

Copyright ©2001 Lippincott Williams & Wilkins  
Chapman, Michael W.  
Chapman's Orthopaedic Surgery, 3rd Edition

---

## CHAPTER 139

# UPPER CERVICAL SPINE FRACTURES AND INSTABILITY

**Claude Gelinas**

**Alan M. Levine**

*C. Gelinas: Southwest Spine Center, Albuquerque, NM.*

*A. M. Levine: Director, Alvin and Lois Lapidus Cancer Institute, Professor of Orthopaedic Surgery and Oncology, Sinai Hospital of Baltimore, Baltimore, Maryland, 21215.*

## INTRODUCTION

Upper cervical spine fractures include a wide spectrum of injuries whose patterns differ from those of injuries in the lower cervical, thoracic, and lumbar spine because of the unique anatomic configuration of the vertebral elements of the craniocervicum (45,57). The craniocervicum includes the base of the skull, the atlas, and axis, and is unique both in its bony as well as ligamentous structure. A variety of conditions can lead to upper cervical spine instability (infections, tumors, spondylosis, and congenital abnormalities), but the most common cause is direct trauma. Although upper cervical fractures occur as a result of mechanisms of injury that are similar to those causing other spine fractures (i.e., motor vehicle accidents, falls, diving, or direct trauma), they are nevertheless unique for several reasons. First, in autopsy series (2,13,17), many injuries to the upper cervical spine resulted in trauma to the brain stem and thus immediate death. In addition, in those patients surviving their initial trauma, the incidence of neurologic injury as a direct result of fractures and dislocations in the craniocervicum is proportionately less than the incidence in other areas of the cervical spine because of the relatively large area available for the spinal cord within the spinal canal. Again, because of the unique relationship of this spinal region to the skull, most fractures in the upper cervical spine result from a force applied through the skull, with resultant excessive motion of the head and upper cervical spine, creating the injury pattern. Although the fractures in the upper cervical spine may be survivable, some of these patients succumb as a result of associated severe head injury. In fact, many of the neurologic deficit patterns are a result not of the injuries to the spine but of direct head injuries. To understand the nature of these injuries and to be able to apply the most appropriate treatment methodologies, the physician must first thoroughly appreciate the anatomic considerations of the

P.3664

craniocervicum and then fully understand the mechanism associated with each injury pattern. Appreciation of the significance of the injury in relation to the immediate and subsequent potential instability is important in preventing both undertreatment and

overtreatment of injuries in this location. It also may alert the physician to potential pitfalls in treatment modalities that may apply to the various injury types.

## REGIONAL ANATOMY

The term “craniocervicum” is generally applied to the area at the base of the skull, the atlas, and the axis. The area is unique because it is the junction between the skull and the cervical spine, and is characterized by extreme mobility (37). It is unique also because of the size, shape, and location of the joints that allow motion between the occiput and the atlas or the atlas and the axis. At the lower end of the craniocervicum (C2–C3), there is a transition in the size, shape, and location of the joints, transitioning to the more usual pattern seen in the lower cervical spine. Forces applied to the craniocervicum may result in injuries having far different patterns and resultant instabilities than those seen in the lower cervical spine.

The occipitocervical articulations lie anterolaterally with reference to the spinal canal in that area. Those joints are made up of convex-shaped lateral masses adjacent to the foramen magnum that articulate with the concave lateral masses of the atlas. The joints are trapezoidally shaped and are somewhat wider medially than laterally. In children, these joints are less concave and flatter, and therefore, they restrict motion to a less significant degree than they do in adults. Therefore, children have more mobility and are more predisposed to injury at this level (5). The normal range of motion at the occipitocervical junction is 21° of extension (which is in part limited by the occiput abutting on the posterior arc of the atlas) (89), 3° of flexion, 7° of rotation, and 5° of lateral bending (64).

The atlas is unique in that it has no distinct body, an element present in the remainder of the vertebrae of the cervical spine. Embryologically, the vertebral body of C-1 is absorbed into the formation of the dens process of C-2; therefore, the atlas has two lateral masses connected by an anterior and a posterior arch. The anterior arch is thicker and shorter than the posterior arch. The posterior arch has a tubercle in its posterior midportion and two relatively flatter areas just posterior to the lateral masses, over which the vertebral artery runs after it exits from the foramen in C-2. The shape of the lateral masses is important because it helps one understand how injuries to C-1 occur. The articular surfaces for C1–C2 and also occiput–C1 are concave, with that of the atlantoaxial joint being somewhat flatter than that of the occipitocervical joint. The resultant shape of the C-1 lateral mass is that it is thinner medially than laterally; thus, when axial loading forces are applied across the craniocervicum, there is a resultant force that serves to displace the lateral masses of C-1 in a lateral direction.

The axis is also unique in its relationship to the atlas because the atlantoaxial joint has two different sets of articulations. The first is the articulation of the slightly convex inferior articular process of the atlas with a slightly convex superior articular process of the atlas. Both joints are oriented in the horizontal plane with a medial inclination of approximately 35°. These joints permit rotation, accounting for nearly 50% of the rotation in the cervical spine (69). The odontoid process projects up inside the ring of the axis, forming a second joint with the anterior arch of the atlas. The dens generally is between 14 and 15 mm in height and thus is approximately 40% of the overall height of the axis (74). The overall diameter of the atlas is quite large in relation to the space necessary for the spinal cord

(82). Generally, the midsagittal diameter of the cord is one third of the midsagittal diameter of the inner surface of the axis. Actual rotation between the occiput and C-1 is generally approximately 5° to 7°, with more than 8° being pathologic, and at the atlantoaxial joint, the amount of normal rotation is approximately 43°, with more than 50° representing hypermobility and approximately 65° of rotation required for atlantoaxial dislocation (20,38). At C-2, the isolation of the pedicles of the axis between the atlantoaxial joint anterior to them and the C2–C3 joint posterior to them contributes to the occurrence of fractures at the base of the pedicles. The relative stability of the craniocervicum as a unit isolates the pedicles of C-2, predisposing them to fractures. Finally, the large bifid process of C-2 is an anatomic landmark for physical examination as well as for anatomic dissection.

An understanding of the embryologic and postnatal development of the upper cervical spine is also helpful in further understanding injuries to this area. Although all other cervical vertebrae develop from at least three ossific nuclei, the atlas develops from only two centers of ossification, which usually fuse together between 3 and 5 years of age. Because there is an ossific center in each lateral mass, defects in both the anterior arch and posterior arch can occur. The axis has four centers of ossification, which also tend to fuse together between 3 and 6 years of age, with the exception of the junction between the odontoid process and the body, which may persist up to 11 years of age. The presence of persistent congenital defects in the ring of C-1 or C-2 in the adult and delayed fusion of ossific nuclei in children should not be confused with acute fractures.

The arterial supply to the dens initially comes from both the anterior and posterior ascending arteries from the vertebral arteries that anastomose to create a rich vascular network. The cartilage plate that separates the odontoid

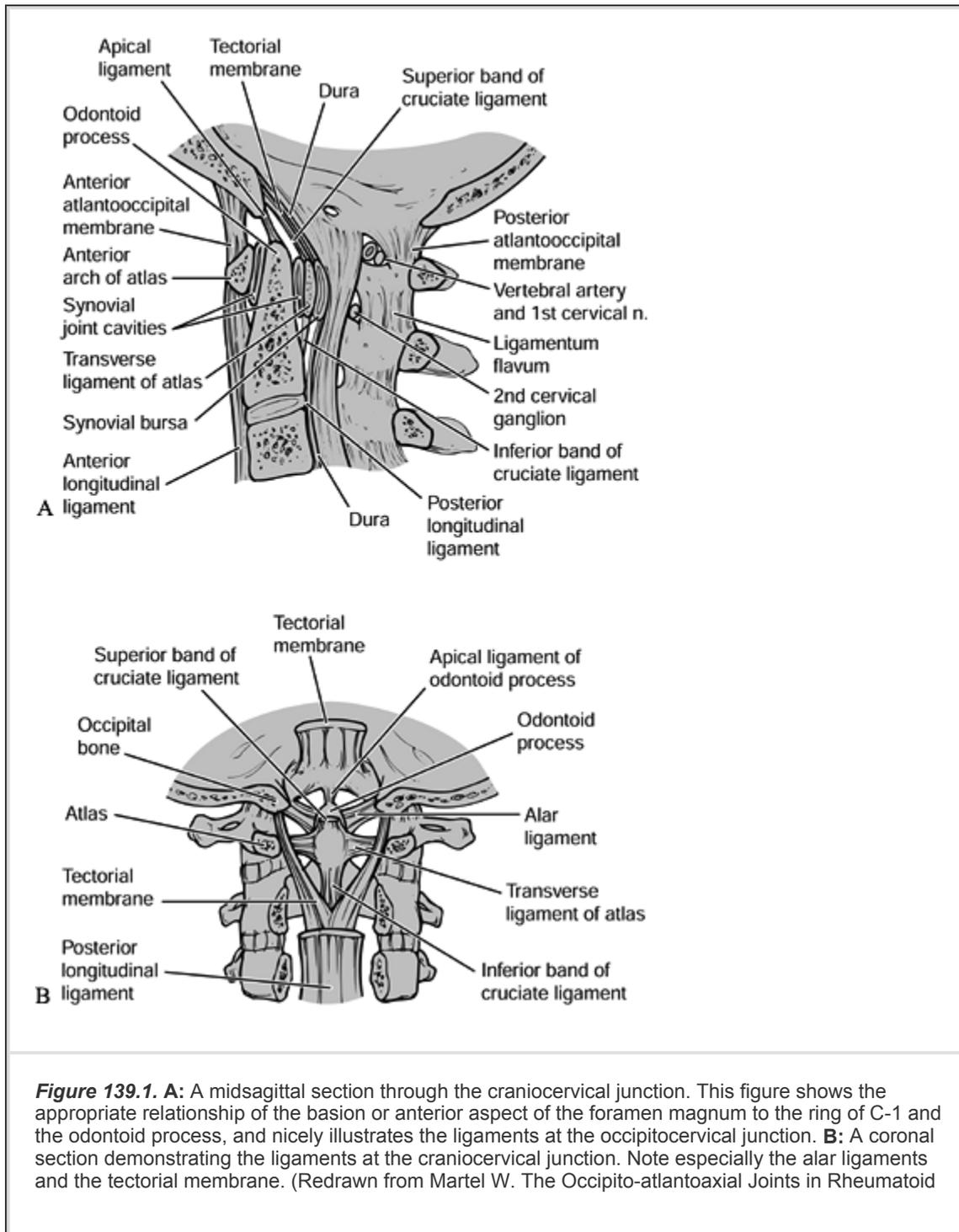
---

P.3665

from the body of C-2, as previously mentioned, tends to ossify around 7 years of age, preventing direct vascularization from the rich plexus in the vascular body. There is also a zone of ossification at the tip of the dens, which appears between 3 and 6 years of age and can remain open until 12 years of age. Both of these delayed closures can be mistaken as fractures.

The relationship between the bony elements at each level of the craniocervicum is far different from that between the bony components of the lower cervical spine. The major difference is that there is no disc between occiput and C-1 or between C-1 and C-2 because there is no vertebral body at C-1. Therefore, without the stability provided by the intervertebral discs, the ligamentous integrity of the craniocervicum is provided by a structure quite different from that in the lower cervical spine. The central point of ligamentous stability in the upper cervical spine is the odontoid process. Affixed to it are several ligaments, which provide resistance to translation, flexion, extension, and rotation. The *transverse ligament* is fixed at the tubercle on the lateral mass at one side of the atlas and traverses just posterior to the odontoid process to attach to the tubercle of the contralateral lateral mass. It secures the anterior surface of the dens in close proximity to the posterior facet of the anterior arch of the atlas. The transverse ligament provides stability in flexion between the atlas and the axis, and also prevents anterior translation of the atlas on the axis (29). The *alar ligaments* attach to the tip of the dens (Fig. 139.1). They actually arise from the medial aspect of the occipital condyles and insert along the tip

of the odontoid. They function to prevent anterior translation at C1–C2 as well as to restrict rotation and lateral bending at that level (22,23). The *apical ligament* arises from the rim of the foramen magnum and inserts more centrally than the alar ligaments into the tip of the dens. Finally, the *accessory ligaments* arise from the lateral masses of C-2 and insert into the base of the dens. These three types of ligaments—the alar, apical, and accessory ligaments—act as important secondary restraints to C1–C2 translation, especially in the event of failure of the transverse ligament (29).



Arthritis and Ankylosing Spondylitis. *AJR* 1961;86:223, with permission.)

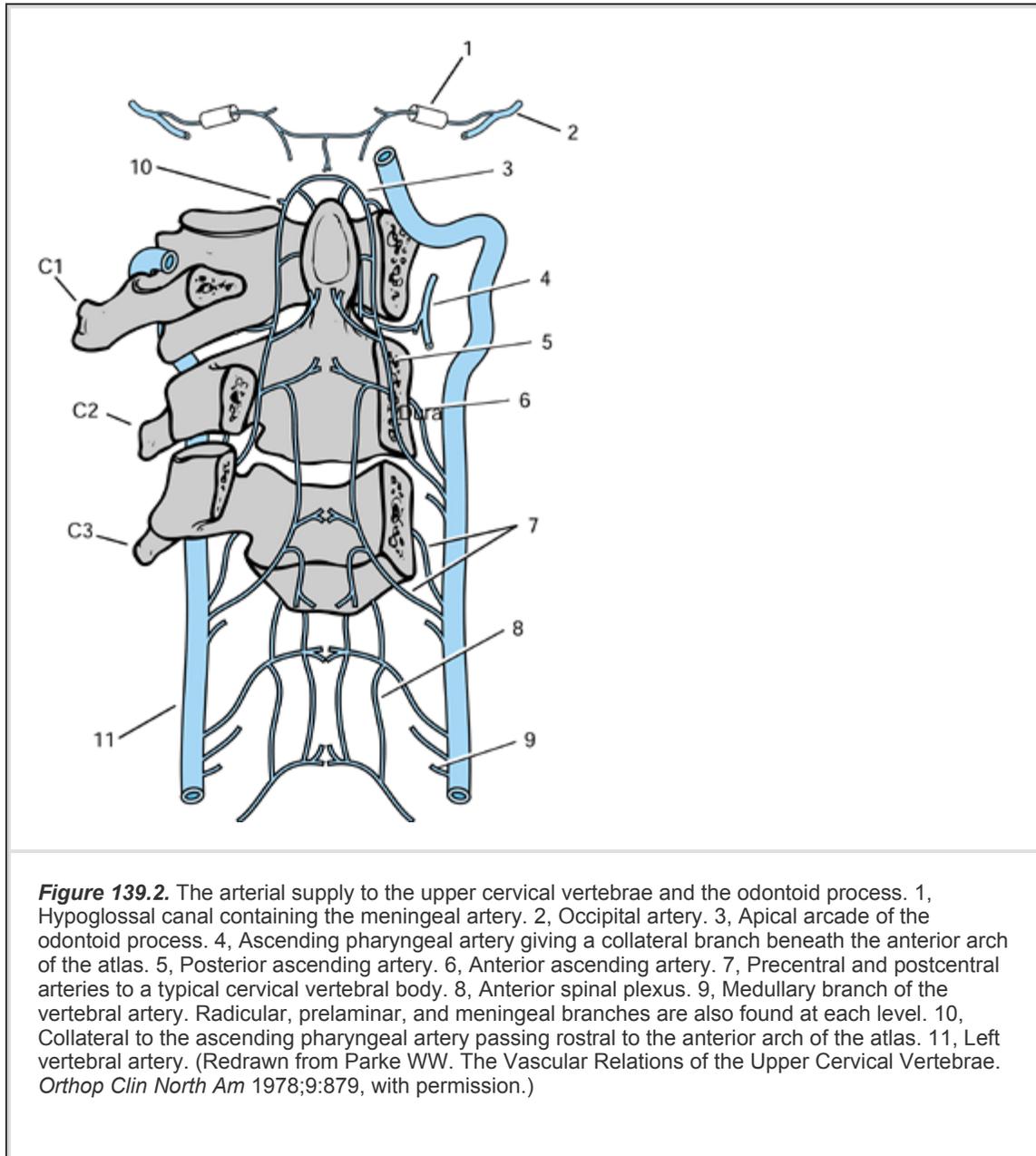
The transverse ligament may become incompetent through two different mechanisms of injury. First, a severe flexion force between C-1 and C-2 may result in failure of the transverse ligament by impingement on the dens process, and this may also result in failure of the alar, apical, and accessory ligaments. In contrast, the transverse ligament can fail in tension with axial loading applied across C1–C2, resulting in failure of the accessory ligaments and transverse ligaments, but because of the direction of attachment, the alar and apical ligaments remain intact. Additional stability to this complex is imparted by the joint capsules, especially the C1–C2 capsules (16). These capsules function to limit rotation and, to a lesser degree, translation at the C1–C2 level. Posterior to the central ligamentous complex is the pectoral ligament. This is an attenuation of the interspinous ligament, which is a direct restraint to flexion. The final ligamentous component in the upper cervical spine is the continuation of the anterior longitudinal ligament. This, again, is somewhat attenuated, although it provides restraint to extension in the upper cervical spine.

P.3666

The final anatomic element with a critical role in treating injuries of the craniocervicum is the vascular anatomy (66). There are three elements in the vascular anatomy of concern: the position and course of the vertebral arteries; the plexus of thin-walled vessels lying just posterior to the facet capsule at C1–C2; and the vascular supply surrounding the dens process. The vertebral arteries course upward through the foramen in C-2, then loop over the posterior arch of the atlas approximately 1.5 to 2 cm lateral to the tubercle of the posterior arch. The vertebral artery is vulnerable to injury during surgery in two separate areas. Dissection of the ring of C-1 more than 2 cm lateral from the midline may expose the vertebral artery to trauma. Also, the insertion of atlantoaxial screws exposes the vertebral artery to injury by direct trauma from a drill bit as it traverses the C-2 body. Because the location of the vertebral artery within C-2 varies, determine its position radiographically before screw fixation (65). It is, however, also important to know that because the vertebral arteries are paired structures (with one usually larger and, therefore, dominant over the other in terms of blood supply), injury to a single vertebral artery rarely results in significant neurologic deficit. In addition, as shown by Rauschnig, there is a plexus of thin-walled vessels lying superficial to the facet capsule of C1–C2 with exposure of the C1–C2 articulation from a posterior direction. Sharp dissection through the soft tissue superficial to these vessels may result in profuse bleeding; there is less probability of injuring this vascular network by blunt dissection of the soft tissues caudal to rostral along the pedicle of C-2. Although the bleeding may be bothersome during the course of surgery, the consequences of disruption of the venous plexus is not significant.

Although it was originally thought that avascularity was the sole reason for the high rate of nonunion of the dens, it has since been found that in fact there is a significant endosteal and ligamentous blood supply (Fig. 139.2). The combination of the carotid arteries and vertebral arteries supply sufficient blood vessels to the dens process. Even the internal

carotid supplies vessels to the dens through arteries that anastomose in a vascular arcade, and the dens may even have a direct blood supply through an ascending pharyngeal artery.



## EVALUATION AND MANAGEMENT OF PATIENTS WITH INJURIES TO THE CRANIOCERVICUM

Although it is vital that any patient with potential trauma to the cervical spine be first assessed for adequacy of airway, breathing, and circulation according to the American Trauma Life Support (ATLS) protocols, it is even more vital in patients with injuries to the upper cervical spine. Especially with injuries caused by distraction at the level of occiput–C1 or C1–C2, brain stem contusion is possible, resulting in cessation of spontaneous

respiration. Emergent maintenance of airway and respiration may be the key to patient survival. Treat any patient with a head injury who is comatose or obtunded as if an injury is present until it is clearly ruled out. As with other spinal injuries, immobilize the entire spine on a backboard with a rigid collar. The physical examination of patients with upper cervical spine injuries begins with an evaluation of the skull for evidence of head trauma, including scalp or facial lacerations. Localizing signs, such as tenderness and especially the location of trauma to the skull, is helpful in

P.3667

the further evaluation of the patient as well as ultimately determining the mechanism of injury. In the awake, alert patient, palpate the entire spine for areas of localized tenderness or asymmetry.

In the initial neurologic examination, test for muscle function and strength; evaluate sensation with pinprick and light-touch; check the deep tendon reflexes, cranial nerves, and rectal tone and perianal sensation. Physical findings help in ordering proper radiographic evaluation of the patient.

In upper cervical spine injuries, dense incomplete neurologic injuries are rare. The most common neurologic patterns are Brown–Séguard syndrome resulting from rotatory injuries at the occiput–C1 or C1–C2 areas, or flexion injuries with rupture of the transverse ligament. Brain stem injuries with impairment of respiration most commonly occur in occipital–cervical dissociations and often result in sudden death because of lack of respiratory effort. Radicular injuries (aside from injury to the occipital nerve, which can occur with fractures at C-1 resulting in numbness in the posterior aspect of the skull) are infrequent in the craniocervicum. Because of the large area available for the spinal cord, incomplete spinal cord injury as seen in the lower cervical spine is uncommon. Neurologic deficit in patients with this type of injury is usually either severe or trivial. Fractures in patients without a neural deficit or with trivial deficits are usually diagnosed either on routine radiographic screening (especially in the elderly where pain may not be a significant component) or by the presence of pain in the upper cervical spine. Document the complete neurologic examination on a form such as the American Spinal Injury Association (ASIA) Neurologic Assessment form.

The initial radiographic series obtained by most surgeons includes a lateral cervical spine roentgenogram and may also include an anteroposterior (AP) roentgenogram, and for the upper cervical spine, an open mouth view. Correlate the findings on the initial roentgenograms of the upper cervical spine with the initial physical examination to determine whether additional radiographic workup is necessary.

## **RADIOGRAPHIC EVALUATION**

Radiographic evaluation of a patient suspected of having a spinal injury has two separate components. The first is to “clear” the cervical spine. The ultimate goal of this phase of evaluation is to ascertain as definitively as possible whether there is an injury in the cervical spine. The second phase is to define fully the nature of the spine injury once it has been shown to exist.

This evaluation ideally should be broken down into two separate approaches. In patients

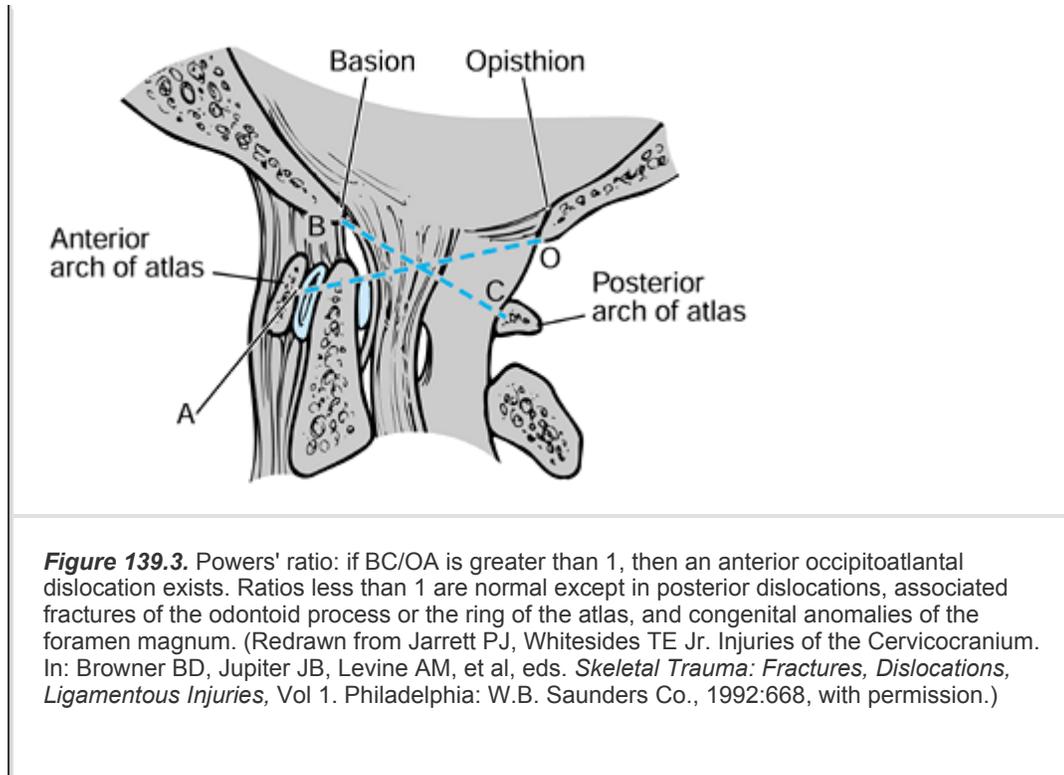
who are alert, oriented, nonintoxicated, and have no pain or neurologic symptoms, more than a single, lateral radiograph is unnecessary. The probability of finding significant injuries is very low in such patients. However, in patients with tenderness of the cervical spine or an altered state of consciousness, or in any polytrauma victim, perform a good quality lateral cervical spine film. An AP as well as an open mouth view may be indicated as part of the initial screening. It is clearly of no additional value to perform a five-view cervical spine radiograph (including two pillar views) unless you are trying to delineate a specific injury further. In patients with negative roentgenograms who are symptomatic and have no neurologic deficit, obtain physician-supervised flexion-extension lateral views in an awake, alert patient to rule out ligamentous instability.

There is also considerable controversy concerning what should contribute final clearance of the cervical spine in an obtunded patient. The opinions range from keeping the patient immobilized until responsive enough to undergo further radiographic evaluation to performing an magnetic resonance imaging (MRI) scan to look for ligamentous disruption. If all radiographs are negative, we prefer to keep the patient immobilized until he or she is responsive enough to cooperate with further testing.

Assess the lateral radiograph in an organized way:

- Assess overall alignment.
- Evaluate each vertebral level (base of the skull, C-1, and C-2) for orientation. If one level is true lateral and the next is oblique, a rotatory abnormality can be inferred.
- Look for translation or kyphosis on the lateral view. Assess routine parameters such as the anterior spinal line, the posterior spinal line, and the spinolaminar line for continuity.
- Identify the line forming the base of the clivus (known as Wachenheim's line) to verify the appropriate gleno-occipital relationships. Draw a line along the posterior surface of the clivus and extend it inferiorly; it should intersect or lie tangentially to the posterior cortex of the odontoid.
- The distance between the tip of the clivus (basion) and the odontoid process, the basion–dental interval, should be less than 1.2 cm in adults.
- The Powers' ratio (71) is also useful in assessing possible occipital–cervical dissociation (Fig. 139.3). This is the ratio of the distance between the basion and posterior arch of C-1 to the distance between the posterior margin of the foramen magnum (opisthion) and the anterior arch of C-1. A ratio of greater than 1.0 is abnormal and further imaging with a computed tomography (CT) scan is indicated.





- The lateral roentgenogram also defines the atlanto–dens interval (ADI), which should be 3 mm or less in adults and 5 mm or less in children (32).
- Actual radiographic visualization of dens fractures may be difficult on the lateral roentgenogram. However, the angle of the dens with reference to the vertebral body of C-2 should be evaluated. Angles exceeding 20° should probably be considered abnormal or at least suggestive of a fracture and requiring additional evaluation.
- Fractures of the posterior arch of C-1 are generally visible on the lateral roentgenogram, but significant angulation of the posterior arch may be the only visible sign when the fracture line is in close proximity to the lateral mass of C-1.

P.3668

Most types of traumatic spondylolisthesis in the axis can be visualized and fully defined on the plain lateral radiograph. Vertical distraction injuries at either occiput–C1 or at C1–C2 are easily visualized on the lateral roentgenogram and are most clearly defined on that study. Finally, the lateral roentgenogram can also be of some value in assessing the retropharyngeal soft-tissue shadow (68,85). The prevertebral soft tissue anterior to C-1 is clearly thicker than that more distal in the cervical spine. An increase in prevertebral soft-tissue shadow may not be present within the first hour or two of injury and is a quite unreliable sign in an uncooperative or screaming or crying patient. Soft-tissue shadows anterior to C-1 of greater than 10 mm in a cooperative patient suggest that there is some anterior column injury causing bleeding into the retropharyngeal space. This finding, in combination with a posterior arch fracture at C-1, would suggest that there is an anterior

element injury as well.

The final critical element in evaluating lateral films is to look for contiguous or noncontiguous injuries in the cervical spine (55). Injuries in combination usually have the same mechanism of injury. The initial lateral roentgenogram may reveal an associated injury in 22% to 50% of patients, depending on the pattern and severity of the upper cervical injury.

The AP view contributes relatively less to the evaluation of the upper cervical spine than it does to the evaluation of the lower cervical spine. However, the posterior elements of C-1 and C-2 can be visualized with this view. One of the more critical features is to assess the orientation of the spinous processes. Loss of alignment of the spinous processes is highly suggestive of a rotatory injury in the upper cervical spine. In addition, an angular deformity on the AP roentgenogram may also be helpful, especially in patients with torticollis, for whom the lateral may be extremely difficult to assess. The AP is also helpful for assessing concurrent injuries in the lower cervical spine.

A well-oriented open mouth view defines the occipital condyles, may show evidence of a fracture of the occipital condyles, and also gives an excellent view of the lateral masses of C-1. Spreading of the lateral masses of C-1 is indicative of a fracture of the anterior arch of C-1, as seen in Jefferson's fractures. The total displacement of the lateral masses can be evaluated (80), providing an indication of rupture of the transverse ligament. The radiographic appearance of a rotatory subluxation at C1–C2 is often defined on the open mouth radiograph with the so-called "wink" sign [overlapping of the inferior edge of the lateral mass of C-1 and the superior edge of the lateral mass of C-2, thus apparently eliminating the joint space (31)]. The odontoid–lateral mass relationship (distance from lateral mass to dens on each side), which sometimes is cited as a pathologic sign, is, in fact, asymmetric in many normal individuals and is of little significance (52,67).

The primary use of CT scans is to enhance the anatomic delineation of fractures that have already been identified. Make the slices at a 1.5 or 2 mm interval to enhance coronal and sagittal reconstructions and three-dimensional reconstructions. In fractures of the atlas, the gantry of the CT scanner must be parallel to the arch of C-1. If care is not taken with the orientation, the views will be difficult to interpret and not add much information to the plain radiographs. At C-1, the CT scan is most helpful in defining the nature of injuries involving the ring. For injuries of the transverse ligament, CT scanning is of help where the disruption of the transverse ligament is with a bony avulsion. In those dens fractures in which the fracture line is not clearly visualized on either the AP or the lateral plain radiographs, but an angular deformity of the dens is noticed, a CT scan with midsagittal reconstructions may define the injury. CT scanning is also helpful for defining dens anatomy before screw fixation (44). It is excellent in defining abnormal C1–C2 relationships, especially in rotatory dislocations and subluxations (21,50,61,63), and as defined by Sonntag and Dickman (79), the CT scan with appropriate reconstruction may also help define the

---

P.3669

position of the vertebral artery and determine whether placement of an atlantoaxial screw is possible in both sides.

MRI in upper cervical spine injuries is becoming more useful. It has recently been used to allow direct visualization of the transverse ligament, especially in patients with head injuries. The gradient echo MRI pulse sequence is of greatest value (18). Although MRI is helpful in delineating compression injuries to the brain stem and spinal cord in the upper cervical spine, it is of less value than the CT scan in defining bony anatomy. Because the majority of concerns in upper cervical spine trauma are about bony anatomic relationships, the role of MRI remains limited.

## ***EMERGENT IMMOBILIZATION OF THE UPPER CERVICAL SPINE***

Patients who have sustained high-velocity vehicular injury, or those who are suspected of having a spine injury, will usually present to the emergency facility immobilized in a collar and on a spine board. Continue this immobilization until the spine has been cleared or until definitive immobilization and treatment can be instituted. Most upper cervical spine injuries in patients without neurologic deficit can be continuously immobilized in a collar until evaluation by CT scan and MRI is completed. Thus, a neurologically intact patient with a posterior arch fracture who is suspected of having a Jefferson fracture may undergo a CT scan using collar immobilization. In contrast, some place patients with transverse ligament rupture and a Brown–Séguard lesion in traction immobilization before initiating any further radiologic studies. It is our preference to keep the patient immobilized in a Philadelphia collar or Miami J collar and not to convert the patient to traction until the workup is completed. This makes transfer into the imaging machinery easier. With transfer in and out of a CT scanner or MRI machine, any traction will generally need to be discontinued several times, with some additional risk to the patient. Furthermore, it is critical with certain injuries, such as traction injuries to the upper cervical spine, that traction not be applied at all. If this mechanism is not recognized, even traction weights as small as 10 lb can cause stretching of the brain stem or cord with additional neurologic injury.

Next, decide what type of traction immobilization to apply once the radiologic examination is completed. The decision depends on two factors: What personnel are available to apply the traction device? What is the goal of applying the device to the patient? It is far simpler and more expeditious in the emergency setting to place Gardner–Well tongs, because this procedure can be done accurately by one person in a very short period of time and with minimal movement of the patient. Placement of a halo ring requires precise positioning of the patient and a surgeon and an assistant to make sure that the ring is applied properly. If the goal is simply to apply a traction force to either reduce or stabilize an injury before surgery, in which the surgical procedure will give definitive stabilization not requiring postoperative immobilization in a halo vest, Gardner–Wells tong traction is preferred. In contrast, in injuries that require initial reduction by traction and that will either be treated definitively in a halo vest or treated by surgery most likely will require additional postoperative immobilization in a halo vest, initial placement of a halo is appropriate. A third group of patients—those with distraction injuries to the cervical spine, such as occiput–C1 dissociations or type IIA traumatic spondylolisthesis of the axis—will be placed in a halo and then immediately in a halo vest for stabilization. No traction is indicated in either of those injuries but ensuring stability is important.

Decide whether the halo can be placed with the patient in a supine position or whether the erect position is safe, which simplifies the placement. Patients with grossly unstable injuries or multiple injuries cannot tolerate a sitting position, and thus require application in the supine position using a head-positioning apparatus and an open ring halo to allow accurate placement. In those patients who have an isolated upper cervical spine injury, such as a minimally displaced dens fracture, the halo ring can be applied by applying a cervical collar and placing the patient in the sitting position, for placement of the ring and, subsequently, the vest.

## Application of Skull Tong Traction

- Apply cervical tongs, such as Gardner–Wells tongs, in the supine position. Cleanse the hair directly above the external auditory meatus of the ear with povidone-iodine (Betadine) solution, but shaving the patient's hair is not necessary.
- Place the sterile pins through the ring and insert at a site directly superior to the external auditory meatus and one fingerbreadth above the pinna. Before application of the tong, inject the area down to the periosteum of the skull with 1% lidocaine, usually with epinephrine (1:100,000).
- Do not incise the skin. Tighten the pins simultaneously and, depending on the manufacturer's recommendations, bring the pressure indicators either to the level of outer surface of the pin or approximately 1 mm beyond.
- The initial traction weight in an adult is generally 10 lb, but before adding any weight, ascertain that the injury will not be made worse by traction.
- Increase the weights incrementally and obtain an appropriate radiograph between each increase to ensure that overdistracted is not occurring.

Although the general formula of 5 lb (2.3 kg) per cervical level above the fracture, with an initial 10 (4.6 kg) to 15 lb (6.8 kg) to overcome the friction of the head on the bed has been suggested, this is often not enough to reduce

P.3670

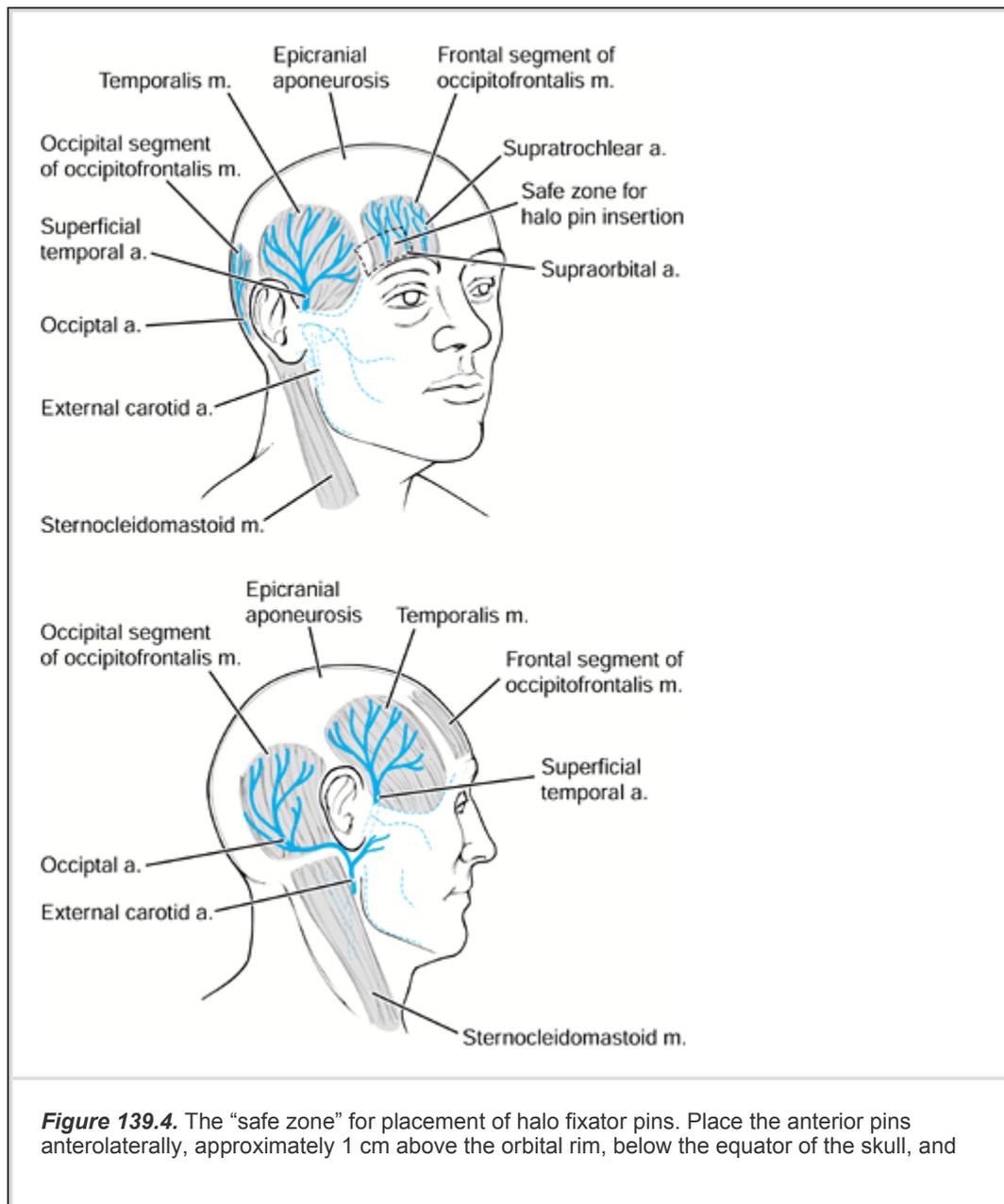
certain cervical spine injuries. The weight in certain types of traumatic spondylolisthesis as well as Jefferson's fractures will need to be increased to as much as 30 lb (13.6 kg) before an acute injury can be reduced. Between each 5 lb (2.3 kg) increment, however, appropriate radiographic evaluation is critical.

## Application of a Halo Vest

Placement of a halo and subsequently a halo vest is more difficult and requires at least two people.

- Before placing the ring, measure the head and torso and size for the halo and vest according to the manufacturer's instructions.

- Place the patient in the supine position or an operating table and use either a mechanical head holder or positioner, or apply the halo with the patient in the sitting position.
- Select the pin sites carefully; four pin sites are adequate in the adult, but more may be needed in the elderly patient with a thin skull or in the child.
- The preferred sites for halo insertion have been determined by a series of radiographic, cadaver, and clinical studies (36): Anteriorly place the pins approximately 1 cm superior to the orbital ridge, below the equator of the skull, and over the lateral two-thirds of the orbit. This will generally avoid the temporalis muscle, the supra-orbital branch of the trochlear nerve, and the frontal sinuses (Fig. 139.4).



cephalad to the lateral two thirds of the orbit. The safe zone avoids the temporalis muscle and fossa laterally, and avoids the supraorbital and supratrochlear nerves and the frontal sinus medially. (Redrawn from Ballock RT, Botte MJ, Garfin SR. Complications of Halo Immobilization. In: Garfin SR, ed. *Complications of Spine Surgery*. Baltimore: Williams & Wilkins, 1989, with permission.)

- Place the pins as far laterally as possible to minimize prominent scarring. Avoid placement within the temporalis muscle and fossa because it is particularly painful with motion and could cause significant bleeding; in addition, the area has a very thin cortical base, making perforation more common.
- The posterior sites are less critical and are generally placed at 180° on the contralateral side. Any area 2 to 3 cm posterior to the edge of the pinna of the ear is generally satisfactory. Shave the areas so that hair is not trapped as the pin is placed.
- Prepare and anesthetize each pin site by passing the needle for the local anesthetic through the selected hole or from above the halo to the exact contact point on the skin. Infiltrate the skin and deep tissues down to the skull.
- Ask the patient to close his or her eyes, and then make a small vertical incision with a #11 blade, directly in line with the selected screw holes. Some surgeons place the pins without using skin incisions (10). Place the four pins through the halo and screw them into the small incisions. Tighten the pins in a sequential fashion so that the halo is not shifted by overtightening one side before tightening the other.
- Tighten the pins in 2-inch-pound increments to a maximum of 8 inch-pounds in the normal adult skull. Tighten to lower levels when multiple pins are used in either the child or the osteoporotic elderly adult (9). Although 6 inch-pounds were initially used, 8 inch-pounds appears to have a lower rate of complications in terms of loosening and infection (9).
- Once the optimal torque is achieved with a torque screwdriver or a disposable wrench, place lock nuts over the pins and tighten them to prevent backing out of the pins.
- Apply traction through the halo ring using a bale, or

---

 P.3671

the halo can now be connected to a vest. After applying a halo vest in the supine position, mobilize the patient to an upright position and recheck the halo vest.

- Now check the reduction of the cervical spine with a radiograph with the patient supine, if applied in the supine position, and then obtain a second radiograph in the upright position to be certain that the reduction does not shift. Obtain another upright roentgenogram 24 hours after the patient is allowed to ambulate, to ensure the maintenance of position. Subsequent adjustments to the halo, in terms of position of the fracture, should be done in the upright position for optimal vest fit.

- With a torque wrench, retighten all four pins in the halo at 24 hours back to 8 inch-pounds. Teach the patient to cleanse the pin sites daily and to inspect for any problems.

## **CLASSIFICATION, PATHOLOGY, AND TREATMENT OF UPPER CERVICAL SPINE INJURIES**

Bony and ligamentous injuries can be classified in a number of different ways, although it is probably easiest to classify them by level as opposed to any type of mechanistic classification (Table 139.1).

<ul style="list-style-type: none"> <li>• <b>Occiput-cervical injuries</b> <ul style="list-style-type: none"> <li>Occipital</li> <li>Condyle fracture</li> <li>Occipital-cervical ligamentous injury</li> </ul> </li> <li>• <b>C-1 injuries</b> <ul style="list-style-type: none"> <li>Posterior ring fractures</li> <li>Lateral mass fractures</li> <li>Jefferson fracture</li> <li>Avulsions of the anterior ring</li> </ul> </li> <li>• <b>C1–C2 injuries</b> <ul style="list-style-type: none"> <li>Rotational (atlantoaxial rotatory) instability</li> <li>Transverse ligament injuries (with atlantoaxial instability)</li> </ul> </li> <li>• <b>C-2 injuries</b> <ul style="list-style-type: none"> <li>Dens fracture</li> <li>Traumatic spondylolisthesis</li> <li>Extension teardrop fracture</li> </ul> </li> </ul> <hr/> <p><i>Table 139.1. Classification of Injuries by Cervical Level</i></p>
--

### **Occipital–Cervical Injuries**

Injuries involving the occipital–cervical junction are extremely rare and often are fatal. This group of injuries includes dislocations that can occur with or without occipital condyle fractures, as well as occipital condyle fractures that occur without any subluxation. In addition, there are pure distraction injuries at the occipital–cervical junction. These are the most commonly fatal. These injuries may be overlooked in the acute emergency because they are uncommon and difficult to diagnose on plain roentgenograms. Many of these injuries are found only at autopsy (3). The injuries are commonly associated with other noncontiguous cervical spine fractures and with head injuries. The presence of a high-level neurologic deficit, often with involvement of all four extremities plus abnormal respiratory function, known as “pentaplegia,” is a tipoff to injury at the occipital–cervical junction. As a

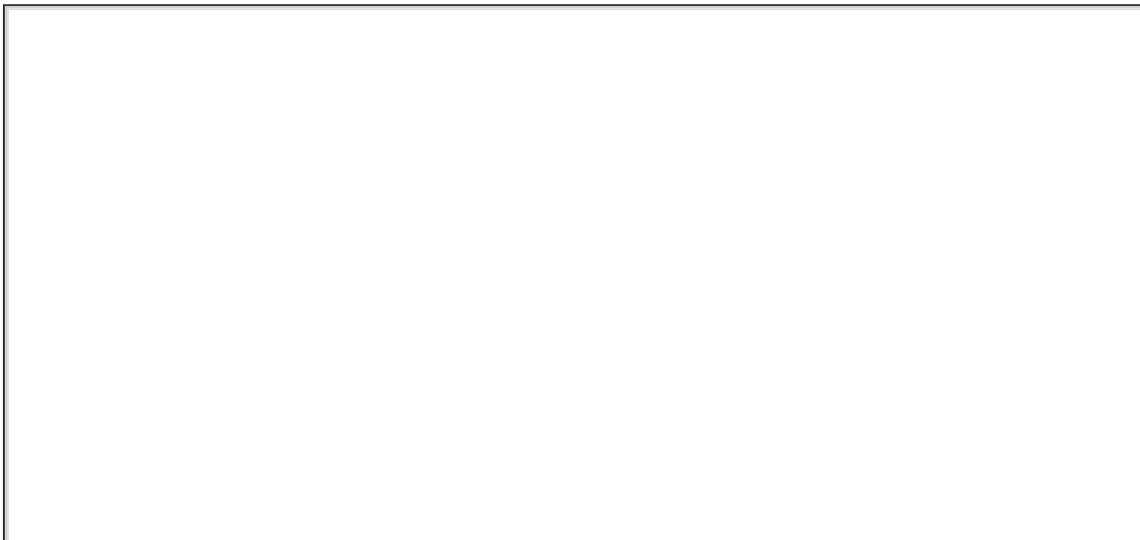
group, these injuries most commonly result from high-speed motor vehicle accidents or are found in pedestrians struck by motor vehicles (3,4,51,53,56,78,86). The cause of death may be due to the associated head injury or sudden loss of voluntary respiratory function because of brain stem injury from the occipital–cervical dissociation (53).

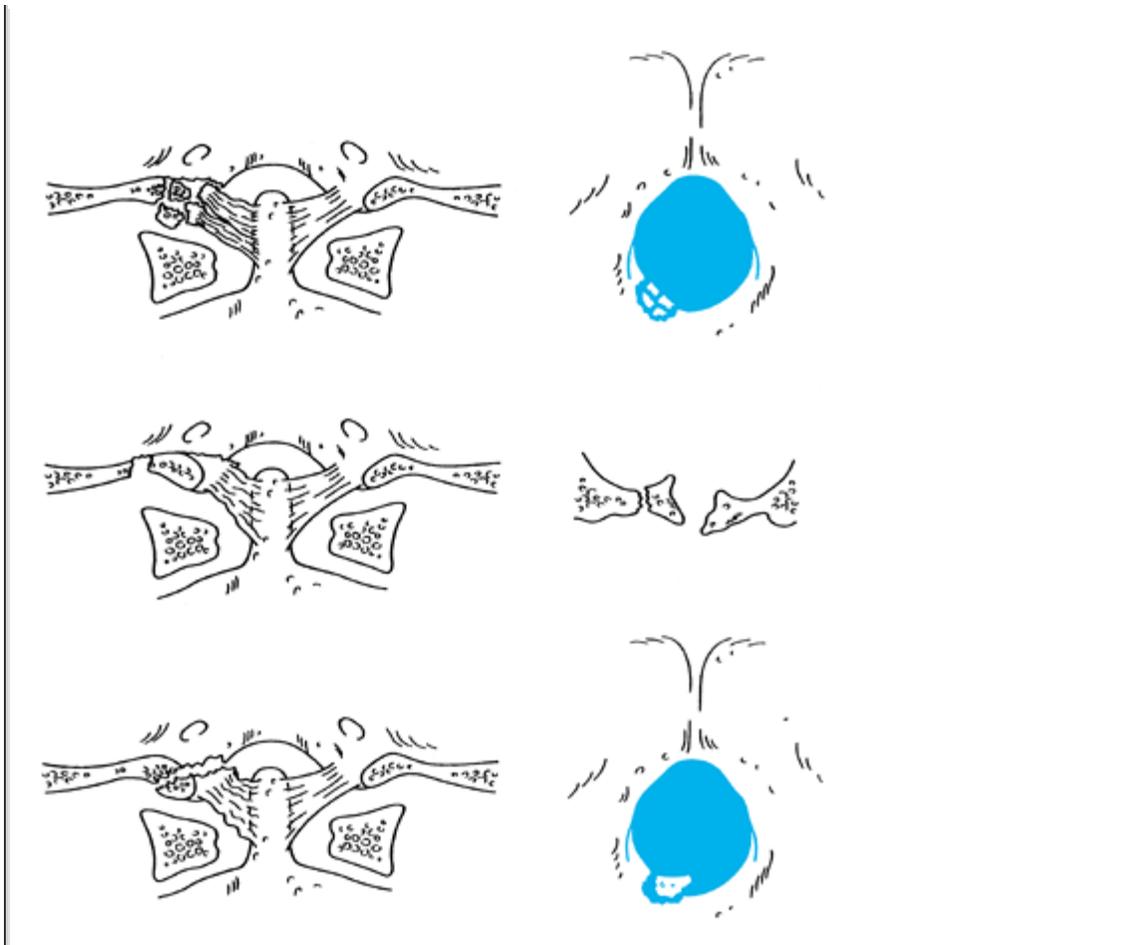
Patients with isolated occipital condyle fractures have a higher rate of survival than occipital–cervical dissociations or dislocations. Patients may present with cranial nerve involvement as well as persistent occipital headaches. The mechanism of injury of all occipital condylar fractures is believed to be either sudden deceleration or direct axial loading on the cranium. Occipital–cervical dislocations can occur as a result of violent hyperextension or distraction forces in which the torso is pinned in position and the distraction force applied to the neck by a force applied beneath the patient's chin. Occipital condyle fractures have been characterized by Anderson and Montesano (4) (Fig. 139.5). A type I fracture (Fig. 139.5A) is a unilateral undisplaced, comminuted fracture of the condyle, usually resulting from axial impact between the skull and the axis. The alar ligament may be disrupted on that side, but the segment is usually stable. A type II fracture (Fig. 139.5B) is a unilateral occipital condyle fracture that is associated with a basilar skull fracture on the same side. The mechanism is generally axial loading with lateral bending, and this injury is generally stable. Type I and II injuries can be treated nonoperatively using a rigid cervical orthosis for 6 to 8 weeks; halo mobilization is not generally required. The type III fracture (Fig. 139.5C) is a unilateral alar ligament avulsion from the occipital condyle. It occurs as a result of extreme lateral bending, rotation, or a combination of the two. This injury, because it has a ligamentous component, may be associated with atlanto-occipital dislocations. Type III fractures may be unstable. Treatment is based on the degree of instability, ranging from collar immobilization, to halo immobilization, to posterior occipital–cervical fusion if associated disruption of the occiput–C1 complex is significant. Perform flexion-extension radiographs at the end of nonoperative management to assess the degree of stability. At that

---

P.3672

point, abnormal motion can be considered evidence of either nonunion or nonhealing of the ligamentous injuries, which requires treatment with an occipital–cervical fusion. Occipital condyle injuries are commonly unilateral but may be bilateral as well.

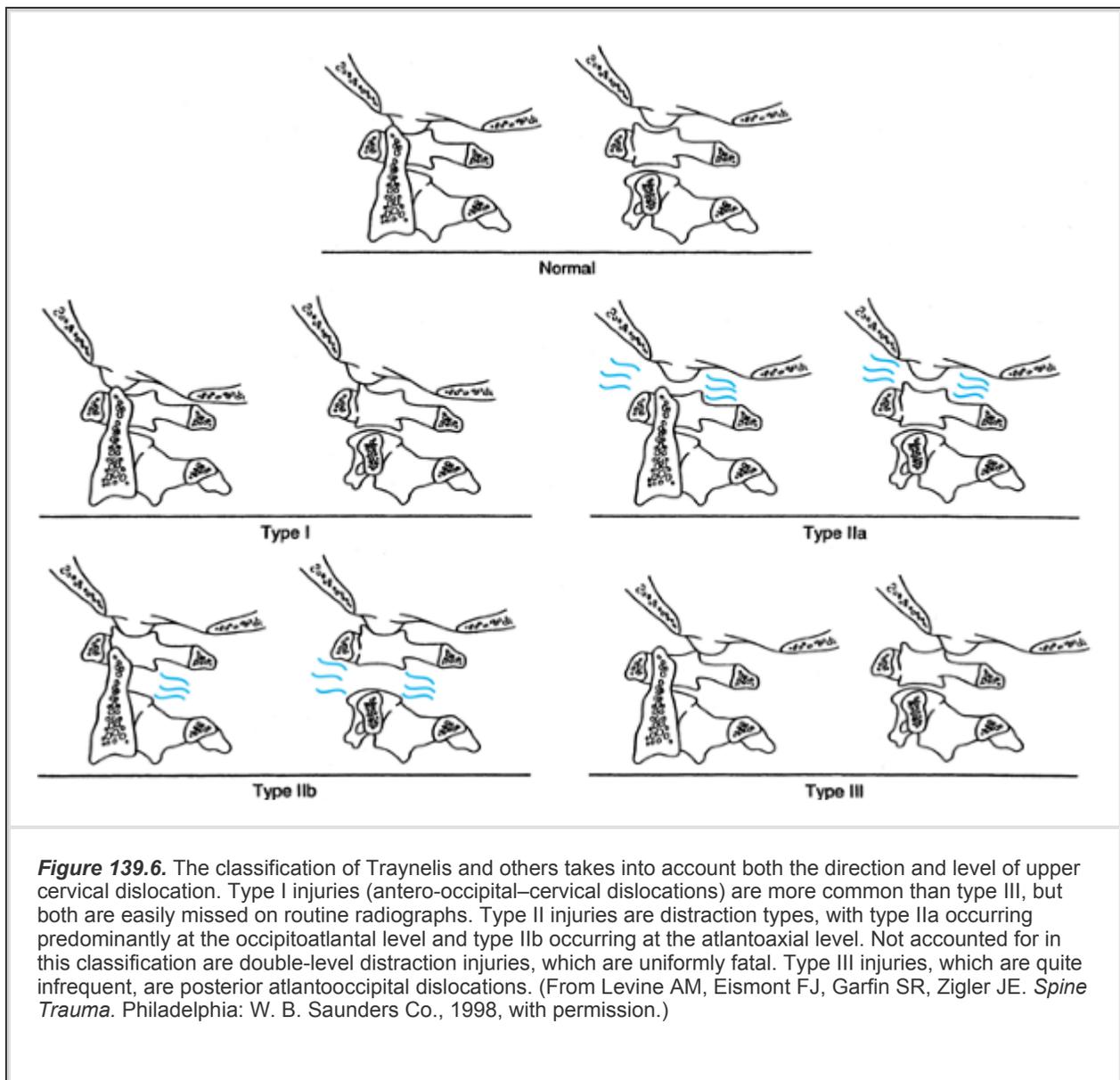




**Figure 139.5.** The classification of Anderson and Montesano describes three basic types of occipital condyle fractures. **A:** An impaction-type fracture, which is usually the result of an asymmetrical axial load to the head; it may be associated with other lateral mass fractures in the upper cervical spine. **B:** A basilar skull-type occipital condyle fracture. **C:** An avulsion-type occipital condyle fracture, which may be the result of a distraction force applied through the alar and apical ligament complex. (Redrawn from Anderson P, Montesano P. Morphology and Treatment of Occipital Condyle Fractures. *Spine* 1988;13:731, with permission.)

Occipital–cervical subluxations and dislocations have been incorporated into a single classification described by Traynelis et al. (86) (Fig. 139.6). Type I injuries are anterior dislocations and generally have the highest survivability. Type II injuries demonstrate vertical displacement, usually from a distraction mechanism: type IIa injuries occur at the occipital–cervical junction, and type IIb injuries occur between the atlas and axis. In some cases, these injuries may be combined injuries. When there is greater than 2 mm of vertical displacement between the occiput and C-1 (IIa), a rupture of the tentorial ligament and alar ligaments must be suspected. At the C1–C2 level (IIb), the joint capsule is usually involved as well as the tentorial membrane and the alar ligaments. Injuries to the transverse ligament can also occur. Type II injuries should not be placed in longitudinal traction. Type III injuries are posterior dislocations and are often fatal, although accompanying fracture of the C-1 arch may increase the chance of survival. Types I and III injuries may be realigned

initially using traction, although the degree of ligamentous disruption is difficult to assess initially. Traction should be used only in type I and type III injuries, with traction restricted to between 2 (0.9 kg) and 5 lb (2.3 kg). Interestingly, gravity itself is usually sufficient to reduce any translation. Increased survival has been reported with traction (26). After closed reduction is achieved, immediately place the patient in a halo vest and obtain a CT scan to identify any fractures. After this assessment, treat only patients with minimal ligamentous destruction and minimal bony disruption definitively in a halo vest for a period of 3 months. At the conclusion of that time, perform flexion-extension roentgenograms to check stability and decide whether a occipital–cervical fusion is necessary based on the degree of residual translation.

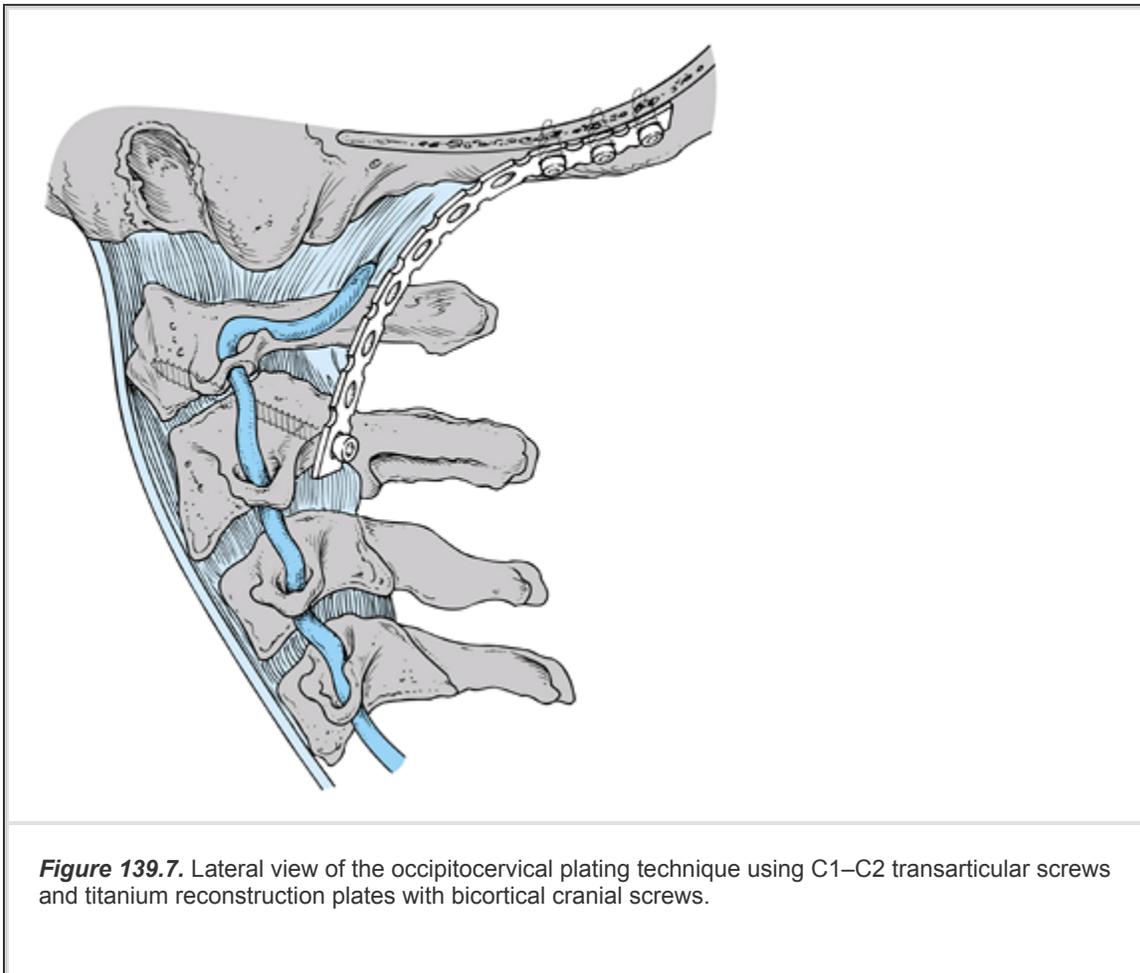


### Posterior Occipital Fusion

In most cases, however, these are extremely unstable injuries and a posterior occipital–cervical fusion is indicated. Various techniques have been used to achieve an occipital–cervical fusion. The most rigid fixation involves the use of a contoured plate secured with multiple occipital screws and a C1–C2 transarticular screw (24,38,39) (Fig. 139.7). Techniques for occipital–cervical wiring, described by Wertheim and Bohlman (90), require postoperative immobilization in a halo vest, but in their series, all 13 patients developed a

P.3673

solid arthrodesis. Other techniques using corticocancellous struts wired into the skull and beneath the spinous processes of C-1 and C-2 similarly have had high rates of union with minimal loss of fixation in patients treated postoperatively in a halo vest. A contoured occipital–cervical rod has also been described by a number of authors, giving additional stability that is not provided by bone graft alone (73,79). Irrespective of the type of construct, overall fusion rates for occipital–cervical fusions, when properly immobilized postoperatively, are in excess of 90%.



The advantage of occipital–cervical fusion with two plates and screws is that there is no need for halo immobilization.

- With the patient in the traction applied at the time of admission, perform an awake

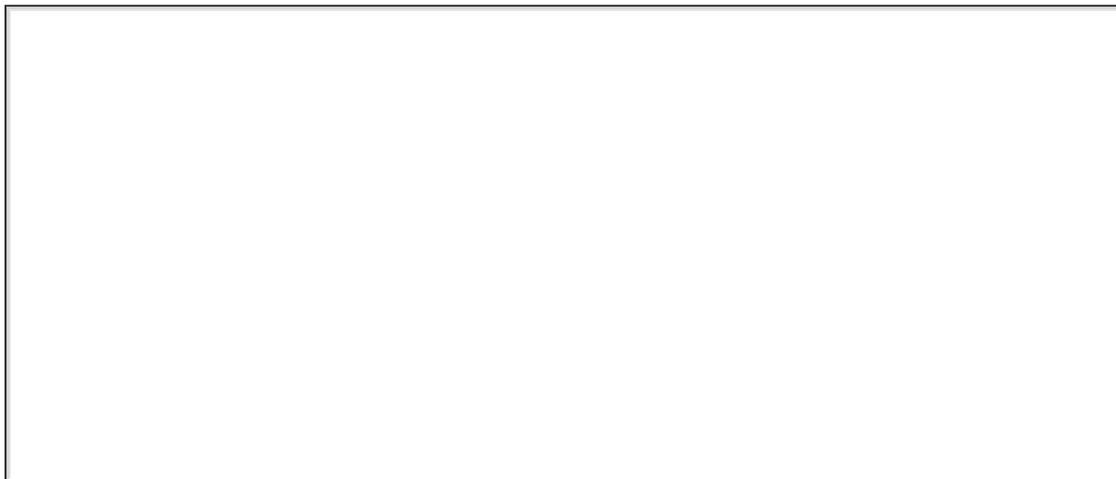
fiberoptic intubation. Then turn the patient into the prone position while still awake.

- Use a three-pin Mayfield (Ohio Medical Instrument Co., Inc., Cincinnati, OH) or halo modified headrest to secure the head. Induce general anesthesia once appropriate positioning is obtained and the patient's neurologic status is reassessed and found to be unchanged.
- Any manipulation of the head is done before inducing general anesthesia. Avoid extreme positions of flexion or extension because the plate fixation is rigid.
- Set up fluoroscopy so that AP and lateral images can be easily obtained, preferably simultaneously with two machines.
- Before incision, hold a guidewire alongside the neck

P.3674

and visualize it on a fluoroscope to be sure that the C1–C2 transarticular screw can be placed with the patient as positioned. This technique generally cannot be accomplished in patients with an upper thoracic kyphosis or gibbous.

- Make a posterior incision from the occipital prominence and extend it to the midcervical spine. Elevate all soft tissue off the bone from the greater occipital prominence to the C2–C3 joint.
- Select two plates with appropriate hole spacing and then contour them to fit the occipital–cervical junction, with at least three fixation holes available in the occiput and extending far enough distally to allow a C1–C2 transarticular screw to be placed on each side.
- Take care in contouring the occipital portion of the plates so that the terminal end is not prominent and the screw fixation is on the undersurface of the occiput rather than on its most prominent posterior portion.
- After templating and drilling the C1–C2 transarticular screw according to the technique described by Magerl and Seemann (Fig. 139.7 and Fig. 139.12) (59), select the appropriate-length screw, place the plate into position, and pass the transarticular screw through the plate, tightening it so that the plate lies in the appropriate position against the occiput on one side.





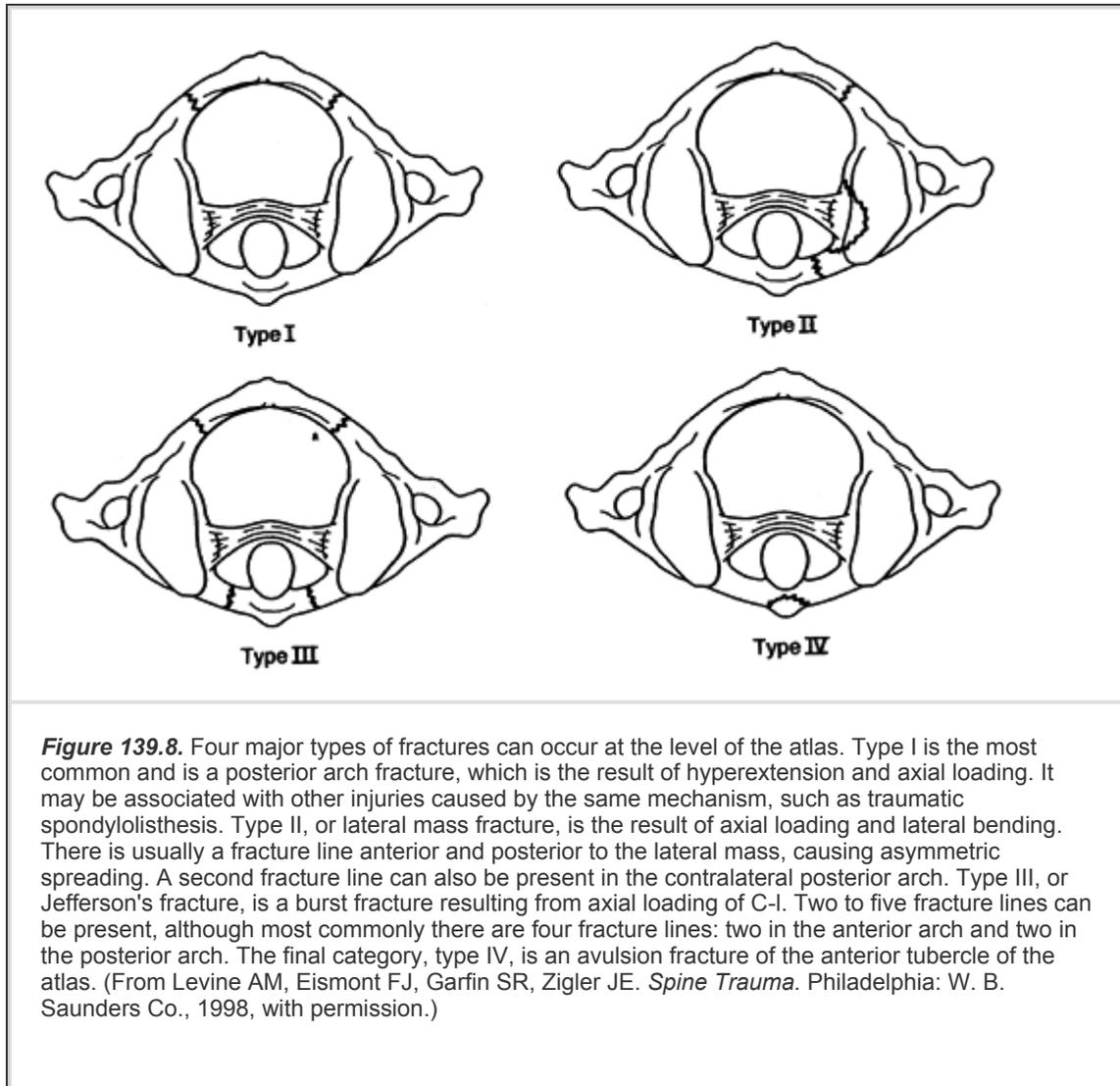
**Figure 139.12.** The C1–C2 fusion technique of Magerl. **A1, A2, B to F:** The surgical technique; see text for details. **G:** Lateral view of the completed fixation. [Redrawn from (parts **C** and **G**) the Barrow Neurological Institute, Phoenix, AZ and (parts **A** and **B**, and **D** to **F**) from Levine AM, Eismont FJ, Garfin SR, Zigler JE. *Spine Trauma*. Philadelphia: W. B. Saunders Co., 1998, with permission.] The C1–C2 fusion technique of Magerl. **A1, A2, B to F:** The surgical technique; see text for details. **G:** Lateral view of the completed fixation. [Redrawn from (parts **C** and **G**) the Barrow Neurological Institute, Phoenix, AZ and (parts **A** and **B**, and **D** to **F**) from Levine AM, Eismont FJ, Garfin SR, Zigler JE. *Spine Trauma*. Philadelphia: W. B. Saunders Co., 1998, with permission.]

- Then place the occipital screws using three bicortical screws per side. The screws are typically between 6 and 12 mm in length. In older patients, the dura may be adherent to the inner surface of the skull, causing a small cerebrospinal fluid (CSF) leak, but this can be easily stopped by simply placing the screw in the hole.
- Then apply the second plate in a similar fashion.
- Fashion a corticocancellous graft to lie between the two plates, covering the posterior portion of the occiput, the posterior arch of C-1, and around the spinous process of C-2. Hold this graft in place using heavy suture or wire.
- If transarticular screw fixation cannot be achieved because of the patient's position, alternatively, a C-2 pedicle screw can be placed, generally in combination with a C-3 lateral mass screw and a wire or suture placed around the arch of C-1 and tied to the plate on either side.
- Immobilize the patient postoperatively in a rigid collar for 12 weeks. While the patient is in the collar, be certain that he does not develop an occipital decubitus either because of the cervical spine trauma resulting in anesthesia in the area of the greater occipital nerve or as a result of the surgical dissection.

## Fractures in the Atlas (C-1 Injuries)

Almost 50% of fractures involving the atlas are associated with a second fracture, and approximately 25% of them are associated with noncontiguous second fractures. The two most common types of fractures associated with a fracture of the atlas are fractures of the dens (27,55,58) or type I traumatic spondylolisthesis (55). Because the majority of injury patterns for fractures of the atlas involve widening of the space available for the cord rather than narrowing of the canal area, these injuries are not generally associated with neurologic deficit. If a deficit is present, its etiology may be from another associated or nonassociated spine or head injury. Multiple types of fractures of the C-1 arch have been identified (Fig. 139.8). The initial description of fractures of the C-1 arch was by Jefferson (48,49). He described isolated fractures of the posterior arch as well as multiple fractures of the arch, although his name is most associated with the four-part fracture. Segal et al. (77) have actually identified six different fracture patterns. However, the most common injury type is the posterior arch fracture. This is thought to be the result of a hyperextension-axial loading injury in which the posterior arch is pinched between the

occiput and the ring of C-2 (92). These fractures tend to occur at the area just behind the lateral mass where the vertebral artery passes over it. Associated with this hyperextension-axial load mechanism of injury are other fractures that have a similar mechanism, such as posteriorly displaced dens fractures, type I traumatic spondylolisthesis of the axis, and C-2 anterior extension teardrop fractures.



The second most common type of injury, the lateral

P.3675

mass fracture, is generally composed of a fracture anterior to the lateral mass and one posterior to the lateral mass. In some instances, there may also be a fracture through the posterior arch on the contralateral side (42,55). These fractures have the same degree of instability, whether they are two-part or three-part injuries. The mechanism of injury is an axial load with lateral bending. The presence of a second fracture on the contralateral side would suggest at least some slight extension associated with this injury. In addition, the most common fracture occurring in association with this type is a lateral mass fracture in the lower cervical spine, which also has the same mechanism of extension, axial loading,

and lateral bending.

The third type of fracture is what has been called the Jefferson fracture, which is a classic bursting injury of the ring of C-1. It has variably been described as having two fractures, one in the anterior arch and one in the posterior arch; or having three fractures, one in the anterior arch and two in the posterior arches; or having four or five fractures, with at least two in the anterior arch and two in the posterior arch. On open mouth radiograph view, this generally shows symmetric displacements of the lateral masses of C-1 (43,48,49,55,77). The injury is believed to be the result of axial loading applied to the skull. Because the lateral masses of C-1 are wider laterally than medially, they act like a wedge when they are axially loaded, driving the lateral masses laterally and disrupting the ring. Splaying of the lateral masses more than 6.9 mm on an open mouth view may indicate disruption of the transverse ligament (80).

The fourth type of fracture is an avulsion fracture off the inferior portion of the anterior tubercle of C-1, where the longest colli muscle inserts. It is generally the result of hyperextension and, therefore, is an avulsion injury. It is completely stable (83). The final type of injury is a transverse process fracture, which may be either unilateral or bilateral (15).

In general, isolated posterior arch fractures can be treated nonoperatively with 6 to 12 weeks of immobilization in a hard collar. Nonunion is exceedingly rare (55,77). Patients who have a dens fracture in association with a posterior arch fracture cannot be stabilized by standard C1–C2 wiring techniques. Without the integrity of the posterior arch, either an anterior dens screw or a posterior transarticular C-1 atlantoaxial arthrodesis may be necessary when operative treatment is indicated. Avulsions

---

P.3676

from the anterior tubercle and transverse process fractures can be treated symptomatically with simple collar immobilization until pain relief is achieved.

Lateral mass and Jefferson's fractures can be divided into two groups: those that are only minimally to moderately displaced (less than 7 mm total displacement on an open mouth view) and those that are more significantly displaced. Controversy remains concerning the most effective treatment for these injuries. For minimally to moderately displaced fractures, the transverse ligament is intact. Immobilization in a hard collar for less significantly displaced injuries or immobilization in a halo vest for more significantly displaced injuries appears to give adequate long-term results. The most common complications of treating these patients is symptomatic nonunion (77) in those patients who have displaced fragments of the ring that do not unite. If the fragments are symptomatic, they may require arthrodesis. Remember that the halo and vest cannot be expected to reduce the ring fragments, even with traction. Once traction is removed, the original displacement will recur. Thus, placing the patient in traction for several days before immobilizing the patient in a halo vest does not improve the degree of displacement (42,94).

Patients who have had rupture of the transverse ligament and, therefore, more than 7 mm displacement on an open mouth radiographic view can be treated in one of two ways. Although it was initially thought that these patients would have long-term instability without surgical intervention, on the basis of the apparent rupture of the transverse ligament (75),

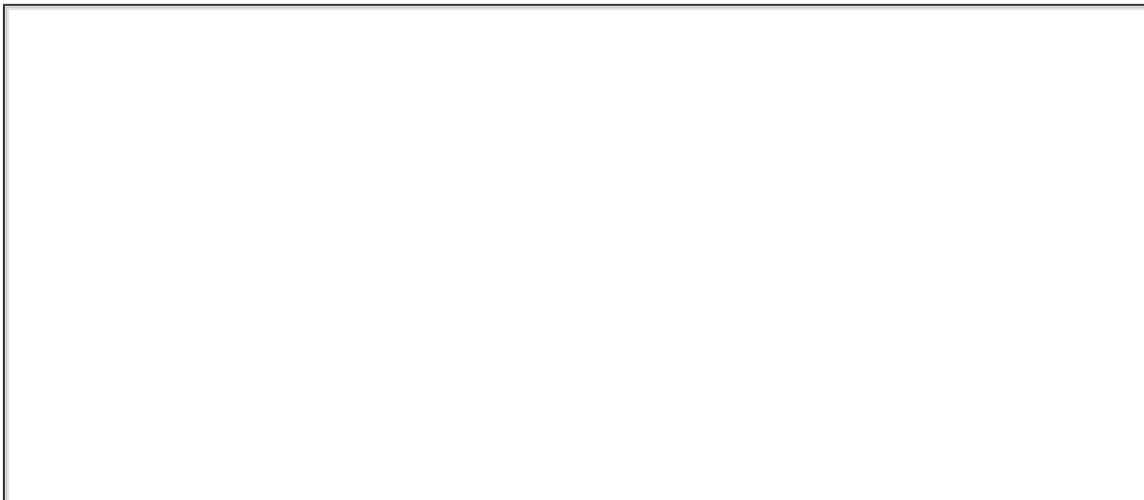
this has turned out not to be the case (51). Thus, if the patient can achieve union of the ring of C-1, the degree of instability, after treatment, is limited. As demonstrated earlier by Fielding (29), this is because only the transverse ligament is ruptured, and the alar, apical, and accessory ligaments as well as the joint capsule are still intact and providing sufficient stability. Thus, the degree of C1–C2 instability is minimal when the ring heals solidly (55). Therefore, patients can be treated with enough longitudinal traction to reduce the splaying of the lateral masses to anatomic position and then held in longitudinal traction until early healing takes place (approximately 6 weeks). Once preliminary healing has occurred, the patient can be mobilized in a halo vest for an additional 6 weeks without risk of loss of reduction.

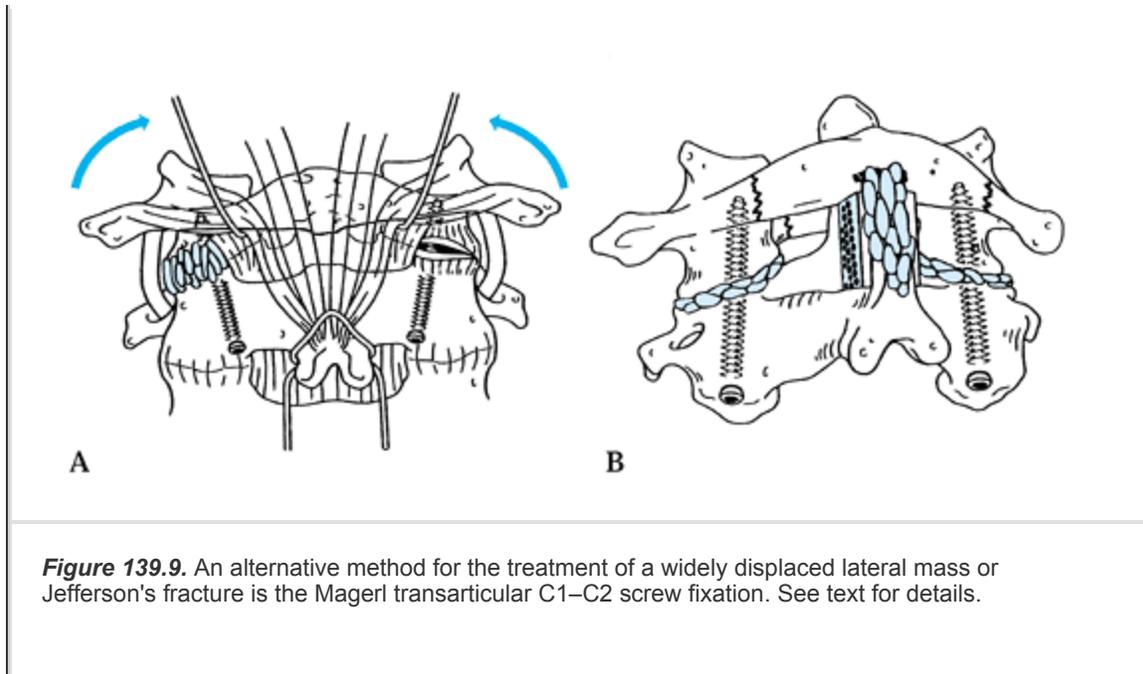
If, however, the reduction is achieved initially and then the patient is immediately mobilized (within the first week), reduction will be lost. Because of the long hospitalization required, long-term traction is less popular than it was previously. In addition, if the patient cannot be left in a supine position on a Stryker (Stryker Corp., Kalamazoo, MI) frame for long periods of time, operative treatment for significantly displaced fractures may be indicated.

In that case, reduce the ring with axial traction and then perform a C1–C2 transarticular screw fixation (62).

### ***Posterior C1–C2 Arthrodesis, Modified Magerl Technique***

The treatment of a widely displaced lateral mass or Jefferson's fracture is the modified Magerl transarticular C1–C2 screw fixation. The technique, however, has to be modified over that originally described by Magerl and Seemann (Fig. 139.9) (59) because a considerable portion of the stability of the technique is with the bone block that is usually placed between the intact posterior arch of C-1 and the spinous process of C-2. Because a Jefferson's fracture has an incompetent C-1 arch, additional stress is placed on the screws, risking early failure of fixation. Therefore, denude the cartilage of the facet joints, and pack bone directly into the posterior aspect of the C1–C2 joint. Also, place graft between the ring of C-1 and C-2, recognizing, however, that its structural integrity is compromised. Postoperatively, additional immobilization may be necessary in the form of a rigid collar or a halo vest, depending on the original degree of instability, the quality of the patient's bone, and the quality of the fixation.





**Figure 139.9.** An alternative method for the treatment of a widely displaced lateral mass or Jefferson's fracture is the Magerl transarticular C1–C2 screw fixation. See text for details.

P.3677

- Reduce the fracture with halo traction using about 30 to 35 lb (13.6 to 15.9 kg) of traction to achieve an anatomic reduction, which makes placement of the screws relatively straightforward. Further reduction is not possible once operative stabilization has begun. Use a biplanar fluoroscope imaging.
- The only variation in the standard technique is that the joints are fully exposed (Fig. 139.9A) so that the cartilage can be curetted out for fusion, and no fixation of bone graft is possible between the fractured arch of C-1 and the lamina of C-2.
- Graft directly into the facet joints and also do an onlay graft from C-1 to C-2 (Fig. 139.9B) so that as healing occurs, a solid arthrodesis will also occur. With satisfactory screw fixation, either the halo vest can be continued postoperatively or hard collar can be used.

In patients treated with arthrodesis who attain a satisfactory fusion, long-term results in terms of stability are excellent. In patients with relatively undisplaced lateral mass fractures and Jefferson's fractures treated only in a collar or halo vest, late instability is rare if union is achieved between all fragments (55,77). The motion between C1–C2 however rarely returns to normal. In the Levine and Edwards series (55), up to 80% of patients had some residual neck pain, although none required secondary fusions for neck pain (55). The significant joint incongruity and resultant degenerative changes in fractures that are significantly displaced at the conclusion of treatment will commonly lead to pain and secondary occipital cervical fusion. In one study, nonunions occurred in 17% of patients (77), and nonunion was directly related to the amount of displacement. Patients with a nonunion and displacement of the posterior arch could sustain neural compression on the basis of the displaced fragment, but this is a rare complication.

## Atlantoaxial Instability (C1–C2 Injuries)

Atlantoaxial instability may occur secondary to trauma, congenital abnormalities, infection, and arthritis. Traumatic atlantoaxial instability can be of two types. It can be related to flexion instability with anterior translation of the atlas on the axis resulting from rupture of the transverse ligament and disruption of the secondary stabilizers—the alar, apical, and accessory ligaments. The second type of atlantoaxial instability is a rotatory instability, which can be of several different types and be the result of both bony and ligamentous injuries. The transverse ligament is the primary stabilizer, preventing anterior translation of C-1 on C-2, but the alar, apical, and accessory ligaments, as well as the capsular ligaments, offer secondary stabilization. Posterior translation of C-1 on C-2 is prevented by the impingement of the anterior ring of C-1 on the dens. As shown by early work by Fielding et al. (29), a maximum of 3 mm of anterior translation of C-1 on C-2 can occur with an intact transverse ligament in the adult. Within the range of 3 to 5 mm of translation, catastrophic failure occurs, usually within the midsubstance of the ligament rather than at the bony attachments. No correlation has been made between the strength of the transverse ligament and age other than that children tend to be slightly more lax and, therefore, an ADI of 5 mm of translation can be accepted in children as normal. Simple experimental sectioning of the transverse ligament without disruption of the alar, apical, and accessory ligaments results in an ADI of only 5 mm in the adult in the experimental setting (29). In patients with gross instability with an ADI greater than 10 mm, not only does the transverse ligament need to be sectioned but all of the secondary restraints as well.

Most of these injuries are the result of significant trauma to the head, although they may occur in older patients with a simple fall and striking of the occiput. Patients may have varying neurologic involvement, from being neurologically normal with severe neck pain to a transient quadriplegia to a Brown–Séguard–type syndrome. The diagnosis of this injury is generally made on a lateral roentgenogram. If roentgenograms are taken in the supine position, the subluxation may reduce, especially in a patient whose chest is disproportionately large in relation to his or her head, thus placing the patient in extension, as is frequently the case with children. If the patient does not have neurologic deficit and injury is suspected, physician-supervised flexion-extension films in the alert, awake, neurologically intact, cooperative patient may be very helpful in making the diagnosis. In contrast, if the patient has severe neck pain and paraspinous muscle spasm, adequate-quality flexion-extension films may not be attainable. There may not be enough motion in the cervical spine to indicate whether the patient has instability. In that case, several options are available. The patient may be simply immobilized in a hard collar, and when the spasm subsides, adequate flexion-extension films can be obtained. Alternatively, under physician supervision, the amount of spasm in the paraspinous musculature can be reduced by intramuscular injection, allowing flexion-extension roentgenograms to be taken. An MRI may be used to investigate the integrity of the ligamentous complex.

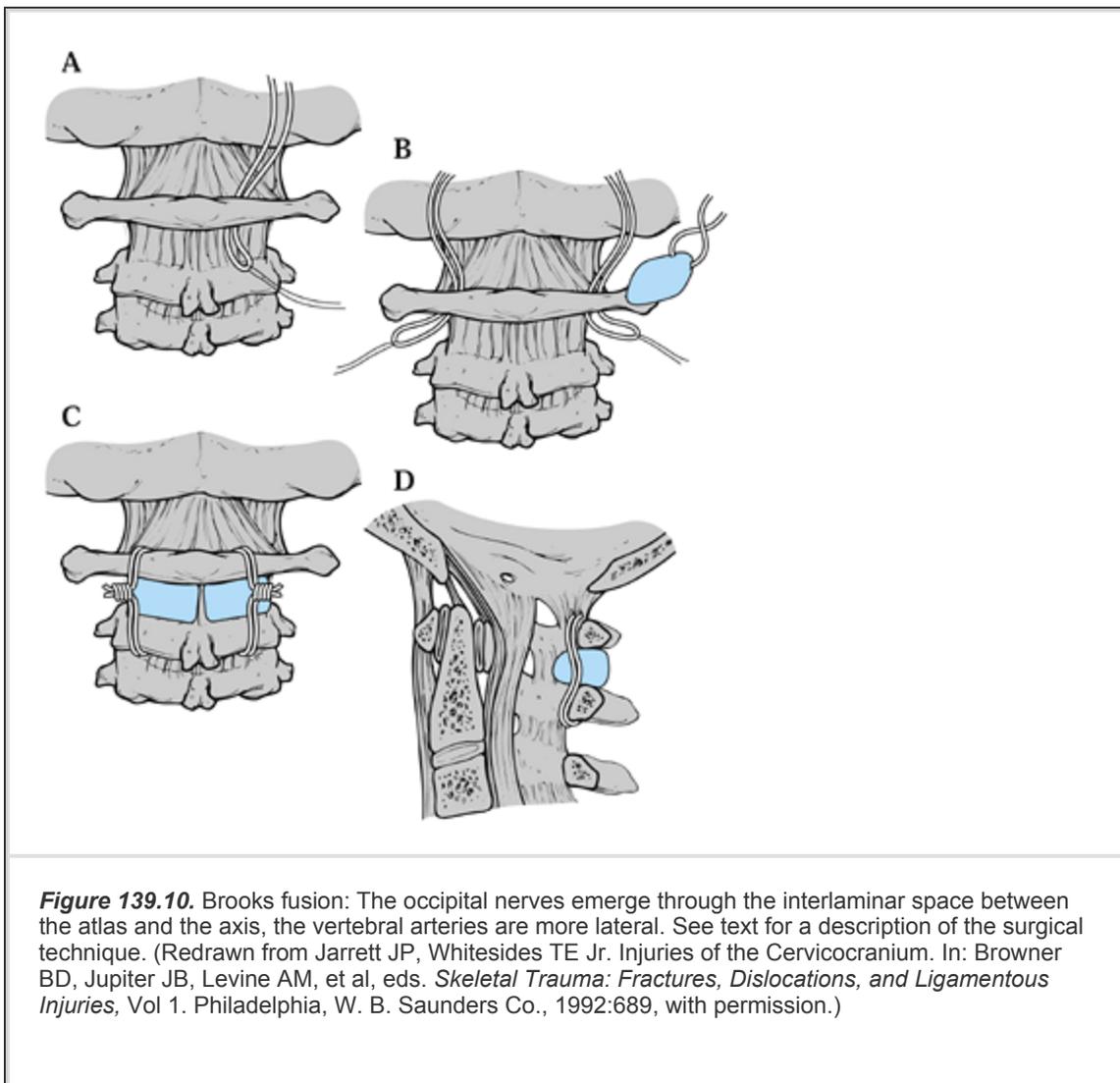
Healing of the transverse ligament, even in the case in which its insufficiency is the result of the avulsion from its insertion on the lateral mass, is uncommon. This is one of the few injuries in the upper cervical spine that routinely requires surgical intervention. There are a variety of techniques to achieve C1–C2 arthrodesis. These are commonly done by posterior

arthrodesis because it is infrequent to have a fracture of the posterior arch and a rupture of the transverse ligament from a flexion type injury. C1–C2 fusion, using either a Gallie (35), Brooks (12), or

P.3678

a Magerl (46) C1–C2 transarticular screw fixation, will give satisfactory results in this situation.

Until recently, the most common method for surgical stabilization for C1–C2 was either a Gallie (35) or a Brooks (12) fusion (Fig. 139.10). With any method, significant loss of rotation at the atlantoaxial joint will occur postoperatively because 50% of neck rotation normally occurs at this joint. In fact, because of compensatory motion at other joints, the loss is often less, as reported by Fielding et al. (30). Fielding demonstrated that an average loss of only 13% of rotational motion occurred in patients younger than 20 years of age; a 25% loss occurred in those in the 20-to-40-year-old age group, and a 28% loss occurred in those older than 40 years of age.



### **Modified Brooks Fusion**

In both the Brooks' and Gallie's techniques, wires are passed beneath the arch of C-1, around the spinous process of C-2 in the Gallie technique and sublaminarly beneath the arch of C-2 in the Brooks technique. With the Gallie technique, a corticocancellous bone lock is laid on the arch of C-1 and notched to fit around the spinous process of C-2. There are a number of different modifications of the Brooks technique, ranging from two wedge-shaped blocks (Fig. 139.10), one on each side, with a single wire around them, to two wires around them, to instances of a single block in the center with wires that pass beneath the lamina at C-1 as well as sublaminar at C-2.

### **Brooks Fusion**

The occipital nerves emerge through the interlaminar space between the atlas and the axis; the vertebral arteries are more lateral.

- Make a midline approach. The arteries and nerves are fairly well protected by the neck muscles. Expose C-1 and C-2.
- On both the right and left, pass sutures under the posterior arch of the atlas (Fig. 139.10A). Then pass the sutures on the lamina of C-2. A twisted wire is then tied to the suture, which is used to guide the wire under the arch of the atlas and the lamina of the atlas (Fig. 139.10B).
- In the Figure 139.10C the wires are now in place and lie anterior to the anterior portion of the atlantoaxial membrane, which was not removed during exposure of the posterior elements of the atlas and axis.
- Harvest either two iliac crest corticocancellous grafts or one larger midline graft and fashion them to fit between the posterior arches of C-1 and C-2. Bevel edges to fit in the interval between the atlas and axis. Hold the graft in place with a towel clip. When they are wired in place, the beveled edges will be in contact with the arch of the atlas and the lamina of the axis.
- Secure the graft or grafts with the wires (Fig. 139.10D)

Several congenital anomalies are associated with atlantoaxial instability. These include Down's, Morquio's, and Klippel–Feil syndromes, as well as occipitalization of the atlas. The incidence of atlantoaxial instability in Down's patients has been reported to be as high as 20%. There is still controversy surrounding the need for prophylactic fusion in these individuals. Most recommend restriction of contact activities in patients with an ADI of less than 7 mm. Prophylactic fusion is recommended for displacement of greater than 7 mm.

### **Atlantoaxial Rotatory Deformities**

Atlantoaxial rotatory deformities have a number of different etiologies including trauma, tumors, and inflammatory conditions (31,54,93). They have been classified anatomically by degree of subluxation (31) and clinically by the duration of symptoms, response to

treatment, or their underlying etiology. They are most commonly due to infection or trauma and have been reported in all age groups, with a higher incidence in children (70) and young adults, regardless of the etiology. The typical presentation is a sudden onset of torticollis in which the head is rotated away and tilted anteriorly toward the rotated side with

P.3679

associated spasm of the sternocleidomastoid muscle. The patients generally have significant neck pain and an inability to rotate the head past neutral. By palpating the posterior wall of the oropharynx, it is possible to feel the difference between the normal and abnormally rotated lateral masses. On the subluxed side, it is possible to appreciate a stepoff from the C-1 lateral mass to the C-2 lateral mass. Any motion produces significant discomfort. In long-standing cases, facial asymmetries may occur. Compensation for the torticollis may occur after some time as a result of counterrotation in the lower cervical spine or atlanto-occipital joint.

The most characteristic finding on the lateral radiograph is an obliquity in the orientation of the posterior arch of C-1 in comparison to the remaining lower spinous processes. A widened ADI may be seen. On the open mouth view, the anteriorly rotated lateral mass can appear wider and closer to the midline than the opposite side. However, the most pathognomonic sign on the open mouth view is the "wink" sign when the inferior edge of the lateral mass of C-1 on the affected side overlaps the lateral mass of C-2, obliterating the joint space. On an AP view the spinous process of C-2 may be rotated away from the side of the anterior displaced lateral mass, known as Sudeck's sign (84). A fixed subluxation can be easily seen on a thin-cut CT scan, which demonstrates the abnormal relationship of C-1 to C-2 (21,33,63). The dimensional reconstructions are also very useful for complete delineation of the injury. For reducible subluxations, a dynamic CT scan in maximal left and right rotation will generally reveal the deformity.

The classification is based on the integrity of the transverse ligament and the direction of the deformity (7,31). A type I deformity indicates an intact transverse ligament and a fixed C1–C2 position within a normal range of rotation. Type II deformities show mild deficiency of the transverse ligament with an ADI of 3 to 5 mm. Mild fixed rotation exceeds the normal motion of the C1–C2 joint. A type III deformity has an ADI greater than 5 mm, and both lateral masses of C-1 are displaced anteriorly, with one side rotated farther than the other. A type IV deformity describes a posterior subluxation of one or both lateral masses. Types III and IV have greater instability with increased neurologic risk, and decreased success with conservative management. Posttraumatic episodes of atlantoaxial deformity have a higher rate of instability and require more aggressive treatment. Rotatory dislocations of traumatic origin may have not only ligamentous disruption but also bony avulsions or fractures from the C-1 joint surfaces, increasing the degree of instability.

With an infectious etiology, treatment is initially geared toward eradicating the organism responsible with intravenous antibiotics. Treatment is then primarily based on the duration of the deformity at presentation. If the deformity has been present for less than 1 week, place the patient in a soft collar and put him on bed rest. If the deformity does not spontaneously reduce, institute halo traction. The weight initially used is based on the age of the patient: 7.7 lbs (3.5 kg) for younger children and up to 13 to 17.6 lb (6 to 8 kg) for

adults. The weight may be increased in increments of 1.1 lb to 2.2 lbs (0.5 to 1 kg) every 3 to 4 days until reduction is achieved to a maximum limit of 13.2 lb (6 kg) in children (70) and 19.8 lb (9 kg) in adults. If the deformity has been present for more than 1 week, start halo traction immediately. Continue traction for up to 3 weeks, but if reduction is not accomplished, a surgical stabilization procedure in symptomatic individuals is indicated.

If reduction is achieved, continue immobilization to allow the capsules and ligaments to heal. Wetzel and La Rocca (91) devised a protocol for immobilization based on the type of deformity. They recommend a soft collar for type I, a rigid collar for type II, and a halo for types III and IV for a duration of up to 3 months. After treatment, obtain flexion-extension radiographs to document stability.

Surgical intervention is indicated when there is evidence of significant instability or neurologic deficits, when there is failure to achieve or maintain a reduction in an acute traumatic deformity, or if symptoms persist after conservative treatment. A posterior C1–C2 fusion is recommended. *In situ* fusion is recommended by some, but the passing of sublaminar wires is more difficult because of the narrowed space behind the posterior ring of C-1. Improvement in the cosmetic deformity is usually slow and often occurs through rotation at cephalad and caudal levels, which may become symptomatic in the future. Some surgeons recommend an attempt at open reduction.

## Open Reduction

- Pass a sublaminar wire under the posterior arch of C-1 and gently applying traction in order to manually derotate the atlas.
- After reduction is achieved, incorporate the wire into a Gallie or Brooks C1–C2 fusion, or C1–C2 transarticular screw fixation can be done. The C1–C2 transarticular screw fixation is the most stable construction to prevent redisplacement if reduction can be achieved either preoperatively or intraoperatively.
- Screw placement is difficult when residual rotatory deformity exists at the time of screw passage.
- If neurologic deficit is present and reduction cannot be achieved, perform a decompression of the posterior arch of C-1, followed by an occipitocervical fusion.

## C-2 Injuries

### ***Fractures of the Odontoid (Dens)***

Fractures of the odontoid account for approximately 15% of all cervical spine fractures. Neurologic deficits occur in approximately 25% of patients with fractures and can range from quadriplegia

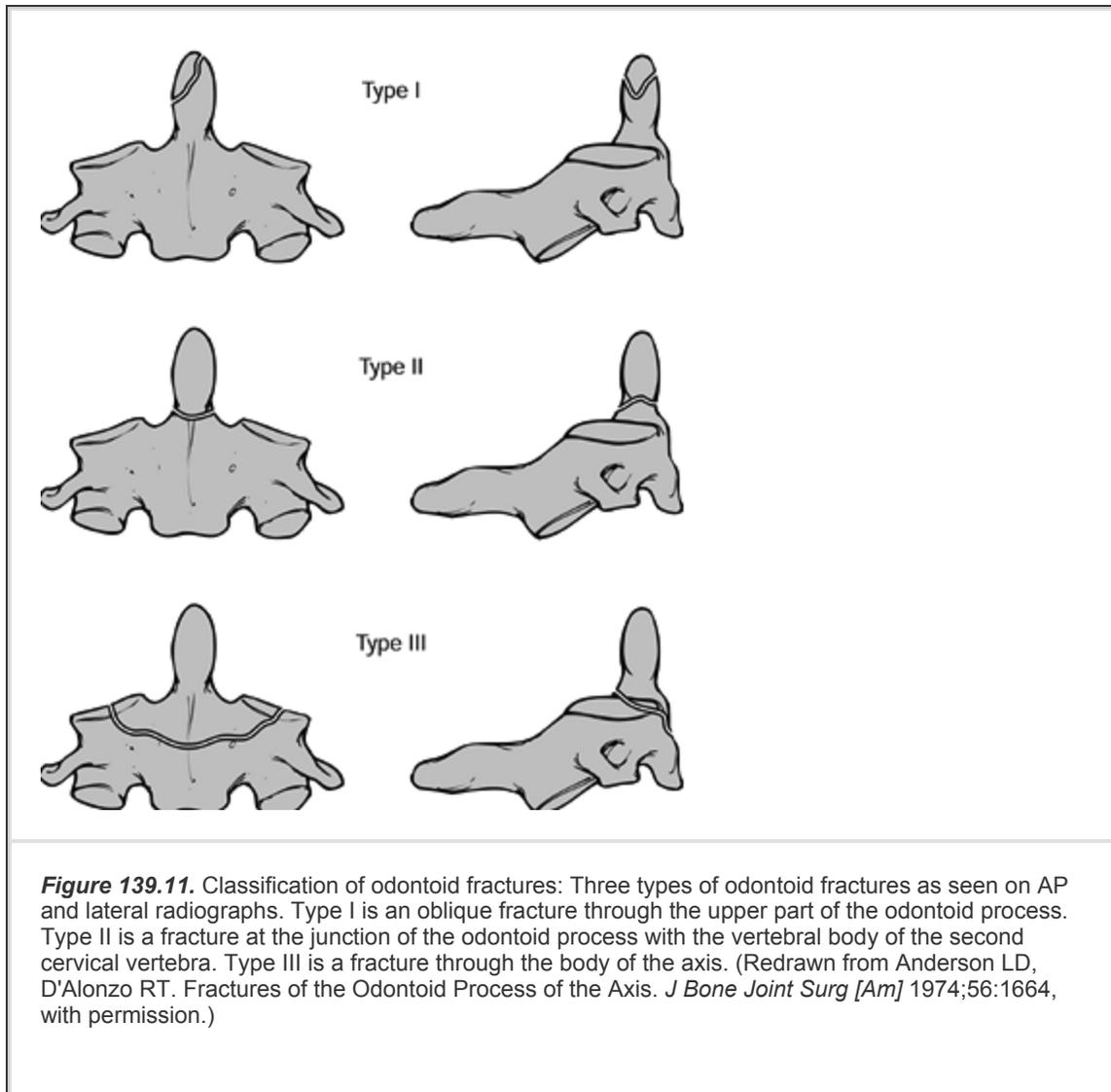
---

P.3680

to slight neuralgias. There is a higher mortality rate associated with this fracture in elderly patients. In younger patients, these fractures tend to occur as a result of motor vehicle

accidents; in older patients, they tend to result from falls. The mechanism is forceful flexion or extension with an axial load. Flexion results in anterior subluxation, whereas extension results in posterior subluxation.

The classification system for dens fractures was described by Anderson and D'Alonzo (3) (Fig. 139.11). A type I fracture is an avulsion fracture at the tip of the odontoid above the transverse ligament. A type II fracture occurs at the junction of the body and dens, and may be transverse or oblique. A type III fracture extends into the cancellous portion of the body of C-2.



The treatment of type I fractures is a period of immobilization with a soft collar until symptoms resolve. However a type I fracture may be an indication of a distraction injury at C1–C2 and thus may be a grossly unstable injury requiring C1–C2 arthrodesis. Take flexion-extension radiographs to document stability because some instances of type I fractures are associated with other significant ligamentous injuries that can be grossly unstable. The outcomes are excellent, with few residual symptoms; even persistent

nonunion of the avulsion fragment offers no long-term problems.

The treatment of type II fractures is somewhat controversial. The nonunion rate for nonoperative treatment is widely variable (1,3,6,14,40,41,60,88) and ranges up to 75% in some series. It appears to correlate with several factors:

- Posterior displacement (19)
- Initial displacement of greater than 5 mm (41)
- Inability to obtain or maintain an anatomic reduction
- Advanced patient age
- Pre-existing diabetes or rheumatoid arthritis in the injured patient

In these high-risk patients, initial surgical stabilization is recommended. In addition, the inability to achieve a reduction in traction or the inability to maintain a reduction in a halo vest is an indication for surgical stabilization.

Type III fractures have relatively low nonunion and malunion rates (less than 15%) when treated appropriately (14). Nondisplaced type III injuries can be treated in a rigid collar, but displaced injuries usually require halo vest immobilization for 12 weeks. If the fracture line is oblique, it is generally not possible to correct collapse, but angulation can be corrected and maintained to healing. Obtain flexion-extension radiographs at 12 weeks to document stability. Treat failures of halo treatment with a C1–C2 fusion. Loss of initial reduction is also an indication for fusion.

The most common method of treatment for dens fractures is C1–C2 arthrodesis by either the Gallie (35) or Brooks (12) methods, as previously described. The Gallie method is not indicated for posteriorly displaced fractures. Results of treatment of dens fractures uniformly demonstrate an arthrodesis rate of approximately 90% irrespective of the technique used.

When the posterior arch of C-1 is fractured or the dens fragment is so unstable that it translates both anteriorly and posteriorly, a C1–C2 transarticular screw (59) or a direct anterior osteosynthesis of the dens is necessary (Fig. 139.12). This technique provides increased initial stability when compared with wiring techniques but is technically challenging.

### **Magerl Fusion C1–C2**

- Perform an awake fiberoptic intubation and turn the patient prone. Position the patient's head in a Mayfield three-pronged head holder. Verify the neurologic status and initiate general anesthesia.
- Set up fluoroscopy so that both AP and lateral images

---

P.3681

can be obtained, preferably simultaneously. Place the patient's neck in as much flexion as possible without displacing the dens. Place a guide wire along the neck and image to verify that the trajectory needed can be obtained.

- The position of the neck that can be achieved consistent with reduction of the deformity influences exposure. If the neck can be flexed (Fig. 139.12A1) and reduction achieved (as is the case with a posteriorly displaced dens fracture), then the drill insertion and instrumentation can usually be done through the primary surgical incision. If the neck cannot be significantly flexed and the position maintained, as is often the case with ruptures of the transverse ligament (Fig. 139.12A2), then use a shorter primary incision with the drills and taps passed percutaneously into the primary incision.
- Make a midline incision from occiput to the C-4 spinous process, exposing the posterior arch of C-1 to the C2–C3 facet joint. Carefully dissect with a Penfield elevator to expose the pedicle of C-2 all the way up to the posterior capsule of the C1–C2 joint. Remove the joint capsule. This dissection is done by elevating carefully along the proximal edge of the lamina of C-2 in a lateral direction until the pedicle is identified. Take care at this point to sweep the soft tissues proximally over the C-1 lateral mass rather than incise them because the greater occipital nerve and a very friable complex of thin-walled venous lakes overlie those structures. Significant bleeding may occur.
- Clearly dissect the medial aspect of the pedicle (Fig. 139.12B). The landmarks for the starting holes for the drill need to be near the medial edge of the facet and inferior margin of the lamina.
- Hold the soft tissue out of the way by placing a small K-wire below it drilled into the upper edge of the facet (Fig. 139.12C).
- Elevate the ligamentum flavum from under the posterior arch, and pass a sublaminar wire (Fig. 139.12E). Gentle traction on the wire may be needed to reduce any residual subluxation. The wire will be used later to secure the bone graft.
- Drill a guidewire under fluoroscopic visualization, entering  


---

P.3682

the most inferior aspect of the C-2 lamina, 2 to 3 mm lateral to the medial border of the C-2 pedicle.

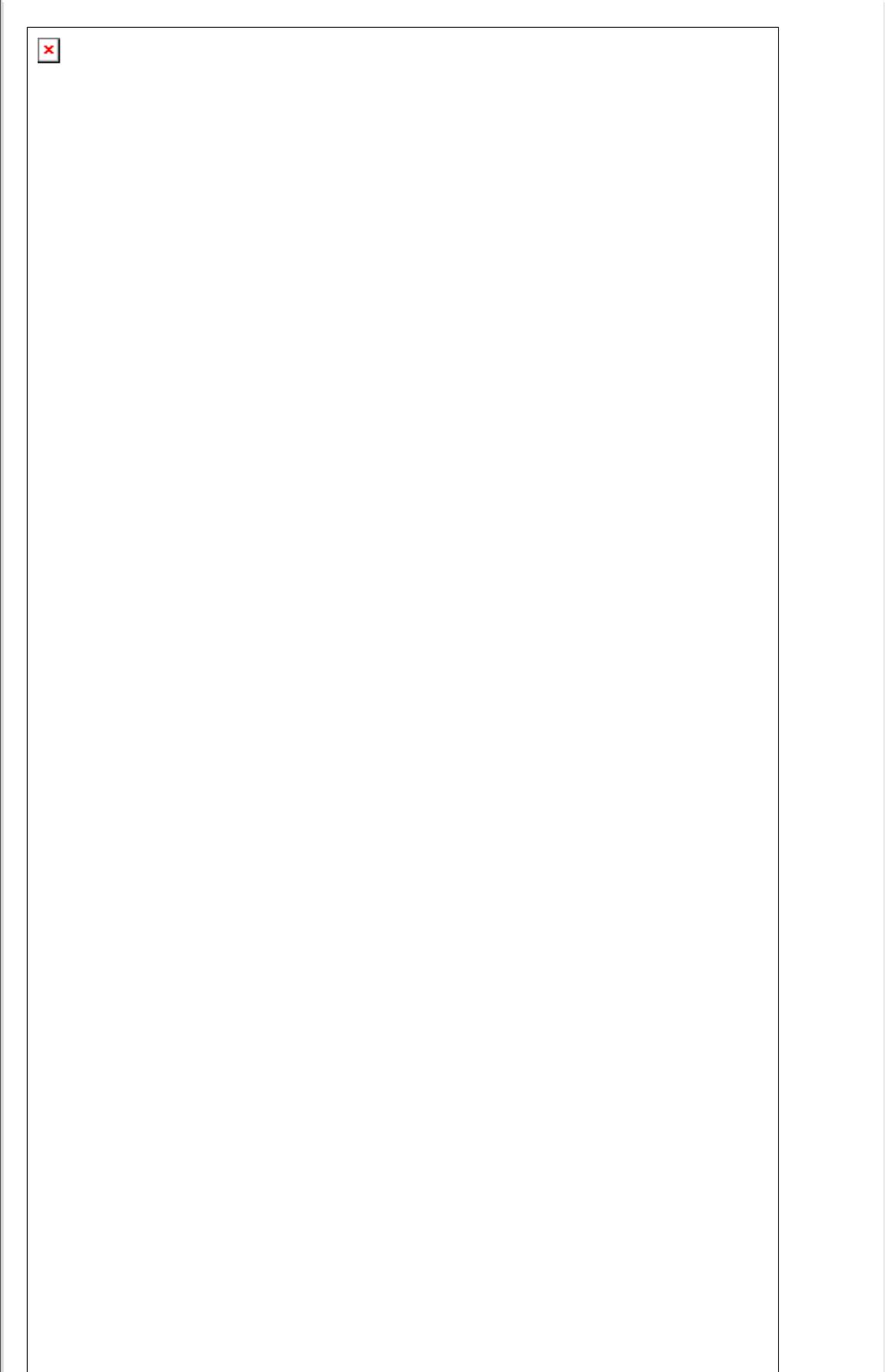
  - The orientation of the drill should be from the medial starting hole to slightly lateral; do this by direct visualization of the path. It is important to monitor the position on the lateral image carefully so that the drill exits the C-2 lateral mass at its posterior aspect (Fig. 139.12E).
  - Advance the wire slowly toward the posterior rim of the superior facet of C-2, across the joint, and into the middle or posterior third of the inferior articular process of C-1. Advance the wire toward the superior margin of the anterior arch of C-1. A percutaneous approach through the soft tissues at the C6–C7 level is sometimes necessary to obtain the correct trajectory.

- Use a cannulated screw system to simplify the remaining steps, but take great care because inadvertent advancement of the guidewire can cause significant injury. This method requires constant imaging.
  - Drill and tap for 3.5 or 4 mm screw and determine the depth (Fig. 139.12F). A 3.5 mm fully threaded screw is most commonly used, with the length varying between 40 and 50 mm, depending on patient size and screw trajectory.
  - Next, harvest a rectangular tricortiocancellous bone
- 
- P.3683
- graft and notch it to fit between the decorticated spinous process of C-2 and posterior arch of C-1.
- Secure it in place with the sublaminar wire previously passed using Gallie technique.

Immobilize the patient postoperatively with a rigid collar for 6 to 8 weeks if no posterior arch fracture is present. If a posterior arch fracture is present or if the fixation is weak, immobilize the patient for 12 weeks in either a halo vest or suboccipital-mandibular immobilization (SOMI)-type brace.

In the interest of preserving as much rotational motion as possible, a direct anterior screw fixation technique has been recommended by some and has shown high union rates, requiring only limited postoperative immobilization (Fig. 139.13) (8,47). The complication rates, however, have been reported to be as high as 20%. The indications include acute type II fractures and very selected type III fractures without much C-2 body involvement. Contraindications include comminuted fractures, associated unstable ring fractures, atypical oblique coronal fractures, irreducible fractures, and nonunion with poor bone quality. It is essential that the fracture be reducible; reducibility must be verified preoperatively with either fluoroscopy or plain radiographs. A small amount of displacement significantly decreases the area available for insertion of the screw. Large amounts of cervicothoracic kyphosis make this procedure technically unfeasible because adequate space must be available for the correct screw trajectory. This procedure is technically difficult in posteriorly displaced fractures because reduction will be lost as extension of the cervical spine as is required to achieve access to C2. The postoperative range of motion has been shown to still be reduced, possibly secondary to adhesions and callus formation.





**Figure 139.13.** Direct anterior screw fixation technique. See text for details. [Part (A) redrawn from Grob D, Magerl F. Operative Stabilisierung bei Frakturen von C1 and C2. *Orthopade* 1987:16; parts (B to I) redrawn from Muller ME, Allgower M, Schneider R, et al., eds. *Manual of Internal Fixation Techniques Recommended by the AO-ASIF Group*, ed 3. Berlin: Springer-Verlag, 1991:638, with permission.]

P.3684

## Anterior Screw Fixation of the Odontoid

- Positioning of the patient for anterior dens osteosynthesis is critically important. Place the patient in the supine position with the neck extended so that exposure of the inferior edge of C-2 is possible. Rest the head on a Mayfield horseshoe head support. If fracture reduction is lost (as may happen with posteriorly displaced dens fractures), use less extension until provisional fixation has been achieved. Biplanar image intensification monitoring is essential (Fig. 139.13A). Perform an awake fiberoptic intubation and document the neurologic status. Aid reduction by placing a rolled towel under the neck for anterior displacement and under the head for posterior displacement.
- Set up fluoroscopy so that satisfactory AP and lateral views can be obtained; simultaneous imaging is preferred.
- When reduction is obtained, make a standard anterior lateral approach through a transverse incision centering the incision at the C5–C6 level (Fig. 139.13B)
- Make a retropharyngeal approach, as described by Smith-Robinson (see Chapter 138), at the C5–C6 disc space level and carry the dissection up to the C2–C3 disc space. Make an incision in the anterior longitudinal ligament at the level of the inferior portion of the C-2 body. A one- or two-screw technique can then be used.
- Starting 3 mm to either side of the midline and on the caudal edge of the body, medially insert a 1.5 mm K-wire to ascertain trajectory and stabilize the fragment (Fig. 139.13C). Insert it across the fracture into the center

P.3685

of the odontoid. Two K-wires can be placed and a cannulated system used, but inadvertent advancement of the wire is a complication; preferably, one wire is removed and replaced at a time with a solid 2.5 mm drill bit advancing to the tip of the dens.

- Pass the drill bit over the guidewire and advance it under fluoroscopic control. Take care—there have been instances in which the guidewire has been advanced into the spinal cord.
- Because a lag effect is desired, either a partially threaded screw can be used or one drill bit can be removed and the near fragment overdrilled with a 3.5 mm drill bit (Fig. 139.13D). Tap the near cortex only (Fig. 139.13E, Fig. 139.13F and Fig. 139.13G).

Be sure that all threads of this lag screw are across the fracture site.

- Final screw fixation should have the screw slightly oblique toward the midline and optionally may perforate the cortex of the tip of the dens (Fig. 139.13H and Fig. 139.13I). Take care to begin the screw on the undersurface and not the anterior surface of the C-2 body to achieve the proper trajectory (Fig. 139.13I).

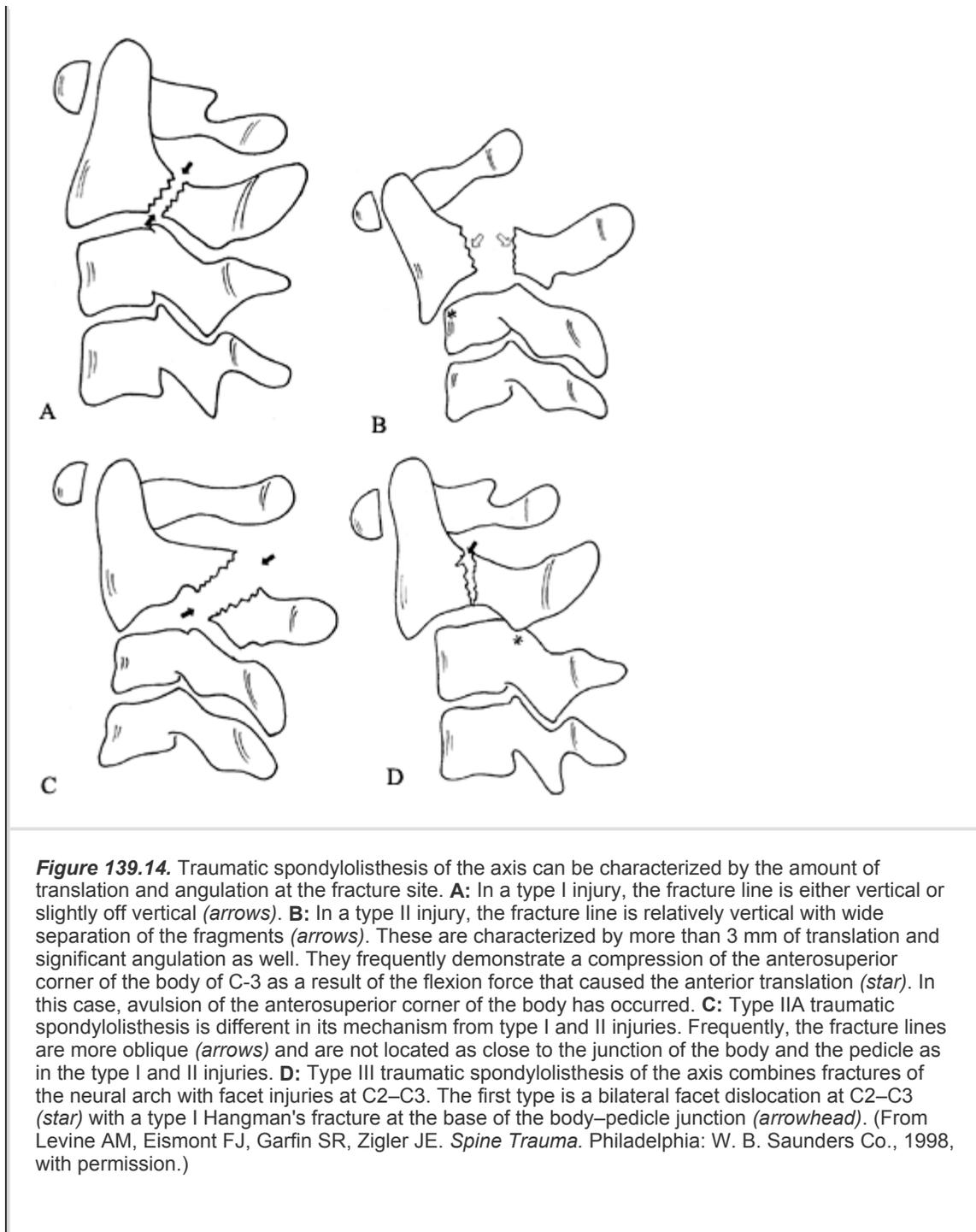
Studies have shown no significant increase in biomechanical stability with two screws, and anatomic studies have revealed that some odontoids are of inadequate size to accommodate two screws (1,8,28,59). Postoperative immobilization in a Philadelphia collar for 6 weeks is generally sufficient.

### ***Traumatic Spondylolisthesis of the Axis***

Traumatic spondylolisthesis of the axis is a fracture that occurs through the pars interarticularis usually at its junction with the posterior aspect of the vertebral body. Such fractures are relatively uncommon and the mechanism of injury varies with the fracture type. These usually occur in motor vehicle accidents in which the head strikes the windshield or dashboard. The amount of displacement and angular deformity is related to the amount of rebound occurring from the associated acceleration and deceleration forces. These fractures are generally not associated with significant neurologic deficits because most of the injury patterns expand the canal diameter. As with fractures of the atlas, if a deficit is present, it may be related to a head injury or to some associated injury. Diligently search for associated injuries that can occur in up to 30% of patients with these fractures. Most of the concurrent injuries occur in the adjacent three cervical levels (56).

Several different classification systems have been used to describe traumatic spondylolisthesis of the axis. The systems have been based on either instability criteria (34), mechanism of injury (56), or anatomic or radiologic criteria (25,56,81). The classification most commonly used now is based on four patterns, each of which has both common radiographic and mechanistic characteristics (Fig. 139.14) (56).





A type I injury has a fracture through the pedicles of C-2, just posterior to the junction of the body and the pedicles. A type I injury (Fig. 139.14A) is either a nondisplaced fracture or minimally displaced, with less than 3 mm of displacement and no angulation. It usually results from an axial load with an associated hyperextension moment. The type IA, or atypical hangman's pattern (81), involves a fracture between the junction of the pedicle and the body of C-2 in which, at least on one side, a portion of the posterior wall breaks off and remains attached to the pedicle. The significance of this pattern is that, if there is any

displacement, the cord can be compressed between the ring of C-1 and the retained portion of the posterior wall. The fracture line frequently traverses the foramen for the vertebral artery and may result in intimal damage. A higher incidence of neurologic deficits is associated with this pattern.

The type II injury (Fig. 139.14B) involves displacement and angulation of C-2 on C-3. A type II injury is the result of a hyperextension axial load, which breaks the neural arch, followed by a flexion injury, which results in significant translation. The pattern of the fracture line is similar to that seen with a type I injury.

The type IIA injury (Fig. 139.14C) has only minimal translation of C-2 over C-3 but has severe angulation. The type IIA injury is characterized by minimal translation and significant angulation with widening of the posterior aspect of the disc space. With application of traction, these are the injuries that will demonstrate significant widening of the disc. The mechanism is different in that this type of injury occurs as a result of a flexion distraction force. The fracture line, instead of being vertical at the junction of the pedicle and the body is obliquely through pedicle. Traction may produce distraction, leading to potential neurologic injury.

The type III injury (Fig. 139.14D) is a pars fracture with an associated C2–C3 unilateral or bilateral facet dislocation. The mechanism most probably is initial flexion-distraction, which causes the dislocation, and then extension, which causes the traumatic spondylolisthesis. Reversing the mechanism would not permit the dislocation to occur, because the inferior facet of C-2 would then be detached from the cervicocranium, which serves as the lever for the dislocation. This pattern is associated with a higher incidence of neurologic deficits.

Radiologic evaluation and determination of the traumatic spondylolisthesis can usually be made on a lateral cervical spine roentgenogram. However, because most radiographs of this injury are performed in the supine position, the true nature of the injury may be obscured because any displacement may be reduced in the supine position. Thus, to ensure that the injury is indeed a type I, physician-supervised flexion-extension radiographs are necessary to

---

P.3686

differentiate it from a reduced type II. In order to undergo flexion-extension radiographs, patients must be awake, alert, and neurologically intact, and able to perform the flexion extensor maneuver themselves. Atypical hangman's fractures may require axial images from a CT scan to fully appreciate the direction and extent of the fracture lines. Finally, in type III injuries, a CT scan with reconstructions may be necessary to characterize the facet component of the injury.

Treat type I injuries nonoperatively with a rigid collar for 8 to 12 weeks. Late-onset degenerative arthritic changes can occur in up to 30% of patients because the initial injury causes severe impaction forces across the facet joint, which can be destructive to the articular cartilage. Patients with type I injuries do not go on to spontaneous ankylosis across the C2–C3 disc, as is seen in type II injuries. Treat type II injuries with significant amounts of displacement or angulation initially by reduction using skeletal traction in a slight amount of extension followed by a halo vest for 12 weeks. It is not uncommon for some reduction to be lost in the halo vest, but this loss of reduction usually does not lead

to any long-term consequences. If the displacement is in the range of 6 to 7 mm, alignment is maintained with a period of 4 to 6 weeks in halo traction, followed by another 6 weeks in the halo vest. Alternatively, after reduction in traction a direct osteosynthesis of the fracture can be accomplished with a lag screw. Treat type IIA injuries with a halo vest placed in compression and extension. This is achieved by placing the halo vest on the patient in a routine fashion and then using the bolts on the uprights to compress the ring down toward the vest.

---

P.3687

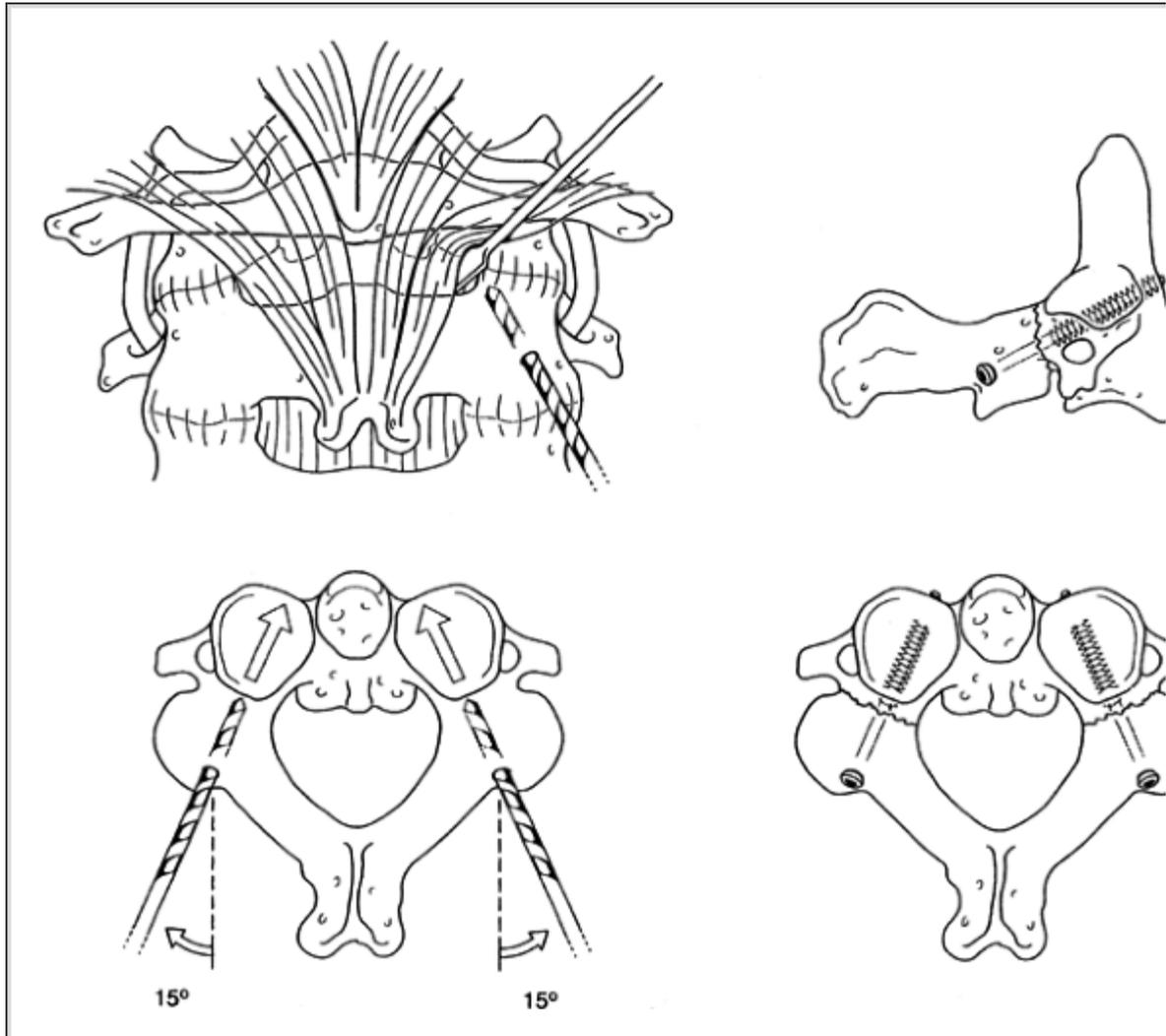
Type III fracture pattern injuries, in contrast, require immediate surgery. When this fracture pattern is identified, closed reduction should not even be attempted because it is rarely achieved and is potentially dangerous. Even if it is achieved, the remaining instability present is enough to warrant arthrodesis. A preoperative MRI is performed to evaluate the C2–C3 disc. The goal of surgical treatment is to stabilize the C2–C3 facet joint. This can be accomplished with a C2–C3 posterior plate with a C-2 pedicle screw and a lateral mass screw at C-3.

### **Reduction and Stabilization of a Type III Hangman's Fracture**

- Carry out a fiberoptic, awake intubation and turn the patient prone on a Stryker frame. Check the patient's neurologic status and induce general anesthesia. Check lateral position on fluoroscopy or plain radiographs. High-quality biplanar fluoroscopy is required to monitor the trajectory of the screws.
- Make a standard approach to the posterior cervical spine from the occiput down to C3–C4 level and expose the C2–C3 and C3–C4 facet joints. Use an elevator to dissect the medial aspect of the C-2 pedicle.
- The facet joint at C1–C2 does not need to be disrupted, but dissection from posterior to anterior toward the facet will usually demonstrate the fracture of the pedicle.
- Then carry out the reduction of the unilateral or bilateral facet dislocation at C2–C3. Place towel clips on the spinous processes of C-2 and C-3. Spread the spinous processes apart with a slight amount of flexion. This should unlock the jumped facets. Apply a posterior translation force to the C-2 spinous process as the towel clamps are brought together to achieve the final reduction.
- A bilateral subluxation is generally easier to reduce than a unilateral subluxation because of the increased ligamentous damage. Traction is not effective in this situation because the break in the pars of C-2 prevents any force from being transmitted to the C2–C3 joint level. Rarely, the C2–C3 facets need to be unlocked manually.
- Place a Freer or small Cobb elevator into the facet joint and gently elevate the C-2 facet until it becomes level with the C-3 facet. Then apply a posterior translation force to the towel clip on C-2 as the elevator is slowly removed to achieve reduction. After reduction is obtained, the C2–C3 joint must be stabilized. A standard interspinous process wiring or C2–C3 lateral mass plating can be used; however, the

pedicle fracture would then be treated as a type II Hangman's fracture with 12 weeks in a halo vest.

- An alternative method of fixation is to insert a C-2 pedicle screw to secure the pedicle fracture (Fig. 139.15A, Fig. 139.15B, Fig. 139.15C and Fig. 139.15D) (72). If this technique is used, a partially threaded lag screw must be placed so that the threads are beyond the fracture site to prevent any distraction.



**Figure 139.15. A:** The surgical technique for osteosynthesis of a traumatic spondylolisthesis of the axis. See the text for a description of the technique. **B:** Orientation of the drills along the pedicle in an axial plane. Slight convergence of the screws is desirable. **C:** Orientation across the fracture line from the posterior fracture to the anterior fragment. A partially threaded screw, with usually about 15 mm of thread and 20 mm of shank, is desirable. The proximal fragment can be overdrilled and lagged to the anterior fragment. **D:** The final axial view.

- Before beginning screw insertion, take care that the fracture is as reduced as possible and that a #4 Penfield elevator can be placed along the medial border of the pedicle for guidance.

- Verify the trajectory of the pedicle and the location of the vertebral arteries on a preoperative CT scan. Palpate the medial wall and gently retract the epidural soft tissue medially. The fracture site and posterior body should be seen. Then pass a drill, starting at the center of the facet and directed along the pedicle into the body beyond the fracture site.
- Select a plate of the appropriate length and contour to fit the lateral masses of C-2 and C-3.
- Place a partially threaded screw through the plate across the pedicle fracture. The threads should be beyond the fracture site, and no distraction of the pedicle fracture should be observed.
- Place a standard C-3 lateral mass screw through the plate.
- A rigid collar for 12 weeks is needed for postoperative immobilization.

Surgery is warranted for the other types of fracture patterns only if there is an associated cervical fracture that requires fixation, if conservative treatment fails, or if the use of a halo is contraindicated. A C-2 pedicle screw (Fig. 139.15A, Fig. 139.15B, Fig. 139.15C and Fig. 139.15D) can be used and offers immediate stability to the fracture. The starting point for the screw is just medial to the C2–C3 facet joint on the inferior edge of the lamina. Check the starting point on a lateral fluoroscopic view. A preoperative CT scan is necessary to identify the angle of the pedicle and the location of the vertebral artery. Use a rigid collar for 8 weeks for postoperative immobilization. Anterior arthrodesis for this injury has also been used with mixed results (40,41,87).

The results of treatment are related to the injury type. For type I fractures, union rates approach 98%. Recognition of other associated injuries is important because these fractures can occur with posterior arch fractures or odontoid fractures. The result of these combined injuries follows that of the associated fracture. The most common long-term problem of type I fractures is arthritic degeneration of the C2–C3 facet joint, which occurs in approximately 10% of injuries. For type IA fractures, the results are related to the fracture pattern but generally are similar to type I fractures. For type II fractures, displacement of 5 mm or more between the anterior and posterior fragments yields a high incidence of nonunion, although more than 70% go on to develop anterior fusions of the disc space. Injuries with symptomatic nonunion and large gaps are generally not amenable to C-2 pedicle screw fixation and

---

P.3688

require an anterior C2–C3 fusion. The results of type III fractures depend on the severity of the commonly associated head injuries and neurologic deficits. The overall success rate of fusion after reduction is achieved is quite high.

### ***Extension Teardrop Fractures***

Although a number of different types of “teardrop fractures” have been described since the term was first used by Schneider and Kahn in 1956 (76) the two most common types are the flexion variant, which occurs in the lower cervical spine, and the extension type, which

occurs predominantly in the upper cervical spine. The extension type of injury results from a hyperextension and axial loading mechanism and may be observed in combination with posterior arch fractures of the atlas and traumatic spondylolisthesis of the axis. The injury can be easily diagnosed on a lateral roentgenogram of the cervical spine. The triangular fragment usually comprises approximately 50% of the height and 50% of the width of the body. The vertebral body of C-2 remains in normal alignment with the body of C-3, but the avulsed fragment is rotated anteriorly (Fig. 139.16). This is in contradistinction to flexion teardrop injuries, in which the fragment remains in relatively normal orientation to the bodies above and below and the affected body is rotated posteriorly.



**Figure 139.16.** Extension teardrop fracture.

These injuries are uniformly stable, although they may occur in combination with unstable contiguous injuries in the upper cervical spine. If they occur alone or in combination with a stable injury collar, immobilization is sufficient to achieve a satisfactory result. If they occur in combination with an unstable injury, the treatment of the second injury determines the overall treatment.

P.3689

## **PITFALLS AND COMPLICATIONS**

The most important aspect of the management of upper cervical spine fractures is diligent and thorough follow-up of the patients after treatment. Progressive deformities and

neurologic deficits are more easily dealt with when recognized early. Union must always be verified with maximum flexion-extension radiographs after treatment.

Because the treatment of many of these fractures requires the use of a halo vest, take care in its proper placement and in follow-up. Complications include pin loosening, bone erosion, skull perforation, pin track infections, and cerebrospinal fluid leaks. If a circumferential collar is used, injury to the greater occipital nerve must be recognized because loss of sensation in this area can lead to occipital decubitus ulcers.

Although posterior wiring techniques are successful, the nonunion rates may be as high as 10%. Take care also with the passage of sublaminar wires because neurologic injuries have been reported. Mechanical testing has shown the transarticular screw to be more stable than wiring techniques. The procedure is difficult, but the early concerns of neurologic injury and the sequelae of perforation of one vertebral artery are not as formidable as they were previously thought to be. Clearly, if a vertebral artery injury does occur on one side, do not attempt screw placement on the other side for any reason. Screw malpositions have occurred in approximately 16% of cases, but complications attributable to this problem are rare (less than 2%) and include hypoglossal nerve irritation from excessive screw length, instability from the screws not crossing the joint, and screw breakage.

Anterior odontoid screws are extremely difficult to use and can cause spinal cord injury, cranial nerve injury, and loss of fixation. Other technical problems include incomplete fracture reduction with residual posterior angulation, incorrect screw entry site, and posterior screw angulation. Because of these problems, only experienced spine surgeons should use transarticular or anterior odontoid screws.

The occipitocervical fusion with plate and screws has added significant benefits to traditional wiring techniques. Complications are associated with the placement of the Magerl screw, as described previously. Leakage of CSF is not uncommon with the placement of bicortical occipital screws, but no persistent leaks or significant problems have been reported.



## **AUTHORS' PERSPECTIVE**

Injuries of the upper cervical spine encompass a wide spectrum of not only fractures but also patterns of instability that result from ligamentous disruption. The most critical features of the treatment of these injuries are to appreciate the true nature of the instability and the pertinent regional anatomy. Injuries of the upper cervical spine have often been treated more aggressively than necessary (e.g., halo vest for a posterior arch fracture or a Type I hangman's fracture). Surgery is often not necessary if appropriate use of nonoperative modalities are employed.

More recently, however, innovative surgical techniques have appeared that have been applicable to the upper cervical spine injuries. The Magerl C1–C2 transarticular screw fixation has simplified fixation for several different types of injuries. However, the rationale for surgery has sometimes been the desire not to use a halo as the immobilization device. Clearly, the risks and benefits have to be discussed with the patient in an objective fashion before the final treatment decision is made. For example, elderly patients have been

reported to have difficult times tolerating a halo as an immobilization device, and physicians have resorted to operative procedures that also have high rates of morbidity. For example, the use of an anterior dens screw in the elderly patient with a Type II fracture without neurologic deficit may have more morbidity than halo immobilization. More recent studies suggest that less rigid immobilization may yield acceptable patient outcomes without either the risks of surgery or a halo. Accurate

P.3690

assessment of the true significance of the injury and its effect on spine stability will ultimately yield the best patient outcomes.

## REFERENCES

Each reference is categorized according to the following scheme: \*, classic article; #, review article; !, basic research article; and +, clinical results/outcome study.

+ 1. Aebi M, Etter C, Cosica M. Fractures of the Dens: Treatment with Anterior Screw Fixation. *Spine* 1989;14:1065.

+ 2. Alker GH, Oh YS, Leslie FV, et al. Postmortem Radiology of Head and Neck Injuries in Fatal Traffic Accidents. *Radiology* 1975;114:611.

+ 3. Anderson LD, D'Alonzo RT. Fractures of the Odontoid Process of the Axis. *J Bone Joint Surg [Am]* 1974;56:1663.

+ 4. Anderson PA, Montesano PX. Morphology and Treatment of Occipital Condyle Fractures. *Spine* 1988;13:731.

+ 5. Apple JS, Kirks DR, Merten DF, et al. Cervical Spine Fractures and Dislocations in Children. *Pediatr Radiol* 1987;17:45.

+ 6. Apuzzo MLJ, Heiden JS, Weiss MH, et al. Acute Fractures of the Odontoid Process: An Analysis of 45 Cases. *J Neurosurg* 1978;48:85.

+ 7. Berkheiser EJ, Seidler F. Nontraumatic Dislocations of the Atlantoaxial Joint. *JAMA* 1931;96:517.

+ 8. Böhler J: Anterior stabilization for acute fractures and non-unions of the dens. *J. Bone Joint Surg Am* 64:18, 1982.

+ 9. Botte MJ, Byrne TP, Garfin SR. Application of the Halo Fixation Device Using an

Increased Torque Pressure. *J Bone Joint Surg [Am]* 1987;69:750.

---

+ 10. Botte MJ, Byrne, TP, Garfin SR. Use of Skin Incisions in the Application of Halo Skeletal Fixator Pins. *Clin Orthop* 1989;246:100.

---

+ 11. Bracken MB, Shepard MJ, Holford PR, et al. Administration of Methylprednisolone for 24 or 48 Hours or Tirilizad Mesylate for 48 Hours in the Treatment of Acute Spinal Cord Injuries: Results of the Third National Acute Spinal Cord Injury Randomized Controlled Study—National Acute Spinal Cord Injury Study. *JAMA* 1997;277:1597.

---

+ 12. Brooks A, Jenkins E. Atlantoaxial Arthrodesis by the Wedge-compression Method. *J Bone Joint Surg [Am]* 1978;60:279.

---

+ 13. Bucholz RW, Burkhead WZ. The Pathological Anatomy of Fatal Atlanto-occipital Dislocations. *J Bone Joint Surg [Am]* 1979;61:248.

---

+ 14. Clark CR, White AA. Fractures of the Dens. *J Bone Joint Surg [Am]* 1985;67:1340.

---

+ 15. Clyburn TA, Lionberger DR, Tullos HS. Bilateral Fracture of the Transverse Process of the Atlas. *J Bone Joint Surg [Am]* 1982;64:948.

---

+ 16. Crisco JJ III, Oda T, Panjabi MM, et al. Transections of the C1-C2 Joint Capsular Ligaments in the Cadaveric Spine. *Spine* 1991;16(Suppl):S474.

---

+ 17. Davis D, Bohlman H, Walker AE, et al. The Pathological Findings in Fatal Craniospinal Injuries. *J Neurosurg* 1971;34:603.

---

+ 18. Dickman CA, Mamourian A, Sonntag VKH, et al. Magnetic Resonance Imaging of the Transverse Atlantal Ligament for the Evaluation of Atlantoaxial Instability. *J Neurosurg* 1991;75:221.

---

+ 19. Dunn ME, Seljeskog EL. Experience in the Management of Odontoid Process Injuries: An Analysis of 128 Cases. *Neurosurgery* 1986;18:306.

---

+ 20. Dvorak J, Hayek J, Zehnder R. CT-functional Diagnostics of the Rotatory Instability of the Upper Cervical Spine: II. An Evaluation on Healthy Adults and

Patients with Suspected Instability. *Spine* 1987;12:726.

---

! 21. Dvorak J, Panjabi M, Gerber M, et al. CT-functional Diagnostics of the Rotatory Instability of the Upper Cervical Spine: I. An Experimental Study on Cadavers. *Spine* 1987;12:197.

---

! 22. Dvorak J, Panjabi M. Functional Anatomy of the Alar Ligaments. *Spine* 1987;12:183.

---

! 23. Dvorak J, Schneider E, Saldinger P, et al. Biomechanics of the Craniocervical Region: The Alar and Transverse Ligaments. *J Orthop Res* 1988;6:452.

---

! 24. Ebraheim NA, Lu J, Bijani A, et al. An Anatomic Study of the Thickness of the Occipital Bone: Implications for Occipitocervical Instrumentation. *Spine* 1996;21:1725.

---

+ 25. Effendi B, Roy D, Cornish B, et al. Fractures of the Ring of the Axis: A Classification Based on the Analysis of 131 Cases. *J Bone Joint Surg [Br]* 1981;63:319.

---

+ 26. Eismont FJ, Bohlman HH. Posterior Atlanto-occipital Dislocation with Fractures of the Atlas and Odontoid Process. *J Bone Joint Surg [Am]* 1978;60:397.

---

+ 27. Ersmark H, Kalen R. Injuries of the Atlas and Axis: A Follow-up Study of 85 Axis and 10 Atlas Fractures. *Clin Orthop* 1987;217:257.

---

+ 28. Etter C, Coscia M, Jaberg H, et al. Direct Anterior Fixation of Dens Fractures with a Cannulated Screw System. *Spine* 1991;16(Suppl 3):S25.

---

\* 29. Fielding JW, Cochran GVB, Lawsing JF, et al. Tears of the Transverse Ligament of the Atlas. *J Bone Joint Surg [Am]* 1974;56:1683.

---

\* 30. Fielding JW, Hawkins RJ, Ratzan SA. Spine Fusion for Atlantoaxial Instability. *J Bone Joint Surg [Am]* 1976;58:400.

---

\* 31. Fielding JW, Hawkins RJ. Atlantoaxial Rotatory Fixation. *J Bone Joint Surg [Am]* 1977;59:37.

---

# 32. Fielding JW, Hawkins RJ. Roentgenographic Diagnosis of the Injured Neck.

*Instruct Course Lect* 1976;25:149.

---

+ 33. Fielding JW, Stillwell WT, Chynn KY, et al. Use of Computed Tomography for the Diagnosis of Atlantoaxial Rotatory Fixation. *J Bone Joint Surg [Am]* 1978;60:1102.

---

+ 34. Francis WR, Fielding, JW, Hawkins RJ, et al. Traumatic Spondylolisthesis of the Axis. *J Bone Joint Surg [Br]* 1981;63:313.

---

\* 35. Gallie W. Fractures and Dislocations of the Cervical Spine. *Am J Surg* 1939;46:495.

---

P.3691

---

! 36. Garfin SR, Botte MJ, Centeno RS, et al. Osteology of the Skull as it Affects Halo Pin Placement. *Spine* 1985;10:696.

---

! 37. Goel VK, Winterbottom JM, Schulte KR, et al. Ligamentous Laxity Across C0-C1-C2 Complex: Axial-torque Rotation Characteristics Until Failure. *Spine* 1990;15:990.

---

+ 38. Grob D, Dvorak J, Panjabi MM, et al. Posterior Occipitocervical Fusion: A Preliminary Report of a New Technique. *Spine* 1991;16:17.

---

+ 39. Grob D, Dvorak J, Panjabi MM, et al. The Role of Plate and Screw Fixation in Occipitocervical Fusion in Rheumatoid Arthritis. *Spine* 1994;19:2545.

---

+ 40. Hadley MN, Browner C, Sonntag VKH: Axis Fractures: A Comprehensive Review of Management and Treatment in 107 Cases. *Neurosurgery* 1985;17:281.

---

+ 41. Hadley MN, Dickman CA, Browner CM, et al. Acute Axis Fractures: A Review of 229 Cases. *J Neurosurg* 1989;71:642.

---

+ 42. Han SY, Witten DM, Mussleman JP. Jefferson Fracture of the Atlas. *J Neurosurg* 1976;44:368.

---

+ 43. Hays MB, Alker GJ. Fractures of the Atlas Vertebra: The Two-part Burst Fracture of Jefferson. *Spine* 1988;13:601.

---

! 44. Heller JG, Alson MD, Schafler MB, et al. Quantitative Internal Dens Morphology.

*Spine* 1992;17:861.

---

# 45. Jarrett PJ, Whitesides TE Jr. Injuries of the Cervicocranium. In Browner BD, Jupiter JB, Levine AM, et al, eds. *Skeletal Trauma: Fractures, Dislocations, Ligamentous Injuries*, Vol 1. Philadelphia: WB Saunders Co., 1992:668.

---

+ 46. Jeanneret B, Magerl F. Primary Posterior Fusion of C1-2 in Odontoid Fractures: Indications Technique, and Results of Transarticular Screw Fixation. *J Spinal Disord* 1992;5:464.

---

+ 47. Jeanneret B, Vernet O, Frei S, Magerl F: Atlantoaxial Mobility after Screw Fixation of the Odontoid: A Computed Tomographic Study. *J Spinal Disord* 1991;4:203.

---

\* 48. Jefferson G. Fracture of the Atlas Vertebra. *Br J Surg* 1920;7:407.

---

\* 49. Jefferson G. Fractures of the First Cervical Vertebra. *Br Med J* 1927;July 30:153.

---

+ 50. Kowalski HM, Cohen WA, Cooper P, et al. Pitfalls in the CT Diagnosis of Atlantoaxial Rotary Subluxation. *AJR* 1987;149:595.

---

+ 51. Lee C, Woodring JH, Goldstein SJ, et al. Evaluation of Traumatic Atlanto-occipital Dislocations. *Am J Neuroradiol* 1987;8:19.

---

+ 52. Lee S, Joyce S, Seeger J. Asymmetry of the Odontoid-lateral Mass Interspaces: A Radiographic Finding of Questionable Clinical Significance. *Ann Emerg Med* 1986;15:1173.

---

+ 53. Lesoin F, Blondel M, Dhellemmes P, et al. Post-traumatic Atlanto-occipital Dislocation Revealed by Sudden Cardiorespiratory Arrest. *Lancet* 1982;2:447.

---

+ 54. Leventhal MR, Maguire JK Jr, Christian CA. Atlantoaxial Rotary Subluxation in Ankylosing Spondylitis: A Case Report. *Spine* 1990;15:1374.

---

+ 55. Levine AM, Edwards CC. Fractures of the Atlas. *J Bone Joint Surg [Am]* 1991;73:680.

---

+ 56. Levine AM, Edwards CC. The Management of Traumatic Spondylolisthesis of the

Axis. *J Bone Joint Surg [Am]* 1985;67:217.

---

# 57. Levine AM, Edwards CC. Treatment of Injuries in the C1-C2 Complex. *Orthop Clin North Am* 1986;17:31.

---

+ 58. Lipson SJ. Fractures of the Atlas Associated with Fracture of the Odontoid Process and Transverse Ligament Ruptures. *J Bone Joint Surg [Am]* 1977;59:940.

---

\* 59. Magerl F, Seemann PS. Stable Posterior Fusion of the Atlas and Axis by Transarticular Screw Fixation. In: Kehr P, Weidner A, eds. *Cervical Spine*. Berlin: Springer-Verlag, 1986:322.

---

+ 60. Maiman DJ, Larson SJ. Management of Odontoid Fractures. *Neurosurgery* 1982;11:471.

---

+ 61. Martel W. The Occipito-atlantoaxial Joints in Rheumatoid Arthritis and Ankylosing Spondylitis. *AJR* 1961;86:223.

---

# 62. McGuire RA, Harkey HL. Unstable Jefferson's Fracture Treated with Transarticular Screws. *Orthopedics* 1995;18:207.

---

+ 63. Ono K, Yonenobu K, Fuji T, et al. Atlantoaxial Rotatory Fixation: Radiographic Study of its Mechanism. *Spine* 1985;10:602.

---

! 64. Panjabi M, Dvorak J, Duranceau J, et al. Three Dimensional Movements of the Upper Cervical Spine. *Spine* 1988;13:726.

---

+ 65. Paramore CG, Dickman CA, Sonntag V. The Anatomic Suitability of the C1-C2 Complex for Transarticular Screw Fixation. *J Neurosurg* 1996;85:221.

---

+ 66. Parke WW. The Vascular Relations of the Upper Cervical Vertebrae. *Orthop Clin North Am* 1978;9:879.

---

! 67. Paul LW, Moir WW. Non-pathologic Variations in Relationship of the Upper Cervical Vertebrae. *AJR* 1949;62:519.

---

+ 68. Penning L. Paravertebral Hematoma in Cervical Spine Injury: Incidence and

Etiologic Significance. *AJR* 1981;136:553.

---

! 69. Penning L, Wilmkink JT. Rotation of the Cervical Spine. A CT Study in Normal Subjects. *Spine* 1987;12:732.

---

+ 70. Phillips WA, Hensinger RN. The Management of Rotatory Atlantoaxial Subluxation in Children. *J Bone Joint Surg [Am]* 1989;71:664.

---

+ 71. Powers B, Miller MD, Kramer RS, et al. Traumatic Anterior Atlanto-occipital Dislocation. *Neurosurgery* 1979;41:12.

---

+ 72. Roy-Camille R, Saillant G, Bouchet T. Technique du Vissage des Pedicules de C2. In: Roy-Camille R, ed. *Cinquiemmes Journees d'Orthopedie de la Pitie, Rachis Cervical Superieur*. Paris: Masson, 1986:41.

---

+ 73. Sakou T, Kawaida H, Morizino Y, et al. Occipitoatlantoaxial Fusion Utilizing a Rectangular Rod. *Clin Orthop* 1989;239:136.

---

! 74. Schaffler MB, Alson MB, Heller JG, et al. Morphology of the Dens: A Quantitative Study. *Spine* 1992;17:738.

---

+ 75. Schlicke LH. A Rational Approach to Burst Fractures of the Atlas. *Clin Orthop* 1981;154:18.

---

P.3692

+ 76. Schneider RC, Kahn EA. Chronic Neurological Sequelae of Acute Trauma to the Spine and Spinal Cord, Part I: The Significance of the Acute Flexion or "Teardrop" Fracture Dislocation of the Cervical Spine. *J Bone Joint Surg [Am]* 1956;28A:985.

---

+ 77. Segal LS, Grimm JO, Stauffer ES. Non-union of Fractures of the Atlas. *J Bone Joint Surg [Am]* 1987;69:1423.

---

+ 78. Shkrum MJ, Green RN, Nowak ES. Upper Cervical Trauma in Motor Vehicle Collisions. *J Forensic Sci* 1989;34:381.

---

+ 79. Sonntag VK, Dickman CA. Craniocervical Stabilization. *Clin Neurosurg* 1993;40:243.

---

- + 80. Spence KF, Decker S, Sell KW. Bursting Atlantal Fracture Associated with Rupture of the Transverse Ligament. *J Bone Joint Surg [Am]* 1970;52:543.
- 
- + 81. Starr JK, Eismont FJ. Atypical Hangman's Fractures. *Spine* 1993;18:1954.
- 
- ! 82. Steel HH. Anatomical and Mechanical Considerations of the Atlantoaxial Articulations. *J Bone Joint Surg [Am]* 1968;50:1481.
- 
- + 83. Stewart GC Jr, Gehweiler JA Jr, Laib RH, et al. Horizontal Fracture of the Anterior Arch of the Atlas. *Radiology* 1977;122:349.
- 
- \* 84. Sudeck P. Torsion Dislocation of Atlas. *Dtsch Z Chir* 1924;183:289.
- 
- + 85. Templeton PA, Young JWR, Mirvis S, et al. The Value of Retropharyngeal Soft Tissue Measurements in Trauma of the Adult Cervical Spine. *Skeletal Radiol* 1987;30:1.
- 
- + 86. Traynelis VC, Marano GD, Dunker RO, et al. Traumatic Atlanto-occipital Dislocation. *J Neurosurg* 1986;65:863.
- 
- + 87. Tuite GF, Papadopoulos MD, Sonntag VK. Caspar Plate Fixation for the Treatment of Complex Hangman's Fractures. *Neurosurgery* 1992;30:761.
- 
- + 88. Wang G-J, Mabie KN, Whitehill R, et al. Nonsurgical Management of Odontoid Fractures in Adults. *Spine* 1984;9:229.
- 
- + 89. Werne S. Studies in Spontaneous Atlas Dislocation. *Acta Orthop Scand* 1957;23 (Suppl):1.
- 
- + 90. Wertheim SB, Bohlman HH. Occipito-cervical Fusion. Indications, Techniques, and Results in 13 patient. *J Bone Joint Surg [Am]* 1987;69:833.
- 
- + 91. Wetzel FT, La Rocca H. Grisel's Syndrome: A Review. *Clin Orthop* 1989;240:141.
- 
- # 92. White AA III, Panjabi MM. *Clinical Biomechanics of the Spine*. Philadelphia: JB Lippincott, 1991.
-

+ 93. White GM, Healy WI. Tumor-associated Atlantoaxial Rotatory Fixation: A Case Report. *Spine* 1987;12:406.

---

+ 94. Zimmerman E, Grant J, Vise WM, et al. Treatment of Jefferson Fracture with a Halo Apparatus. *J Neurosurg* 1976;44:372.

---