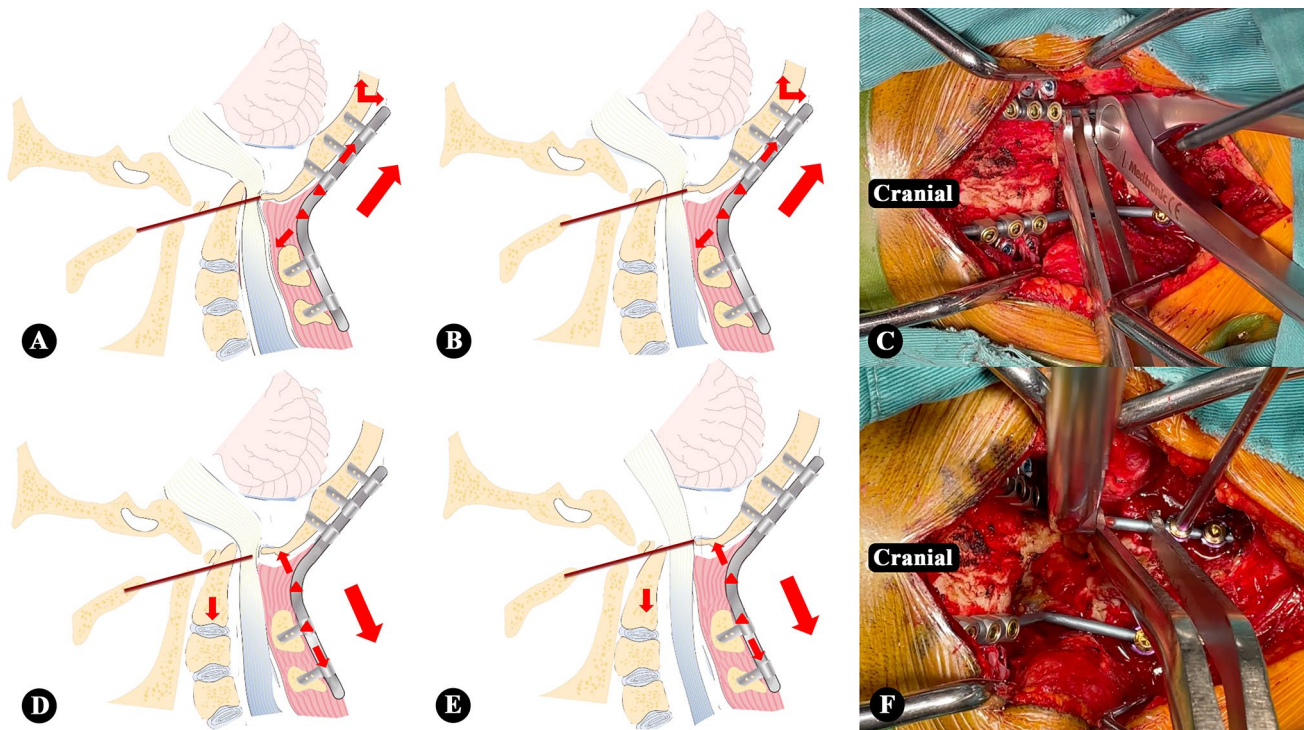
(12–68 m). The mean operative time was 140 min (95–217 min), and the mean blood loss volume was 161 mL (90–325 mL). Occipital neck pain was present in 90.9% of patients. All patients had BI with AAD, and 90.9% had occipitalization of the atlas (Table 1); 14 patients also underwent foramen magnum decompression.

### Clinical outcome and complications

No patient had neurovascular injuries, postoperative wound infections, or device-related adverse events. Postoperative neurological function improved compared with preoperative status in 54 patients (98.2%). The mean postoperative JOA score ( $15.1 \pm 1.1$ ) was significantly higher than the preoperative score ( $11.0 \pm 1.6$ ). Six patients had mild dysphagia but recovered within 6 months postoperatively. One patient developed pneumonia post-operation but recovered after anti-infective treatment.

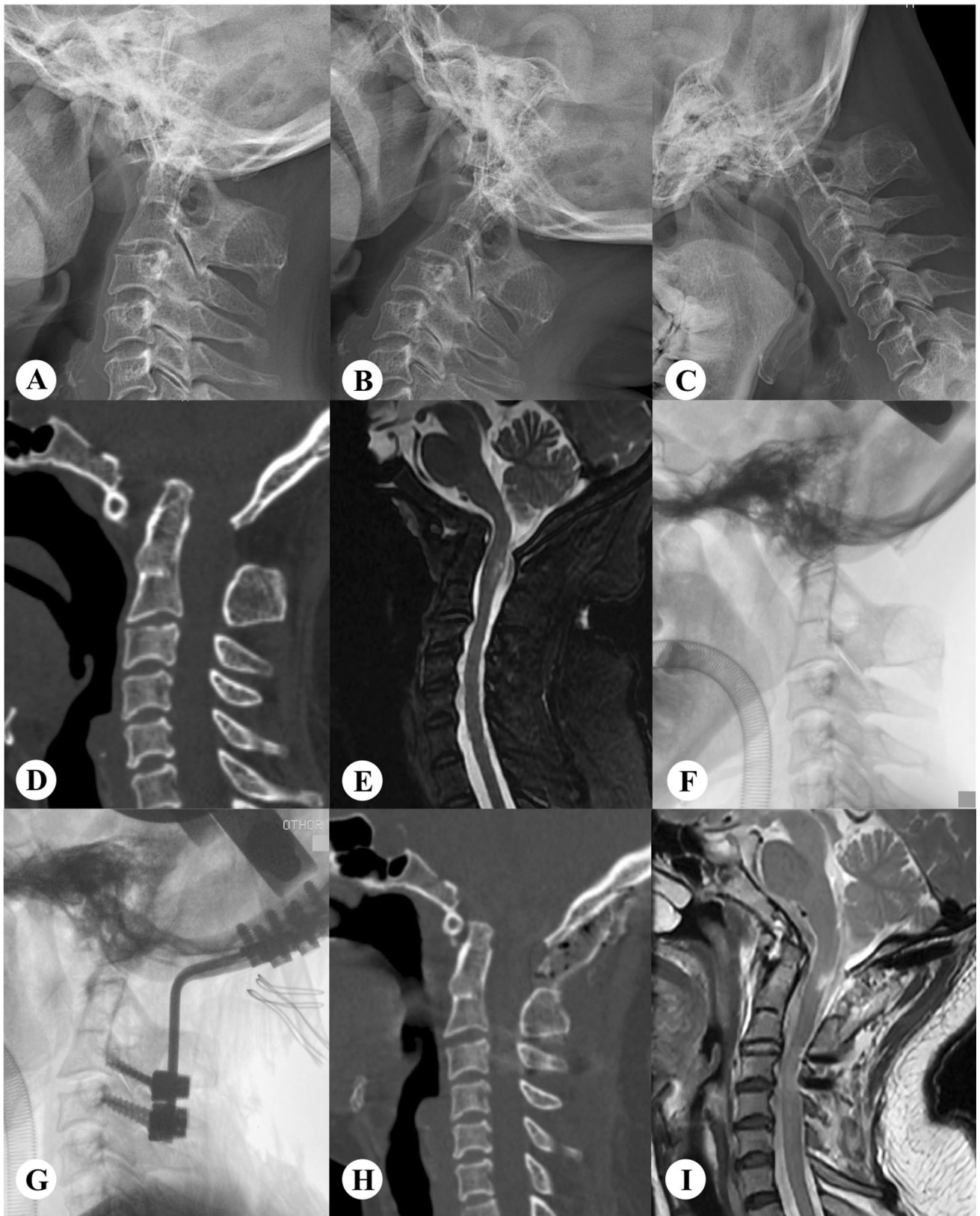
### Radiological outcome

Postoperative ADI, CL, WL, and ML were significantly lower than preoperative values. O-C2 did not change significantly after surgery. Thirty-six patients had a CMA greater than  $135^\circ$  postoperatively. Patients whose CMA did not reach  $135^\circ$  had an average reduction of  $18.4^\circ$ , and



**Fig. 3** Two-step distraction reduction technique in the posterior approach. **A–B** Horizontal and partial vertical reductions were achieved by distraction between the rod holder and the occipital

screw. **C** Intraoperative pictures of the first step. **D–E** Vertical reduction was achieved by distraction between the rod holder and the C2 lateral mass screw. **F** Intraoperative pictures of the second step



**Fig. 4** A 43-year-old male complained of neck pain, weakness, and paresthesia for 1 year. **A–C** X-ray and **D** sagittal reconstructed CT scan showed basilar invagination (BI) with atlantoaxial dislocation (AAD). **E** MRI showed compression of the cervical spinal cord, and the cervicomedullary angle (CMA) was 119.7°. **F–G** Intraoperative fluoroscopy showed that the effect of vertical and horizontal reduction was satisfactory. **H** Postoperative sagittal reconstructed CT scan confirmed that horizontal and vertical reductions were achieved after TSDR and occipitocervical fixation. **I** Postoperative MRI showed that the compression had been relieved, and CMA was corrected to 136.5°

the detailed data are summarized in Table 2. Fifty-one patients (92.7%) obtained appropriate horizontal reduction ( $RD \geq 50\%$ ), and 47 (85.5%) obtained satisfactory horizontal reduction ( $RD \geq 80\%$ ). Appropriate vertical reduction ( $RD \geq 50\%$ ) was achieved in at least 90.9% of patients, and satisfactory vertical reduction was achieved in at least 80% of patients ( $RD \geq 80\%$ ). The detailed data are shown in Table 3. At the last follow-up, 52 patients (94.5%) achieved fusion. Fusion was not observed in 3 patients during the follow-up, but no atlantoaxial instability or neurological deficit was found during their follow-up.

In the early cases, we routinely performed skull traction. However, through experience, we later found that good reduction could also be achieved without traction. To compare the postoperative reduction effect between patients with traction and those without traction, we allocated patients to two groups according to whether skull traction was performed or not. A total of 24 patients underwent preoperative skull traction, with an average traction time of 8.3 days (6–14 days) and an average hospital stay of 11.1 days (7–18 days). Thirty-one patients did not undergo preoperative skull traction (Table 4). No significant difference in radiological parameters and JOA scores was found between both groups (Table 5). Postoperative JOA scores improved compared with preoperative scores in both groups (traction group:  $10.7 \pm 1.7$  vs.  $15.1 \pm 0.9$ ,  $p < 0.001$ , non-traction group:  $11.1 \pm 1.6$  vs.  $15.1 \pm 1.2$ ,  $p < 0.001$ ). There was no statistical difference in the fusion rate between both groups at the last follow-up.

## Discussion

In this study, we described in detail a TSDR technique and reported the results of its application in patients with BI and AAD. Although there was no preoperative skull traction, the intraoperative TSDR technique was still safe and had a satisfactory reduction degree. For patients with BI and irreducible AAD, the traditional anterior oral odontoidectomy and decompression combined with posterior fixation and fusion had a higher risk of infection, greater trauma, and long fasting time [18, 19]. With the development of new surgical instruments, several atlantoaxial distraction

techniques emerged. Goel's technique [8, 9] can achieve vertical reduction and firm fixation after traction. However, it cannot provide sufficient horizontal reduction force, and it requires loosening the facet joint and removing the C2 nerve root during the operation, resulting in more bleeding. Peng et al. [13] fixed the cervical end of the rod after traction, then pressed down on the occipital end of the rod, which pulled the dentate process out of the foramen magnum. The procedure could not easily control the vertical and horizontal reduction. Jian et al. [12] directly distracted between the C1 screw and occipital screw without traction. While this procedure can achieve a reduction in both directions simultaneously, it cannot separately control the horizontal and vertical reduction degree easily. Yin et al. [20, 21] used a posterior C1 and C2 screw and rod systems to achieve better reduction. Although this improved the procedure, it still needs loosening of the facet joint and cannot control the degree of vertical and horizontal reduction.

The TSDR technique has the following advantages: (1) no preoperative traction is required; (2) the degree of horizontal and vertical reduction can be controlled separately and accurately; (3) there is no need to open the atlantoaxial lateral mass joint; and (4) it eliminates the need to cut the C2 never root.

This method is unsuitable for patients with an irreducible bony fusion between C1 and C2. In such cases, anterior release or odontoidectomy should be performed before reduction and fusion. For patients with posterior spinal cord compression caused by posterior fossa stenosis or atlas deformity, enlargement and decompression of the foramen magnum should be performed simultaneously. Therefore, the degree and type of dislocation and the compression direction of the spinal cord should be determined before operation.

Importantly, preoperative traction is not necessary when using the TSDR technique. In early cases, we routinely use preoperative skull traction to relax the muscles, ligaments, and joint capsule around the atlantoaxial spine, facilitating intraoperative instrumental distraction and reduction. However, with the increasing surgical cases, we noticed that the force of instrumental distraction is enough. Some patients had no reduction in hyperextension X-ray preoperation in the traction group, and no significant reduction was observed after skull traction. However, a successful reduction was achieved after intraoperative use of the TSDR technique. Thus, in recent years, we have stopped routine preoperative traction in cases of AAD without bony fusion between C1 and C2. In our study, there was no significant difference in radiological parameters between traction and non-traction groups. No neurovascular injury occurred in either group. Postoperative JOA scores increased in both groups compared to preoperative status. This indicates that TSDR can achieve satisfactory reduction even without preoperative traction. Additionally, the length of hospital stay for

**Table 1** Demographic data, symptoms, and radiological abnormalities in 55 Patients

Variable	Value
Age (years)	50.0 ± 13.7
Gender (male/female)	20/35
<i>Symptom</i>	
Occiput/neck pain	50 (90.9%)
Weakness	42 (76.4%)
Paresthesia	37 (67.27%)
Ataxia	23 (41.8%)
Lower cranial nerve dysfunction	18 (32.7%)
Dyspnea	8 (14.5%)
Dizziness	7 (12.7%)
Dysuria	5 (9.1%)
Decreased vision	2 (3.6%)
<i>Radiological abnormalities</i>	
Basilar invagination	55 (100%)
Atlantoaxial dislocation	55 (100%)
Occipitalization of atlas	50 (90.9%)
Klippel–Feil syndrome	26 (47.3%)
Chiari malformation	5 (9.1%)
Syringomyelia	17 (30.9%)

**Table 2** Neurological and radiological outcomes before and after surgery

	Preoperative	Postoperative	<i>p</i>
JOA score	11.0 ± 1.6	15.1 ± 1.1	< 0.001
<i>Horizontal reduction</i>			
ADI (mm)	6.4 ± 2.3	2.2 ± 2.1	< 0.001
<i>Vertical reduction</i>			
CL (mm)	9.0 ± 3.5	3.5 ± 3.0	< 0.001
WL (mm)	6.2 ± 2.9	0.5 ± 2.9	< 0.001
ML (mm)	5.2 ± 3.2	0.2 ± 3.6	< 0.001
O-C2A (°)	4.6 ± 12.5	5.4 ± 11.3	0.501
CMA (°)	120.3 ± 18.3	138.3 ± 12.5	< 0.001

JOA, Japanese orthopedic association. ADI, atlanto-dental interval. CL, Chamberlain line. WL, Wackenheim's line. ML, McRae line. O-C2A, O-C2 angle. CMA, cervicomedullary angle

**Table 3** The reduction degree after surgery

	Horizontal	Vertical		
	ADI	ML	WL	CL
RD ≥ 80%	85.5%	80%	81.8%	83.6%
50% ≤ RD < 80%	7.3%	10.9%	9.1%	9.1%
RD < 50%	7.3%	9.1%	9.1%	7.3%

RD, reduction degree. ADI, atlanto-dental interval. CL, Chamberlain line. WL, Wackenheim's line. ML, McRae line

**Table 4** Comparison of demographic data between traction group and non-traction group

	Traction	Non-traction	<i>p</i>
Number	24	31	-
Age (years)	48.3 ± 13.6	50.9 ± 14.5	0.487
Gender (male/female)	12/12	8/23	0.091
Blood loss (ml)	174.4 ± 81.3	162.3 ± 54.9	0.513
Hospital stay (days)	11.1 ± 2.4	8.9 ± 1.8	< 0.001
Follow-up time (months)	26.0 ± 17.0	22.7 ± 12.0	0.409

**Table 5** Comparison of neurological and radiological outcomes between traction group and non-traction group

	Traction	Non-traction	<i>p</i>
<i>JOA score</i>			
Preoperative	10.7 ± 1.7	11.1 ± 1.6	0.346
Postoperative	15.1 ± 0.9	15.1 ± 1.2	0.813
Last follow-up	15.7 ± 0.8	15.5 ± 0.9	0.418
<i>Horizontal reduction</i>			
Pre-ADI (mm)	7.0 ± 2.5	6.0 ± 1.9	0.085
Post-ADI (mm)	2.5 ± 1.9	2.0 ± 2.2	0.407
<i>Vertical reduction</i>			
Pre-CL (mm)	9.0 ± 2.8	9.0 ± 4.0	0.972
Post-CL (mm)	3.3 ± 2.6	3.7 ± 3.4	0.690
Pre-WL (mm)	6.5 ± 3.4	6.0 ± 2.5	0.543
Post-WL (mm)	0.4 ± 2.9	0.6 ± 3.0	0.824
Pre-ML (mm)	5.3 ± 2.4	5.2 ± 3.8	0.896
Post-ML (mm)	0.6 ± 2.8	-0.2 ± 4.1	0.430
Pre-CMA (°)	121.0 ± 20.0	119.8 ± 17.2	0.824
Post-CMA (°)	140.9 ± 11.0	136.3 ± 13.4	0.180
Fusion rate	95.8%	93.5%	-

JOA, Japanese orthopedic association. ADI, atlanto-dental interval. CL, Chamberlain line. WL, Wackenheim's line. ML, McRae line. CMA, cervicomedullary angle

patients without preoperative traction was reduced by 20%, effectively reducing the patient's medical costs and associated bedside complications.

The accuracy of TSDR is mainly reflected in the following aspects: (1) Previous techniques [12, 13] are used for simultaneous repositioning in both directions. However, many patients do not have the same or matched degree of horizontal and vertical dislocation, hampering satisfactory reduction in both directions. In contrast, through TSDR, an appropriate reduction can be achieved separately in horizontal and vertical dislocations. For example, for patients with serious horizontal dislocation and relatively mild vertical dislocation, TSDR could achieve more distraction in the first step (horizontal reduction) and less distraction in the second step (vertical reduction), thus avoiding over reduction; (2) Goel–Harms technology could achieve separate reductions



in two directions. Nevertheless, this technique mainly carries out horizontal reduction through manual lifting and the “lever principle” during screw tightening; the degree of vertical reduction depends primarily on the size of the interarticular implant. Conversely, TSDR can reduce through the strong distraction force in two almost straight directions on the titanium rod; (3) preoperation, surgeons estimate the requirement of distraction in two directions through CT three-dimensional reconstruction. Thus, during operation, surgeons could mark the titanium rod before distraction, estimate the reduction degree immediately after distraction, and evaluate whether the reduction is enough; (4) after reduction, intraoperative C-arm fluoroscopy was used to assess whether the reduction degree was adequate during surgery.

It should be noted that horizontal reduction should be performed before vertical reduction. Execution of vertical reduction before horizontal reduction may aggravate the compression of the dentate process on the ventral medulla oblongata or spinal cord. There is a risk of screw loosening for patients with osteoporosis, and surgery should be carefully considered, although there were no cases of screw loosening in our study.

After reduction, occipitocervical fixation should be done at the appropriate O-C2A. Dysphagia is one of the important complications after occipitocervical fusion [22, 23]. Dysphagia after occipitocervical fusion affects patients’ quality of life and is a common cause of aspiration pneumonia and asphyxia [24, 25]. A previous study [26] found a significant positive correlation between the change of O-C2A and the change of oropharyngeal distance. A small O-C2A may cause the mandible to move backward. The space between the mandible and the cervical spine is reduced, and the tongue root presses backward against the oropharynx causing its narrowing. This is the main mechanism by which dysphagia occurs after occipitocervical fusion. In patients with BI and AAD, because the head moves forward and downward relative to the cervical spine, the preoperative O-C2A is often significantly less than the normal value. In addition, while adjusting the head holder from flexion to a neutral position to increase O-C2A, the lower cervical spine compensates for part of the extension angle, making it difficult to obtain a better O-C2A by adjusting the head holder during operation. Therefore, we suggest that the intraoperative O-C2A should be fixed at an angle greater than the preoperative angle. In our experience, a small O-C2A can effectively be corrected as follows: (1) Due to the need for exposure at the beginning of surgery, the head should be flexed to tighten the skin and subcutaneous tissue. Since this flexed position would lead to a small O-C2A, the head and neck should be returned to a neutral position. And the O-C2A should be fixed in a proper position (in an angle not smaller than the angle before operation) by loosening and tightening the head holder and catering to the cranial side of

the pre-bent titanium rod. (2) When pre-bending the titanium rod, the degree of reduction should be reserved. (3) Finally, fluoroscopy should be performed before locking the screw to verify O-C2A. If it is smaller than before surgery, it should be adjusted again.

This study has limitations. First, we have not completed biomechanical tests. The strong forces used in this technique are a challenge for the screw-rod system and bone conditions. However, according to our clinical experience, the current instruments and bone conditions are sufficient to bear the force required for reduction. None of the patients had impaired spinal cord function at follow-up. Also, although the sample size of this study is not small in the field of BI with AAD, a larger sample size and multicenter study would be needed to verify the effectiveness and safety of this technology.

## Conclusion

The TSDR technique allows for an appropriate separately horizontal and vertical reduction in patients with BI and AAD. Despite the absence of preoperative skull traction, the degree of reduction is satisfactory. Performing TSDR without opening the lateral mass joint or removing the C2 nerve root is safe and easy.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s00586-022-07313-9>.

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## Declarations

**Conflicts of interest** All authors declare that they have no conflict of interest related to this work.

**Ethics approval and consent to participate.** All participants provided signed, informed consent prior to study participation. This study was permitted by Ethics Committee on Biomedical Research, West China Hospital of Sichuan University (2,019,946) and in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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