

## ORTHOPAEDICS COURSE

# Current Trends in Management of Atlantoaxial Dislocation

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Atlantoaxial dislocation (AAD), often caused by trauma, tumors or congenital malformations, is a challenging disorder of the craniocervical junction. Because of its deep location and intricate anatomic structure, the craniocervical junction is always a difficult region for spine surgery. With recent developments in medical science, great progress has been made in the diagnosis and treatment of AAD such that more instructive clinical classifications and efficacious treatment strategies, various novel operation techniques including innovative posterior or transoral anterior reduction, and novel fixation instruments are now widely used in clinical practice for managing AAD. However, surgeons continue to face more special characteristics and difficulty in carrying out upper cervical surgery than they encounter in other regions of the spine. Consequently, this high risk surgery should only be performed by extremely skilled and experienced surgeons and only when stringent indications have been met. Therefore, the aim of this course is to assist surgeons who are dealing with AAD by providing comprehensive information about AAD, including related anatomy, classification, clinical manifestations and diagnosis, imaging examinations and surgical techniques, thus decreasing the occurrence of complications and improving the level of diagnosis and treatment.

**Key words:** Atlantoaxial dislocation; Classification; Treatment

## Introduction

Atlantoaxial dislocation (AAD) which often arises from trauma, tumors or congenital malformations in the upper cervical region, is a challenging disorder of the cranio-cervical junction. AAD can cause compression of the spinal cord or medulla, resulting in limb numbness and weakness, sphincter dysfunction, disordered circulation and respiration center dysfunction. The mortality of trauma-related AAD is reportedly 60%–80%; serious injuries in this region can lead to paralysis and death<sup>1–3</sup>. As we all know, AAD is a difficult condition to treat because surgery involving the craniocervical junction poses technical challenges for spine surgeons because of its deep location and intricate and complex anatomic structures.

With recent developments in medical science, great progress has been made in the diagnosis and treatment of AAD. Recently devised clinical classifications and treatment strategies for AAD are more instructive than earlier ones for diagnosis and treatment. Additionally, various novel operation

techniques for AAD are rapidly being developed and used widely in the clinic; these include many innovative posterior or transoral anterior reduction and fixation instruments for AAD. It has been reported that, overall, China is more advanced than many other countries in the diagnosis and treatment of AAD, consequently we are now more confident in treating various upper cervical disorders than we used to be. One example of the factors that make upper cervical surgery more difficult than surgery in other parts of the spine is that there are many variations in the structure of the atlas and axis and course of the vertebral artery. Therefore, when operating in this region, it is important to thoroughly and carefully check for anatomic variations by performing preoperative MRI and CT scanning. Individualized procedures are necessary to minimize the risk as much as possible. Otherwise, complications such as intraoperative vertebral artery injury may lead to adverse outcomes<sup>4–7</sup>. Therefore, the aim of this course is to provide information about progress in management of AAD and to improve its diagnosis and treatment.

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**Relevant Anatomy Regarding AAD**

The atlas looks like a ring and comprises the anterior and posterior arches and lateral masses on both sides. The vertebral artery passes through a groove on the surface of the posterior arch and pierces the dura mater, then proceeds cranially through the foramen magnum.

The axis consists of the odontoid, vertebral body and bilateral upper articular facets. The upper facets articulate with the lower facets of the atlas, the lower facets of which articulate with the upper facets of C<sub>3</sub>.

As shown in Fig. 1, the atlas and axis are connected by the rigid cruciate ligament, anterior and posterior longitudinal ligament, joint capsules on both sides and other structures. The cruciate ligament, which is posterior to the odontoid, consists of horizontal and longitudinal parts. The horizontal part of the cruciate ligament (transverse ligament) originates from the inside of the lateral mass of the atlas and surrounds the posterior surface of the dens, which is a crucial structure in preventing the atlas from being displaced forward<sup>8</sup>. AADs are usually caused by odontoid fracture or rupture of the transverse ligament.

The apical odontoid ligament connects the tip of the dens and anterior rim of the foramen magnum, which go between the cervicobasilar ligament and anterior atlanto-occipital membrane. The alar ligament, which starts from the upper rim of the odontoid and ends in the middle of the occipital condyle, prevents excessive rotation between the atlas and axis. The cervicobasilar ligament is an extension of the posterior ligament, which lies over the surface of the dens and cruciate ligament, stretching from the rim of the foramen magnum to the back of axis. All of the above-listed structures strongly connect the foramen magnum to the atlas, thus acting as a second defensive line to prevent atlantoaxial dislocation. The atlantoaxial joint capsule also plays a vital role in maintaining stability of the atlantoaxial joint. If all the structures

above are injured seriously, atlantoaxial instability or dislocation may occur.

**Classification of AAD****Classification According to Cause**

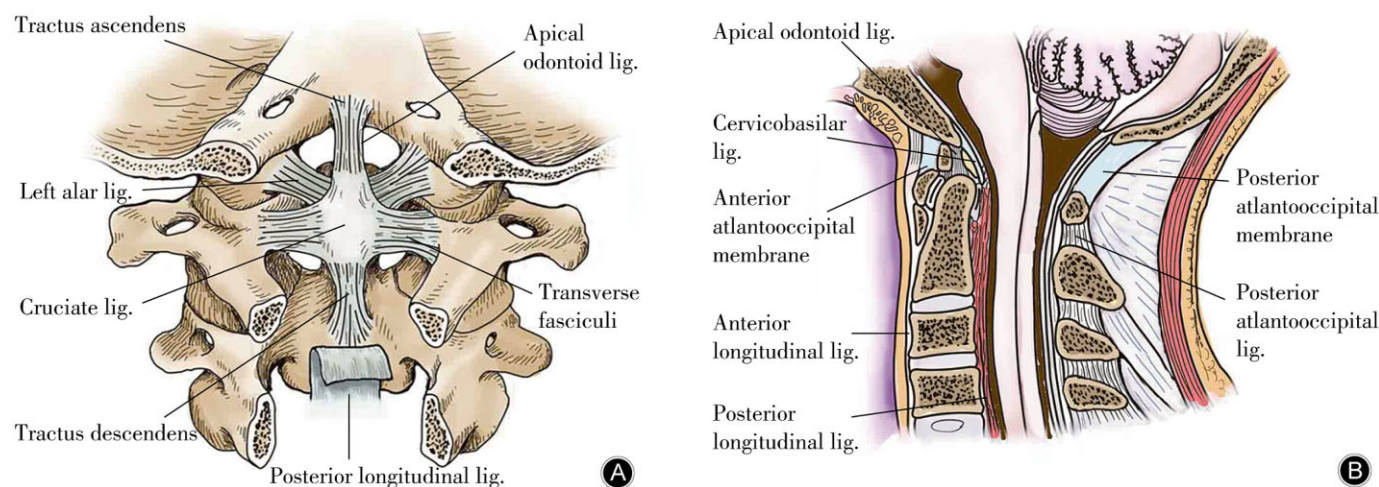
There are traumatic, congenital and pathologic causes for AAD. Traumatic AAD is most common in China, often arising from odontoid fracture, transverse ligament rupture, and so on. The second most common type of AAD is that associated with congenital deformity in the occipital cervical junction, such as dens malformation, assimilation of the atlas, Klippel-Feil syndrome and basilar invagination. The pathologic type of AAD is the least common and includes AAD caused by tuberculosis, infection or tumors of the atlas or axis.

**Classification According to Direction of Dislocation**

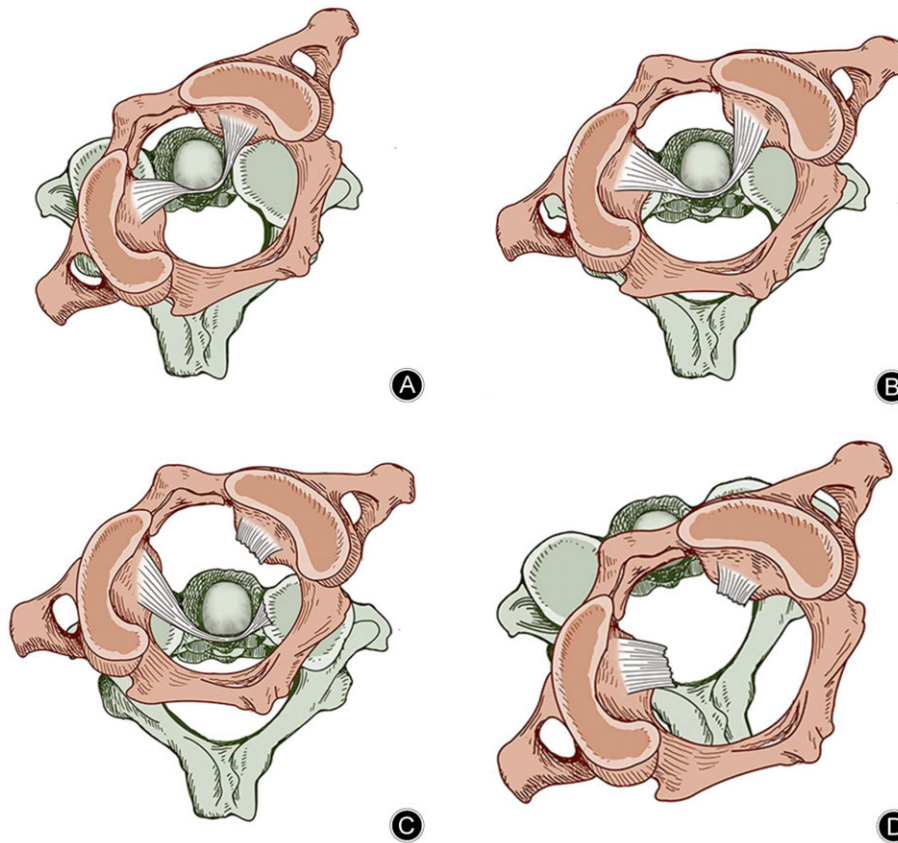
Possible directions of dislocation are anterior, posterior and rotational. Anterior dislocation is most common, often resulting from rupture of the transverse ligament or deformity of the dens. Posterior AAD is relatively uncommon and often associated with odontoid fracture. Rotational AAD is a relative rare and special type that can easily diagnosed on a CT scan. Rotational AAD may be further divided into several sub-types according to the degree of rotational dislocation or whether it is combined with lateral mass joint locking and atlantoaxial anterior or posterior dislocation<sup>9,10</sup> (Fig. 2).

**Classification According to Time since Dislocation**

There are fresh and old types of AAD, depending on the interval between dislocation and diagnosis. The fresh type is the term used when a definite diagnosis is made within 3 weeks of occurrence of dislocation and the old type when it is over 3 weeks.



**Fig. 1** Anatomy of the atlas, axis and related ligaments. (A) Beginning and end points of cruciate and alar ligaments. (B) Sagittal view showing the connection between atlantoaxial-related ligaments and the spinal cord. Lig., ligament.



**Fig. 2** Fielding classification of atlantoaxial rotational dislocation. (A) Type I: the lateral mass of the atlas is displaced anteriorly on one side, while the other side has not moved and acts as the rotation axis (ADI < 3 mm). (B) Type II: the lateral mass atlas is displaced anteriorly on one side, while the other side has not moved and acts as the rotation axis (ADI 3–5 mm). (C) Type III: the atlas is rotated with the lateral mass displaced anteriorly on both sides (ADI > 5 mm). (D) Type IV: the atlas is rotated and displaced posteriorly.

#### **Classification According to Reducibility of Dislocation**

There are reducible, irreducible and non-reducible types of AAD depending on the reducibility of dislocation.

#### **Clinical Manifestations and Diagnosis of AAD**

Patients with traumatic AAD often complain of neck pain and limitation of movement (especially rotation) after injuries to the neck or head. Cervical muscle spasm, tenderness and torticollis may be found on physical examination. The patients sometimes feel they need to keep holding their heads with their hands because of a terrible feeling of neck loss. When the medulla or spine cord are being compressed, patients may complain of numbness and weakness in the extremities, which may culminate in paralysis and even death if the respiratory center is affected.

Patients with AAD related to congenital deformities in the craniocervical junction often have a microtrauma history that may be obscure. Common symptoms include neck pain, limitation of cervical movement and numbness and weakness in the limbs. Some patients are mistakenly diagnosed as having cervical spondylopathy because the symptoms, such as

like limb numbness and claudication, are similar. Radiography, CT or MRI examination can identify both AAD associated with malformations in the craniocervical junction and compression of the upper spinal cord, allowing a final definite diagnosis.

Tuberculosis may destroy the lateral mass of the atlas, causing atlantoaxial instability and dislocation, this being more common in children. Rotational dislocation can occur if one side of the lateral mass collapses, in which case the patient would complain of neck pain and show torticollis. A final definite diagnosis can be made by CT or MRI.

Tumors in the upper cervical vertebrae can also cause AAD. The early symptoms include occipital and cervical pain that is usually continual, progressive, more severe at night and often accompanied by torticollis or awkward postures. Neck movement may increase the pain. If the tumor invades the soft tissue around the vertebrae, the pain may also intensify. Compression of the spinal cord or nerve root by a tumor leads to pain in the zone served by nerves from the related segment. Tumor-related vertebral body collapse can result in spinal deformity accompanied by severe pain. Dysfunction of nerve

centers seldom occurs because there is more buffer space at the atlantoaxial level than in the lower cervical spine. Compression of the medulla or spinal cord by an enlarging tumor may lead to limb numbness, movement problems, knee tendon hyper-reflexia and even the Brown–Séquard syndrome. Extension of a tumor to the foramen magnum may lead to acoustic loss, vertigo, dysphagia and dysarthrosis.

Another type of AAD often found in children is spontaneous atlantoaxial subluxation, which is usually associated with pharyngeal or neck infection. Continuous neck pain and limitation of cervical movement are early symptoms; these may gradually intensify. Rotational AAD is also common in children; it is reducible in the early stage but can develop into a rotatory deformity in the later stage if not treated appropriately.

### Imaging and Diagnosis of AAD

#### Radiography

Lateral and open mouth views are the basic ones required for diagnosing AAD (Fig. 3). The following principles apply to interpretation of open mouth films:

1. The correlation between the anatomic axis of  $C_1$  and  $C_2$  must be assessed to determine whether they overlap or deviates more than normal situation (usually no more than 3 mm). A bigger departure means transverse or rotational subluxation may have occurred.
2. Asymmetry of the lateral mass of the atlas hints at rotational dislocation.
3. Asymmetry of the lateral gap between the atlas and dens accompanied by restriction in cervical rotation indicates rotational dislocation or transverse displacement between  $C_1$  and  $C_2$ .
4. A discontinuous line from the lateral rim of  $C_1$  to  $C_2$  means transverse displacement between  $C_1$  and  $C_2$ .
5. Separation of the atlas masses by more than 7 mm denotes transverse ligament rupture or atlas fracture.

The following principles apply to interpretation of lateral radiography.

1. The anterior line from the posterior arch of  $C_1$  to the spinal process of  $C_2$  normally presents a natural curve with a little lordosis; this curve is discontinuous in patients with AAD.
2. The atlas dens index (ADI), the distance from the anterior node of the atlas to the dens, is normally  $< 3$  mm in adults and  $< 4$  mm in children, this varies by  $< 1$  mm with neck flexion or extension.  $ADI > 5$  mm hints at transverse ligament loosening or rupture or odontoid malformation.
3. The inclination angle is the angle between the posterior rim of  $C_2$  and the axis of the dens and average  $11.7^\circ (8^\circ-25^\circ)$ , anteversion hints at odontoid fracture.
4. The gap from the posterior arch of the atlas to the  $C_2$  spinal process may enlarge when the atlas has been displaced forward.

#### CT Scanning

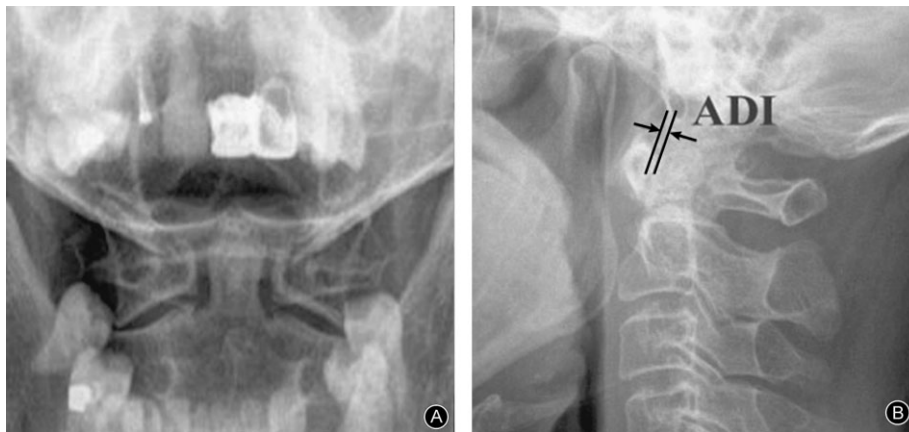
Continuous thin slice CT scanning is strongly recommended for patients with AAD. Additionally, coronal, sagittal and three dimensional reconstruction images should be obtained. Thin slice CT images of  $C_2$  allow assessment of variations in the vertebral artery foramen (Fig. 4), which could be helpful when devising a safe strategy for screw placement<sup>9,11,12</sup>.

#### MRI

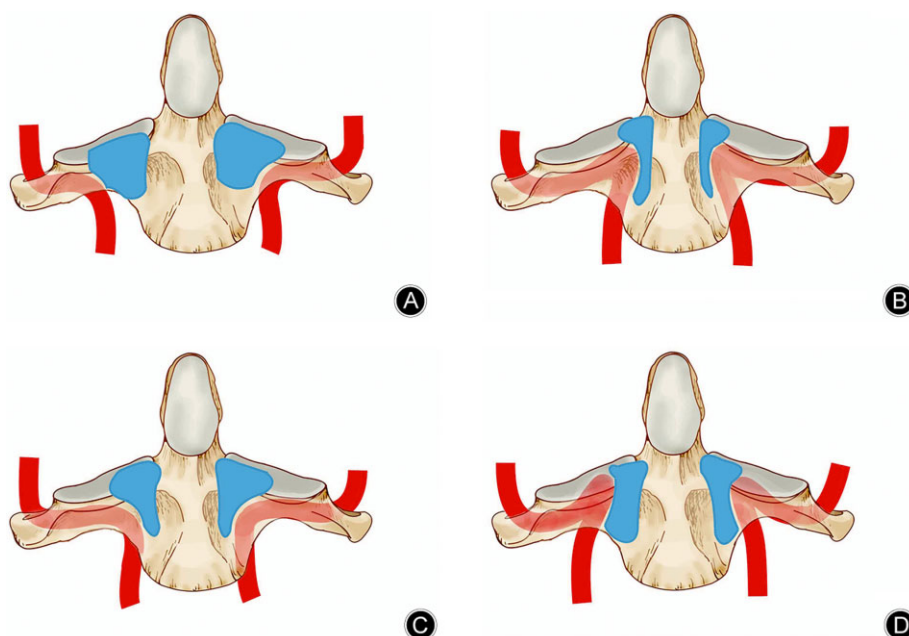
Cervical MRI can reveal the site and extent of medullar compression, which is helpful when selecting an operation strategy and assessing prognosis.

### Clinical Classification of AAD and Treatment Strategies

As is well known, the goals when treating AAD include reduction, decompression, fixation and fusion; additionally, it is important to protect occipitocervical function when performing fixation. Individualized surgical strategies for treating AAD are highly recommended for achieving good clinical results.



**Fig. 3** Radiography is important in the diagnosis of AAD. (A) Open mouth view showing the relationship between the anatomic axis of  $C_1$  and the dens, shape of the lateral mass of the atlas and the gap between the dens and lateral mass on both sides. (B) Cervical lateral view allowing evaluation of the continuity of the atlantoaxial joint and ADI.

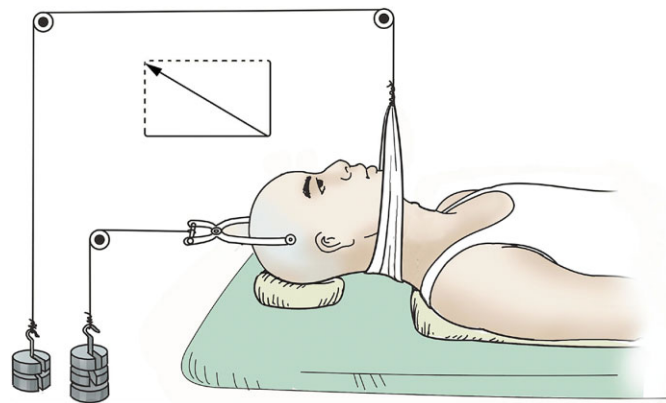


**Fig. 4** The variations in the vertebral artery groove (VAG) and pedicle of the axis can be classified into four types according to the findings on continuous thin slice CT scanning. (A) Type I: loose and lower ride. (B) Type II: tight and high ride. (C) Type III: tight and lower ride. (D) Type IV: loose and high ride.

### Clinical Classification of AAD

As described earlier, classification of AAD can be based on various characteristics, including direction of displacement (anterior, posterior and rotational), cause (traumatic, congenital and pathological), or interval between dislocation and diagnosis (fresh and old).

In 1986, we designed a dual direction traction apparatus for treating AAD (Fig. 5) that is more effective in achieving reduction of AAD than single direction cervical traction. Based



**Fig. 5** Diagrammatic representation of dual direction traction. The patient is put in a supine position and a horizontal force used to apply traction to the neck while a perpendicular force is applied to the neck. The combined effect achieves atlas reduction.

on dual direction traction technology, AAD can be classified into three clinical types<sup>13–16</sup>: namely, a reducible type that can easily be reduced by dual direction traction; (ii) an irreducible type that can be reduced after transoral release but not by dual direction traction; and (iii) a non-reducible type that cannot be reduced even by transoral release, this type is usually associated with fusion of the lateral mass.

### Treatment Strategy for AAD

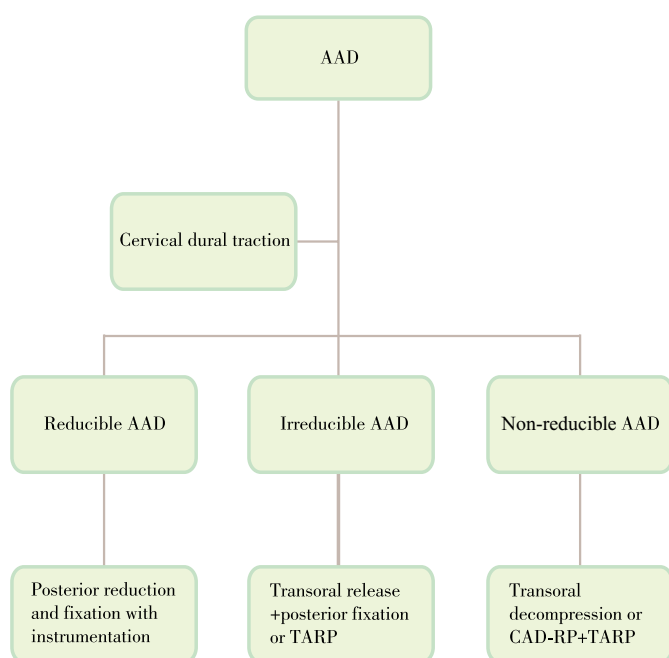
The recommended strategy for treating AAD is as follows (Fig. 6): In most cases of irreducible ADD fixation and reduction can be achieved by posterior or anterior instrumentation provided this is preceded by transoral release. Recently developed new techniques such as computer-assisted design prototyping, three dimensional printing or surgical guides can help surgeons to deal with some non-reducible dislocations surgically.

### Surgical Techniques for AAD

#### Posterior Approaches

##### Posterior Wire and Lamina Clamp Fixation

Classic posterior atlantoaxial fixation techniques include the Gallie and Brooks wire techniques, which can only be used in patients with intact posterior structures and without odontoid fractures<sup>17</sup>. There is little difference between these two techniques. With the Gallie technique, the wire passes only through the posterior arch of the atlas (Fig. 7), after which an appro-



**Fig. 6** Clinical classification of AAD, and operation strategies. CAD-RP, computer-aided design-rapid prototyping.

propiately shaped bone structure is implanted between the  $C_1$  posterior arch and  $C_2$  spinal process. In contrast, with the Brooks tech (Fig. 8), the wire passes through both the  $C_1$  and  $C_2$  posterior arches and is then attached to the posterior bone structures. Although the wire techniques are easy to perform, care must be taken to prevent spinal cord injury during insertion of the wire. Because a wire has insufficient anti-rotation strength, a rigid cervical brace is also recommended postoperatively until bone fusion has been confirmed by radiography. Lamina clamp techniques, such as the Apofix system of Medtronic (Minneapolis, MN, USA) is safer than the wire technique and easy to perform; however, like wires, it also has

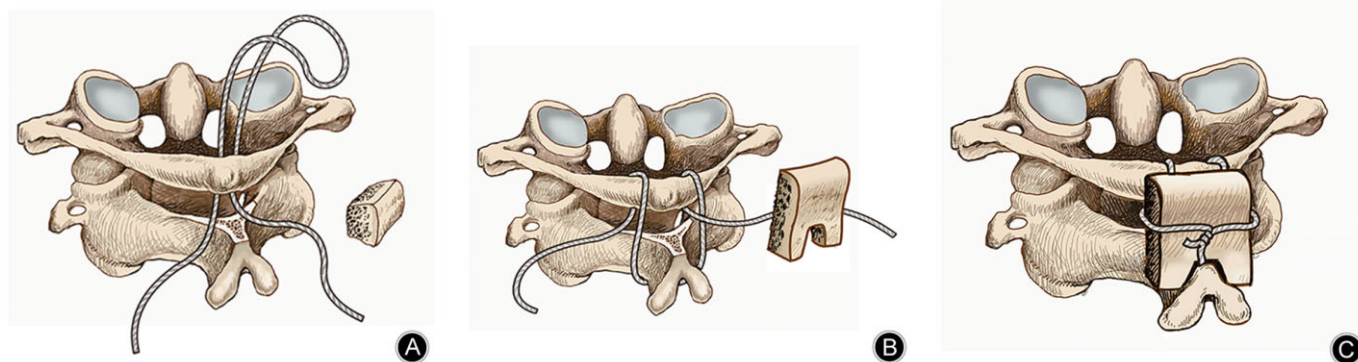
insufficient anti-rotation strength. Therefore a rigid cervical brace is also highly recommended postoperatively.

#### Posterior Transarticular Screw Fixation

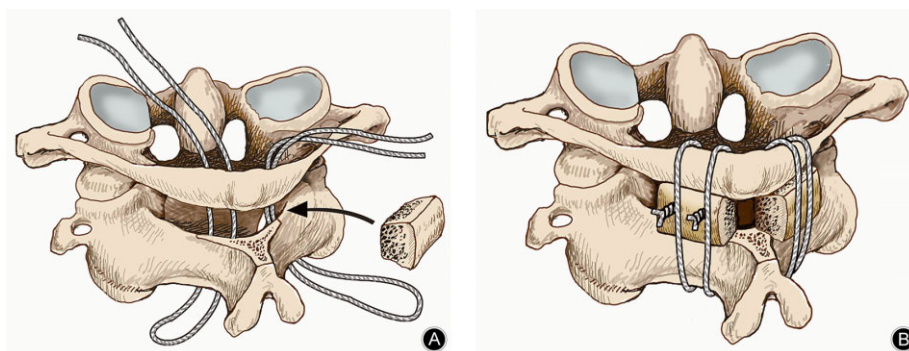
Because the transarticular screw technique was first reported by Magerl, it is also called the Magerl technique. With this technique, two screws pass through both lateral masses of both  $C_2$  and  $C_1$ . This technique can be used in patients with or without intact posterior structures of  $C_1$  and  $C_2$ . Compared with the wire technique, the Magerl technique has a more rigid fixation strength and better anti-rotational ability. As shown in Fig. 9A, the entrance point for the screw is usually located at the cross point between the axis pedicle and lower facet, around 2–3 mm outside the inner rim of lower facet. Sometimes a micro adjustment to achieve fit with the actual anatomic structure is necessary intraoperatively. A tip for this technique is to make a pit on the lamina surface with a burr before drilling, thus preventing sliding of the head. The screw trajectory is  $0^\circ$ – $10^\circ$  inward in the cross plane and points to the anterior arch of atlas; this can be monitored by fluoroscopy. After an ideal trajectory path has been achieved, a lag screw is inserted along the path. The following are two important points about the Magerl screw technique: (i) the Magerl technique should only be performed when the AAD has been reduced, otherwise, vertebral artery injury may occur; and (ii) preoperative thin slice CT scan is mandatory for ensuring that the surgeon know about any variations in the vertebral artery groove (VAG). The Magerl technique should only be used in patients with type II VAG (tight and high ride) because of the high risk of vertebral artery injury. The Magerl technique can also be combined with a wire technique to achieve more strong anti-rotation strength (Fig. 9b)<sup>18–22</sup>.

#### Posterior Pedicle (Lateral Mass) Screw-Rod (Plate) Fixation

Goel *et al.* (India) and Harms and Melcher (Germany) first proposed the posterior screw technique for treating AAD. With this technique, the lateral mass of the atlas and the axis pedicle provide two rigid anchor sites for fixation by plate or rod (Fig. 10)<sup>23,34</sup>. Compared with other techniques (wire or



**Fig. 7** Gallie fusion. (A) A wire is halved; the wire loop passed under the lamina of  $C_1$  and fixed beneath the  $C_2$  spinous process. (B) A graft is notched to straddle the  $C_2$  spinous process. (C) The free ends of the wire are wrapped around the graft and twisted together.



**Fig. 8** Brooks fusion. (A) Loops of wire are passed sequentially beneath  $C_1$  and  $C_2$  and wedges of bone fitted bilaterally between  $C_1$  and  $C_2$ . (B) The wires are twisted to compress the grafts between the bone surfaces.

Magerl), the great advantage of Goel–Harm is that it could not only provides much greater strength than earlier techniques, but also allows the atlas to be pulled backward for reduction with rod or plate. Tan *et al.* reported that atlas transpedicle screws are safer and stronger than lateral mass screws<sup>35</sup>. The ideal atlantoaxial posterior screw-rod fixation is to insert pedicle screws in both  $C_1$  and  $C_2$ <sup>36,37</sup>. Variations in the VAG in  $C_1$  or  $C_2$  sometimes limit the placement of pedicle screws. Therefore, many related improved screw techniques have been developed, such as axis lamina screws, atlas and axis lamina hook tech and so on; these can serve as alternatives to the standard posterior pedicle screw-rod (plate) for treating AAD<sup>38–40</sup>. Because of the many possible variations in the occipitocervical junction, we strongly recommend the surgeon choose an individualized screw placement method to prevent vertebral artery injury and decrease the risk of surgery<sup>41,42</sup>. Appropriate combinations of fixation methods can be helpful in dealing effectively with the variation problem.

#### Posterior Occipital Cervical Fixation

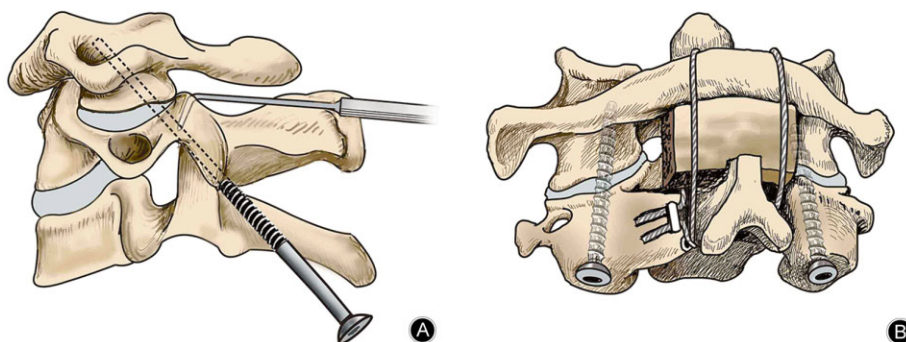
Short segment fixation and fusion is strongly recommended for AAD; this procedure preserves cervical motion and has

minimal negative effects on the patients' quality of life. However, occipital–cervical fixation should be considered when there is associated congenital atlanto-occipital fusion, incomplete posterior atlas or atlanto-occipital instability. Many instrumentation systems can be used to achieve occipital-cervical fusion, including the Sumit (Depuy, Raynham, MA, USA) and ceverfix systems (AO). An important principle when performing occipital–cervical fixation is to ending the fixation at  $C_2$ ; more extensive fixation and fusion is not usually advisable.

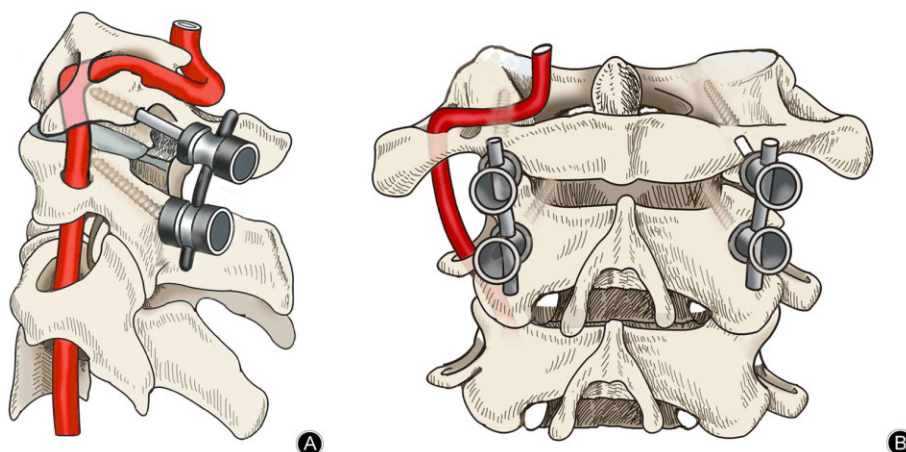
#### Anterior Approaches

##### Transoral Release Technique

Transoral release is an important technique for dealing with irreducible AAD (Fig. 11). Because soft scarring behind the anterior arch of the atlas or bone bridge between the lateral mass joints restrict reduction in these cases, debriding soft scarring and removing the bone bridge by transoral release is vital. The patient is placed in a supine position and the cervical vertebrae kept in extension with skull traction. Transoral release, which can now be performed with the assistance of a



**Fig. 9** Diagram showing the Magerl screw technique combined with posterior wire fixation. (A) The Magerl screws must be inserted after the AAD has been reduced. The screw passes through the lateral mass, isthmus and articular surface of the axis and lateral mass of the atlas and points toward the anterior node of the atlas. (B) To augment the anti-rotation strength, an improved Magerl screw technique combined with posterior wire fixation is recommended.



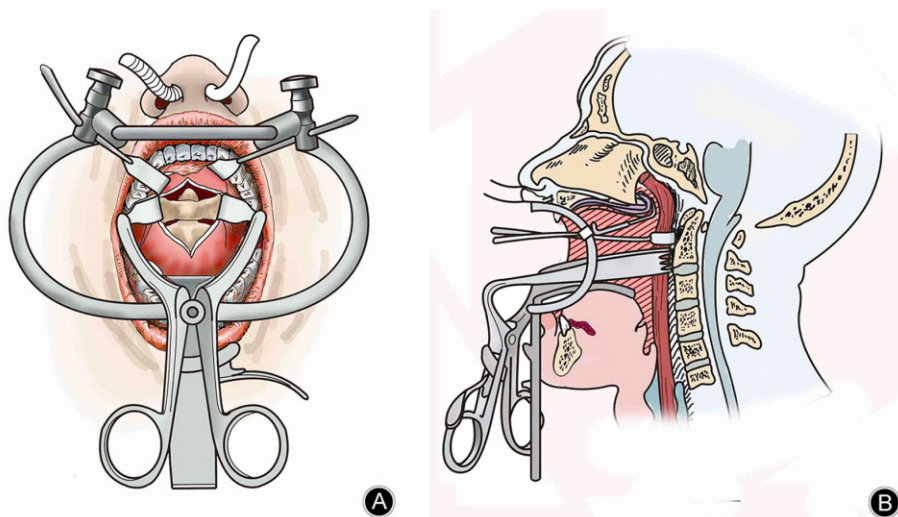
**Fig. 10** Diagrams showing the posterior screw-rod fixation technique (Goel-Harm's technique). The entrance point of the atlas screw is in the posterior rim of lateral mass under the posterior arch and it goes through the mass of the atlas. The axis screw entrance point is in the middle portion of the lower facet and it goes through the isthmus, pedicle and body of the axis. In the Goel technique, the screws are connected to a plate, whereas in the Harms technique a rod is preferred. Both techniques are called the Goel-Harm's technique. (A) Lateral view. (B) Anterior view.

microscope or endoscope, entails thorough removal of soft scarring with an electric knife and of the bone bridge with a high speed power drill. The lateral facet joint can then be opened. Full release facilitates reduction. Liu *et al.* reported a serial approach to treating patients with irreducible AAD, in which transoral release is performed first, followed by dual direction cervical traction for 1–2 weeks, and finally posterior approach fixation is performed as a second-stage procedure. Wang *et al.* reported a two-step procedure in which transoral

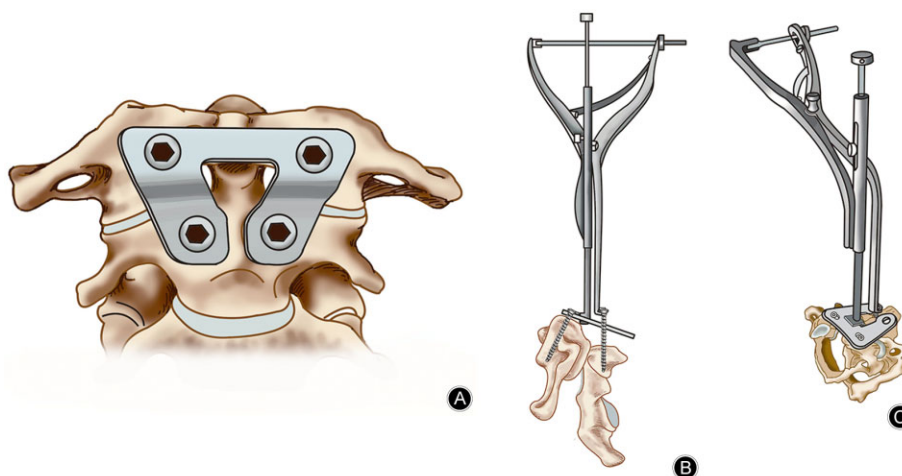
release is the first step and reduction by traction and fixation via a posterior approach the second step, both steps being performed in a single stage<sup>43</sup>.

#### *Transoral Decompression Technique*

In some cases of non-reducible AAD, transoral release doesn't work because bone fusion has occurred in the lateral facet joints. In such cases, perform odontoidectomy or extensive axis resection must be performed to achieve decompression. Pre-



**Fig. 11** Diagram shows transoral exposure and release technique. (A) The mouth is held open with a Codman retractor and a longitudinal incision made along the middle line of the pharyngeal wall under full illumination, clearly exposing the anterior structures of the atlas and axis. (B) Soft scarring is removed with an electric knife and the bone bridge with a high-speed power drill. When performing transoral release, all soft scarring between the anterior arch of the atlas and dens must be thoroughly eradicated to allow opening of the lateral facet joint.



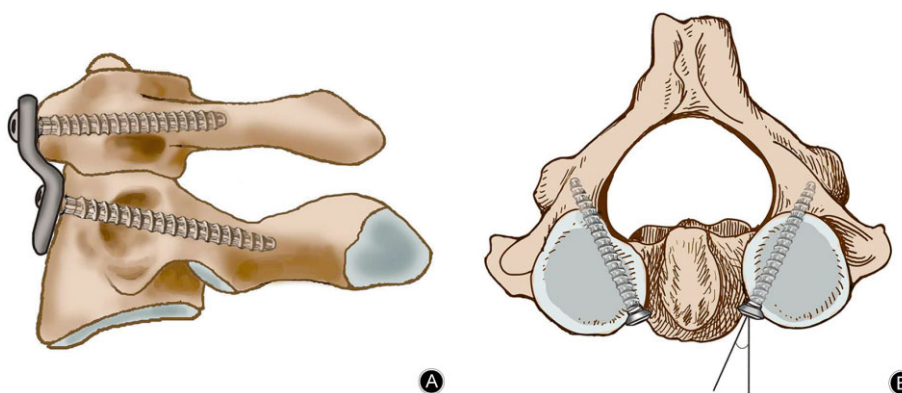
**Fig. 12** Diagram showing the reduction clamp and principles of reduction by TARP. (A) The plate is butterfly-shaped. (B) After transoral release, the upper beam of the plate is initially fixed to the atlas masses with two screws. Next, an instant screw is inserted into the axis vertebra along the plate's slide groove such that the screw can slide freely up and down the groove. (C) The upper and lower hooks of the reduction clamp are then connected to the plate's upper beam and instant screw, respectively, after which a perpendicular force is applied by clamp to pull the atlas cranially and a horizontal force to push the atlas posteriorly to achieve full reduction.

operative cervical MRI and sagittal reconstruction CT images are helpful for determining the required scope of decompression and choosing an appropriate surgical approach. All procedures could be performed under a microscope or endoscope with adequate illumination. First, the bone is removed layer by layer with a high-speed burr until only a very thin slice of bone remains. A thin rongeur is then used to carefully remove this thin slice of bone. Next, the transverse and posterior ligaments are removed by rongeur little by little until the dura is visible.

#### *Transoral Anterior Reduction and Fixation with Plate (TARP)*

There are two techniques for treating IAAD after transoral release: (i) the patient's position is changed to allow achievement of posterior fixation and fusion with instrumentation; and (ii) anterior reduction and fixation is performed by TARP<sup>44-48</sup>.

As shown in Fig. 12, the plate is butterfly-shaped. After transoral release, the upper beam of the plate is initially fixed to the atlas masses with two screws. Next, an instant screw is inserted into the axis vertebra along the plate's slide groove such that the screw can slide freely up and down the groove. The upper and lower hooks of the reduction clamp are then connected to the plate's upper beam and instant screw, respectively, after which a perpendicular force is applied by clamp to pull the atlas cranially and a horizontal force to push the atlas posteriorly to achieve full reduction. After reduction has been achieved, a drill is used to create a screw path in the axis, then two appropriate screws are inserted into the axis along the pedicles. After the reduction clamp and instant screw have been dismantled, the gaps between the facet joints and surface of the dens are decorticated with a high-speed burr. Finally,



**Fig. 13** An anterior reverse axis pedicle screw is used in the generation IV TARP plate, which has improved screw length and fixation strength. (A) Lateral view. (B) Supero-inferior view.

cancellous bone obtained from the ilium is packed into the implant bed and the incision sutured layer by layer.

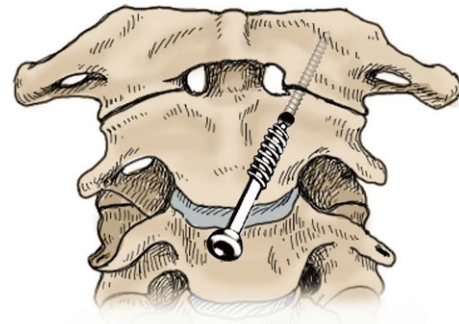
Because generation I TARP reportedly has a high rate of loosening of the vertebral screw in the axis, a reverse pedicle screw technique is used in generation IV TARP (Fig. 13); this provides excellent fixation strength compared with the posterior screw-rod technique<sup>49</sup> (Videos S1 and S2).

#### Anterior Cervical Transarticular Screw

The anterior cervical transarticular screw is an alternative transoral fixation technique for treating AAD when the posterior structure of the atlas or axis have been extensively destroyed, making posterior transarticular screw or other such method impossible. The anterior cervical transarticular screw technique can be performed through a hypermandibular or high cervical approach. After performing release and reduction, two lag-screws are inserted through the lateral mass of the axis and atlas just as in the posterior Magerl technique; this approach is therefore called the anterior Magerl technique. One limitation of this technique is difficulty in getting bone graft into the facet joint, additional bone implant via a posterior approach is therefore sometimes necessary (Fig. 14).

#### Morbidity of AAD Surgery

Because AAD surgery is high risk, it should be performed only when specific indications are present and by skilled and experienced surgeons. Complications of AAD surgery comprise intraoperative, postoperative short-term and long-term complications. Intraoperative complications include spinal cord injury (during positioning of the patient or operative manipulations) and vertebral artery injury (when obtain-



**Fig. 14** Diagram showing the anterior transarticular screw technique. Two lag-screws are inserted through the lateral masses of the axis and atlas as in the posterior Magerl technique.

ing exposure or inserting screws). Short-term postoperative complications comprise wound infection, loosening of fixation and redislocation. Long-term complications include instrumentation failure, nonunion of bone graft and redislocation. It is vital to take effective measures to prevent all of these complications to achieve good results. These measures will be further discussed in another segment of this course.

#### Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

**Videos S1 and S2** Transoral anterior reduction and fixation with plate (TARP) for irreducible atlantoaxial dislocation.

#### References

1. Yang SY, Boniello AJ, Poorman CE, Chang AL, Wang S, Passias PG. A review of the diagnosis and treatment of atlantoaxial dislocations. *Global Spine J*, 2014, 4: 197–210.
2. Syre P, Petrov D, Malhotra NR. Management of upper cervical spine injuries: a review. *J Neurosurg Sci*, 2013, 57: 219–240.
3. Jain VK. Atlantoaxial dislocation. *Neurol India*, 2012, 60: 9–17.
4. Lall R, Patel NJ, Resnick DK. A review of complications associated with craniocervical fusion surgery. *Neurosurgery*, 2010, 67: 1396–1403.
5. Tumialan LM, Wippold FJ 2nd, Morgan RA. Tortuous vertebral artery injury complicating anterior cervical spinal fusion in a symptomatic rheumatoid cervical spine. *Spine (Phila Pa 1976)*, 2004, 29: E343–E348.
6. Wright NM, Laurusen C. Vertebral artery injury in C1-2 transarticular screw fixation: results of a survey of the AANS/CNS section on disorders of the spine and peripheral nerves. *American Association of Neurological Surgeons/ Congress of Neurological Surgeons. J Neurosurg*, 1998, 88: 634–640.
7. Neo M, Fujibayashi S, Miyata M, Takemoto M, Nakamura T. Vertebral artery injury during cervical spine surgery: a survey of more than 5600 operations. *Spine (Phila Pa 1976)*, 2008, 33: 779–785.
8. Han YC, Pan J, Wang SJ. A biomechanical study on the effects of the craniocervical junction area ligaments on atlantoaxial stability. *Zhonghua Gu Ke Za Zhi*, 2013, 33: 628–634 (in Chinese).
9. Mazzara JT, Fielding JW. Effect of C1-C2 rotation on canal size. *Clin Orthop Relat Res*, 1988, 237: 115–119.
10. Ishii K, Toyama Y, Nakamura M, Chiba K, Matsumoto M. Management of chronic atlantoaxial rotatory fixation. *Spine (Phila Pa 1976)*, 2012, 37: E278–E285.
11. Wang JH, Yin QS, Xia H, Wu ZH. The role of the axis pedicle classification system in pedicle screws placement. *Zhongguo Ji Zhu Ji Sui Za Zhi*, 2007, 17: 593–595 (in Chinese).
12. Wang JH, Yin QS, Xia H, Wu ZH, Ma XY. Application of thin CT scan of vertebral artery groove of axis for preoperative evaluation of pedicle screw placement procedure. *Zhongguo Gu Ke Lin Chuang Yu Ji Chu Yan Jiu Za Zhi*, 2011, 3: 126–130 (in Chinese).
13. Yin QS, Liu JF, Xia H, et al. The clinical classification, operative treatment and evaluation of the clinical effects of atlantoaxial dislocation. *Zhongguo Ji Zhu Ji Sui Za Zhi*, 2003, 13: 38–43 (in Chinese).
14. Yin QS, Chang YB, Xia H, et al. Synthetic typing and its clinical application in atlantoaxial dislocation. *Zhonghua Wai Ke Za Zhi*, 2008, 46: 280–282 (in Chinese).
15. Yin QS, Liu JF, Xia H, et al. Decompression and internal fixation with transoral approach and posterior approach for the treatment of old atlantoaxial dislocation with spinal cord compression. *Jiefang Jun Yi Xue Za Zhi*, 2001, 26: 483–484 (in Chinese).
16. Liu JF, Li CH, Su B, et al. Anterior decompression and internal fixation for irreducible atlantoaxial dislocation with paralysis. *Lin Chuang Jie Pou Xue Za Zhi*, 1986, 4: 17–19 (in Chinese).
17. Jacobson ME, Khan SN, An HS. C1-C2 posterior fixation: indications, technique, and results. *Orthop Clin North Am*, 2012, 43: 11–18.
18. Elliott RE, Tanweer O, Boah A, et al. Atlantoaxial fusion with transarticular screws: meta-analysis and review of the literature. *World Neurosurg*, 2013, 80: 627–641.
19. Haid RW Jr. C1-C2 transarticular screw fixation: technical aspects. *Neurosurgery*, 2001, 49: 71–74.
20. Jun BY. Anatomic study for ideal and safe posterior C1-C2 transarticular screw fixation. *Spine (Phila Pa 1976)*, 1998, 23: 1703–1707.
21. Neo M, Matsushita M, Iwashita Y, Yasuda T, Sakamoto T, Nakamura T. Atlantoaxial transarticular screw fixation for a high riding vertebral artery. *Spine (Phila Pa 1976)*, 2003, 28: 666–670.
22. Qu DB, Jin DD, Zhu ZH, et al. Anatomical study of atlantoaxial transarticular screw fixation in Chinese population. *Zhongguo Jiao Xing Wai Ke Za Zhi*, 2000, 7: 1117–1119 (in Chinese).

23. Goel A, Desai KI, Muzumdar DP. Atlantoaxial fixation using plate and screw method: a report of 160 treated patients. *Neurosurgery*, 2002, 51: 1351–1357.
24. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. *Spine (Phila Pa 1976)*, 2001, 26: 2467–2471.
25. Elliott RE, Tanweer O, Boah A, *et al.* Atlantoaxial fusion with screw-rod constructs: meta-analysis and review of literature. *World Neurosurg*, 2014, 81: 411–421.
26. Stulik J, Vyskocil T, Sebesta P, Kryl J. Atlantoaxial fixation using the polyaxial screw-rod system. *Eur Spine J*, 2007, 16: 479–484.
27. Mandel IM, Kambach BJ, Petersilge CA, Johnstone B, Yoo JU. Morphologic considerations of C2 isthmus dimensions for the placement of transarticular screws. *Spine (Phila Pa 1976)*, 2000, 25: 1542–1547.
28. Hong X, Dong Y, Yunbing C, Qingshui Y, Shizheng Z, Jingfa L. Posterior screw placement on the lateral mass of atlas: an anatomic study. *Spine (Phila Pa 1976)*, 2004, 29: 500–503.
29. Xia H, Zhong SZ, Liu JF, *et al.* Research on the feasibility of posterior screw fixation on the lateral mass of the atlas. *Zhongguo Jiao Xing Wai Ke Za Zhi*, 2002, 10: 888–891 (in Chinese).
30. Ma XY, Yin QS, Wu ZH, Xia H, Liu JF, Zhong SZ. Anatomic considerations for the pedicle screw placement in the first cervical vertebra. *Spine (Phila Pa 1976)*, 2005, 30: 1519–1523.
31. Ma XY, Zhong SZ, Liu JF, *et al.* An anatomic study on the feasibility of posterior pedicle screw fixation on the atlas. *Zhongguo Lin Chuang Jie Pou Xue Za Zhi*, 2003, 21: 554–555 (in Chinese).
32. Ma XY, Wu ZH, Zhong SH, *et al.* Anatomic and clinical study of pedicle screw placement on the atlas. *Zhongguo Jiao Xing Wai Ke Za Zhi*, 2003, 11: 1238–1240 (in Chinese).
33. Hao DJ, He BR, Xu ZW, Guo H, Liu TJ, Wang XD. Comparative results between C1 pedicle screw and C1 lateral mass screw. *Zhonghua Gu Ke Za Zhi*, 2011, 31: 1297–1303 (in Chinese).
34. Shao J, Jia LS, Chen XS, *et al.* Surgical treatment of irreducible atlantoaxial dislocation. *Zhonghua Gu Ke Za Zhi*, 2010, 30: 192–197 (in Chinese).
35. Tan MS, Zhang GB, Li ZR, *et al.* Anatomic study of the atlas and the mass using screw fixation via posterior arch and lateral mass. *Zhongguo Ji Zhu Ji Sui Za Zhi*, 2002, 12: 5–8 (in Chinese).
36. Tan M, Wang H, Wang Y, *et al.* Morphometric evaluation of screw fixation in atlas via posterior arch and lateral mass. *Spine (Phila Pa 1976)*, 2003, 28: 888–895.
37. Resnick DK, Lapsiwala S, Trost GR. Anatomic suitability of the C1–C2 complex for pedicle screw fixation. *Spine (Phila Pa 1976)*, 2002, 27: 1494–1498.
38. Richter M, Schmidt R, Claes L, Puhl W, Wilke HJ. Posterior atlantoaxial fixation: biomechanical *in vitro* comparison of six different techniques. *Spine (Phila Pa 1976)*, 2002, 27: 1724–1732.
39. Dorward IG, Wright NM. Seven years of experience with C2 translaminar screw fixation: clinical series and review of the literature. *Neurosurgery*, 2011, 68: 1491–1499.
40. Henriques T, Cunningham BW, Olerud C, *et al.* Biomechanical comparison of five different atlantoaxial posterior fixation techniques. *Spine (Phila Pa 1976)*, 2000, 25: 2877–2883.
41. Yin QS, Wang JH. Individualized management for atlantoaxial dislocation complicated with occipitocervical junction deformity. *Zhongguo Ji Zhu Ji Sui Za Zhi*, 2012, 22: 97–99 (in Chinese).
42. Wang J, Xia H, Ying Q, *et al.* An anatomic consideration of C2 vertebrae artery groove variation for individual screw implantation in axis. *Eur Spine J*, 2013, 22: 1547–1552.
43. Wang C, Yin SM, Yan M, Zhou HT, Dang GT. Posterior occipitocervical fixation using C2 pedicle screws and occipitocervical plate systems. *Zhonghua Wai Ke Za Zhi*, 2004, 42: 707–711 (in Chinese).
44. Yin Q, Ai F, Zhang K, *et al.* Irreducible anterior atlantoaxial dislocation: one-stage treatment with a transoral atlantoaxial reduction plate fixation and fusion. Report of 5 cases and review of the literature. *Spine (Phila Pa 1976)*, 2005, 30: E375–E381.
45. Ai F, Yin Q, Wang Z, *et al.* Applied anatomy of transoral atlantoaxial reduction plate internal fixation. *Spine (Phila Pa 1976)*, 2006, 31: 128–132.
46. Ai FZ, Yin QS, Wang ZY, Xia H, Wu ZH. Surgical anatomy of transoral atlantoaxial reduction plate internal fixation. *Zhongguo Ji Zhu Ji Sui Za Zhi*, 2004, 42: 1325–1329 (in Chinese).
47. Ai FZ, Yin QS. Anterior atlantoaxial reduction plate by a transoral anterior approach. *Zhonghua Gu Ke Za Zhi*, 2004, 24: 313–316 (in Chinese).
48. Yin QS, Ai FZ, Zhang K, *et al.* Design and preliminary clinical application of transoral pharyngeal atlantoaxial reduction plate. *Zhonghua Gu Ke Za Zhi*, 2008, 28: 177–181 (in Chinese).
49. Wang JH, Xia H, Yin QS, *et al.* Individual screw placement of TARP III plate based on variations in the vertebral artery for atlantoaxial dislocation. *Zhongguo Ji Zhu Ji Sui Za Zhi*, 2013, 23: 405–410 (in Chinese).