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ORIGINAL ARTICLE

Effectiveness of posterior reduction and fixation in atlantoaxial dislocation: a retrospective cohort study of 135 patients with a treatment algorithm proposal

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Abstract

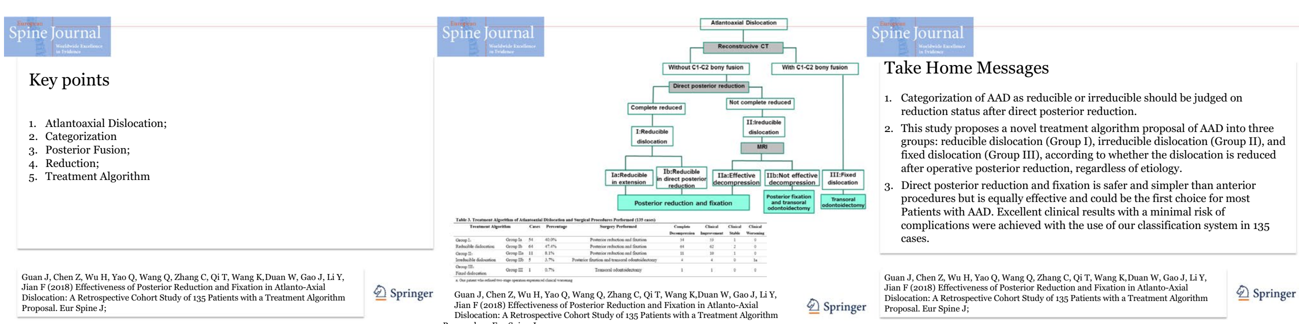
Purpose Surgical procedures on atlantoaxial dislocation remain controversial. The aim of this observational retrospective study was to investigate the treatment algorithm of surgical procedures.

Methods According to CT and intraoperative evaluation during direct posterior reduction, 135 AAD cases were categorized into three groups: Group I: reducible dislocation; Group II: irreducible dislocation (Group IIa: effective decompression achieved after posterior reduction; Group IIb: no effective decompression after posterior reduction); and Group III: fixed dislocation. Group III presented with extensive bony fusions. Group I and Group IIa were treated with direct posterior reduction and fixation. Group IIb underwent posterior fixation and transoral odontoidectomy. Group III underwent transoral odontoidectomy alone. Japanese Orthopedic Association scores (JOA) were assessed to evaluate clinical status before and 6, 12 months after surgery.

Results Our study included 118 Group I cases, 16 Group II cases (Group IIa: 11 cases; Group IIb: 5 cases), and one Group III case. Follow-up ranged from 12 to 36 months. Primary outcome: Anatomic atlantoaxial reduction was achieved in 118 of 135 patients (87.4%). Clinical improvements were seen in 96.3% (130/135) all the patients. Solid atlantoaxial fusion was shown in 134 patients. Secondary outcome: The overall complication rate was 3.7% (5/135). For Group I, the mean postoperative 6-month JOA was 14.5 versus 12.2 in preoperative patients (paired Student's *t* test, $P<0.01$).

Conclusions This article proposes a clinical procedure that assists with therapeutic decision making and indicates the severity and difficulty of reduction of the atlantoaxial joint.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



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Extended author information available on the last page of the article

Keywords Atlantoaxial dislocation · Categorization · Posterior fusion · Reduction · Treatment strategy

Introduction

Atlantoaxial dislocation (AAD) is a rare and potentially fatal disturbance of the normal atlantoaxial joint [1, 2]. The craniovertebral junction (CVJ) can be affected by congenital, inflammatory, idiopathic, or traumatic abnormalities [3–5]. AAD is traditionally categorized as irreducible or reducible [6]. However, the characterization of reducibility is somewhat controversial: Some surgeons depend on dynamic X-ray or preoperative traction findings [6–8], whereas others make this judgment on the basis of skeletal traction under general anesthesia [9, 10]. The delineation between reducible AAD (RAAD) and irreducible AAD (IrAAD) is important because the management of the two types differs. IrAAD usually requires anterior release or transoral ventral decompression, whereas RAAD can be treated with direct posterior reduction and fixation [2, 11].

Recently, several studies involving direct posterior release and reduction of dislocation for the treatment of IrAAD have been reported [7, 8, 12–15]. With the techniques of joint reduction, this posterior-only approach can achieve reduction while avoiding all risks of the transoral or retropharyngeal approach in most AAD cases. Thus, the definition of reducibility should be revised, not according to dynamic X-ray or skeletal traction findings under general anesthesia, but according to the results of direct posterior reduction.

The objective of this article is to propose a clinical procedure to guide surgical decision making and to indicate the severity and difficulty of reduction in AAD cases. We propose that the aim of AAD treatment is decompression rather than anatomic reduction. The importance of magnetic resonance imaging (MRI) in postoperative assessment is emphasized. Additionally, the roles of dynamic radiography and intra/preoperative traction are discussed.

Materials and methods

General data

This observational retrospective study evaluated a novel surgical treatment algorithm. Between May 2012 and December 2016, a total of 135 patients with a diagnosis of AAD were treated at our institution. The patients were categorized according to the flowchart and received corresponding surgical procedure (Fig. 1).

The patient population comprised 61 male patients and 74 female patients with ages ranging from 6 to 75 years (mean age 41.6 years). The sole criterion for AAD was an atlantodental interval greater than 3 mm among adults (≥ 18 years) and greater than 5 mm among younger individuals. Patients with AAD with a history of previous surgery at the craniovertebral junction (excluding posterior fossa decompression), acute fracture, or evidence of tumor were excluded from the study. The clinical presentations and etiologies are summarized in Tables 1 and 2, respectively. The

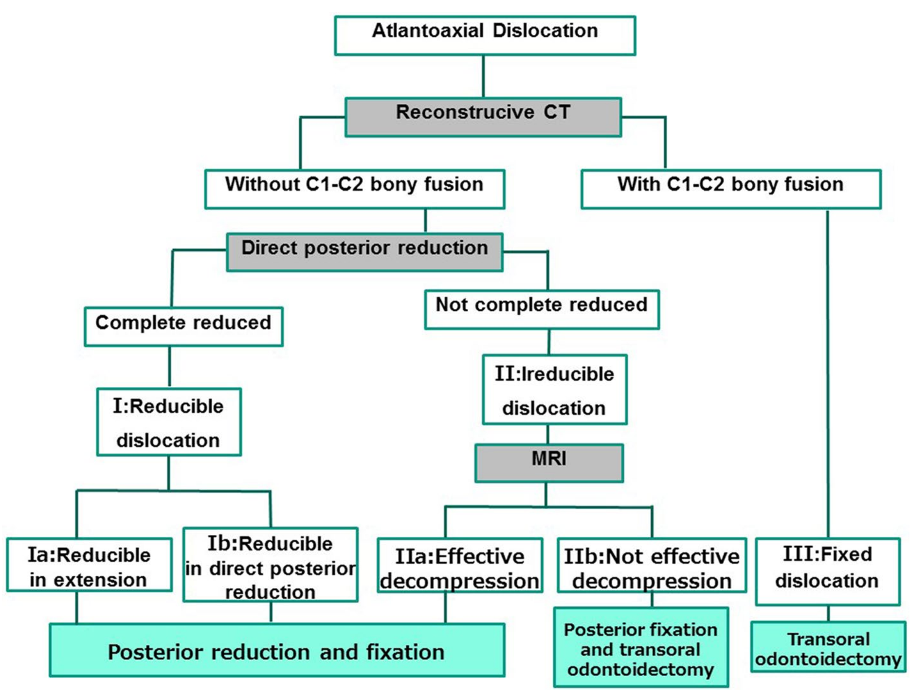

Fig. 1 The treatment algorithm categorization and surgical strategy. CT, computed tomography

Table 1 Clinical manifestations* ($N=135$)

Symptoms and signs	No. of patients (%)
Head and neck pain	76 (56.2)
Quadriparesis	62 (45.8)
Hemiparesis	21 (15.6)
Numbness of limbs	87 (64.4)
Ataxia	53 (39.3)
Torticollis	16 (11.9)
Dysphagia	7 (5.2)
Respiratory difficulty	6 (4.4)
Sphincteric dysfunction	5 (3.7)

*One patient may have more than 1 clinical feature

Table 2 Etiologies of AAD in 135 cases

Diagnosis	Cases
Basilar invagination and atlas occipitalization	74
Os odontoideum	21
Atlas occipitalization and block vertebra C2–C3	10
Rheumatoid arthritis	9
Old odontoid fracture, nonunion	5
Unknown	16
Total	135

duration of symptoms ranged from 3 months to 20 years; limb numbness, progressive weakness of the extremities, and occipitocervical pain were the top three main complaints. All patients underwent dynamic lateral radiography, reconstructive computed tomography (CT), and MRI of the cervical spine preoperatively. Some of the patients underwent dynamic CT scans with reconstruction views of the craniovertebral junction if anatomic structures could not be discerned on plain X-rays of basilar invagination. Patients were observed prospectively for a minimum of 12 months (range 12–36 months). Japanese Orthopedic Association scores were assessed to evaluate clinical status before and 6, 12 months after surgery. Every patient was evaluated by the same operator.

Approval from Institutional Review Board was obtained before medical records were accessed.

Clinical categorization

Cases were categorized according to dynamic radiograph/CT, reconstructive CT, and MRI findings and the results of posterior reduction. The categorization of AAD as reducible or irreducible was determined based on reduction status after direct posterior reduction (Fig. 1). A postoperative atlantodental interval less than 3 mm was considered complete reduction.

The three groups of AAD are as follows:

Reducible atlantoaxial dislocation (Group I)

If no evidence of extensive osseous fusion between C1 and C2 was found on reconstructive CT, patients underwent direct posterior reduction. If full reduction was achieved, patients were categorized as Group I. These patients were further divided into two subgroups according to the difficulty of reduction. Patients with reduction in extension who underwent direct posterior fixation and fusion were categorized as Group Ia. Those with partial reduction in extension but with complete reduction in direct posterior reduction were categorized as Group Ib.

Irreducible atlantoaxial dislocation (Group II)

If direct posterior release and reduction failed to anatomically reduce the atlantoaxial joint, posterior fixation and fusion was performed. Postoperative MRI was used to assess the effect of decompression. The "good decompression" was determined as effective spinal cord decompression induced by the ectopic odontoid process on MRI, and the arachnoid space between the spinal cord and odontoid process could reappear. Patients who achieved complete decompression were grouped into Group IIa. Those with insufficient decompression underwent odontoidectomy in a second-stage operation and were categorized as Group IIb.

Fixed dislocation (Group III)

If preoperative CT demonstrated extensive bony fusion between C1 and C2, including fusion in lateral mass on the both side of atlantoaxial joint, fusion in atlas and odontoid process and fusion in the vertebral arch of atlas and vertebral plate of axis, then a categorization of Group III was given. For these patients, direct posterior reduction was not attempted and the surgical option was direct transoral odontoidectomy.

Surgical treatments

Direct posterior reduction and fixation

Patients with Group I and Group II AAD underwent direct posterior reduction and fixation. The following two techniques for short-segment posterior fixation were used:

① C1 lateral mass screw and C2 pedicle screw fixation [16, 17]. Patients without occipitalization of the atlas underwent this procedure.

② Occiput to C2 fixation with C2 pedicle screws [18]. Some Group I patients have occipitalization of the atlas or dysplasia of the C1 posterior arch. In this condition, inserting C1 pedicle screws is quite hard and risky. For the patients with C1 assimilation, abnormal course of vertebral artery and abundance of venous plexus prevented the proper exposure of C1 lateral mass and screw placement. Hypoglossal canal also had potential risk of injury during screw placement. Thus, patients with occipitalization of the atlas or dysplasia of the C1 posterior arch underwent this procedure.

The procedure has been previously described [12]. Reduction of the AAD was achieved with longitudinal distraction between the C2 pedicle and occiput/C1 screws, which pulled the odontoid process downward and anteriorly in patients with AAD with basilar invagination. To avoid posterior tilt of the odontoid process, we pushed the handle of the C2 pedicle screw upward to resist the distraction between the occiput/C1 and C2 pedicle screws. After 2012, the posterior reduction technique was further modified. First, a cantilever technique was used [19, 20]. The odontoid process was initially pushed forward by compressing the rod, which was tightly connected to the C2 pedicle screw, toward the occiput. If complete reduction was not achieved, the distraction maneuver between the occiput and C2 screws described above was performed. Many AADs were successfully reduced using only the cantilever technique. In AAD without basilar invagination, we used only the cantilever technique; distraction was not necessary. If the AAD was not reduced completely after the above procedure, we tried to further reduce the AAD by opening and releasing the bilateral facet joints, as described by Goel and Salunk [15, 21]. If the C1–C2 facet joints were opened, the soft endplates were cleaned and corticocancellous bone harvested from the posterior iliac bone or metallic spacers packed with bone were used to support the facet joint space.

Transoral odontoidectomy

If direct posterior reduction failed to achieve effective decompression (Group IIb), as confirmed by postoperative MR, then odontoidectomy was performed via a transoral approach [22, 23]. Patients categorized as having fixed dislocation (Group III) underwent odontoidectomy alone. Five cases were categorized as Group IIb dislocations. Four of these underwent odontoidectomy; the fifth patient declined surgery.

Postoperative assessment

The patients underwent postoperative X-ray, reconstructive CT scan, and MRI to determine reduction, decompression, bone graft status, and internal fixation at 1 week, 3, 6, and 12 months after surgery, and annually thereafter. Japanese Orthopedic Association scores were assessed postoperatively and at 6-month follow-up to determine neurological recovery. Bone fusion was confirmed by continuous trabecular bones passing the interface between the graft and donor bone bed and no abnormal activity in dynamic radiographs.

Statistical analysis

For the primary outcome, no statistical method was used. For the secondary outcome, paired Student's *t* test was used for comparing mean values of the Group I patients before and after the surgery. Statistical analysis was performed using IBM SPSS (IBM, Chicago, IL, USA). Statistical significance was established as $p < 0.05$. The parameter is JOA score. We have assessed the normal distribution of the sample, and it is in accordance with normal distribution.

Results

Primary outcome

One hundred eighteen cases were categorized as Group I, 11 as Group IIa, five as Group IIb, and one as Group III. The surgical strategies chosen based on each patient's categorization are summarized in Table 3.

Of the 118 patients with RAAD (Group I), 54 were Group Ia (Fig. 2) and 64 were Group Ib (Fig. 2). The C1–C2 joint was opened in some Group Ib patients. It was important to mobilize the C1–C2 joint for patients with these groups of AAD. Patients were treated with posterior C1–C2 ($n = 48$) or occipitocervical fixation ($n = 70$). All patients obtained complete atlantoaxial reduction. Clinical improvement was achieved in 115 of 118 patients (97. 5%). All patients underwent posterior fusion obtained fusion by 12-month follow-up.

One patient developed a superficial wound infection, which healed gradually over 6 weeks. Partial loss of the AAD reduction was confirmed on CT scan in one patient 1 month after surgery because of improper tightening of one screw head during surgery. The patient achieved complete reduction after revision surgery. One patient presented with occipital pain 40 days after surgery; occipital screw loosening was confirmed on X-rays. The patient underwent revision surgery and recovered well. Two patients experienced dysphagia but made full recovery within 3 days to 1 month. No other complications occurred intra/postoperatively. Of the 16 patients with irreducible AAD (Group II), eleven achieved complete decompression after posterior reduction and fixation (Group IIa) (Fig. 3). Clinical improvements were seen in 10 of the 11 patients; clinical symptoms were stable in one patient.

Table 3 Treatment algorithm of atlantoaxial dislocation and surgical procedures performed (135 cases)

Treatment algorithm	Cases	Percentage	Surgery performed	Complete decompression	Clinical improvement	Clinical stable	Clinical worsening
Group I: reducible dislocation							
Group Ia	54	40.0%	Posterior reduction and fixation	54	53	1	0
Group Ib	64	47.4%	Posterior reduction and fixation	64	62	2	0
Group II: irreducible dislocation							
Group IIa	11	8.1%	Posterior reduction and fixation	11	10	1	0
Group IIb	5	3.7%	Posterior fixation and transoral odontoidectomy	4	4	0	1[a]
Group III: fixed dislocation							
Group III	1	0.7%	Transoral odontoidectomy	1	1	0	0

[a]One patient who refused two-stage operation experienced clinical worsening

Five patients had insufficient decompression after posterior surgery (Group IIb); four of these were treated with transoral odontoidectomy (Fig. 3). These four patients obtained effective decompression and bony fusion during the follow-up period. Neurological improvement was seen in all four patients. One patient who refused two-stage operation experienced clinical worsening.

The one patient with bony dislocation (Group III) was treated with direct transoral odontoidectomy (Fig. 4). Postoperative MRI showed favorable decompression.

Secondary outcome

The overall complication rate was 3.7% (5/135). For Group I, the mean postoperative Japanese Orthopedic Association score 6 months after surgery was 14.5, compared with a preoperative score of 12.2 (paired Student's t test, $P<0.01$).

Discussion

Surgical treatments are generally required for AAD because of compression of the spinal cord and medulla oblongata in the region of the craniovertebral junction, regardless of the various causes of AAD (Table 3). Optimal treatment achieves decompression by restoring the anatomic relationship between the axis and atlas and reconstructing stability. In some patients, dislocation at C1–C2 is a dynamic process; if timely treatment is not offered, the muscles and ligaments become contracted, deforming the C1–C2 joint. In these cases, displacement may become difficult to reset. These dislocations are termed irreducible. However, the definition and assessment of AAD reducibility remain controversial.

Definition of reducibility

Greenberg initially described AAD as reducible or irreducible based on reduction during full neck extension on dynamic X-rays. Reducibility is a very important factor in determining treatment strategy [6]. For IrAAD, the goal of treatment is to achieve immediate decompression and stabilization [23]. Traditional treatment of IrAAD is transoral odontoidectomy and posterior fusion. However, this treatment is associated with high morbidity and mortality rates and complications such as cerebrospinal fluid leakage, infection, and abscess formation [24].

In the past decade, researchers have proposed a categorization system that defines IrAAD as a failed attempt at reduction with skeletal traction performed under general anesthesia and the presence of muscle paralysis [9, 10, 25]. Because of the solutions of neck pain, muscle tension, and positional restrictions, some AAD cases that appear irreducible on dynamic radiographs become reducible with skeletal traction under general anesthesia. Wang el al. [26] reported that 37% of patients with an incompletely reducible atlantoaxial joint on dynamic X-rays achieved complete reduction with skeletal traction under general anesthesia. For these IrAAD patients, one-stage anterior release followed by posterior fixation or transoral atlantoaxial reduction and plate fixation was performed [10, 25, 26]. The anterior release procedure can cause conversion from irreducible to reducible dislocation; the restoration procedure can bring down the odontoid process and relieve ventral cord compression with less invasiveness. This technique was a great step forward in treatment; however, complications with the anterior approach remain inevitable.

Currently, the treatment trend has shifted from traditional anterior release/decompression and posterior fusion to direct posterior release and reduction [7, 8, 12–14]. Visocchi et al. [27] proposed the so-called always posterior strategy. The force exerted on the screws by intraoperative distraction and

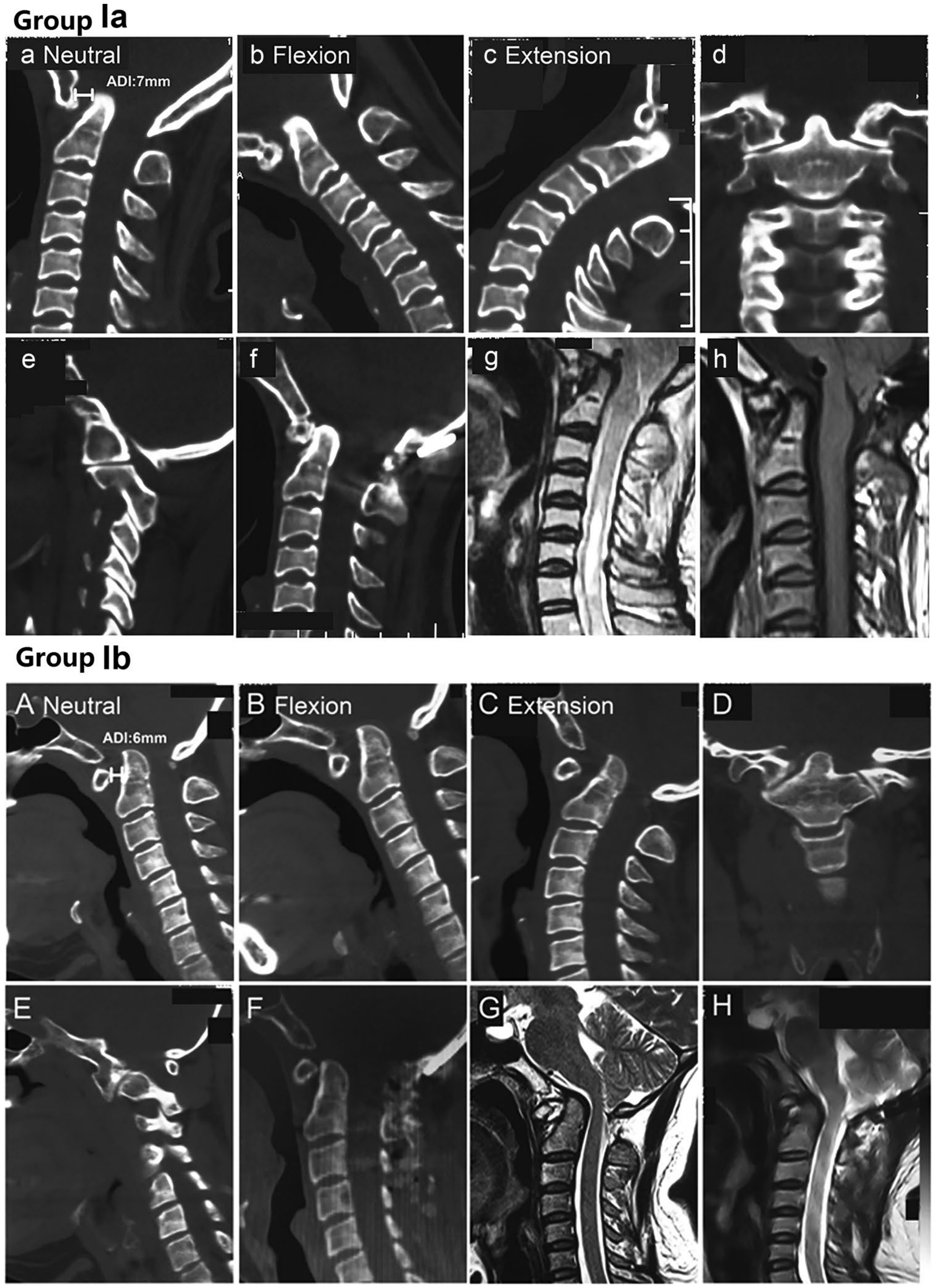

Fig. 2 Case presentation of Group I. Group Ia: A 48-year-old woman with Group Ia atlantoaxial dislocation (AAD) treated with direct posterior reduction and fixation. **a**–**c** Preoperative dynamic computed tomography (CT) sagittal reconstruction of the cervical spine shows reducible AAD. **d**, **e** Coronal and parasagittal CT images show normal facet orientation. **f** Postoperative CT shows anatomical reduction and solid fusion. **g** Preoperative magnetic resonance imaging (MRI) shows compression at the cervicomedullary junction. **h** Postoperative MRI shows complete decompression. ADI, atlantodens interval; Type Ib: A 43-year-old man with Group Ib AAD treated with direct posterior release, reduction, and fixation. **a**–**c** Preoperative dynamic CT sagittal reconstruction of the cervical spine shows less than 50% reduction in extension. **d**, **e** Coronal and parasagittal CT images show severe sloping of the left facet orientation. **f** Postoperative CT shows anatomic reduction and solid fusion. **g** Preoperative MRI shows compression of cervicomedullary junction. **h** Postoperative MRI shows complete decompression. ADI, atlantodens interval

cantilever technology acts directly on the dislocated joint much more than cervical traction; this force combined with opening and manipulating the C1–C2 joint allows most so-called IrAADs to be realigned with intraoperative posterior reduction. The delineation between RAAD and IrAAD is very important because IrAAD is treated with anterior release/decompression, whereas RAAD can be treated with posterior reduction alone. But those patients who needed an additional odontoidectomy after posterior stabilization were hard to be identified prior to the posterior stabilization. Only after an attempt at posterior reduction surgery can we determine the reducibility of AAD. Therefore, novel criteria for defining irreducibility are needed to guide surgical decision making, so we propose that the categorization of AAD as reducible or irreducible should be judged on reduction status after direct posterior reduction.

Significance of clinical categorization for treatment options

This study proposes a new clinical categorization of AAD into three groups: reducible dislocation (Group I),

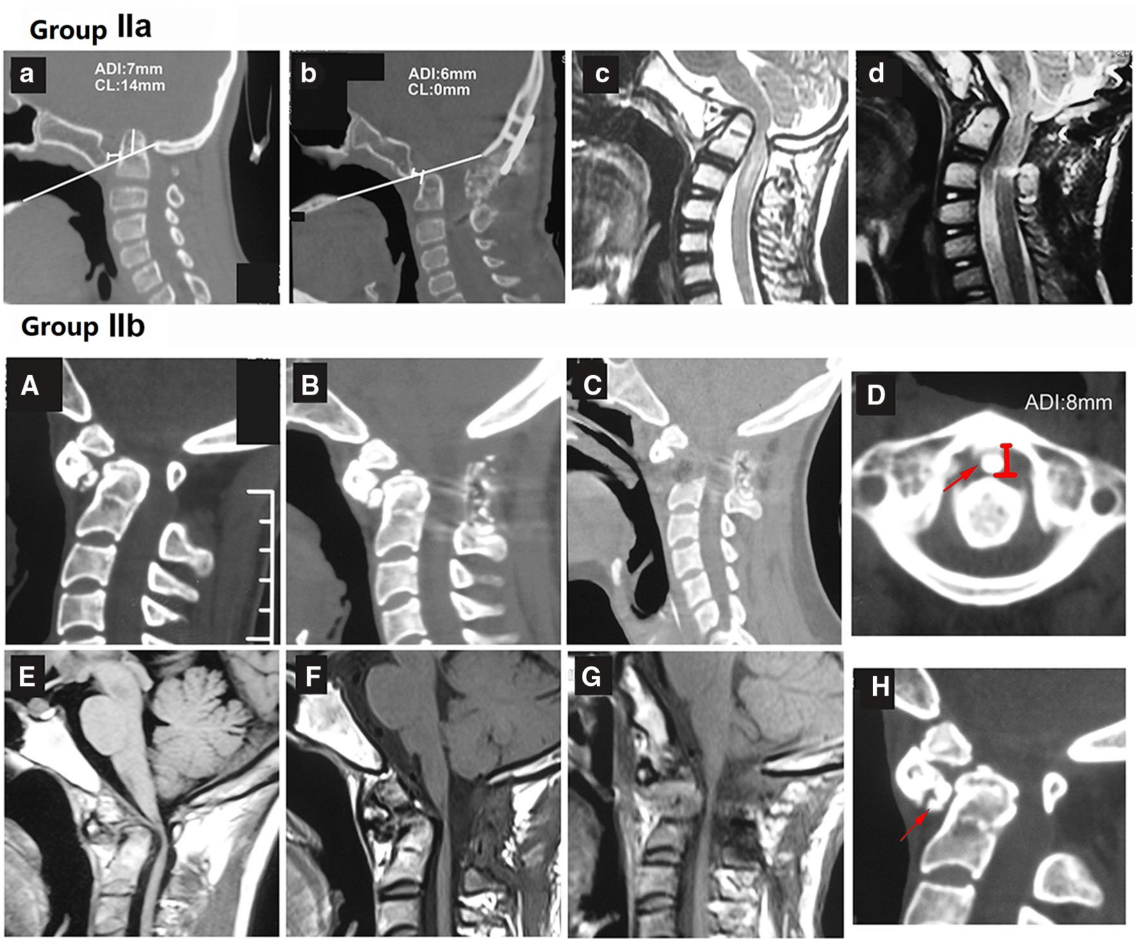

Fig. 3 Case presentation of Group II. Group IIa: An 11-year-old boy with Group IIa AAD treated with posterior reduction. **a** Preoperative CT sagittal reconstruction of the cervical spine. **b** Postoperative CT shows partial reduction after posterior reduction, fixation, and fusion. **c** Preoperative MRI shows compression of the cervicomedullary junction. **d** Postoperative MRI shows complete decompression after posterior reduction. ADI, atlantodens interval; CL, Chamberlain's line; Group IIb: A 45-year-old woman with Group IIb AAD treated with posterior fixation and transoral odontoidectomy. **a** Preoperative CT sagittal reconstruction of the cervical spine. **b** Postoperative CT shows that posterior release and reduction failed to reduce the atlantoaxial joint; posterior fixation and fusion was performed. **c** Second-stage odontoidectomy was performed. Postoperative CT sagittal reconstruction shows effective decompression. **e** Preoperative MRI shows compression of the cervicomedullary junction. **f** MRI shows ongoing compression of the medulla oblongata by the odontoid process after posterior reduction and fixation. **g** MRI shows decompression after odontoidectomy. **d**, **h** Preoperative CT axial view and sagittal reconstruction illustrate that the reason for irreducibility was the bone anomaly. ADI, atlantodens interval

irreducible dislocation (Group II), and fixed dislocation (Group III), according to whether the dislocation is reduced after operative posterior reduction, regardless of etiology. This study comprised 135 cases: 118 Group I cases, 16 Group II, and one Group III, according to the proposed categorization.

Group I was the predominant group of AAD in this study, seen in 118 of 135 cases (87.4%). We performed posterior reduction and fixation in these patients. Complete reductions of the AAD were achieved in all Group I patients. These results indicate that the vast majority of AAD patients can be treated with direct posterior surgery alone. The reduction rate with direct posterior surgery is similar to that with anterior release and posterior fixation [25, 26, 28]. To indicate the severity and difficulty of reduction, we further divided Group I into Groups Ia and Ib. Group Ia achieved reduction in extension that reaffirmed the feasibility of intraoperative reduction. The surgery for Group Ib was more challenging. The C1–C2 joints were often more acutely angled in Group Ib than in Group Ia in AAD patients with basilar invagination. It was important to mobilize the C1–C2 joint in these patients, an additional relatively difficult step that was not required in Group Ia patients.

Group IIa accounted for 8.1% of cases in this study (11 of 135 cases). Although CT images did not show complete reduction of the atlantoaxial joint in these patients, good decompression was shown on MRI. Further ventral decompression was not necessary in these patients.

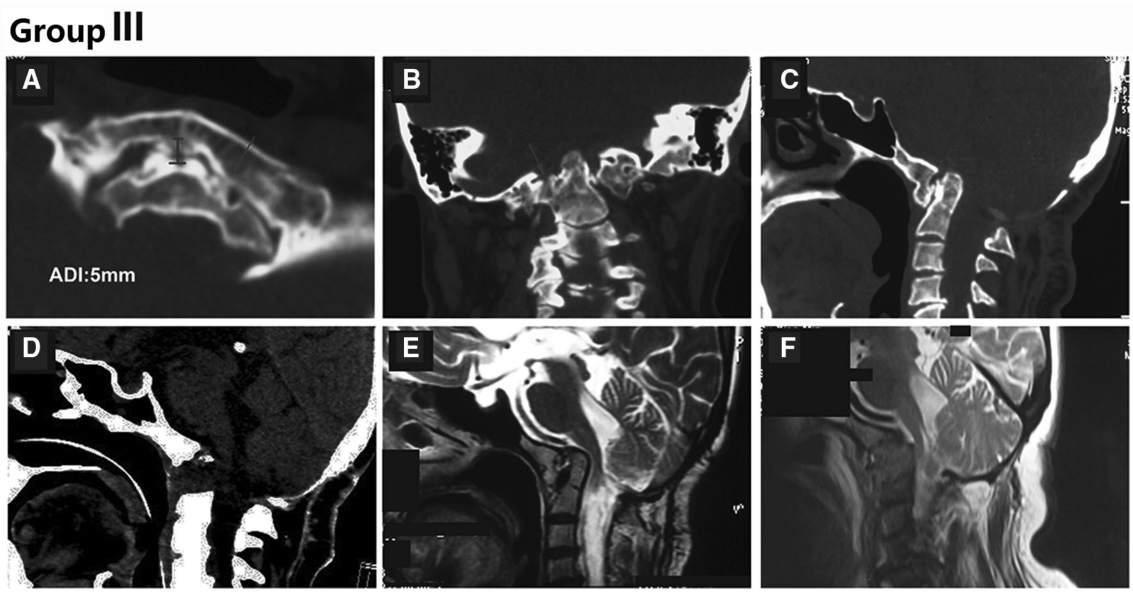

Fig. 4 Case presentation of Group III. A 47-year-old woman with Group III AAD (fixed dislocation) treated with transoral odontoidectomy directly without restoration and immobilization. The patient had undergone posterior cranial fossa decompression surgery for Chiari malformation at a local hospital 36 years ago. **a**, **b** Extensive bony fusion between C1 and C2 is seen on the axial and coronal CT views. **c** Preoperative CT sagittal reconstruction of the cervical spine. **d** Postoperative CT sagittal reconstruction shows effective decompression. **e** Preoperative MRI shows compression of the cervicomedullary junction. **f** MRI shows decompression after odontoidectomy. ADI, atlantodens interval

Posterior reduction and fixation alone can be applied to Group IIa patients because the aim of treatment for AAD is decompression rather than anatomic reduction. In traditional postoperative assessment, researchers have focused on the degree of reduction on CT images. In this study, we focused on the effects of decompression by using MRI for postoperative assessment.

Only 3.7% of our patients (5 of 135 cases) had Group IIb AAD. In previous studies, up to 30% to 40% of AAD cases underwent anterior operation [10, 26]. Our treatment algorithm sharply reduced the proportion of patients for whom anterior surgery was recommended. The authors define Group IIb as AAD that does not achieve reduction and sufficient decompression after posterior reduction and that must be treated with ventral decompression. We considered Group IIb truly irreducible dislocation. The reason for irreducibility was a bone anomaly such as facet joint orientation or bony fusion of the facet joints that prevented reduction. For Group IIb patients, the reduction and decompression were not sufficient after posterior surgery and a second-stage transoral odontoidectomy was performed.

Group III is the least common of the three groups of AAD. In Group III, preoperative reconstructive CT scanning shows extensive bony connection between C1 and C2. For such cases, we perform transoral odontoidectomy directly with no attempt at posterior release and reduction. Because the extensive bony connection provides sufficient stability, fixation and fusion is not necessary.

Therefore, our treatment algorithm focused on the most appropriate surgical procedures during the whole treatment processes, including preoperative categorization, intraoperative judgment, and postoperative MR results, not just preoperative categorization because of its limited guidance value.

Of note, the present case series include basilar invagination and/or C1 assimilation (vertical AAD), and some patients were not simple AAD patients. Many deformities can lead to AAD. But no matter what deformities were accompanied, the surgical purposes and procedures were same: reducing odontoid process through the posterior reduction technique to relieve the oppression on ventral spinal cord. After the surgical treatment, both vertical and horizontal dislocations are well reduced. Therefore, the surgical treatment algorithm mainly depended on the group of AAD. Thus, we did not set more detailed subgroups for AAD patients, such as AAD with basilar invagination or AAD with C1 assimilation.

Role of traction

Traction has played a major role in AAD in the past, because reducibility on traction completely changed the surgical strategy. When dynamic X-rays demonstrate no reduction, intraoperative or preoperative traction is utilized to attempt reduction. Some surgeons have applied preoperative traction over a longer period to slowly reduce the dislocation, which can be a long and painful process [29, 30]. Some have applied skeletal traction with the patient under general anesthesia for rapid reduction before one-stage fixation [26]. These procedures are also time-consuming, surgically complex, and technically demanding.

We believe that most cases of AAD that are irreducible with anesthesia and traction can achieve reduction through intraoperative posterior release and reduction. In this series, one Group Ib patient had initially attempted traction under anesthesia. However, further reduction was not achieved; that patient underwent posterior release and reduction. Full reduction was obtained, indicating that AAD that does not reduce under skull traction and anesthesia can sometimes be converted to reducible AAD through posterior reduction (Fig. 5). Because posterior reduction can achieve reduction for most patients with AAD, the necessity of preoperative or intraoperative traction is debatable. Some surgeons have reported using preoperative traction before posterior reduction to improve clinical status and to make it easier to open the joint space [31]. In this study, no cervical traction was necessary before or during surgery.

Complications

Vertebral artery injury is a common and serious complication during posterior craniovertebral junction fixation [32, 33]; however, this complication is avoidable. No vertebral artery injury occurred in this series of patients. Preoperative CT reconstruction views and CT angiograms help evaluate the position of the transverse foramen of C2, the size of the pedicles, and the size and course of the vertebral artery. This knowledge should decrease vertebral artery injuries during screw insertion. Deepak et al. reported that the incidence of anomalous vertebral arteries was 26.9% in AAD that was irreducible in preoperative traction, compared with 5.75% in AAD that was reducible in preoperative traction [31]. Therefore, special attention should be paid during insertion of the C2 pedicle screw for Group Ib and Group II patients.

In our previous study, we searched for articles published from 1999 to 2015 that described IrAAD and observed that the incidence of complications was significantly higher in the anterior release and posterior fixation group than in the direct posterior reduction and fixation group (11.4% vs. 3.5%, respectively) [34]. Many complications in the anterior release and posterior fixation group were anterior release related, such as dysphagia, hoarseness, and nasal phonation. Compared with posterior fusion after anterior release, direct posterior reduction of the dislocation was a simpler process associated with less surgical trauma and a shorter operation time. The overall complication rate was 3.7% (5/135) in this study. Our surgical treatment algorithm and technique have significantly decreased the complication rate of AAD surgery.

Limitation

Our study has some limitations. (1) There was significant difference in number of each group. Group III (bony fusion) has a small number of cases and thus is poorly described. However, this does not mean that this categorization method has any statistical flaws, because this categorization is just a kind of sorting scheme to evaluate the operation effects and prognosis and it does not involve statistical comparison or statistical analysis. Group III is just one case, the reason for which is that Group III represents a kind of relatively rare group. Most patients would go to the hospital when the illness was not serious. Only a small portion of patients would not see the doctors until the disease has progressed to a tough point (Group III). That is why Group III is just one case. (2) The secondly main limitation of our study is that we actually only suggested a categorization that was based on the results of surgery, which is a categorization of the surgical results rather than a true classification. Fortunately, we are accumulating more and more data regarding the preoperative and intraoperative differences for the three groups;

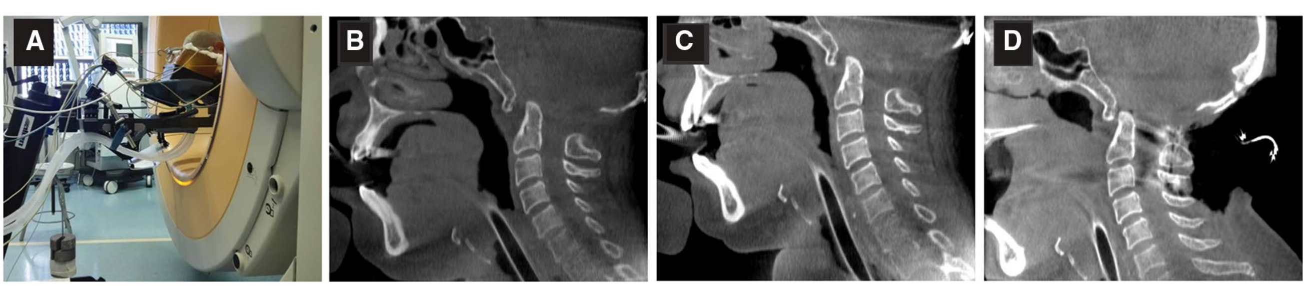

Fig. 5 The role of traction. **a** Cranial traction at one-sixth of the patient's body weight was performed under general anesthesia. An intraoperative O-arm was used to assess reduction. **b** Pretraction CT sagittal reconstruction of the cervical spine shows AAD. **c** After 30 min of traction, the patient did not achieve full reduction. **d** Postoperative CT sagittal reconstruction shows that full reduction was achieved with direct posterior release, reduction, and fixation without anterior release

and we believe some meaningful finding could be found and clear clues to identify preoperatively patients who would need odontoidectomy could be provided in the near future. (3) This is a single-center experience, and it is retrospective. Reducibility can depend on the surgical skill and methods and may vary from center to center and from surgeon to surgeon. So, in the future, we will cooperate with more hospitals and surgical centers to accumulate more data to get more robust results with little selection bias. 4) Growing data on the role of endoscopic trans-nasal odontoidectomy show that this method has low invasiveness, low infection rate, small impact on postoperative deglutition and patients' nutrition and thus might change the decision process to an increased number of anterior-first or even anterior-only procedures.

Conclusion

The authors propose a clinical treatment algorithm for AAD based on the dislocation's reducibility after posterior reduction. The treatment algorithm is useful in therapeutic decision making and indicates the severity and difficulty of reduction of the atlantoaxial joint. Direct posterior reduction and fixation is safer and simpler than anterior procedures but is equally effective and could be the first choice for most patients with AAD. Excellent clinical results with a minimal risk of complications were achieved with the use of our treatment algorithm in 135 cases.

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Compliance with ethical standards

Conflict of interest The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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