127 Classification and Management of Occipitocervical Injuries

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SUMMARY OF KEY POINTS

- Occipitocervical injuries should always be suspected in cases of high-impact trauma.
- It is relevant to evaluate for additional injuries.
- Special attention should be paid to pure transverse ligament injuries that cannot expect to heal with nonoperative management.
- When appropriate, incomplete spinal cord injuries with compressive lesions warrant surgical intervention as soon as possible.
- When possible, early surgical intervention is desirable to promote early mobilization and rehabilitation.

The occipitocervical junction includes the skull base at the foramen magnum, C1, C2, and the associated ligamentous, neural, and vascular structures. Because of the important neural and vascular structures in the region, occipitocervical junction injuries have the potential to cause significant neurologic morbidity or mortality. Therefore, careful recognition, diagnosis, and management of these injuries are essential. The association with high-impact trauma and occipitocervical junction injuries is well recognized. However, the potential for injuries even with relatively minor trauma should be remembered, especially with abnormal bone (e.g., osteoporosis) or ligaments (e.g., rheumatoid arthritis).

Occipitocervical junction injuries can be classified in several ways (Box 127-1). One useful system describes occipitocervical junction injuries as isolated ligamentous injuries, isolated fractures, or mixed ligamentous and bony injuries. Occipitocervical junction trauma can also be described by the site or level(s) of injury. At most sites, classification systems have been developed for specific injury patterns (e.g., C2 odontoid fractures). Finally, occipitocervical junction injuries can be described on the basis of their stability. Stability is generally determined with clinical and radiographic assessment, sometimes using dynamic flexion/extension radiographs. A stable injury does not demonstrate significant radiographic deformity, pain, or neurologic dysfunction with normal physiologic loads and movement. An example of a stable injury would be an isolated C2 spinous process fracture that meets the preceding criteria. Some injuries are clearly unstable, such as occipitocervical dislocations. Other injuries may initially appear stable but have a reasonable chance of developing delayed instability with time, gravity, movement, or relaxation of paraspinal muscle spasm. This category reflects the reality that clinical and radiographic assessment of long-term stability may be indeterminate.

The preceding classification systems are helpful in injury assessment and planning management. However, the management of a patient with occipitocervical junction trauma is best determined by considering the nature of the injury (including associated injuries), patient characteristics (e.g., age, medical risk factors, bone quality, desire and ability to tolerate use of a halo orthosis), and the physician's experience. Although much less common, penetrating trauma to the occipitocervical junction presents unique issues that relate to the specific location and trauma modality (e.g., bullet, knife). This class of injuries is not specifically discussed in this chapter but is addressed in Chapter 142. Although most of the principles from blunt trauma are applicable to penetrating trauma, it is important to point out some important differences. Compared with blunt trauma, penetrating trauma typically results in less ligamentous injury and, therefore, for a similar fracture, may be more stable. However, penetrating trauma more commonly results in trauma to vascular or other important regional structures.

GENERAL PRINCIPLES

The initial management of occipitocervical junction injuries is focused on basic trauma management principles, including the establishment and maintenance of airway, breathing, and circulation; careful immobilization and transportation; and recognition and management of any associated injuries. These principles have evolved over time and have been published in numerous settings.[1,2]

Occipitocervical junction injuries are frequently recognized on routine cervical spine imaging. However, these injuries may be difficult to detect on initial diagnostic studies. Clinical suspicion based on history and physical examination can aid recognition. Routine radiographs and clinical assessment are often inadequate to fully characterize the injury, and more specialized imaging is usually indicated. Coronal, curved coronal, sagittal, or three-dimensional computed tomography (CT) reconstruction views can be extremely helpful in characterizing the presence and nature of injury. Magnetic resonance imaging (MRI) may be difficult or impossible to obtain acutely but can often provide essential information on spinal canal compromise and may suggest the presence and degree of ligamentous injury. Dynamic imaging with plain radiographs, CT, or MRI can be valuable in assessing stability but should be performed carefully. Occasionally, stability is checked with real-time fluoroscopy during careful flexion and extension controlled by a qualified examiner. For example, fluoroscopic flexion/extension imaging may be helpful when there is urgent need to assess the stability of the cervical spine in an unresponsive patient but there is still controversy about its interpretation.[3]

Once occipitocervical junction injuries are diagnosed, management decisions are based on several factors, including the extent and stability of injury, the presence or progression of neurologic deficits, and patient-specific factors that influence the risks with different treatments. Nonoperative management typically includes some type of rigid (halo) or semirigid (collar) orthosis. Operative management is generally indicated for injuries that are unstable, have significant potential for delayed instability, have progressive neurologic deficits, or cause significant deficits or symptoms that are not controlled with nonoperative measures. Operative planning

BOX 127-1 Occipitocervical Junction Injury Classification Systems

A. LOCATION OF BONE OR LIGAMENTOUS INJURY

- Pure ligamentous injuries
  Occipitoatlantal dislocations
  Transverse ligament injuries
  Rotatory C1-2 dislocations
- Isolated fractures
  - Occipital condyle fractures
  - C1 (lateral mass, ring)
  - C2 (odontoid, body, hangman, dorsal element)
- Mixed ligamentous and bony injuries

B. SITE/LEVEL OF INJURY

Occipital bone (C0) (e.g., condyle fracture)
C0-1 ligaments (e.g., occipitoatlantal dislocation)
C1 (e.g., lateral mass, ring fractures)
C1-2 ligaments (e.g., transverse ligament injuries)
C2 (odontoid, body, hangman, dorsal element fractures)

C. DEGREE OF STABILITY

Stable
Low probability of delayed instability
High probability of delayed instability
Unstable

may include obtaining additional imaging (e.g., dedicated studies for image guidance), ensuring the availability of appropriate instrumentation, and arranging neurophysiologic monitoring where appropriate.

DIAGNOSIS AND MANAGEMENT

Atlantooccipital Dislocations

Atlantooccipital (AODs) dislocations are relatively uncommon ligamentous injuries that usually result from hyperflexion and distraction during high-impact blunt trauma that is more common in pediatric patients due to flatter condyles and increased ligamentous laxity.[4,5] These injuries are highly unstable, frequently fatal, and usually result in significant neurologic injury from stretching, compression, or distortion of the spinal cord, brainstem, and cranial nerves.[6] In addition, significant morbidity and mortality can result from associated cerebrovascular injury, which varies significantly among trauma series (0.53% to 88%), diagnosis test used (computed tomography angiography [CTA], conventional angiogram), and severity of injuries.[7-9] Recognition and rapid management of these injuries may limit further injury, but even with appropriate care, neurologic deficits can progress. Although these were initially felt to be rare, several series of trauma fatalities have revealed an incidence between 8% and 19%.[4]

Lateral cervical spine radiographs may recognize atlantooccipital dislocations (sensitivity, 0.57), especially in severe injuries. However, these injuries can be difficult to diagnose with plain radiographs alone, especially with less severe dislocations. In addition, the frequent presence of coexisting significant head trauma can delay recognition of spinal injury. Diagnostic clues include prevertebral soft tissue swelling, an increase in the dens-basion distance, and separation of the occipital condyles and C1 lateral masses (Fig. 127-1). CT imaging with reconstruction views (sensitivity 0.84) usually provides a better assessment of fractures and alignment than plain radiographs do. The presence of subarachnoid hemorrhage supports but does not confirm the diagnosis. MRI can be helpful for diagnosis (sensitivity 0.86), to assess the extent of spinal cord compression and injury, and to demonstrate compressive hematoma lesions.[2]

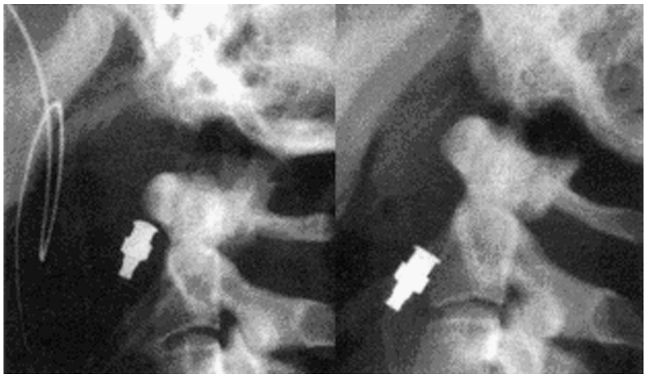

Figure 127-1. Lateral cervical radiographs demonstrating occipitocervical dislocation. The craniovertebral instability is apparent in the two images. *(From Dickman CA, Spetzler RA, Sonntag VKH, editors:* Surgery of the craniovertebral junction, *New York, 1998, Thieme.)*

On the basis of the injury pattern, Traynelis and colleagues[10] classified atlanto-occipital dislocations into four types: type I (anterior), type II (longitudinal), type III (posterior), and "other" (complex). Multiple diagnostic radiographic criteria have been described to assess the relationship between the skull base and the cervical spine (Fig. 127-2). Although developed for lateral plain radiographs, these criteria can also be used on sagittal reconstruction CT views, provided that there are no significant artifactual distortions. Currently, if a radiologic method for measurement is used to determine AOD on the lateral radiograph, the basion-axial interval–basion dental interval (BAI-BDI or Harris) method is recommended.[11] This method demonstrated increased diagnostic accuracy compared with the Powers ratio.[12] A BDI above 12 mm in adults and children is considered abnormal. The BAI is mainly used for anterior or posterior AOD (Traynelis type I and III) and measures the distance between basion and a line drawn tangentially to the posterior cortical surface of C2 with rostral extension (also known as the posterior axial line), and its normal values range from −4 to 12 mm in adults and from 0 to 12 mm in children. The Wackenheim clival line extends along the dorsal surface of the clivus and should be tangential to the tip of the dens.[13] Ventral or dorsal translation of the skull in relation to the dens will shift the clival line to either intersect or run dorsal to the dens, respectively. The Powers ratio is based on the relationship of the B–C line (from the basion to the C1 dorsal arch) and the O–A line (between the opisthion and the C1 ventral arch).[14] Normal B–C/O–A ratios average 0.77, whereas pathologic ratios (> 1) typically represent occipitocervical dislocations. However, false negatives can occur with longitudinal or dorsal dislocations.[15] The Wholey dens-basion technique assesses the distance from the basion to the dens tip.[16] Although variability is common, the average distance in adults is about 9 mm, and pathologic distances are greater than 15 mm.[17] The Dublin method, the least reliable method, measures the distance from the mandible (posterior ramus) to the ventral part of C1 (normally 2 to 5 mm) and C2 (normally 9 to 12 mm).[18]

Initial management of these injuries focuses on immobilization, almost always with a halo orthosis. Cervical collars are potentially dangerous because they may produce distraction and thereby promote further injury. Similarly, traction can cause neurologic worsening (2 of 21 patients) and should be avoided or used with extreme caution.[1,2] Nonoperative

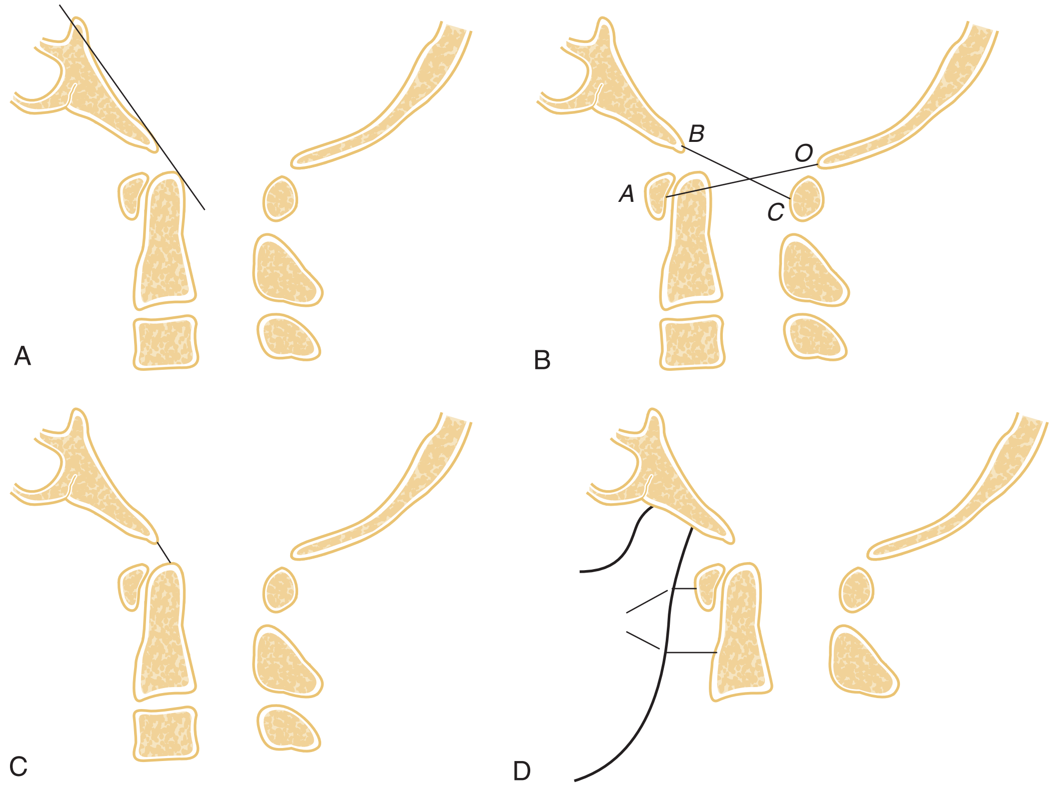

Figure 127-2. Four radiographic methods for assessing occipitocervical dislocation. **A,** Wackenheim clival line. **B,** Power ratio (*B–C/O–A*). **C,** Wholey dens-basion technique. **D,** Dublin method. See text for details. *(From Barrow Neurological Institute, Phoenix, Arizona, with permission.)*

management does not provide definitive treatment of these injuries because of the significant ligamentous disruption that cannot be expected to heal even with prolonged rigid (halo) external immobilization (11 of 40 patients had a nonunion or neurologic deterioration).[2] Operative stabilization consists of an occipitocervical arthrodesis with rigid internal fixation (discussed later and in Chapter 53). Decompression and restoration of alignment may also be necessary to maximize neurologic recovery.

Transverse Ligament Injuries

Isolated traumatic transverse ligament injuries are unstable injuries that can result in significant upper cervical spinal cord injury either during the initial trauma or afterward. These injuries are more common in hyperflexion injuries. Because transverse ligament injuries may be difficult to recognize on initial (neutral) plain radiographs, an elevated index of suspicion is required in some settings—for example, high-impact trauma.

Transverse ligament injuries are suggested or diagnosed indirectly with radiographic imaging. A widened atlantodental interval (ADI) on flexion lateral cervical radiographs (> 3 mm in adults, > 5 mm in children) suggests transverse ligament insufficiency. Thin-cut CT imaging with reconstruction views may suggest the diagnosis by demonstrating a C1 lateral mass avulsion fracture at the ligamentous insertion. Thin-cut MRI with attention to the transverse ligament when using gradient echo sequences can directly demonstrate a transverse ligament injury.[19] If the diagnosis is uncertain, dynamic (flexion/extension) imaging is appropriate for cooperative patients. On the basis of CT and MRI, traumatic transverse ligament injuries can be classified into two categories (Fig. 127-3). Type I injuries involve disruptions of the midportion (IA) or periosteal insertion laterally (IB). Type II injuries involve fractures that disconnect the C1 lateral mass tubercle for insertion of the transverse ligament via a comminuted fracture (IIA) or an avulsion fracture (IIB).[20]

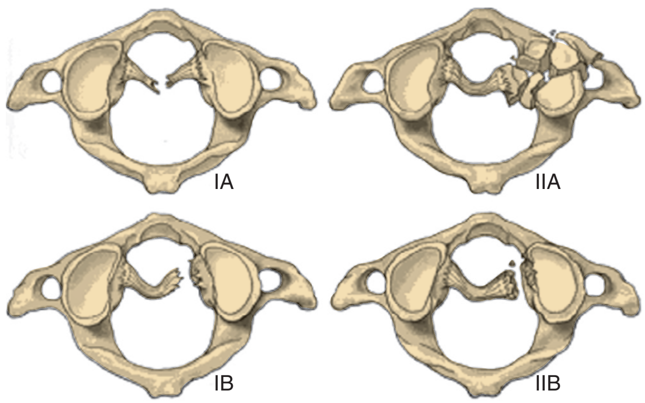

Figure 127-3. Classification of transverse ligament injuries. Type I injuries are disruptions of the transverse ligament in its midportion (IA) or periosteal insertion laterally (IB). Type II injuries lead to transverse ligament insufficiency through fractures that disconnect the C1 lateral mass tubercle (insertion of the transverse ligament) via a comminuted fracture (IIA) or an avulsion fracture (IIB). *(From Barrow Neurological Institute, Phoenix, Arizona, with permission.)*

The management of transverse ligament injuries should be individualized. In a retrospective series of 39 patients by Dickman and colleagues, type I injuries that affect mainly ligamentous tissue were managed surgically with dorsal C1-2 arthrodesis and fixation. The surgical options included C1-2 dorsal wiring, C1-2 Halifax clamps, C1-2 transarticular screws, or C1-2 segmental screw fixation (discussed later and in Chapter 53). Type II injuries were considered to have a much higher chance of healing with halo immobilization (up to 74%).[20] If a nonunion was still present after a prolonged period of immobilization (> 3 months), then operative stabilization was considered appropriate.

Rotatory C1-2 Subluxations

Rotatory C1-2 subluxations are ligamentous injuries that are more common in children and adolescents with less morbidity and mortality than AOD. These injuries typically present with neck pain and a fixed, rotated "cock-robin" head position. Open-mouth radiographs may demonstrate an asymmetry of the C1 and C2 lateral masses. CT imaging can confirm the rotatory subluxation diagnosis and demonstrate coexisting fractures. C1-2 axial rotation greater than 47 degrees confirms the diagnosis. Three-view CT imaging (15 degrees to the left, neutral, and 15 degrees to the right) can also be helpful in establishing the diagnosis.[21,22] MRI may detect a coexistent transverse ligament injury.

The treatment of C1-2 rotatory subluxations is generally nonoperative. Axial traction with a halter device or Gardner-Wells tongs can usually achieve reduction of the injury. Prolonged traction or the use of muscle relaxants may be needed. Periodic imaging may help to assess progress, but clinical improvement in the alignment and symptoms often provides confirmation of a successful reduction. Operative reduction and fixation are reserved for irreducible injuries, recurrent subluxations, and transverse ligament injuries.

Occipital Condyle Fractures

Occipital condyle fractures generally occur with axial trauma and are almost always unilateral (> 90%). The historical classification according to Anderson and Montesano[23] described three types of injuries: type I injuries are comminuted fractures that result from axial trauma; type II fractures are extensions of linear basilar skull fractures; type III injuries are avulsion fractures of the condyle that can result from a variety of mechanisms. The incidence of occipital condyle fractures has been estimated to be between 1% and 3% of blunt craniocervical trauma cases.[24] Although plain radiographs (usually open-mouth radiographs) may occasionally identify the injury, they have an unacceptably low sensitivity (estimated at 3.2%) and should not be relied on when the diagnosis is suspected. CT imaging with reconstruction views provides the best assessment of fracture pattern and alignment.[24,25]

Occipital condyle fractures are generally stable and therefore are typically managed with an external nonrigid orthosis (collar) until the fracture heals (often 12 weeks). If occipitocervical misalignment is identified upfront, occipitocervical fusion or halo fixation is recommended.[26]

C1 Fractures

Isolated C1 fractures account for approximately 5% of cervical spine fractures. These injuries occur with axial trauma with or without lateral bending.[27] Open-mouth radiographs may suggest the injury, but CT imaging with reconstruction views provides the best assessment of fracture pattern and alignment. Fractures can include almost any part of the ring or lateral masses of C1. Aside from unilateral lateral mass fractures, the fractures usually occur at multiple sites (Fig. 127-4). Jefferson fractures are four-part fractures with bilateral ventral and dorsal ring fractures. The assessment of these injuries is focused on evaluating the integrity of the transverse ligament and on recognizing any additional fractures.

The management of C1 fractures is based on the integrity of the transverse ligament that can be assessed indirectly with several radiographic criteria such as a widened atlantodental interval (> 3 mm) and increased spread of the lateral masses of C1 over C2 (> 6.9 mm, rule of Spence)[28] or directly through high-resolution MRI (Fig. 127-5). If the transverse ligament is

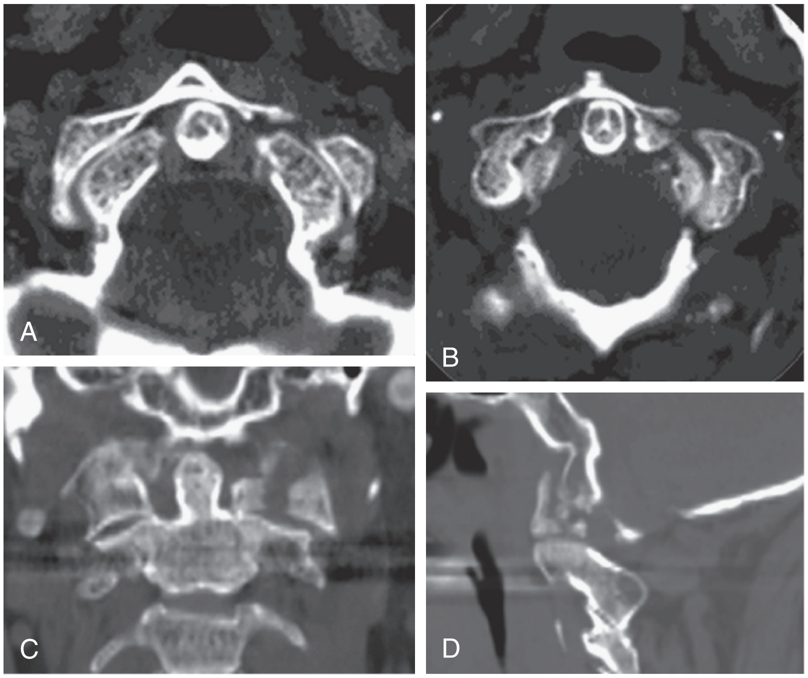

Figure 127-4. C1 lateral mass fracture. Axial CT images (**A** and **B**) and coronal (**C**) and sagittal (**D**) CT reconstruction views of right C1 lateral mass fracture from high-speed motor vehicle accident. The fracture healed with 3 months of external immobilization.

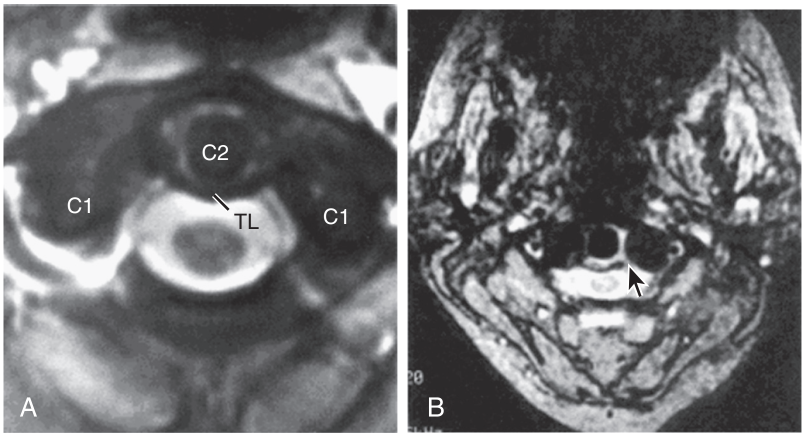

Figure 127-5. Axial MRI images demonstrating an intact (**A**) and ruptured (**B,** *arrow*) transverse ligament (TL). *(From Dickman CA, Spetzler RA, Sonntag VKH, editors:* Surgery of the craniovertebral junction, *New York, 1998, Thieme.)*

intact, isolated C1 fractures are generally stable and can be treated with an external orthosis (e.g., sterno-occipital-mandibular immobilization [SOMI] device) primarily for symptom control until the fracture heals. With transverse ligament insufficiency, operative stabilization is indicated by using a C1-2 fusion technique such as dorsal C1-2 wiring techniques, C1-2 transarticular screws, C1 lateral mass-to-C2 pars/pedicle/translaminar screws, or ventral C1-2 screw fixation (see Chapter 143). The surgical choice is based primarily on patient anatomy and fracture pattern as well as the surgeon's experience and preference. Postoperatively, most operations employing rigid internal fixation can be managed with a nonrigid external orthosis (e.g., a collar, SOMI), but C1-2 dorsal wiring without additional instrumentation generally warrants the use of a halo.[29]

C2 Fractures

C2 fractures make up about 20% of all cervical spine fractures and are classified as odontoid, body, or other fractures (e.g., hangman, laminar, or spinous process).

Odontoid Fractures

C2 odontoid fractures can occur from a number of mechanisms but most often are caused by hyperextension injuries. Although lateral cervical spine radiographs may demonstrate some fractures, especially those with displacement, this technique can easily miss fractures, especially those with degenerative changes or minimal displacement. Open-mouth radiographs are very helpful for diagnosing most odontoid fractures, but these also may be inconclusive. Thin-cut CT images with sagittal and coronal view reconstruction views are the best way to diagnose and characterize odontoid fractures as well as to find associated fractures and plan treatment.[30,31]

Anderson and D'Alonzo classified odontoid fractures into three types based on the location of the fracture line through the odontoid tip (type I), odontoid base (type II), or C2 body (type III)[32] (Fig. 127-6). Type I fractures are essentially avulsion fractures of the odontoid tip and are rare, generally stable, and usually managed with an external semirigid (collar) or rigid (halo) orthosis. Type II fractures are the most common type of odontoid fracture. These fractures are unstable and prone to nonunion because they occur in an area of relatively reduced osseous vascularity. Therefore, rigid halo immobilization or surgical stabilization is often necessary. Hadley and associates described type IIA fractures that are comminuted fractures at the base of the dens with associated free fragments.[33] These fractures are considered particularly unstable, and surgical stabilization is advisable, usually with a dorsal C1-2 fusion. Type III fractures involve the vertebral body and are discussed later.

Figure 127-6. C2 odontoid fractures as described by Anderson and D'Alonzo. Type II fractures are better described as C2 body fractures, as discussed later in this chapter. *(From Barrow Neurological Institute, Phoenix, Arizona, with permission.)*

C2 Body Fractures

The C2 body can be defined as the C2 bone mass caudal to the dens and ventral to the pars interarticularis bilaterally. Benzel and coworkers[34] have classified C2 body fractures on the basis of the orientation of the fracture line: coronal, sagittal, or transverse (also known as horizontal rostral). The transverse type of C2 body fracture is a more appropriate description of type III odontoid fractures. The coronal and sagittal types represent vertical" fractures. Of the vertical fractures, the coronal type was much more common (4 : 1 ratio) and resulted from multiple (four) mechanisms. Sagittal type C2 body fractures were caused by axial loading trauma. Figure 127-7 shows an example of a C2 body fracture.

Although standard cervical radiographs will often recognize the fracture, the injury is best characterized with high-resolution CT scanning with multiplanar reconstruction views. It is important to look for radiographic evidence of involvement of the foramen transversarium and clinical signs of vertebral artery injury (5.8% symptomatic).[9] If there is a significant degree of suspicion, an assessment of the vertebral artery with CTA, magnetic resonance angiogram (MRA), or transfemoral catheter angiography should be obtained. Currently, no guidelines exist for vertebral artery injury management, although decision of treatment (anticoagulation, antiplatelet agents, or no treatment) should be individualized based on associated injuries and bleeding risk.[35] The stability of C2 body fractures can be assessed either with fracture characteristics (e.g.,

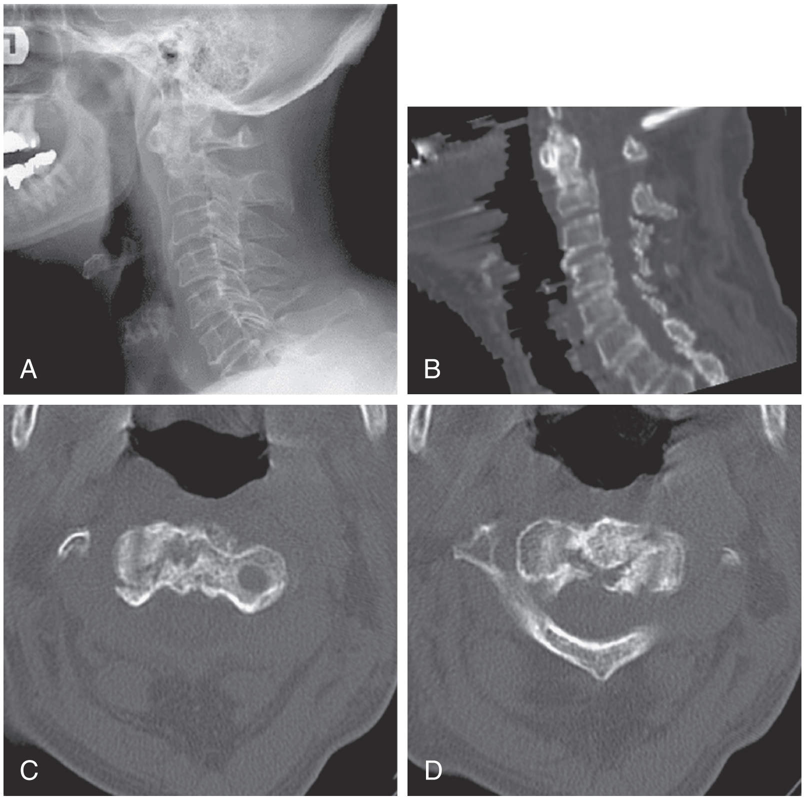

Figure 127-7. C2 body fracture. An 80-year-old woman presented with neck pain after a fall. A lateral cervical radiograph (**A**) suggests C1-2 instability from a C2 fracture. A sagittal CT reconstruction image (**B**) suggests a C2 body fracture with a transverse fracture line (also described as type III odontoid fracture) and a vertical (coronal) fracture line in addition. Axial CT images (**C** and **D**) confirm the C2 vertical fracture component.

displacement) or with careful dynamic (flexion/extension) imaging when stability appears likely.

A majority of C2 body fractures can be managed nonoperatively. Depending on the alignment, degree of displacement, and fracture location, either a collar or a halo may be advisable. Occasionally, surgical intervention with a dorsal C1-2 fusion is indicated, particularly for highly unstable fractures and in patients who are prone to nonunion.

Other C2 Fractures

Traumatic spondylolisthesis fractures of the axis (also known as hangman fractures) are characterized by bilateral fractures through the C2 pars/pedicle (Fig. 127-8). Although these fractures may be unstable, they do not generally cause significant compromise of the spinal canal or neurologic injury. Effendi and colleagues[36] have classified these injuries into three groups based on mechanism. Type I fractures are single hairline fractures of the pedicle of axis and occur with axial loading and hyperextension. Type II fractures have displacement of the ventral fragment with an abnormal disc below the axis and are hyperextension injuries with rebound hyperflexion. Type III fractures have displacement of the ventral element with the body of the axis in the flexed position, and the facet joints at C2-3 are dislocated and locked and are primarily flexion injuries with rebound extension. Levine and Edwards[37] modified the system by adding a type IIA, which represents flexion-distraction injuries with mild or no displacement but severe angulation. Types I and II injuries are generally stable and can usually be managed with a collar. With significant displacement (> 4 to 6 mm), halo immobilization may be advisable. Type IIA injuries are more likely to be unstable, especially with displacement greater than 4 to 6 mm or angulation more than 11 degrees. If one or both of these findings are present, surgical stabilization may be necessary. Type III injuries are unstable and typically require surgical stabilization. Isolated C2 laminar or spinous process fractures are stable and therefore are usually managed with an orthosis (e.g., a collar).

Combination Occipitocervical Junction Injuries

Combination occipitocervical junction fractures involve bony and ligamentous injuries of the foramen magnum (e.g., occipital condyles), C1, or C2. These injuries are usually unstable, occur with high-impact trauma, and frequently result in death or major neurologic injury. Management of these injuries is similar to that of occipitocervical dislocations. Initial management involves airway management, craniovertebral immobilization, and medical stabilization. Patients who are medically stable are considered for more prolonged stabilization with rigid external halo immobilization or surgical stabilization. For incomplete spinal cord injuries, decompression of any compressive bony or hematoma lesions may also be necessary and is performed when the patient is medically stable. With complete spinal cord injuries, the timing of surgical stabilization or decompression is less urgent.

Combined C1-2 fractures occur with axial trauma with or without lateral bending. Although plain radiographs may indicate a combined fracture, a CT with multiplanar reconstruction views is usually necessary to fully characterize the fractures and alignment and to plan treatment. Compared with isolated C1 and C2 fractures, combined C1-2 fractures are typically associated with a higher rate of instability, nonunion, and neurologic

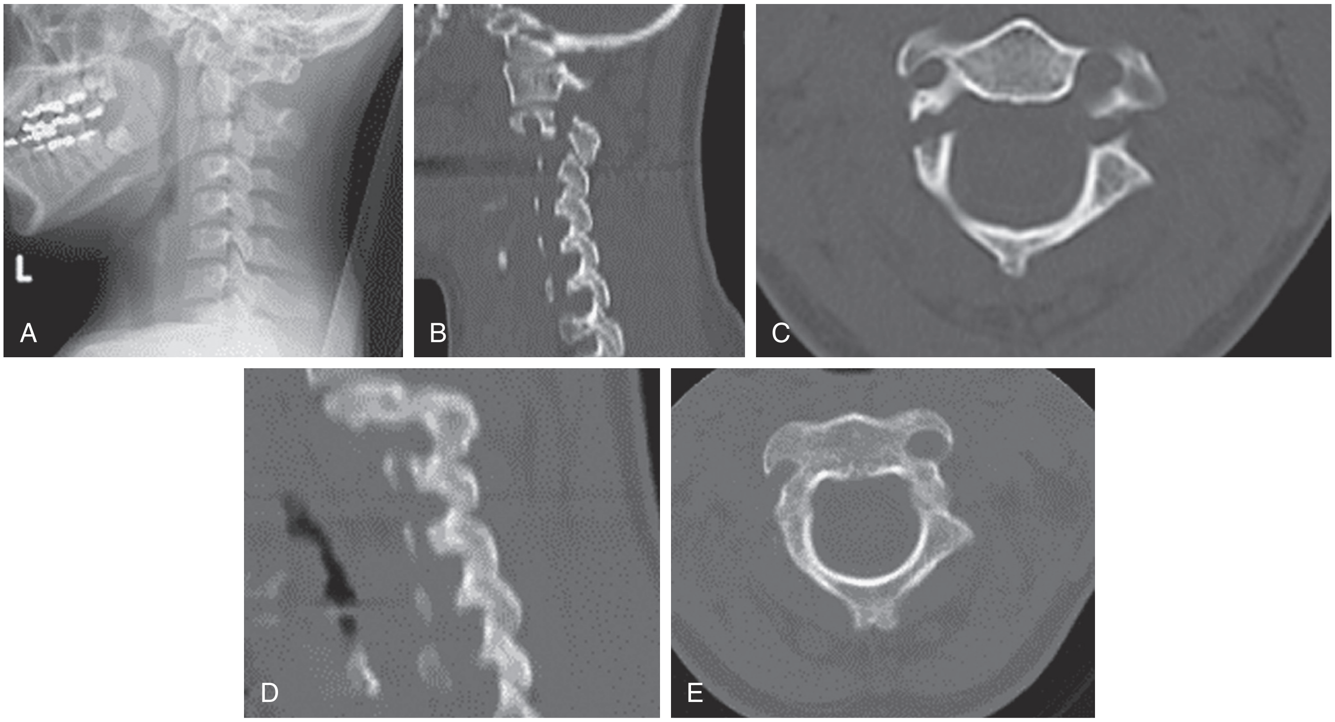

Figure 127-8. C2 hangman fracture. A 21-year-old woman presented with neck pain after a motor vehicle accident. Initial studies with a lateral cervical radiograph (**A**), sagittal CT reconstruction image (**B**), and axial CT image (**C**) demonstrate the fracture through the C2 pars/pedicle with moderate displacement. The fracture healed with 3 months of external immobilization, as is evidenced by the delayed sagittal CT reconstruction (**D**) and axial CT (**E**) images.

injury. Treatment of these injuries is based on the degree and location of bony and ligamentous injuries. Because of the instability, rigid external (halo) or internal fixation is usually required. Standard surgical procedures (e.g., dorsal C1-2 interspinous fusion) might not be possible because of the extensive fractures. Advances in instrumentation and surgical technique have allowed the development and increased use of newer types of surgical stabilization such as C1-2 transarticular screws or C1-2 segmental fixation.[38-42]

SURGICAL PROCEDURES

General Principles

Preoperative Care

There are multiple indications for surgical intervention with occipitocervical trauma. Decompression may be necessary to relieve compromise of the spinal canal or neural foramina from bone or soft tissue (e.g., hematoma) lesions. Internal stabilization may be necessary to treat acute or impending instability, to promote fracture healing, and to improve or correct alignment.

Preoperative care is focused on optimizing medical stability; obtaining the necessary imaging to assess the injury location, alignment, and stability; and determining the nature and timing of any needed intervention. The timing of surgery is based on the patient's medical stability, the degree of spinal compression, the presence or progression of neurologic deficits, and the availability of optimal operating room equipment and personnel. Incomplete spinal cord injuries with compressive lesions warrant surgical intervention as soon as possible. This is particularly true when there are progressive neurologic deficits. However, it is important to note that neurologic deterioration may be related to the natural history of the neurologic injury or medical deterioration (such as hypoxia, hypotension, or fever) that would not necessarily be assisted with surgical intervention. Rather, it is possible that the patient would have a better chance of tolerating, and hopefully benefiting from, the procedure by delaying surgery until the medical issues have been optimized. When possible, early surgical intervention is desirable to promote early mobilization and transfer to rehabilitation.

Preoperative planning includes selection of a primary surgical plan as well as backup plans, which may become necessary. When needed, specialized equipment (e.g., image guidance, instrumentation) or neurophysiologic monitoring should be reserved or arranged in advance. When possible, preoperative studies should be loaded onto image guidance equipment (if used) in advance to permit preoperative surgical planning.

Intraoperative Care

The intraoperative setup and positioning are directed by the nature of the injury and surgical approach. With occipitocervical instability it is recommendable to keep full cervical spine precautions and external orthosis during transfer to the surgical bed and positioning until cranial fixation is achieved. In general, occipitocervical junction trauma procedures use a midline dorsal approach in the prone position with cranial fixation or a high ventral cervical approach in the supine position. Transoral, transfacial, and far lateral skull base approaches are not commonly used in the trauma setting. When there is sufficient neurologic function and degree of potential new or exacerbated neurologic injury, spinal monitoring (sensory or motor evoked potentials) may prove useful for determining whether the final surgical positioning is satisfactory.

Exposure of the occipitocervical junction for trauma may require special considerations. For example, throughout the case, careful attention is advised to maintain appropriate alignment and minimize or avoid pressure on unstable or compressed neurologic structures. Traumatic injuries to the subcutaneous and paraspinal soft tissues can distort and obscure anatomic landmarks. Additional exposure (e.g., length of incision, number of levels) may aid in the recognition and management of the abnormal anatomy because of increased exposure of adjacent normal anatomy.

Decompression and stabilization are two primary objectives of surgery. Decompression of neurologic structures may be accomplished by correcting alignment or removing compressive bone, ligaments, or other space-occupying lesions such as hematomas. The goals of stabilization are to achieve stability and, where appropriate and possible, to maintain or improve alignment, maximize neurologic function, and improve symptoms. Achieving bony fusion is the best way to achieve long-term stability. At surgery, the standard principles of arthrodesis should be followed with careful attention to the exposure and preparation of bone fusion surfaces and the choice of structural or morselized bone graft material. For the majority of cases, internal fixation with instrumentation is utilized to maintain alignment and promote osseous union. Nonrigid external orthoses (e.g., collar, SOMI) do not provide substantial immobilization of the occipitocervical junction. Therefore, instrumentation should be optimized with some (or all) of the following strategies including all segments involved in the construct, using larger-diameter or longer screws as possible, and achieving bicortical purchase where advisable.

Occipitocervical junction trauma operations may require special closure considerations. For example, these cases may have an increased risk of postoperative infection, as the incision typically extends beyond the suboccipital hairline. Copious irrigation is therefore advised before closure. Leaving one or more Jackson-Pratt or Hemovac drains may reduce the incidence of postoperative hematoma or seroma collections. However, these drains should be used cautiously if the dura was compromised from the trauma or during the procedure. In the event of dural compromise, primary closure or augmentation (e.g., patch, fibrin glue product) and extra attention to fascial closure are often used. A running locked suture may be used for the skin closure. For cases with significant dural compromise that is not possible to repair, several days of postoperative spinal drainage via local (through or near incision) or distal (typically lumbar) placement of an intrathecal catheter may reduce chances of a postoperative spinal fluid collection or leak.

Postoperative Care

Postoperatively, a rigid external orthosis (halo) is used if instrumentation is not used or if concern exists regarding the instrumentation or bone quality. Otherwise, some type of nonrigid orthosis is advisable in most cases. Because standard cervical collars do not immobilize the occipitocervical junction well, special orthoses are often used (e.g., SOMI braces). Currently, there is no consistent medical evidence to support or refute the use of bone stimulator devices.[43] Although not officially studied, bone stimulators have been used as a primary adjunct in patients who are prone to nonunion (e.g., smokers) or in an attempt to salvage a nonunion. Patients with spinal cord injury require special attention to nutrition, skin care, pulmonary toilet, deep vein thrombosis prophylaxis, and often psychiatric support. Patients with poor nutrition are prone to wound-healing problems, and sutures may need to be left for a prolonged period (2 to 3 weeks or more).

Postoperative imaging with plain radiographs or CT imaging is generally obtained when possible to assess the final anatomy and alignment, extent of decompression, and position of instrumentation. Interval imaging is followed as needed to assess bony fusion. When sufficient stability is achieved from the internal fixation or bone fusion, the orthosis can be weaned. Dynamic imaging with flexion/extension views can provide an assessment of stability and bony fusion.

Occipitocervical Junction Fusions

Occipitocervical junction fusions are performed through a dorsal midline approach. Ventral occipitocervical junction fusions may be technically possible, but the transoral approach for trauma is prone to infection and may be difficult to expose because of the altered anatomy and difficult to close because of the instrumentation. Finally, the ventral approach is not ideal for placement of instrumentation because the surgeon is limited in the extent of rostrocaudal exposure.

At surgery, careful transfer to the prone position is required. The patient's head is fixed with a Mayfield head clamp unless the patient is already in a halo ring/vest. In this case, it is possible to turn the patient in the halo ring/vest. After the halo ring is locked to the operating table with a Mayfield halo adapter, the dorsal part of the halo vest and connecting bars are disassembled to permit adequate exposure. As much as possible, the head should be positioned in an appropriate alignment such that the patient will naturally look forward (i.e., avoid hyperflexed or hyperextended positioning to maximize patient visualization and comfort). The iliac crest region is prepped to harvest bone graft. The exposure should extend from the inion down to C3 at least, with the ability to continue further caudally as necessary. Decompression of the foramen magnum should be performed if necessary, but the ability to achieve a midline fusion and take advantage of the thicker midline bone is limited by an extensive midline suboccipital decompression.

Structural unicortical strips are harvested from the iliac crest along with cancellous bone. Local autograft from the cranium or dorsal spinal elements is significantly less effective in achieving fusion. Allograft is least likely to achieve fusion and generally should not be relied on. Instrumentation options include inverted U-rods with wiring, inverted-Y-plate/screw constructions, and specialized cranial plate attachments for polyaxial cervical screws.[44,45] The midline bone is thickest and allows placement of longer screws with better purchase. The construct should be extended to at least C2 and sometimes lower to achieve optimal fixation. However, advances in instrumentation have made the longer constructs to the lower cervical spine or cervicothoracic junction uncommon unless additional subaxial cervical spine injuries exist. Dorsal C0-1 transarticular screw fixation has been described by Grob[46] and by Gonzales and coworkers.[47] The utility of this procedure is still evolving. The instrumentation options and techniques are discussed further in Chapter 111. Postoperatively, a collar or SOMI brace is used until bony fusion occurs (usually 12 weeks). Halo immobilization is used when the bone quality or fixation is suboptimal.

Dorsal C1-2 Fixation

Dorsal C1-2 fusions are indicated for unstable C1 or C2 fractures and are performed through a dorsal midline approach. C1-2 fusion requires sacrifice of the movement at C1-2 (primarily rotation); therefore, for appropriate fractures with an intact transverse ligament, odontoid screw fixation may be preferable.

At surgery, the positioning is similar to that used in occipitocervical junction fusions. However, if transarticular screw placement is planned, the head should be flexed as possible to facilitate screw placement. The exposure should extend from the foramen magnum through C3. If the dorsal elements of C1 and C2 are intact and do not need to be decompressed, then structural autograft from the iliac crest is harvested for placement between or along the dorsal elements of C1 and C2. Careful exposure, preparation, and decortication of the fusion surfaces are important to maximize the chances of achieving fusion. The caudal edge of C1 is a common site for nonunion and deserves special attention. Additionally, during dissection of C1 lateral mass, careful identification of trajectory of vertebral artery is critical and Doppler ultrasound can give useful guidance.

Instrumentation options include C1-2 wiring alone or with additional screw instrumentation, C1-2 Halifax clamp fixation, C1-2 transarticular screw fixation, and C1-2 segmental screw fixation.[38-42] The wiring options include the Brooks, Gallie, and Sonntag interspinous fusion operations.[48-54] The relative advantages and disadvantages of the various options are listed in Box 127-2. Postoperatively, a collar or SOMI brace is used until bony fusion occurs (usually 12 weeks). Halo immobilization is used when the bone quality or fixation is suboptimal.

BOX 127-2 Advantages and Disadvantages of Dorsal C1-2 Fusion Operation

C1-2 WIRING (Brooks, Gallie, Sonntag)

Advantages: Familiar technique
Disadvantages: Least rigid, requires more external fixation, higher nonunion rate

C1-2 TRANSARTICULAR SCREW FIXATION

Advantages: Most rigid
Disadvantages: Potential for vertebral artery injury

C1-2 SEGMENTAL FIXATION

Advantages: Familiar technique, avoids screw, very rigid
Disadvantages: Venous plexus bleeding, potential vertebral artery injury

C1-2 SUBLAMINAR HOOKS (Halifax Clamps)

Advantages: Avoids screw placement risks
Disadvantages: Less rigid than screws, weak in extension, may narrow canal

Odontoid Screw Fixation

Ventral odontoid screw fixation is appropriate for many unstable C2 odontoid fractures that require operative fixation. The main advantages of odontoid screw fixation are the preservation of C1-2 mobility and the relatively short and well-tolerated nature of the procedure. However, the procedure is not possible for many patients and fractures because of anatomic limitations. For example, patients with short necks, barrel chests, an inability to tolerate cervical extension, insufficient transverse ligaments, oblique fracture lines, or significantly comminuted fractures are poor candidates for this procedure. For these patients, a dorsal C1-2 fusion is typically chosen.

At surgery, the patient is positioned supine with the head extended, usually in a fixed position with a Mayfield head holder. Biplanar fluoroscopy is generally used. Using a lower cervical incision about at C5-6, a standard high ventral cervical approach is followed to the C2-3 region. A variety of standard or specialized retractors can be used to maintain exposure. By using a Kerrison rongeur or high-speed drill, a midline trough is made in the ventral-rostral C3 vertebral body. Next, by using the trough, a power drill with a 2-mm bit is used to drill a pilot hole from the ventral caudal border of C2, across the fracture line, and to the tip of the odontoid process. The appropriate-length screw is determined by preoperative radiograph or CT measurements, intraoperative fluoroscopy, or measuring the length of the drill bit. If the fracture needs to be reduced, then a lag screw of an appropriately shorter length should be selected. Even without significant fracture displacement, lag screws can promote fusion by providing a compressive force across the fracture line. The screw is threaded into the pilot hole in the same trajectory. One or two screws may be placed, but one is typically used because the outcomes appear similar.[55,56] Several odontoid screw systems exist with specialized instrumentation and screws.[57] One system includes cannulated screws that can be placed over a threaded drill bit (Fig. 127-9).[58] See Chapter 143 for additional details on the instrumentation.

Patients are managed with a postoperative external orthosis (collar) until the fracture heals (usually 10 to 12 weeks). Success rates are high, with fusion rates between 81% and

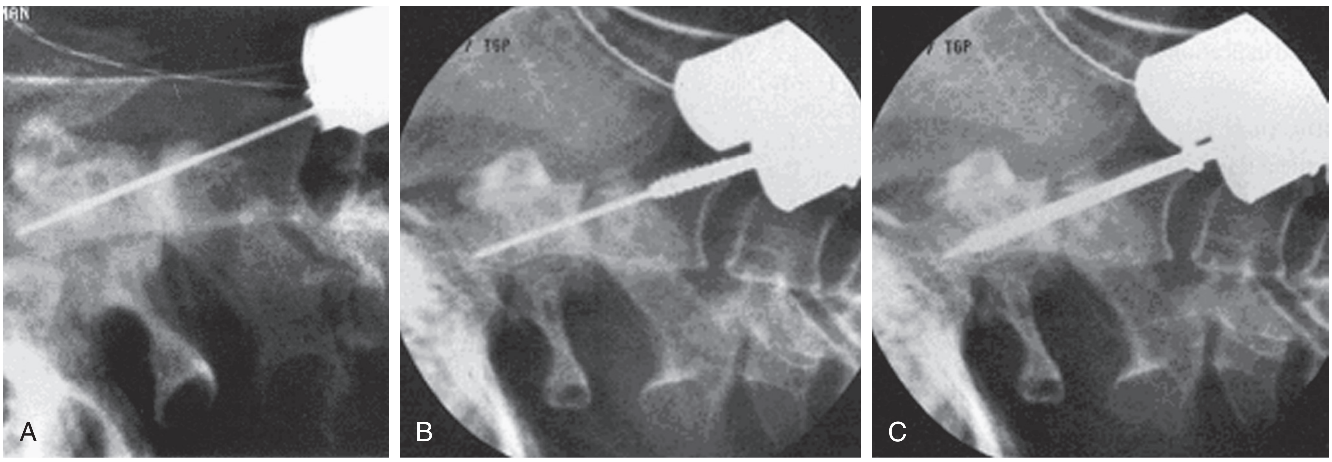

Figure 127-9. C2 odontoid screw placement with a cannulated screw system. Initially, a K-wire drill bit is placed (**A**). Next, the screw is carefully threaded over the drill bit under fluoroscopic guidance (**B** and **C**). *(From Dickman CA, Spetzler RA, Sonntag VKH, editors:* Surgery of the craniovertebral junction, *New York, 1998, Thieme.)*

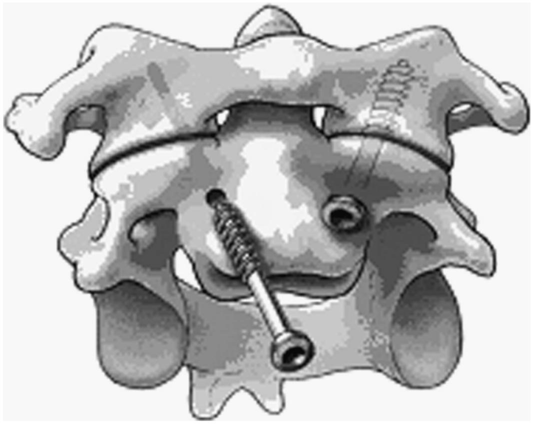

Figure 127-10. Anterior C1-2 transarticular instrumentation. *(From Barrow Neurological Institute, Phoenix, Arizona, with permission.)*

96%.[55,56] In the event of a nonunion, a dorsal C1-2 technique can be used.

Ventral C1-2 Fixation

Ventral C1-2 transarticular fixation can be used if an odontoid screw fixation is not successful during a ventral approach. In addition, the approach may be used if a dorsal approach is not feasible for some reason or a dorsal C1-2 fusion has failed. The technique involves bilateral screws through the lateral vertebral body of C2 into the lateral mass of C1. Careful preoperative assessment of the course of the vertebral artery is essential to determine whether the procedure is feasible.

At surgery, the positioning, approach, and exposure are similar to odontoid screw placement. An entry point is marked with a pilot hole at the groove between the C2 body and superior articular facet. This point is just medial to the vertebral artery. The screw trajectory is about 20 degrees lateral and rostral as needed to engage the C1 lateral mass securely. The screws are placed with fluoroscopic guidance (ideally biplanar) (Fig. 127-10). Although placing an onlay bone graft may be possible, the technique does not allow direct placement of bone between C1 and C2 and aims to have fusion occur at the articulation between the C1 and C2 lateral masses. Therefore, the C1-2 facet should be scraped with a small curette as possible to promote arthrodesis. Postoperatively, a collar or SOMI brace is used until bony fusion occurs (usually 12 weeks). Halo immobilization is used when the bone quality or fixation is suboptimal.

Ventral C2-3 Fixation

Ventral C2-3 discectomy and fusion are used for some traumatic C2 hangman fractures that demonstrate sufficient instability to warrant operative fixation.[59] Using a high cervical incision, a standard high ventral cervical approach and limited C2-3 discectomy are performed. If there is canal compromise from osteophytes or a herniated disc, then a more extensive dorsal osteophytectomy or discectomy is performed. The alignment, if abnormal, is optimized as much as possible. After preparation of the end plates, a C2-3 arthrodesis is performed with structural iliac crest autograft or allograft. Then C2-3 ventral cervical plating is performed (see Chapters 143 and 144). Extra attention is required for the C2 screws because of the unique anatomy. A narrow low-profile plate is preferred to facilitate placement. The patient is managed with a postoperative external orthosis (collar) for 6 or more weeks depending on the degree of preoperative instability.

Dorsal C2-3 fixation does not adequately treat these fractures unless direct dorsal C2 screw placement across the fracture is used. C1-3 dorsal segmental instrumentation with intervening screw or sublaminar wiring at C2 is another alternative procedure.

SUMMARY

Occipitocervical junction trauma can result in a variety of injury patterns involving the regional bony, ligamentous, neurologic, and vascular structures. Because of the vital nature of these threatened structures, accurate diagnosis and careful management are required. In particular, careful attention is directed to achieving and maintaining an appropriate alignment from the onset of trauma. After initial airway management and medical stabilization, relevant diagnostic imaging should be obtained. Although many of the injuries can be recognized on plain radiographs, high-resolution CT scanning with multiplanar reconstruction views generally provides the most useful information. MRI may be difficult to obtain but is usually best to assess any spinal canal compromise and the integrity of important ligaments. Flexion/extension imaging is most useful for cooperative patients who do not have significant spinal canal compromise.

The primary focus of the imaging is to identify and characterize injuries and to guide management. If instability is documented or presumed on the basis of imaging, then some combination of external or internal stabilization is necessary to protect neurologic function and permit mobilization. If malalignment is present, correction with an orthosis, traction, or operation is considered, depending on the degree of deformity and its relationship to current or potential neurologic injury. When needed, traction should be performed cautiously and only with a solid understanding of the injury, as distraction can exacerbate certain injuries (e.g., occipitoatlantal dissociation).

Operative procedures generally require rigid intraoperative fixation via a halo ring/adaptor or Mayfield head clamp. Surgical intervention is focused on decompressing significant compressive lesions (e.g., bone, hematoma), restoring alignment, and achieving stabilization with arthrodesis and usually internal fixation. Advances in instrumentation and surgical technique (e.g., image guidance, surgical innovation) have led to the development of better, stronger internal fixation constructs that can spare motion (e.g., odontoid screw fixation), reduce the number of levels to be fused, and avoid or minimize the use of uncomfortable orthoses such as halos, which have inherent risks themselves (e.g., pulmonary compromise, skull pin site complications). These instrumentation techniques are discussed further in Chapter 53. Achieving bony fusion is an important goal of stabilization, and careful attention to technique is required. Although many trauma patients are good fusion candidates (young, healthy patients), liberal use of autograft is advised in most cases, because many patients may be or become critically ill and malnourished because of spinal or systemic injuries. Furthermore, nonunions can be difficult to manage and may require more substantial operative intervention. Overall, the treatment of occipitocervical injuries must be individualized on the basis of patient and injury characteristics, the surgeon's knowledge of the different operative risk factors, complication avoidance and management, instrumentation options, and experience.

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