

# Odontoid screw fixation for fresh and remote fractures

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Fractures of the odontoid process are common, accounting for 10% to 20% of all cervical spine fractures. Odontoid process fractures are classified into three types depending on the location of the fracture line. Various treatment options are available for each of these fracture types and include application of a cervical orthosis, direct anterior screw fixation, and posterior cervical fusion. If a patient requires surgical treatment of an odontoid process fracture, the timing of treatment may affect fusion rates, particularly if direct anterior odontoid screw fixation is selected as the treatment method. For example, type II odontoid fractures treated within the first 6 months of injury with direct anterior odontoid screw fixation have an 88% fusion rate, whereas fractures treated after 18 months have only a 25% fusion rate. In this review, we discuss the etiology, biomechanics, diagnosis, and treatment (including factors affecting fusion such as timing and fracture orientation) options available for odontoid process fractures.

**Key Words:** Bone screws; fracture fixation or spinal fractures/surgery; odontoid process

## Introduction

Fractures of the odontoid process (the dens) of the axis account for 10–20% of acute cervical spine fractures.<sup>[1–8]</sup> Certain types of odontoid process fractures can lead to gross instability of the atlantoaxial complex and present a significant risk for a potentially catastrophic spinal cord injury.<sup>[9]</sup> The treatment of odontoid process fractures remains controversial and ranges from external orthosis to various internal fixation techniques. This paper will review the treatment options for fresh and remote dens fractures.

### Fractures of the odontoid

Anderson and D'Alonzo classified fractures of the odontoid

process into three types.<sup>[10]</sup> Type I fractures involve the apical portion of the dens and are typically considered stable, although Scott et al.<sup>[11]</sup> suggested they may represent an avulsion of the alar ligaments and thus result in instability. If instability is suspected with a type I fracture, flexion/extension x-rays may reveal whether there is abnormal motion of the atlantoaxial joint.

Type II fractures involve the neck of the odontoid process (where it joins the body of C2). These are the most common odontoid fractures and are unstable. The fractured odontoid process may be displaced anteriorly or posteriorly relative to the body of C2.

Type III fractures extend into the body of C2. True type III fractures are typically managed with external immobilization, which is often successful, although they are also amenable to surgery.<sup>[12]</sup> Some odontoid fractures are comminuted at the base of the dens and are associated with free fracture fragments. This subset of fractures, designated type IIA,<sup>[52]</sup> is less likely to be treated successfully with external immobilization.

Type II fractures have been further classified, based on the direction of the fracture line, as anterior oblique, posterior oblique, or horizontal fractures (Figure 1).<sup>[1]</sup> The fracture line of an anterior oblique fracture slopes superiorly from posterior to anterior, whereas a posterior oblique fracture slopes superiorly from anterior to posterior. A horizontal fracture slopes minimally or not at all. The slope of the fracture is an important consideration regarding treatment; for example, an anterior oblique fracture has a lower fusion rate when treated with a direct anterior odontoid screw.<sup>[1]</sup>

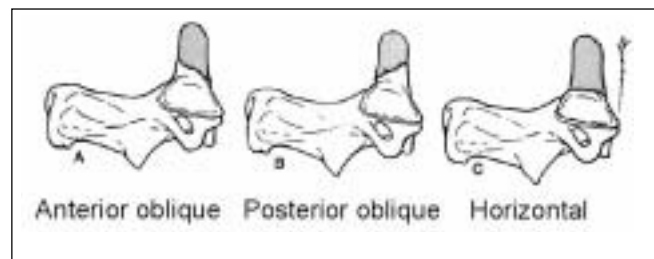


Figure 1: Illustration of the three types of fracture lines of type II odontoid fractures

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Evaluation of an odontoid fracture generally begins with plain x-rays, including lateral, anterior-posterior (AP), and open-mouth radiographs of the cervical spine. If an odontoid fracture is suspected, thin-section computerized tomography (CT) with reconstructions in the coronal and sagittal planes is recommended for further evaluation.<sup>[14,15]</sup> Magnetic resonance imaging may also be used to assess the integrity of the transverse ligament.<sup>[14,16]</sup>

### **Mortality and neurological injury**

Estimates of mortality from dens fractures at the time of the injury are 25%–40%.<sup>[17,18]</sup> Survivors of the injury are usually neurologically intact, although Anderson and D'Alonzo<sup>[10]</sup> found that 15 (25%) of 60 patients had various neurologic deficits, including Brown-Sequard syndrome, mild upper-extremity weakness, hyper-reflexia of the lower extremities, and decreased occipital sensation. Delayed onset of symptoms has also been reported.<sup>[9,19]</sup> The most common presenting symptom with an undiagnosed odontoid fracture is neck pain, although patients may also complain of hand weakness and lower extremity "stiffness."<sup>[9]</sup> These fractures must be treated because the potential for ongoing neurologic compromise is well known.<sup>[19-22]</sup>

### **Treatment of odontoid process fractures**

#### **Conservative management**

Type I and Type III fractures have been treated with external immobilization with a high degree of success. Julien et al.<sup>[23]</sup> performed an evidence-based analysis of the literature to evaluate the management of odontoid fractures. Halo/Minerva fixation or cervical traction followed by immobilization in a rigid cervical collar resulted in fusion of all type I odontoid fractures and 84-88% of type III fractures.<sup>[23,24]</sup>

Cervical traction followed by immobilization is not the most effective treatment of type II odontoid fractures. Julien et al.<sup>[23]</sup> reported that treatment of type II fractures with cervical traction/cervical collar resulted in a fusion rate of only 57%. Management with a halo-type orthosis has a variable nonunion rate from 7%<sup>[25]</sup> to 100%.<sup>[26]</sup> Nonunion rates varying from 21% to 45% have been reported often.<sup>[3,4,27-30]</sup>

#### **Posterior fusion**

Historically, posterior cervical fusion was the primary operative alternative when external immobilization failed or was considered unsuitable. Wiring techniques, including those described by Brooks, Gallie, and later Dickman and Sonntag, have been used to achieve posterior cervical fusion. Brooks' technique involves two wedge bone grafts secured between C1 and C2 with sublaminae wiring.<sup>[31]</sup> In Gallie's technique, a superior notch in the spinous process of C2 holds the H-shaped on-lay graft more securely in place, and the graft is secured with a wire that is only sublaminae at C1.<sup>[32]</sup> Finally, Dickman and Sonntag described an atlantoaxial arthrodesis secured with a sublaminae wire at C1 that incorporated an iliac crest strut-graft between the posterior arches of C1 and C2 secured with wire around the base of the spinous process of the axis.<sup>[33]</sup>

In 1992, Jeanneret and Magerl<sup>[34]</sup> recommended the use of transarticular screws rather than a Gallie or Brooks fusion alone. They reported 100% fusion and only one complication with C1-C2 transarticular screw fixation in addition to posterior fusion. Dickman et al.<sup>[35]</sup> reported a 98% fusion rate for patients undergoing C1-2 transarticular screw fixation and an 86% fusion rate for patients undergoing C1-2 fixation with only wires and arthrodesis.

Fusion rates for transarticular screws are almost 100%.<sup>[35-39]</sup> When the anatomy is favorable, this technique is generally preferred because of excellent results. Posterior fusion may be preferred in patients who have a comminuted type II or III fracture or an associated unstable Jefferson fracture, or who cannot tolerate external immobilization.

Several issues must be considered concerning C1-2 posterior fusion. The passage of cables or wires, especially C2 sublaminae wires, into the spinal canal may injure neural elements. Structural bone grafting should always be used to achieve solid fusion, which is critical to achieving long-term stability, as hardware is unreliable for long-term stability. If an intact posterior arch of C1 is not present, alternative fusion techniques such as decortication and bone packing into the C1-2 joint or the lasso technique can be applied.<sup>[40]</sup> C1-2 joint fusion eliminates 50% of the rotation of the head, a significant loss of motion. Consequently, a technique for treating odontoid fractures, anterior odontoid screw fixation, has been developed to preserve the normal motion of the C1-2 joint.

#### **Anterior fusion**

Beginning with Nakanishi<sup>[41]</sup> in 1980, several authors have described the surgical technique for anterior odontoid screw fixation.<sup>[2,42-46]</sup> The technique has gained increased acceptance as instrumentation has improved, advances in minimally invasive approaches have been developed, and improvements in fluoroscopic guidance have been made.<sup>[47,48]</sup> Direct anterior screw fixation is an osteosynthetic technique that provides immediate spinal stabilization, preserves rotation of C1 on C2, and allows rapid return to normal lifestyle.<sup>[45,49]</sup> Retention of full range of motion has been reported to be as high as 83%.<sup>[50]</sup>

#### **Anterior odontoid screw fixation**

##### **Surgical technique**

The patient is positioned supine with a folded blanket under the shoulder to allow for neck extension and under the head to maintain neutral position until lateral fluoroscopy is obtained. The extension required for standard intubation may put the patient at risk, thus care is required when intubating the patient. Holter traction (5 lbs.) is applied, and under fluoroscopy, the padding underneath the patient's head is removed to provide extension except in the case of a retrolisthesed odontoid fragment.

Bipolar fluoroscopy is used to monitor head positioning and alignment of the odontoid. Figure 2 demonstrates the positioning of the patient and orientation of the fluoroscopes for the procedure. The AP view is obtained transorally, with a radiolucent prop (e.g., a cork) used to keep the mouth open. The lateral view is achieved

by placing a second fluoroscope with the C-arm are 30° above the horizontal.

The initial approach to the spine at the C5 level is the same as for an anterior cervical discectomy (Figure 3). Upon exposure of the prevertebral space, the carotid lies laterally and the trachea and esophagus medially. The longus colli muscles are elevated over about 1½ vertebrae, and a sharp-bladed special self-retaining retractor is inserted below these muscles. The loose prevertebral areolar tissue is opened by sweeping a peanut dissector side-to-side to prepare a working tunnel to the C1-C2 level (confirmed fluoroscopically). A special self-retaining retractor, attached to the lateral retractor base, maintains a working tunnel up to the caudal edge of C2.

Under fluoroscopy, a K-wire is positioned on the anterior, inferior lip of C2 at the entrance site for the fixation screw. The K-wire is placed in the midline or 3-4 mm from the midline for one or two screws, respectively. An 8-mm hollow drill is placed over the K-wire and rotated manually to create a shallow trough in the ventral body of C3 for the guide tube system and to incise the C2-3 annulus without cutting into the C2 body (Figure 4). The drill guide tube

system, with inner and outer guide tubes, is “walked” up until the spikes on the outer tube are over the body of C3 (Figure 5). These are set into the body to fix the guide tube system using an impactor. The inner guide tube is advanced to the anterior, inferior edge of C2 in the trough and the K-wire is removed. With the guide tube firmly engaged in the body of C3, C2 alignment is optimized using fluoroscopic guidance by pushing C2 and C3 dorsally relative to the odontoid-C1 complex or pulling C2 and C3 ventrally. In the case of a retrolisthesed odontoid fragment, realignment can be achieved and maintained while the patient’s head is gradually extended as the padding under the head is removed.

After satisfactory alignment is obtained, a pilot hole is drilled through C2 to the apex of the odontoid (Figure 6). Penetration of the distal cortex is important for screw placement. The angle of the drill is coaxial with the odontoid process and tangential to the dura, so injury to the spinal cord is easily avoided. Repeated fluoroscopic checks of the trajectory are necessary to control the drilling process (Figure 7). The pilot hole is then tapped, and a lag screw is inserted through the guide tube using a special screwdriver designed to hold the screw (Figure 8A). The lag screw is selected based on the measured drilled depth and is typically 4 mm in diameter. The screw is not threaded proximally to allow the odontoid fragment to be pulled down to the body of C2 (Figure 8B). If a second screw is to be placed these steps are repeated. The second screw can be fully threaded as no additional lagging effect is anticipated (Figure 8C).

### Considerations of odontoid screw fixation

Various parameters have been identified as predictors of failure for fusion of type II odontoid fractures.<sup>[27,29,51,52]</sup> The degree of displacement of the dens fracture has been associated with nonunion. Generally, displacement less than 4 mm has been associated with improved fusion rates, whereas displacement greater than 6 mm is associated with higher rates of nonunion.<sup>[5,27,53]</sup>

Age is another important factor in the successful healing of

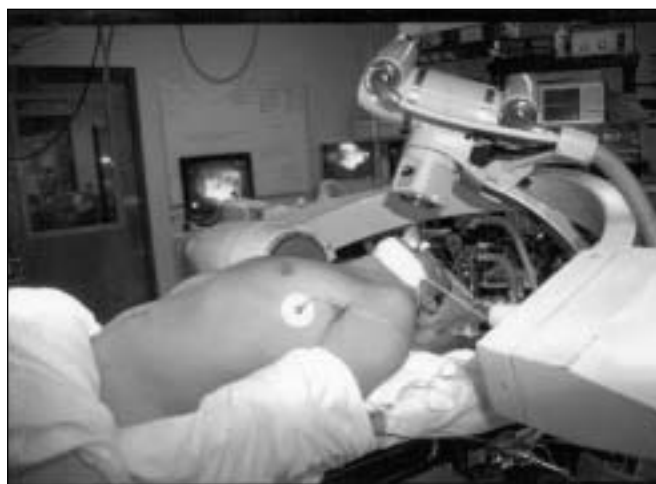


Figure 2: Patient positioning for direct anterior odontoid screw fixation



Figure 3: Incision and retractor placement for direct anterior odontoid screw fixation

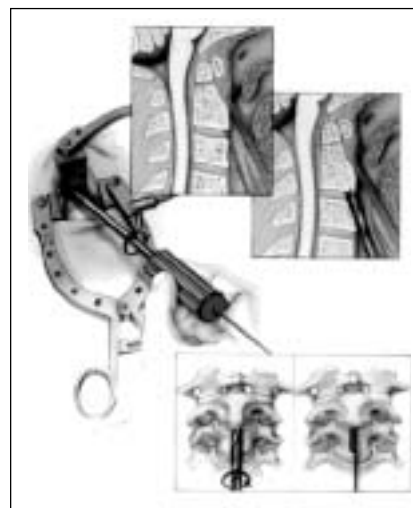


Figure 4: Placement of the K-wire into the body of C2. The K-wire serves as a guide for the hollow hand drill that is used to create a trough through the ventral body of C3 and to incise the C2-3 annulus



**Figure 5:** Illustration demonstrating the mating of the inner and outer guide tubes and the insertion of the spikes into the body of C3.



**Figure 6:** Drilling of the pilot hole into C2



**Figure 7:** Fluoroscopic image of the drill into the body of C2 and crossing into the fractured odontoid process

odontoid fractures. Children with odontoid process fractures generally achieve stable fusion with halo immobilization,<sup>[54-56]</sup> whereas adult patients fare poorly with external immobilization<sup>[57-61]</sup> In a case-control study of 33 patients, individuals over 50 years had a nonunion rate 21 times higher than those under 50 when treated with halo immobilization.

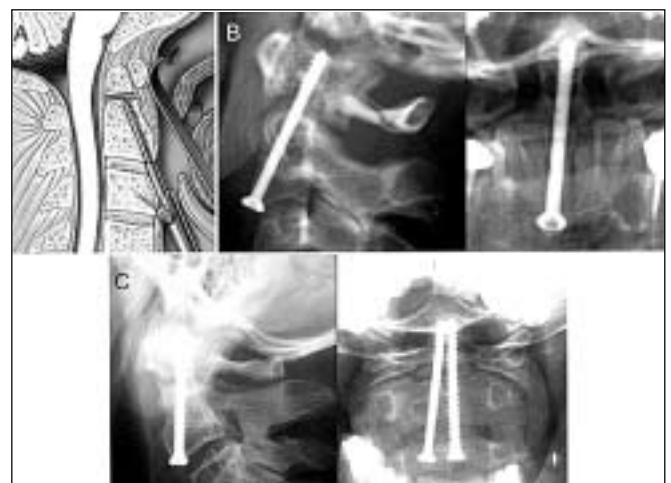
The issue of whether to place one or two odontoid screws is controversial. Two-screw constructs have been advocated to prevent an axis of rotation around a single screw. In some patients, however, the odontoid process is not large enough to accommodate two screws.<sup>[62]</sup> We generally advocate placement of two screws, if possible, although there appears to be similar clinical success with both the one- and two-screw constructs.<sup>[1,63]</sup>

For patients who present with recent injury and no concomitant transverse ligament rupture, the senior author (RIA) prefers using direct anterior screw fixation to retain rotation of C1 on C2.<sup>[1]</sup> The procedure is well tolerated, does not rely on bone graft harvest, and generally requires no other postoperative treatment (e.g., cervical collar). The fusion rate is 88% when the surgery is performed within the first 6 months of injury but drops to 25% for remote fractures (i.e., >18 months following injury).<sup>[1]</sup> Therefore, it is clear that the timing of surgery is important. If a patient fails external immobilization and is within 6 months of the injury, anterior odontoid screw placement is still an option.

#### *Surgical technique for C1-2 transarticular screws*

Because remote type II fractures have a higher rate of nonunion than recent fractures, they usually should be treated with posterior C1-2 fixation and fusion. Similarly, when atlantoaxial instability is not remediable by placement of an odontoid screw, posterior cervical fusion is indicated. When favorable anatomy exists, placement of C1-C2 transarticular screws may be used for stabilization.

Several important anatomic elements must be evaluated in patients requiring posterior fusion. Poor bone quality, although not an absolute contraindication, may require external fixation in



**Figure 8:** (A) Illustration of the lag screw prior to its engagement of the fractured odontoid process. Final AP and lateral fluoroscopic images of a single (B) and two (C) odontoid screws

addition to internal fixation. For C1-C2 transarticular screw fixation, an adequate pathway for the screw trajectory is essential. A vertebral artery that courses into the pars of C2 may interfere with potential screw trajectory, with obvious potentially disastrous neurologic effects. This is best evaluated using thin-section CT scans reconstructed in the sagittal plane. Multiplanar reconstructions or the use of a stereotaxic workstation can assist in defining a safe trajectory and the latter can provide invaluable intraoperative guidance as well.

A technique for posterior C1-2 fusion with polyaxial screw-and-rod fixation minimizes the risk of injury to the vertebral artery and is especially valuable when posterior wiring techniques cannot be performed such as when the posterior elements are deficient.<sup>[64]</sup> This is a modification of a technique described way back in 1994 by Goel and Laheri.<sup>[65]</sup> The earlier description by Goel et al involves uniaxial screws in the lateral mass of C1 and pedicle of C2 anchored to plates bilaterally. The authors later presented the application of this technique in cases of trauma and odontoid non-unions.<sup>[66,67]</sup>

Once the criteria for transarticular screw placement have been met, the patient is positioned prone with the head supported in a pin-head holder (Figure 9). The patient is placed in a "military posture" with the lower cervical spine extended while slightly flexing and posteriorly translating the skull and C1. Lateral fluoroscopic images are used to optimize the C1-2 position. Extension of the lower cervical spine and flexion of the occiput will usually reduce the atlantoaxial subluxation by posteriorly translating the atlas.

A midline dorsal incision from the inion to C3 exposes the posterior elements of C1 and C2 and the C2 isthmus and associated venous complex. The lamina of C2 is dissected free of soft tissue to the facet joints of C2 and C3 (Figure 10). Once the anatomic structures have been adequately exposed, fixation screws are placed just rostral to the C2-C3 facet joint and aligned with the pars interarticularis. The appropriate trajectory for the screw is determined by aligning a drill or K-wire fluoroscopically to the

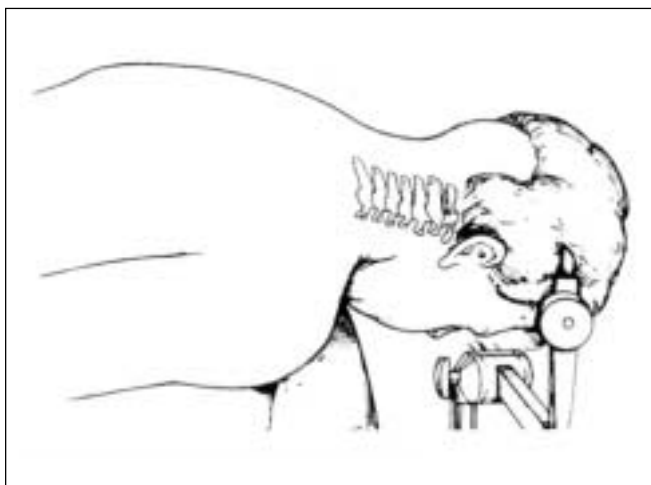
desired screw position. The screw should pass through the isthmus of C2 and cross the C1-2 articulation into the lateral mass of C1. Imaging also allows the surgeon to determine the incision sites for placement of the drill. Initial 1.5-cm stab incisions 1-2 cm off the midline, usually in the region of T2, are carried down to the dorsal fascia. As with odontoid screw fixation, a guide tube is used. A smooth tube fitted with a conical-tipped obturator is passed from the skin incision up to the drill entry site at the C2-C3 junction (Figure 11) by pressing firmly in a rostral direction and rotating the instrument to advance it into the surgical field. After the guide tube is placed, the obturator is removed and an awl is placed into the guide tube to begin a starting hole in the C2 lamina.

The drill must be passed carefully within the limits of the pars interarticularis using fluoroscopic confirmation of the trajectory. The trajectory should be low-angled just under the dorsum of the pars to engage the maximum amount of C1 lateral mass (Figure 12A) and to keep the drill above the vertebral artery. On the lateral fluoroscopic image, the ventral arch of C1 is a helpful target for the drill. The depth of the pilot hole is noted on the calibrated drill guide (Figure 12B) and the images are stored on the fluoroscope. The drill is removed, the hole is tapped, and the fully threaded screw is placed (Figure 13A-C). Fluoroscopy is also used to optimize the vertebral alignment before crossing the C1-C2 articulation.

The same steps are repeated for placement of the contralateral screw. Brisk arterial bleeding after drilling the pilot hole may indicate vertebral artery compromise. If this occurs after drilling the first hole, we recommend placing the first screw for fixation and a tamponade effect but forgoing placement of the second screw. Postoperative imaging (e.g., angiography) is suggested to determine the status of the vertebral artery.

After both screws have been placed, bone grafting is placed to provide long-term stability. The screws initially provide fixation, but bone fusion is key to long-term stability. If fusion fails to occur, the hardware will ultimately fail. The Sonntag-Dickman construct using an interpositional bicortical iliac crest is typically used,<sup>[33]</sup> although other constructs may be used.<sup>[31]</sup> Decortication is necessary for the surfaces of the C1 and C2 lamina that will be apposed to the graft. The mating cortical surfaces are denuded using a high-speed drill. The graft is contoured to fit snugly within the graft site. A braided titanium cable is placed in a sub-laminar fashion at C1 and around the spinous process of C2 to secure the graft, which is thus "sandwiched" between two layers of cable (Figure 14A,B). Additional bone chips or shavings may be placed around the graft for enhancement of fusion (Figure 15A-C).

Chronic dens fractures may also result in ventral compression of the spinal cord, which can result in progressive spinal cord damage.<sup>[9,21,69]</sup> Therefore, it is important to realign the spine before posterior fusion. If realignment is not possible, transoral odontoid resection to decompress neural element preceding posterior fusion is indicated.<sup>[9,13,19,68,69]</sup> However, although this procedure has become more common, it is technically demanding.<sup>[67]</sup>



**Figure 9: Illustration depicting positioning for C1-2 transarticular screw fixation**

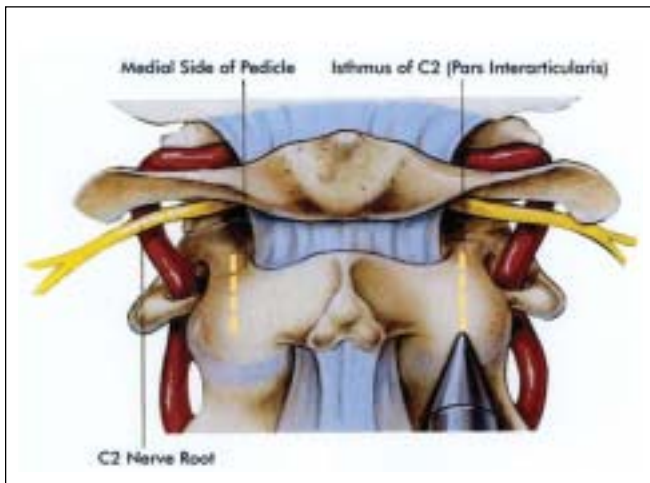


Figure 10: Illustration showing the pars interarticularis and the exposed facet joints of C2-3

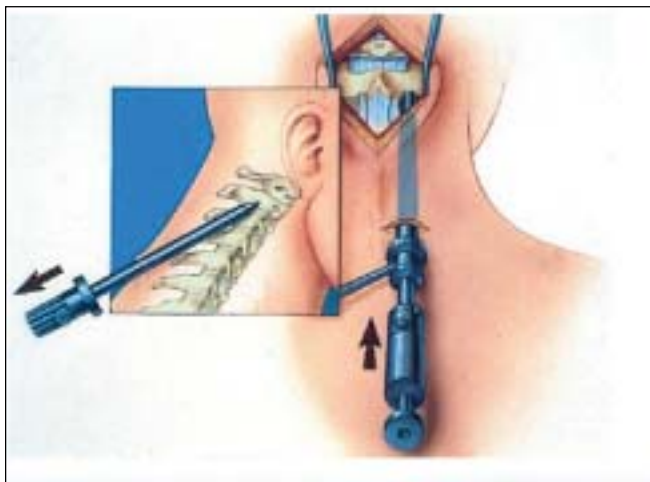


Figure 11: Placement of the drill guide tube with a conical obturator passed from a stab incision in the upper back to the entry point for the C1-2 transarticular screw at the C2-3 junction

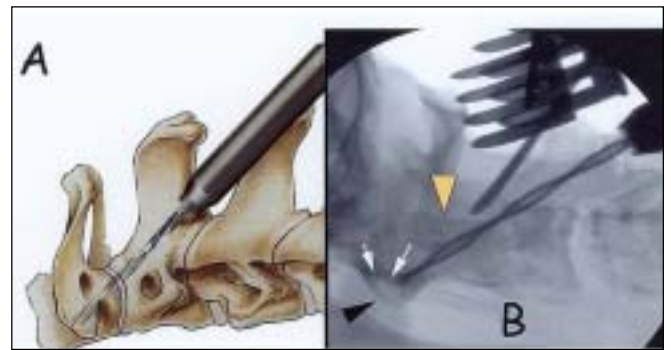


Figure 12: (A) Illustration of the trajectory for drilling. (B) Fluoroscopic view of the drilling process. The black arrowhead indicates the anterior arch of C1. The white arrows indicate the edge of the lateral mass of C1, and the yellow arrow indicates the C1-2 joint

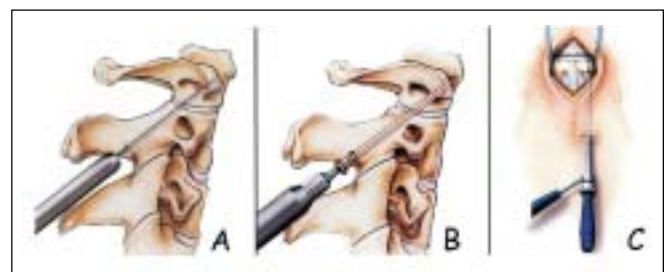


Figure 13: (A) Illustration showing the drill at its full depth. (B) Placement of the screw across the C1-2 joint. (C) Placement of the screw through the drill guide

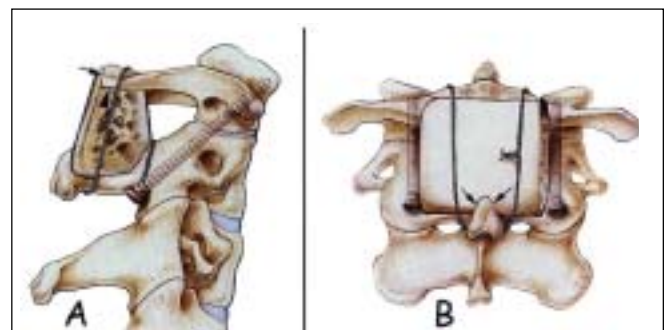


Figure 14: Lateral (A) and posterior (B) views of the graft held in place by a braided titanium cable



Figure 15: Lateral (A) and AP (B) plain x-rays of the final C1-2 transarticular screw construct with posterior fusion mass. Sagittal CT reconstruction (C) showing one transarticular screw. The arrows indicate the width of the pars interarticularis; the asterisk indicates the vertebral artery foramen.



## Conclusions

Odontoid fractures are a common injury to the cervical spine. The classification scheme constructed by Anderson and D'Alonzo has proven useful with minor modifications. Type II and shallow type III odontoid fractures are most common and are often best treated with surgery. Of the surgical techniques available, direct anterior screw fixation appears to provide the best option chance for retention of the normal rotation of the cervical spine, a rapid return to normal lifestyle, and a high fusion rate if it is performed when the fracture is reasonably fresh (i.e., less than 6 months old). Remote fractures of the odontoid and os odontoidum should be treated with posterior C1-2 transarticular screw fixation with arthrodesis. Posterior fixation and fusion following transoral odontoid resection is used if ventral spinal cord compression is present, from irreducible chronic odontoid fractures. Because delayed neurologic compromise is a well-established danger of dens fractures, physicians should be aware of appropriate treatment measures.

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