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Research article

Clinical effect and prognosis of transoral or endoscope-assisted transoral release for irreducible atlantoaxial dislocation: A retrospective cohort study

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ABSTRACT

Background: The clinical applications of endoscope-assisted transoral release for irreducible atlantoaxial dislocations are limited. This study aimed to investigate the clinical effect and prognostic factors of traditional and endoscope-assisted transoral release, as well as posterior reduction and fixation, in treating irreducible atlantoaxial dislocations.
Materials and methods: We conducted a retrospective study on 59 patients with irreducible atlantoaxial dislocation who underwent either traditional or endoscope-assisted transoral release, posterior fixation, and fusion between January 2018 and January 2023. Various data, including surgical time, blood loss, drainage volume, oral intake, hospital stay, complications, and neurological status (assessed by the Japanese Orthopedic Association [JOA] score and Oswestry Disability Index [ODI]), were recorded. Imaging parameters such as the atlantodontoid interval (ADI), space available for the cord (SAC), and cervicomedullary angle (CMA) were analyzed and compared. In addition, the correlation between ODI, JOA and patient age, course of disease, preoperative ADI, SAC and CMA were analyzed.
Results: No significant differences were observed in age, sex, BMI, preoperative ADI, preoperative SAC, or preoperative CMA. All patients achieved excellent reduction with no significant differences between the two groups. Patients in the endoscopic group experienced significantly reduced blood loss, earlier oral intake, and shorter hospital stays compared to those in the open group ($P < 0.05$). The ODI and JOA scores improved significantly in both groups at 1, 6, 12, 18, and 24 months postoperatively ($P < 0.05$). Postoperative ADI, SAC, and CMA values in both groups were significantly better than preoperative values ($P < 0.001$). The patient age, course of disease and the preoperative ADI were negatively correlated with the postoperative ODI and the JOA improvement ratio ($P < 0.01$), and the preoperative SAC and preoperative CMA had positive correlations with the postoperative ODI and the JOA improvement ratio ($P < 0.01$) at 6, 12 and 24 months postoperatively.

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Conclusion: Patient age, course of disease, preoperative ADI, SAC and CMA are correlated with the operative prognosis of irreducible atlantoaxial dislocation. The endoscope-assisted transoral approach, compared to the traditional transoral approach, is minimally invasive, resulting in less operative blood loss, earlier oral intake and a shorter length of hospital stay, which could be offered as an alternative for irreducible atlantoaxial dislocation.

1. Introduction

Irreducible atlantoaxial dislocations pose a significant threat to both life and well-being, with a high disability rate. This condition can lead to serious consequences, such as compression of the medulla oblongata and instability of the craniocervical junction. Wang's classification suggests that the typical approach for managing irreducible atlantoaxial dislocations involves transoral atlantoaxial release and posterior fusion [1]. However, the complexity of multiple pathologic changes and variations in anatomy presents challenges in both the diagnosis and treatment of irreducible atlantoaxial dislocation. Moreover, this condition is recognized as a challenging problem in the international arena of spinal neurosurgery because of its serious implications, particularly the compression of the medulla oblongata and craniocervical junction instability [2–4]. Research has shown that the traditional methods employed in managing this condition, at times, come with drawbacks such as extensive exposure, prolonged postoperative intubation, risks of bacterial meningitis, the necessity for tracheostomy, or oronasal regurgitation [5–8].

With the continuous advancement of medical imaging technology and enhancements in internal fixation devices, the approach to treating irreducible atlantoaxial dislocations is constantly evolving [9,10]. The growing experience with the endoscopic transnasal approach in addressing ventral lesions of craniocervical junction abnormalities [11–14] has led to the development of both endoscope-assisted and purely endoscopic techniques for managing irreducible atlantoaxial dislocation. This study aimed to evaluate the advantages of endoscope-assisted transoral release, posterior reduction, and fusion for irreducible atlantoaxial dislocation. We hypothesized that the findings of this study would potentially provide an optimized treatment approach based on the evaluation of these techniques.

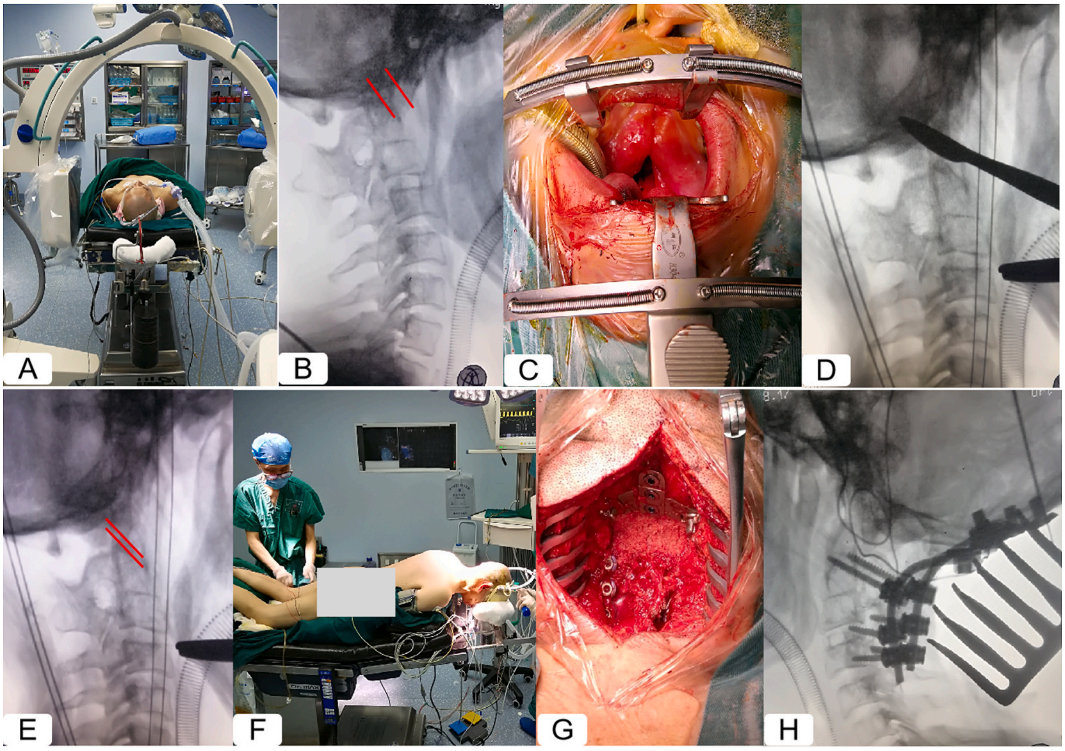

Fig. 1. Surgical procedures of the transoral release technique. (A, B) Unsuccessful attempt at reduction with continuous skull traction under general anesthesia (marked with red lines in b). (C–E) Successful transoral release and complete reduction achieved (ADI ≤3 mm, indicated by red lines in e). (F–H) Posterior fixation and fusion.

2. Materials and Methods

2.1. Patients

This was a retrospective cohort study. All procedures involving human participants performed in this study were in accordance with the ethical standards of our institution's institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

This study was conducted in line with the STROCSS criteria [15], Supplementary Table 1, Supplemental Digital Content 1. We included 59 patients diagnosed with irreducible atlantoaxial dislocation who underwent various procedures, including traditional transoral release (open group), endoscope-assisted transoral release (endoscopic group), and posterior fixation and fusion between January 2018 and January 2023. The inclusion criteria for irreducible atlantoaxial dislocation were based on Wang's classification of atlantoaxial dislocation [1]. The cases of atlantoaxial dislocation were classified into 4 types according to the treatment algorithm that included preoperative evaluation using dynamic radiograph, reconstructive computed tomography, and skeletal traction test. Type I, unstable dislocation, and Type II, reducible dislocation, which were fused in the reduced position from a posterior approach. Type III, which were irreducible dislocations, were converted to reducible dislocations using a transoral atlantoaxial release, followed by a posterior fusion. Type IV presented with bony dislocations and required transoral osseous decompressions prior to posterior fusion. The exclusion criteria encompassed reducible dislocation according to Wang's classification [1]; oropharyngeal malformations, infections, or tumors; and patients who underwent revision surgery or those who could not undergo surgery. The surgeries were performed by a senior surgeon with over 10 years of experience who had performed more than 500 cases of percutaneous endoscopic lumbar discectomy and 500 cases of cervical spinal surgery.

2.2. Surgical technique

Patients diagnosed with irreducible atlantoaxial dislocation received continuous skull traction starting at 2 kg and progressively

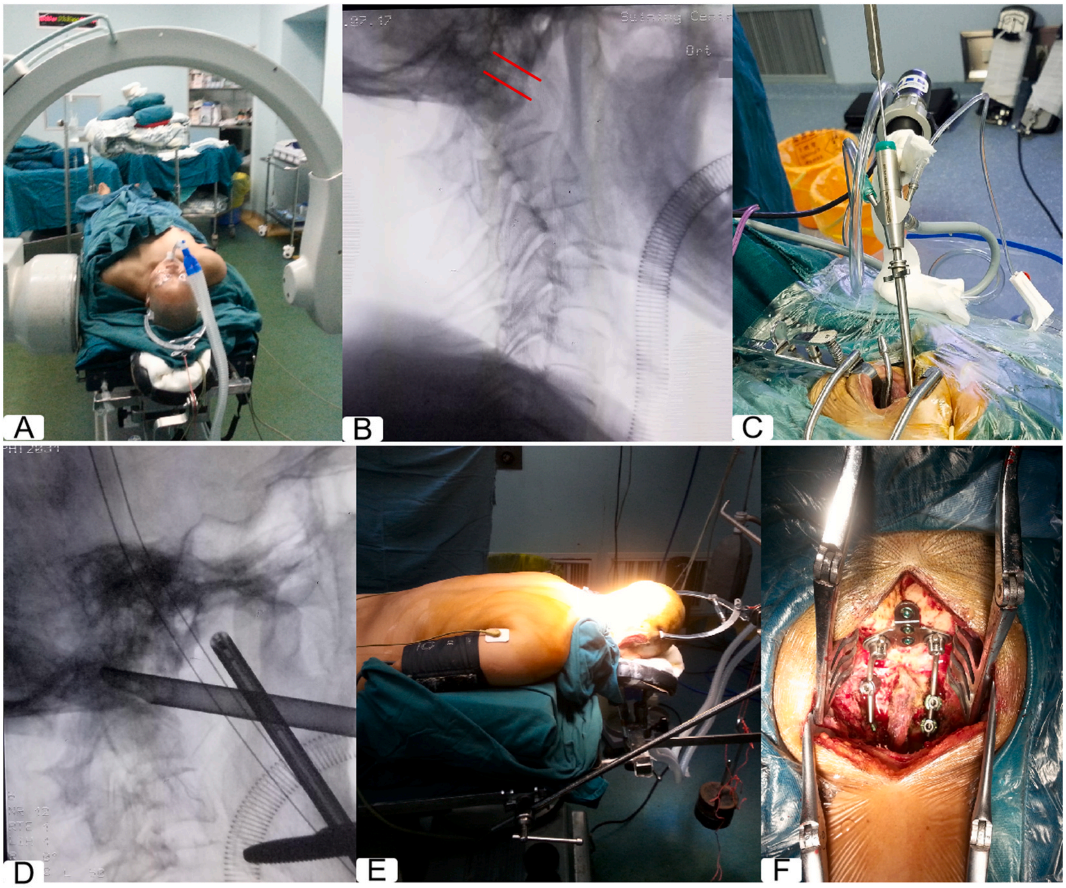

Fig. 2. Illustration of endoscope-assisted transoral anterior release. (A, B) Unsuccessful attempts at reduction with continuous skull traction under general anesthesia (indicated by red lines in b). (C, D) Endoscope-assisted transoral release and reduction of C1 – C2 (See Supplemental Digital Content, Videos 1 - 5). (E, F) Posterior fixation and fusion.

increased to 8–10 kg after diagnosis. Preoperative preparations comprised smoking cessation, consultation with the Department of Stomatology, oral and temporomandibular joint examinations, oral cavity gargling with 5 % sodium bicarbonate typically performed three times a day for 2–4 days, and skin preservation of the scalp.

Open group (Fig. 1): Patients, under general anesthesia, were placed in a supine position with continuous skull traction (ranging from 8 to 10 kg) and under neurophysiological monitoring. The maxillofacial region, nasal cavity, oral cavity, and upper pharynx were sterilized using iodophor. Subsequently, a mouth gag was placed and gradually expanded to expose the oropharyngeal region. The uvula was then sutured and pulled upward through the nostril using a rubber tube to fully expose the surgical field. Then, the C1 tubercle was palpated and a median incision was made in the posterior pharyngeal wall, and the pharyngeal mucosa, muscles, and ligaments were meticulously dissected and laterally retracted to expose the arch of C1 and the vertebral body of C2. Tissue flaps were carefully separated subperiosteally from the anterior elements of C1–C2, lateral dissection was complete when the point where the lateral border of the anterior aspect of C1 lateral mass was reached, and the anterior-inferior rim of the C1 anterior arch was dissected to expose the base of the odontoid process using a high-speed burr or monopolar electrocautery. Following this, the hypertrophic scar tissue and osteotylus between the odontoid process and the anterior arch of C1, as well as around the C1–C2 lateral masses, were resected and released thoroughly. Subsequently, a three angles awl was inserted into the left and right joint spaces respectively and the handle of the awl was rotated as a lever. Finally, the lateral mass of C1 was repositioned backward and upward, and the anterior part of C2 was situated forward and downward to effectively reattach the atlantoaxial joint. Successful tissue release was achieved when the joint space between the lateral masses of the atlas and axis elevated to 3–5 mm [11,16].

Endoscopic group (Fig. 2): For the endoscope-assisted transoral approach, the patient was placed in the supine position with continuous skull traction (8–10 kg) and under neurophysiological monitoring. After disinfecting the surgical area and exposing the oropharyngeal region, the anterior tubercle of C1 was positioned using the C-arm. A 5–7 mm incision was then made in the posterior pharyngeal wall for the insertion of the endoscopic working channel. The endoscope (3.75 mm in diameter and 181 mm in length with a lens angle of 30°; SPINENDOS, Munich, Germany) connected to the irrigation system was inserted through the view portal, and then the irrigation system was turned on for continuous irrigation. The first visual field was the junction between the odontoid process and the anterior arch of C1. Then, the pharyngeal mucosa and submucosal muscle tissue were separated subperiosteally to obtain an effective operation space below the posterior pharyngeal wall. Subsequently, the surgical field was expanded outward and downward by adjusting the direction of the endoscope to fully expose the base of the odontoid process and the lateral border of the anterior aspect C1–C2 lateral masses. And the joint capsules, hypertrophic scar tissue and osteotylus of the bilateral C1–C2 lateral joints, as well as the hyperplastic scar tissue or osteotylus between the odontoid process and the anterior arch of C1, were excised using a high-speed drill or grasping forceps under endoscope guidance. Finally, a nerve root retractor was inserted into the left and right joint spaces respectively and the handle of the retractor was rotated as a lever. Detailed procedures, including excising a hyperplastic scar between the odontoid process and the anterior arch of C1 using bipolar radiofrequency and removing scar tissue or osteotylus in front of the odontoid process with a high-speed drill, are demonstrated in Supplemental Digital Content 2 (Video 1) and Supplemental Digital Content 3 (Video 2). Subsequently, the atlantoodontoid joint and bilateral C1–C2 zygapophyseal joints were released, as demonstrated in Supplemental Digital Content 4 (Video 3) for the endoscope-assisted transoral release of the C1–C2 zygapophyseal joint and Supplemental Digital Content 5 (Video 4) for the endoscope-assisted transoral release and reduction of the atlanto-odontoid joint. If deemed necessary, the anterior arch of C1 and the odontoid process were partially resected using a high-speed drill to facilitate the release of scar tissue and reduction of the atlantoaxial joint, as depicted in Supplemental Digital Content 6 (Video 5) showcasing endoscopic observation of the medullospinal junction after decompression.

Supplementary video related to this article can be found at doi:10.1016/j.heliyon.2024.e35298

All patients in both groups underwent posterior fixation and fusion. C1–C2 fusion was routinely performed, and occipitocervical fixation was performed in patients presenting with occipitalization of the atlas or absence of the posterior arch of C1.

2.3. Postoperative care

All patients in both groups were transferred to the post-anesthesia care unit (PACU) until extubation. Afterward, antibiotics were routinely administered for 48 h. In addition, nasogastric tube feeding was performed for 3–5 days postoperatively, followed by the initiation of semi-liquid feeding the next day. Ultrasonic nebulization was performed postoperatively to relieve oropharyngeal discomfort and edema, and the drainage tube was removed two days postoperatively. Immobilization with a semi-rigid cervical collar was maintained for a period of three months.

2.4. Clinical evaluation

We conducted a comprehensive summary and compared all patient information, including surgical time, blood loss, drainage volume, oral intake, hospital stay, and complications. Functional assessments were carried out using the Japanese Orthopaedic Association (JOA) scores and Oswestry Disability Index Questionnaire (ODI), with evaluations performed preoperatively and at the 1-month, 6-month, 12-month, 18-month and 24-month follow-ups. The JOA improvement ratio (%) was calculated as follows: (postoperative JOA score - preoperative JOA score)/(17 - preoperative JOA score) $\times$ 100. Postoperatively, cervical anteroposterior (A-P) and lateral radiographs, cervical computed tomography (CT), and magnetic resonance imaging (MRI) were obtained at 1 week and 1, 6, 12 and 24 months, respectively. The analysis and comparison of imaging parameters involved the atlantodontoid interval (ADI), space available for the cord (SAC) and cervicomedullary angle (CMA). ADI, defined as the distance between the posterior border of the anterior ring of C1 and the anterior border of the odontoid process, was considered to reflect complete reduction if postoperative ADI

≤3 mm. SAC, representing the narrowest space of the cervical spinal cord at the surgical segment, was calculated on the midline sagittal plane of the MRI images [17]. CMA, the angle formed between the line extending the anterior border of the ventral medulla and the line extending the anterior border of the ventral upper cervical spinal cord, was measured using midline sagittal T2 MRI [18]. Correlation between the neurological function recovery and patient age, course of disease, preoperative ADI, SAC and CMA were performed by Pearson correlation analysis in all patients.

2.5. Statistical analysis

Statistical analyses were performed using Statistical Product and Service Solutions (SPSS) 20.0 statistical software (IBM, Armonk, NY, USA). Measurement data were expressed as the mean ± standard deviation (SD). An independent *t*-test was used to analyze the individual groups, and a chi-square test was used to analyze the enumeration data. Pearson correlation coefficient (r) was used to assess the associations between variables. The strength of correlations was described as weak ($|r| < 0.3$), moderate ($0.3 < |r| < 0.5$), or strong ($|r| > 0.70$). A *P*-value <0.05 was considered statistically significant.

3. Results

A total of 59 patients were included in this study. The Open group comprised 35 patients (18 males and 17 females) with an average age of 62.4 years (range, 34–84 years), while the Endoscopic group consisted of 24 patients (11 males and 13 females) with an average age of 60.5 years (range, 14–76 years). The mean course of disease was 8.9 ± 6.4 months for the Open group and 9.4 ± 6.3 months for the Endoscopic group. The mean follow-up time was 26.5 ± 8.8 months for the Open group and 24.6 ± 5.7 months for the Endoscopic group. Baseline characteristics, including age, sex, body mass index (BMI), preoperative ODI, preoperative JOA score, preoperative ADI, preoperative SAC, preoperative CMA, the course of disease and the mean follow-up time were not significantly different between the two groups (P > 0.05, Table 1).

3.1. Comparison of treatment effects and complications

As shown in Table 2, there were no statistically significant differences observed between the two groups with respect to operating time (Open group: 264.4 ± 37.9 min, Endoscopic group: 277.8 ± 30.1 min, P = 0.148). However, patients in the Endoscopic group exhibited less blood loss (Open group: 364.0 ± 34.7 ml, Endoscopic group: 335.8 ± 38.6 ml, P = 0.006; and 117.3 ± 22.9 ml in anterior approach of Open group, 98.6 ± 22.1 ml in anterior approach of Endoscopic group, P = 0.002), shorter duration of oral intake (Open group: 4.9 ± 0.9 days, Endoscopic group: 3.2 ± 1.0 days, P = 0.000) and shorter length of hospital stays (Open group: 18.2 ± 1.7 days, Endoscopic group: 16.9 ± 1.9 days, P = 0.011) compared to those in the Open group. And no statistically significant differences were found in volume of drainage (Open group: 334.3 ± 164.3 ml, Endoscopic group: 330.4 ± 171.5 ml, P = 0.929).

In the open surgery group, seven patients experienced complications, while four patients in the endoscopic surgery group had complications (P = 0.747, Table 2). Complications in the Open group included one case of pulmonary infection, three case of cerebrospinal fluid leakage in the posterior approach, and three cases of incision infection in the anterior approach. In comparison, complications in the endoscopic group comprised one case of pulmonary infection, two case of cerebrospinal fluid leakage in the posterior approach, and one case of urinary tract infection.

3.2. ODI and JOA scores

ODI and JOA score was utilized to evaluate postoperative functional outcomes. As shown in Fig. 3A, in the Open group, the ODI reduced from 57.7 % ± 7.5 preoperatively to 52.5 % ± 7.3 at 1 month postoperatively (n = 35, P = 0.004), 42.3 % ± 7.6 at 6 months postoperatively (n = 35, P < 0.001), 35.0 % ± 8.5 at 12 months postoperatively (n = 35, P < 0.001), 28.0 % ± 9.1 at 18 months postoperatively (n = 32, P < 0.001), and 23.6 % ± 8.1 at 2 year after the operation (n = 25, P < 0.001). In contrast, the ODI changed

Table 1
Clinical characteristics of included patients between the two groups.

Groups	Open group (n = 35)	Endoscopic group (n = 24)	*P*-value
Male/female	18/17	11/13	0.673
Age (years)	62.4 ± 9.3	60.5 ± 11.7	0.508
BMI	23.3 ± 2.5	23.8 ± 2.7	0.401
Pre ODI (%)	57.7 ± 7.5	59.4 ± 8.2	0.408
Pre JOA	9.9 ± 1.7	9.8 ± 1.7	0.801
Pre ADI (mm)	5.9 ± 0.6	5.6 ± 0.8	0.180
Pre SAC (mm)	8.0 ± 1.7	8.1 ± 1.8	0.797
Pre CMA (°)	114.9 ± 8.6	116.3 ± 8.9	0.542
Course of disease (months)	8.9 ± 6.4	9.4 ± 6.3	0.218
Follow-up time (months)	26.5 ± 8.8	24.6 ± 5.7	0.358

BMI: body mass index; Pre: Preoperative; ODI: Oswestry Disability Index; JOA.
Japanese Orthopedic Association score; ADI: atlantodontoid interval; SAC: space available for the cord; CMA: cervicomedullary angle.

Table 2
Comparison of surgical results between the two groups.

Groups		Open group (n = 35)	Endoscopic group (n = 24)	*P*-value
Operating time (min)		264.4 ± 37.9	277.8 ± 30.1	0.148
Total blood loss (ml)		364.0 ± 34.7	335.8 ± 38.6	0.006
Anterior approach	117.3 ± 22.9	98.6 ± 22.1	0.002	
Posterior approach	246.7 ± 30.8	237.2 ± 33.9	0.262	
Oral intake (days)		4.9 ± 0.9	3.2 ± 1.0	0.000
Hospital stay (days)		18.2 ± 1.7	16.9 ± 1.9	0.011
Volume of drainage (ml)		334.3 ± 164.3	330.4 ± 171.5	0.929
Complications (n)		7	4	0.747
Complete reduction (n)		28	19	0.938

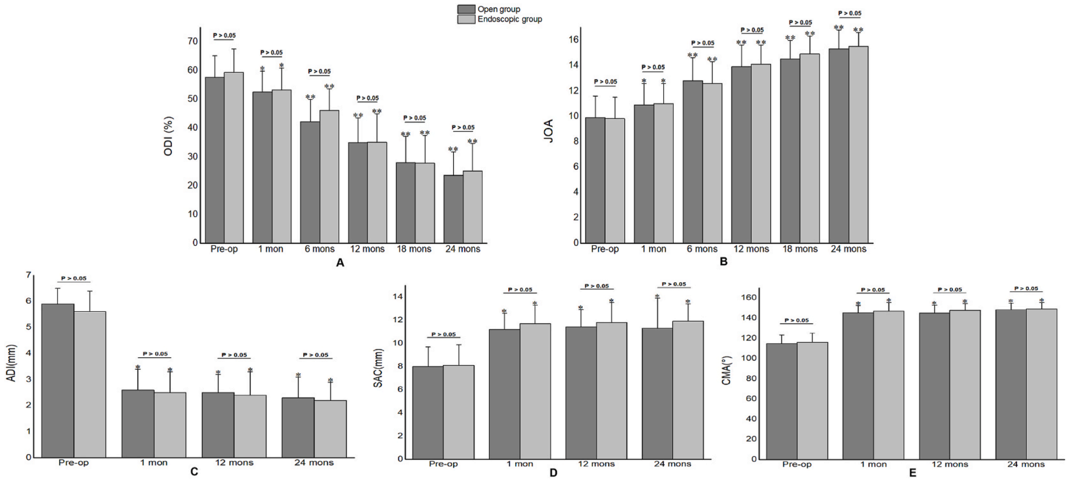

Fig. 3. The improvement of ODI, JOA, and radiological reduction outcomes. (A) For ODI and (B) for JOA scores: *P < 0.05, indicating a significant difference compared with preoperative ODI in both groups at 1 months postoperatively; **P < 0.001, indicating a significant difference compared with preoperative JOA in both groups at 6, 12, 18 and 24 months postoperatively; P > 0.05, no statistically significant differences between the groups. (C) For ADI, (D) for SAC, and (E) for CMA: *P < 0.001, representing a significant difference compared with preoperative values in both groups at 1, 12 and 24 postoperatively; P > 0.05, no statistically significant differences between the groups.

from 59.4 % ± 8.2 preoperatively to 53.3 % ± 7.6 at 1 month postoperatively (n = 24, P = 0.009), 46.2 % ± 7.5 at 6 months postoperatively (n = 24, P < 0.001), 35.1 % ± 9.9 at 12 months postoperatively (n = 24, P < 0.001), 27.8 % ± 9.7 at 18 months postoperatively (n = 19, P < 0.001), and 25.1 % ± 9.5 at 2 year after the operation (n = 19, P < 0.001) in the Endoscopic group. No statistically significant differences were identified between the two groups during the postoperative follow-up visits (P > 0.05).

As illustrated in Fig. 3B, the JOA score exhibited the following trends: In the Open group, the JOA score improved from 9.9 ± 1.7 preoperatively to 10.9 ± 1.7 at 1 month postoperatively (n = 35, P = 0.015), 12.8 ± 1.8 at 6 months postoperatively (n = 35, P < 0.001), 13.9 ± 1.7 at 12 months postoperatively (n = 35, P < 0.001), 14.5 ± 1.5 at 18 months postoperatively (n = 32, P < 0.001), and 15.3 ± 1.5 at 2 year after the operation (n = 25, P < 0.001). Similarly, in the Endoscopic group, the JOA score changed from 9.8 ± 1.7 preoperatively to 11.0 ± 1.6 at 1 month postoperatively (n = 24, P = 0.014), 12.6 ± 1.7 at 6 months postoperatively (n = 24, P < 0.001), 14.1 ± 1.5 at 12 months postoperatively (n = 24, P < 0.001), 14.9 ± 1.4 at 18 months postoperatively (n = 19, P < 0.001), and 15.5 ± 1.1 at 2 year after the operation (n = 19, P < 0.001). No statistically significant differences were identified between the two groups during the postoperative follow-up visits (P > 0.05).

3.3. Postoperative imaging evaluation

All patients achieved excellent reduction with no significant differences between the two groups (P = 0.938, Table 2). In the Open group, where 28 patients achieved complete reduction, the ADI decreased from 5.9 ± 0.6 mm preoperatively to 2.6 ± 0.8 mm at 1 month postoperatively (n = 35, P < 0.001), 2.5 ± 0.7 mm at 12 months postoperatively (n = 35, P < 0.001), and 2.3 ± 0.8 mm at 24 months postoperatively (n = 25, P < 0.001). Similarly, in the Endoscopic group, with 19 patients attaining complete reduction, the ADI decreased from 5.6 ± 0.8 mm preoperatively to 2.5 ± 0.8 mm at 1 month postoperatively (n = 24, P < 0.001), 2.4 ± 0.9 mm at 12 months postoperatively (n = 24, P < 0.001), and 2.2 ± 0.7 mm at 24 months postoperatively (n = 19, P < 0.001). No statistically significant differences were observed between the two groups during the postoperative follow-up visits (P > 0.05, Fig. 3C). As depicted in Fig. 3D, the SAC increased from 8.0 ± 1.7 mm preoperatively to 11.2 ± 1.4 mm at 1 month postoperatively (n = 35, P < 0.001), 11.4 ± 1.5 mm at 12 months postoperatively (n = 35, P < 0.001), and 11.3 ± 2.6 mm at 24 months postoperatively (n = 25, P < 0.001) in the Open group. Similarly, in the Endoscopic group, the SAC increased from 8.1 ± 1.8 mm preoperatively to 11.7 ± 1.6 mm at 1 month postoperatively (n = 24, P < 0.001), 11.8 ± 1.7 mm at 12 months postoperatively (n = 24, P < 0.001), and 11.9 ± 1.5 mm at 24 months postoperatively (n = 19, P < 0.001). No statistically significant differences were found between the two groups during the postoperative follow-up visits (P > 0.05). With comparable outcomes, the CMA improved from 114.9° ± 8.6 preoperatively to 145.2° ± 7.4 at 1 month postoperatively (n = 35, P < 0.001) and 145.1° ± 7.6 at 12 months postoperatively (n = 35, P < 0.001), and 148.2° ± 6.7 at 24 months postoperatively (n = 25, P < 0.001) in the Open group. In the Endoscopic group, CMA increased from 116.3° ± 8.9 preoperatively to 146.9° ± 8.7 at 1 month postoperatively (n = 24, P < 0.001) and 147.7° ± 6.8 at 12 months postoperatively (n = 24, P < 0.001), and 149.1° ± 6.4 at 24 months postoperatively (n = 19, P < 0.001). No statistically significant differences were found between the two groups during the postoperative follow-up visits (P > 0.05, Fig. 3E). All patients achieved solid fusion, an illustrative case of the Open group is shown in Fig. 4, and an illustrative case of the endoscopic group is shown in Fig. 5.

3.4. Correlation analysis of neurological function recovery

Pearson correlation analysis was conducted to test the correlation between neurological function recovery and patient age, the course of disease as well as maging parameters in all patients. There were moderate significant negative correlation between patient age and ODI at 6, 12 and 24 months postoperatively (P < 0.001 and r = - 0.52, r = - 0.66, r = - 0.58, respectively; Fig. 6A–C). There was a middle level negative correlation between patient age and the JOA improvement ratio at 6 months postoperatively (P < 0.001, r = - 0.52), and there were strong negative correlations between age and postoperative JOA improvement ratio at 12, 24 months postoperatively (P < 0.001 and r = - 0.77, r = - 0.89, respectively; Fig. 6D–F). The course of disease was strong negatively correlated with postoperative ODI (P < 0.001 and r = - 0.72, r = - 0.74, r = - 0.71, respectively; Fig. 6G–I), meanwhile moderate negatively correlated with the JOA improvement ratio (P < 0.001 and r = - 0.41, r = - 0.56, r = - 0.57, respectively; Fig. 6J–L) at 6, 12 and 24 months postoperatively.

On the other hand, the postoperative ODI had middle to strong level of negative correlation with preoperative ADI (P < 0.001 and r = - 0.62, r = - 0.73, r = - 0.67, respectively; Fig. 7A–C), and had middle to strong level of positive correlations with preoperative SAC (P < 0.001 and r = 0.69, r = 0.82, r = 0.78, respectively; Fig. 7G–I) and preoperative CMA (P < 0.001 and r = 0.76, r = 0.82, r = 0.81, respectively; Fig. 7M–O) at 6, 12 and 24 months postoperatively. Similarly, there was moderate significant negative correlation

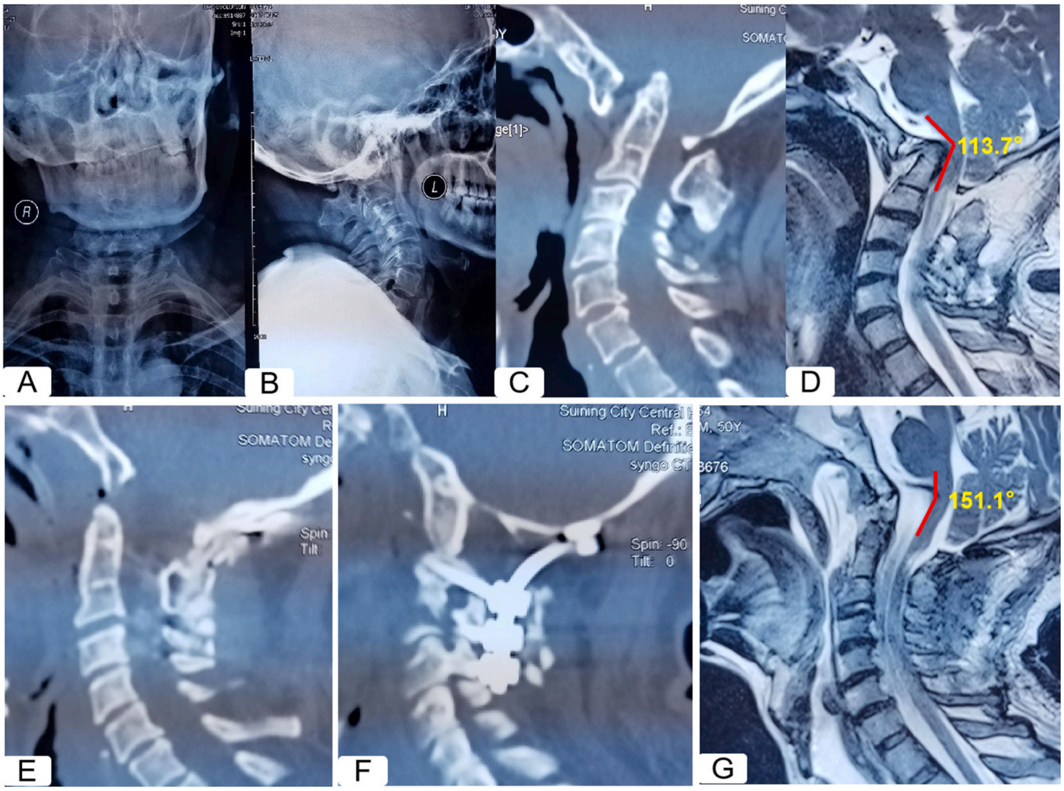

Fig. 4. A 50-year-old female with irreducible atlantoaxial dislocation and occipitalization underwent transoral release and C0 – C5 fixation and fusion. (A, B) Preoperative anteroposterior and lateral plain radiographs of the cervical vertebrae. (S, D) Preoperative CT and MRI revealed atlantoaxial dislocation, with the dens compressing the ventral spinal cord and a preoperative CMA of 113.7°. (E, F) Postoperative CT demonstrated a complete reduction of the atlantoaxial joint, with solid fusion achieved at the 12-month follow-up. (G) Postoperative sagittal MRI showed an improved CMA of 151.1° at the 12-month follow-up.

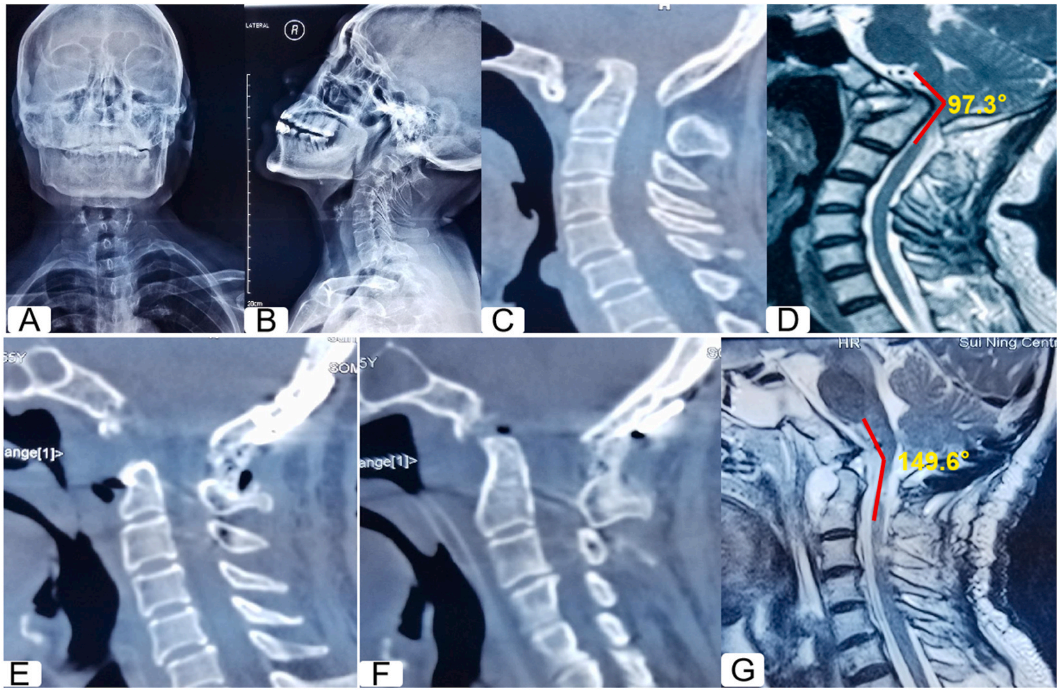

Fig. 5. A 56-year-old male with irreducible atlantoaxial dislocation and occipitalization underwent endoscope-assisted transoral release and C0 – C4 fixation and fusion. (A, B) Preoperative anteroposterior and lateral plain radiographs of the cervical vertebrae. (C, D) Preoperative CT and MRI revealed the dens compressing the ventral spinal cord, with a preoperative CMA of 97.3°. (E, F) Postoperative CT demonstrated solid fusion achieved at the 12-month follow-up. (G) Postoperative sagittal MRI showed an improved CMA of 149.6° at the 12-month follow-up.

between the JOA improvement ratio and preoperative ADI ($P < 0.01$ and $r = -0.34$, $r = -0.45$, $r = -0.49$, respectively; Fig. 7D–F), and there were moderate significant positive correlation between the JOA improvement ratio and preoperative SAC ($P < 0.01$ and $r = 0.35$, $r = 0.45$, $r = 0.42$, respectively; Fig. 7J–L) and preoperative CMA ($P < 0.001$ and $r = 0.53$, $r = 0.59$, $r = 0.59$, respectively; Fig. 7P–R) at 6, 12 and 24 months postoperatively.

4. Discussion

Atlantoaxial dislocation refers to a condition characterized by a loss of stability between the atlas and axis, resulting from various causes such as trauma, congenital factors, or inflammation. The etiology is often multifactorial [19]. The clinical presentation of atlantoaxial dislocation includes symptoms such as neck pain and/or neck movement restriction, weakness and/or numbness, pyramidal signs, and other preoperative manifestations such as sphincter disturbances, lower cranial nerve dysfunction, and respiratory distress [9,20,21]. Surgical intervention for patients with symptomatic atlantoaxial dislocation is widely acknowledged to protect against potential respiratory failure, progressive neurological deterioration, and even death [22]. However, there is a lack of consensus on the surgical indications for asymptomatic atlantoaxial dislocation. According to most studies [23,24], surgical treatment may be considered for adults if the ADI is greater than 5 mm, whereas, in young adults, fusion is recommended when moderate displacement is observed on flexion and extension cervical radiographs or when there is instability with or without pain. Furthermore, surgical fusion is indicated in children if they present with one or more of the following: neurological involvement, persistent anterior displacement with ADI greater than 4 mm, deformity persisting for >3 months, or recurrence of deformity after 6 weeks of immobilization [19]. Greenberg emphasized the importance of immediate decompression and stabilization for irreducible atlantoaxial dislocation [25]. According to reports by Mouchaty and Landeiro [26,27], the anterior transoral approach involving odontoidectomy or lesion excision is considered the most direct route for addressing ventral compression in the craniovertebral junction. However, this surgical approach raises the risks of complications such as dural laceration, cerebrospinal fluid leakage, and meningitis. Recent advancements have enabled endoscopic excision of the odontoid process in irreducible atlantoaxial dislocations through transnasal, transoral, and transcervical approaches, which have proven to be effective and safe [14,28–30]. Nevertheless, an undesirable side effect could be excessive bone removal from the odontoid and parts of the C2 body, potentially compromising the C2 pedicle and disrupting posterior fixation [19,31]. Wang et al. [31] first proposed and demonstrated the safety and efficacy of a one-stage anterior release, posterior instrumentation, and fusion for reducing irreducible atlantoaxial dislocation. However, the transoral approach carries a higher risk for complications such as infection, abscess formation, cerebrospinal fluid leakage, incomplete decompression, vertebral artery injury, spinal cord injury, and other more serious complications like death from vertebral artery injury and respiratory distress [31–34].

With advancements in techniques and equipment, less-invasive endoscopic approaches have gained popularity as a preferable

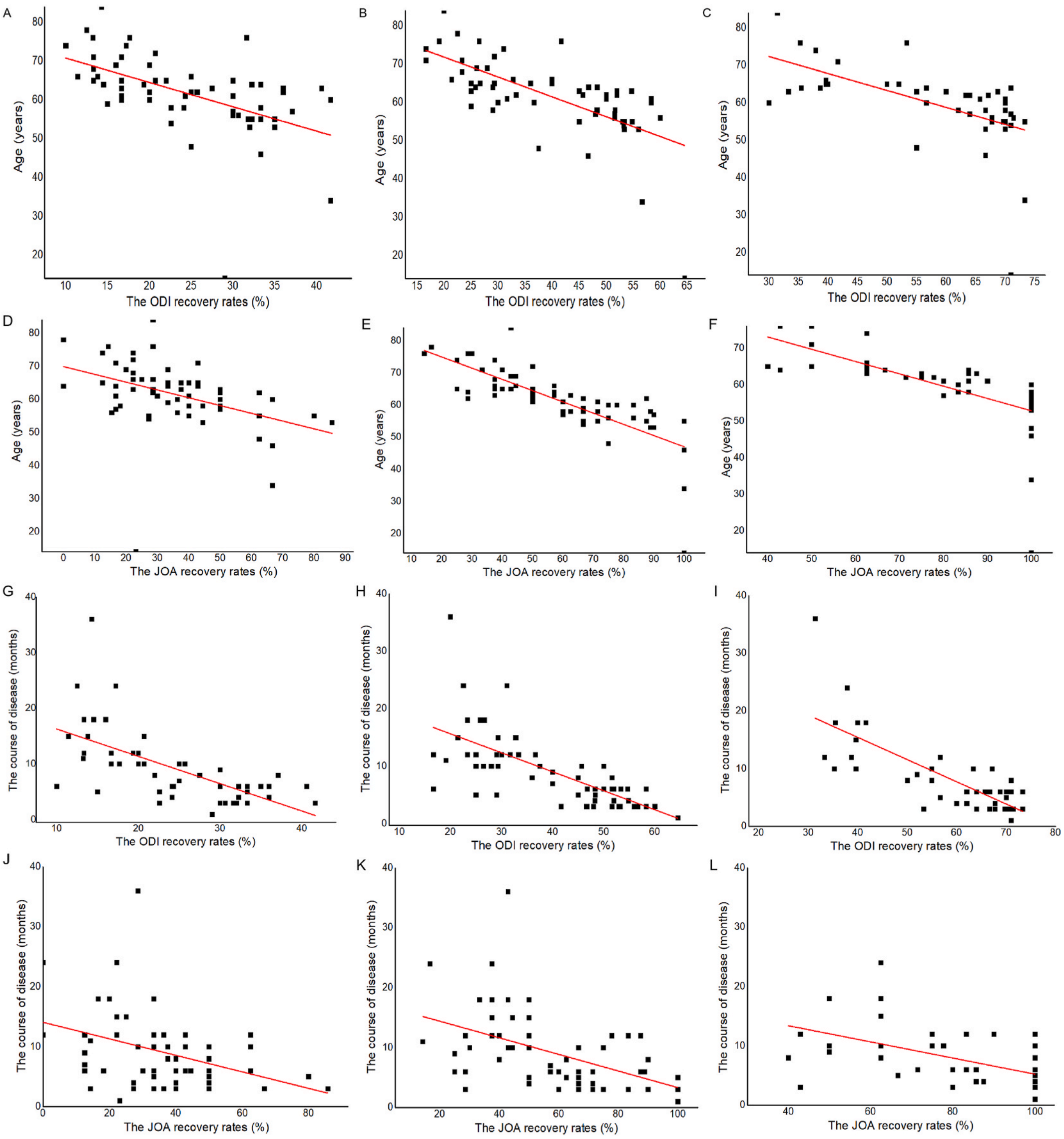

Fig. 6. Correlation between patient age, course of disease and neurological function recovery. (A–C) The fitted curves between patient age and ODI recovery rates at 6, 12 and 24 months postoperatively ($P < 0.001$; r = - 0.52, r = - 0.66 and r = - 0.58, respectively). (D–F) The fitted curves between patient age and JOA improvement ratio at 6, 12 and 24 months postoperatively ($P < 0.001$; r = - 0.52, r = - 0.77 and r = - 0.89, respectively). (G–I) The fitted curves between course of disease and ODI recovery rates at 6, 12 and 24 months postoperatively ($P < 0.001$; r = − 0.72,r = − 0.74 and r = − 0.71, respectively). (J–L) The fitted curves between course of disease and JOA improvement ratio at 6, 12 and 24 months postoperatively ($P < 0.001$, r = − 0.41, r = − 0.56 and r = − 0.57, respectively). * 59 patients at the 6-month, 59 patients at the 12-month and 44 patients at the 24-month, respectively.

option. In recent years, the endoscopic transnasal approach has emerged as a viable method for treating patients with irreducible atlantoaxial dislocation [11–14]. Compared to the transoral approach, the endoscopic transnasal route is less invasive, leading to earlier extubation, quicker resumption of oral intake, shorter length of hospital/ICU stays, and lower medical costs. These advantages contribute to a more favorable postoperative recovery. Additionally, Lv et al. [35] reported successful outcomes using an endoscopically assisted retropharyngeal approach to treat 21 patients with reducible atlantoaxial dislocation. All patients had an uneventful recovery, with remarkable improvement in neurological function and radiographic parameters and no complications. The authors suggested that endoscopically assisted anterior retropharyngeal release, when combined with posterior fixation, is a safe and effective alternative for treating irreducible atlantoaxial dislocations. However, the effectiveness of endoscope-assisted anterior release remains unclear. Herein, we conducted a comparison of the short to medium term clinical outcomes between traditional transoral and endoscope-assisted transoral anterior release, followed by posterior reduction and fixation for irreducible atlantoaxial dislocation.

For surgical findings, we found that the Endoscopic group had significantly less blood loss (335.8 ± 38.6 ml vs. 364.0 ± 34.7 ml, P

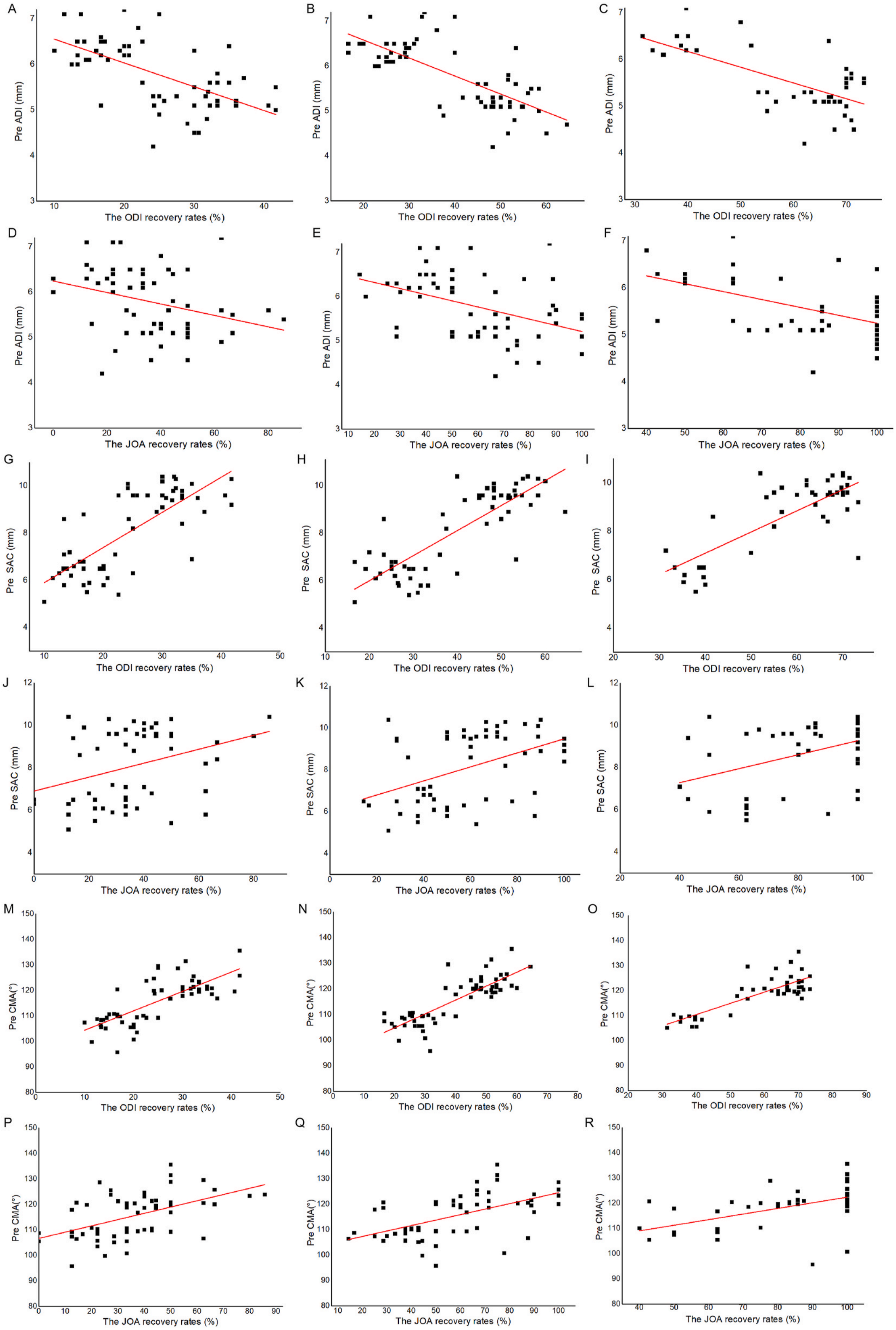

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Fig. 7. Correlation between imaging parameters and neurological function recovery. (A–C) The fitted curves between preoperative ADI and ODI recovery rates at 6, 12 and 24 months postoperatively, $P < 0.001$, r = - 0.62, r = - 0.73, r = - 0.67, respectively) (D–F) The fitted curves between preoperative ADI and JOA improvement ratio at 6, 12 and 24 months postoperatively ($P < 0.01$, r = - 0.34, r = - 0.45, r = - 0.49, respectively). (G–I) The fitted curves between preoperative SAC and ODI recovery rates at 6, 12 and 24 months postoperatively ($P < 0.001$, r = 0.69, r = 0.82, r = 0.78, respectively). (J–L) The fitted curves between preoperative SAC and JOA improvement ratio at 6, 12 and 24 months postoperatively ($P < 0.01$, r = 0.35,r = 0.45, r = 0.42,respectively). (M–O) The fitted curves between preoperative CMA and ODI recovery rates at 6, 12 and 24 months postoperatively ($P < 0.001$, r = 0.76, r = 0.82, r = 0.81,respectively). (P–R) The fitted curves between preoperative CMA and JOA improvement ratio at 6, 12 and 24 months postoperatively ($P < 0.001$, r = 0.53, r = 0.59, r = 0.59,respectively). * 59 patients at the 6-month, 59 patients at the 12-month and 44 patients at the 24-month, respectively.

< 0.05), shorter oral intake (3.2 ± 1.0 days vs. 4.9 ± 0.9 days, $P < 0.001$), and shorter hospital stay (16.9 ± 1.9 days vs. 18.2 ± 1.7 days, $P < 0.05$) than did the Open group. Unlike the traditional transoral approach, endoscope-assisted transoral anterior release was performed with a smaller incision (5–7 mm) under full-view endoscopy and continuous irrigation with normal saline. The posterior pharyngeal mucosa and muscle can be better protected, which may be the primary factors that decrease blood loss and promote wound healing. Thus, most patients in the endoscopic group did not require a prolonged postoperative fasting time and started oral intake 2–3 days after surgery. All these factors may contribute to shortening hospital stays. The ODI and JOA score showed remarkable improvement at 1, 6, 12, 18 and 24 months postoperatively in both groups. Although the ODI and JOA relief level was not significantly different between the two groups, it has been well demonstrated that with an endoscope, it is possible to achieve the same neurological decompression as that of the traditional transoral approach.

We found no significant difference in the total incidence of complications between the two groups, nonetheless, oral wound infection occurred postoperatively in 3 cases in the Open group, which was higher than that in the Endoscopic group. Previous studies reported that postoperative complication rates of the transoral approach for non-tumorous pathogenesis varied from 6 % to 21.4 % [36–38]. Oral wound infection was the major complication of the transoral approach for craniovertebral junction lesions [39,40]. In our study, three cases of incision infection occurred in the open group, which was higher than those reported in the literature [41,42]. In the open surgery group, the posterior pharyngeal muscle and mucosa were stripped wider and constantly tracked intraoperatively, increasing the risk of postoperative oral wound infection. Comparatively, the endoscope-assisted transoral approach was performed with a smaller incision (5–7 mm) under full-view endoscopy and continuous irrigation with normal saline. The posterior pharyngeal mucosa and muscle were better protected, which promoted wound healing. Additionally, all three 3 patients were older (71, 74, and 78 years, respectively) with an operation time of more than 4 h, which may be a risk factor for incision infection [38]. All 3 patients were treated with intravenous antibiotics for 1–2 weeks until the incision healed.

In our study, all patients achieved excellent reduction with no significant differences between the two groups. In addition, 19 patients in the endoscopic group achieved complete postoperative reduction, which was similar to the reduction effect of the endoscopic transnasal approach recommended by Dong [11]. All patients achieved bone fusion at the final survey. C1– C2 fixation and fusion were routinely performed (18 in the endoscopic group and 23 in the open group), and occipitocervical fixation was performed in patients with occipitalization of the atlas or absence of the posterior arch of C1. The imaging results showed that the postoperative ADI, SAC, and CMA in both groups were significantly better than those before surgery ($P < 0.001$), and the ADI, SAC, and CMA were not significantly different between the two groups at 1, 12 and 24 months postoperatively. Our operative manipulation and postoperative results demonstrate that with an angled-lens endoscope, it is possible to approach the craniocervical junction transorally, improve the exposure of the atlantoaxial joint, and more easily remove scar tissue and osteophytes by looking directly under endoscopic observation. Simultaneously, endoscope-assisted transoral release combined with posterior reduction and fixation can achieve cervical stability.

In this study, we comprehensively analyzed the correlation between ODI, JOA and patient age, course of disease, preoperative ADI, SAC and CMA in all patients. The patient age was moderate negatively correlated with postoperative ODI ($P < 0.001$), and strong negatively correlated with the JOA improvement ratio ($P < 0.001$) at 6, 12 and 24 months postoperatively. The course of disease was strong negatively correlated with postoperative ODI ($P < 0.001$) and moderate negatively correlated with the JOA improvement ratio ($P < 0.001$) at 6, 12 and 24 months postoperatively. The preoperative ADI had middle to strong level of negative correlation with postoperative ODI ($P < 0.001$), meanwhile moderate significant negative correlation the JOA improvement ratio ($P < 0.01$) at 6, 12 and 24 months postoperatively. The preoperative SAC and CMA were middle to strong positively correlated with postoperative ODI ($P < 0.001$), simultaneously moderate positively correlated with the JOA improvement ratio ($P < 0.01$) at 6, 12 and 24 months postoperatively. Our results indicated that these parameters are the predictors for prognosis in the treatment of irreducible atlantoaxial dislocation.

Although endoscope-assisted transoral approach has certain advantages such as less operative blood loss, earlier oral intake and a shorter length of hospital stay, several limitations remain for it to be widespread. First of all, potential serious complications of craniocervical junction surgery such as neurovascular injuries, CSF leakages, meningitis and oropharyngeal infections have been the main obstacle to irreducible atlantoaxial dislocation. Secondly, because of the endoscopic vision is comparatively small, especially under the condition of inadequate endoscopic hemostasis, the scar tissue and osteotylus between the odontoid process and the anterior arch of C1 may be difficult to excise. In addition, this endoscopic surgery is 2-dimensional, which lack depth of field and contribute to image distortion. Novel technologies such as navigation, robotics, and 3-dimensional and ultraresolution visualization should be introduced. Finally, the learning curve of endoscope-assisted transoral release is comparatively long due to the complexity of multiple pathologic changes and the variations in anatomy. The key factors for a good clinical outcome include a detailed understanding of patient's condition and imaging characteristics, adequate preoperative planning, reduction of atlantoaxial joint, neurological decompression, endoscopic hemostasis and less surgical complications.

For the first time, we retrospectively analyzed traditional transoral and endoscope-assisted transoral release as well as posterior reduction and fixation in the treatment of irreducible atlantoaxial dislocation. Despite the valuable insights gained, this study had some limitations that should be acknowledged. First, the retrospective nature of this study introduces the potential for selection bias, as surgeons use their discretion to determine the appropriate surgical approach. In addition, the experience and proficiency of the surgeon's skillsets may have also influenced the results. Second, we used a relatively small sample size and had a short to medium term follow-up. Future research should address these limitations through additional prospective randomized controlled clinical trials and long-term follow-up studies. Lastly, the economic aspect of the treatment was not considered, and additional detailed cost-effectiveness analyses will be necessary in the future.

5. Conclusion

Both raditional and endoscope-assisted transoral approaches have proven to be effective in treating patients with irreducible atlantoaxial dislocation. The patient age, course of disease and the preoperative ADI were negatively correlated with the postoperative ODI and the JOA improvement ratio, and the preoperative SAC and CMA had positive correlations with the postoperative ODI and the JOA improvement ratio. Moreover, the endoscope-assisted transoral approach, compared to the traditional transoral approach, is minimally invasive, resulting in less operative blood loss, earlier oral intake, and a shorter length of hospital stay, which is more favorable for postoperative recovery.

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Data availability statement

All data are available in the main text or the supplementary materials. Requests for these materials should be submitted to Zhiqiang Wang (zhiqiangzxyy@163.com) or Wenzhi Chen (wenzhiBio@163.com).

Ethical approval

This retrospective cohort study was approved by the Ethics Committee of the Suining Central Hospital (KYLLKS20240004) and registered with medicalresearch. org.cn (MR-51-24-055,057). This study included one 14-year-old patient, and we confirm that the consent was obtained from this minor in addition to his parental consent.

Research registration Unique Identifying Number (UIN)

Name of the registry: Chinese Clinical Trail Registry.
Unique Identifying number or registration ID: ChiCTR2400082473.
Hyperlink to the registration (must be publicly accessible): https://www.chictr.org.cn/bin/project/edit?pid=218186.

CRediT authorship contribution statement

Zhaojun Song: Writing – original draft, Validation, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Kai Zhang:** Investigation, Data curation. **Guangzhou Li:** Investigation, Formal analysis. **Zhi Zhang:** Investigation, Formal analysis. **Jiazhuang Zheng:** Investigation, Formal analysis. **Maobo Ran:** Visualization, Investigation. **Juan Luo:** Investigation, Data curation. **Zhiqiang Wang:** Supervision, Project administration, Funding acquisition. **Wenzhi Chen:** Supervision, Project administration, Funding acquisition.

Declaration of competing interest

All other authors declare they have no competing interests.

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Appendix A. Supplementary data

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