Cervical spinal injury occurs in 4 to 10% of patients who sustain traumatic brain injuries due to blunt force trauma. Cervical spinal injury should be suspected in any trauma patient with loss of consciousness. All of the following patients should undergo a radiographic search for a cervical spinal injury: patients who present awake with neck pain or tenderness, patients with a neurologic deficit, patients who have sustained a traumatic brain injury, patients with a distracting injury that clouds the cervical spine examination, and patients who present following a sufficient mechanism of injury.

This chapter discusses the presentation, classification, radiographic characteristics, and management options for cervical spinal injuries, grouped by injuries of the craniocervical junction and injuries of the subaxial cervical spine.

## Craniocervical Junction

### Occipital Condyle Fractures

Occipital condyle fractures were first described by Bell\(^1\) in 1817, and the association of occipital condyle fractures and severe head trauma was initially drawn in autopsy series, with an incidence as high as 4% in fatal head injuries.\(^2\) However, the clinical diagnosis and management of occipital condyle fractures are principally phenomena of the computed tomography (CT) era.

Conventional cervical spine plain films miss between 50 and 93% of occipital condyle fractures,\(^3,4\) which are the most common cervical spine fracture missed by radiology residents.\(^5\) With the advent of routine CT scanning in high-energy blunt trauma, the spectrum of this disease has become much better elucidated.

Occipital condyle fractures should be suspected in trauma patients with lower cranial nerve palsies, upper cervical spine mobility restriction, or persistent neck pain. The 12th cranial nerve is most commonly involved, due to the proximity of the hypoglossal canal, but palsies of cranial nerves VI, IX, and X also occur with occipital condyle fractures. Cranial nerve palsies resulting from occipital condyle fractures may occur acutely or in a delayed fashion. Prognosis is more favorable with cranial nerve palsies with delayed presentation; acute cranial nerve palsies rarely heal completely.

Brainstem compression from displaced fracture fragments, torticollis, and retropharyngeal hematoma with acute respiratory distress have also been reported following occipital condyle fractures.\(^1,6,7\) These fractures can also precipitate rotatory subluxation. Full clinical assessment is often difficult because many patients have concomitant traumatic brain injury and altered level of consciousness. Brainstem compression from displaced occipital condyle fractures is rare, reported only five times in the literature, but surgical decompression is indicated.

Anderson and Montesano\(^8\) first classified occipital condyle fractures in 1988 based on the vector of force precipitating the injury (Table 9.1 and Fig. 9.1):

- Type I fractures result from axial loading. The fractured condyle is comminuted with minimal or no displacement.
- Type II fractures result from direct trauma to the skull. Type II fractures occur in conjunction with basilar skull fractures (Fig. 9.1A).

### Table 9.1 Occipital Condyle Fracture Classification Systems

<table>
<thead>
<tr>
<th>Classification System</th>
<th>Type</th>
<th>Description</th>
<th>Stability</th>
<th>Treatment Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson and Montesano(^8)</td>
<td>I</td>
<td>Comminuted fracture with no or minimal displacement</td>
<td>Stable</td>
<td>C-collar</td>
</tr>
<tr>
<td>III</td>
<td>Direct trauma with basilar skull fracture</td>
<td>Stable</td>
<td>C-collar</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Avulsion fracture from alar ligament</td>
<td>Unstable</td>
<td>Halo or surgical fixation</td>
<td></td>
</tr>
<tr>
<td>Tuli et al(^9)</td>
<td>1</td>
<td>Nondisplaced</td>
<td>Stable</td>
<td>No treatment or C-collar</td>
</tr>
<tr>
<td>2A</td>
<td>Displaced with intact ligaments</td>
<td>Stable</td>
<td>C-collar, halo</td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>Displaced and craniocervical instability</td>
<td>Unstable</td>
<td>Halo or surgical fixation</td>
<td></td>
</tr>
</tbody>
</table>
Type III fractures are avulsion fractures that occur from lateral flexion or rotatory forces with resultant pulling by the alar ligament (Fig. 9.1B).

Anderson and Montesano concluded that type I and II fractures were stable, whereas type III fractures were unstable and require rigid immobilization.

In 1997, Tuli et al proposed an alternative classification scheme for occipital condyle fractures (Table 9.1):

- Type I fractures are nondisplaced and stable (Fig. 9.1A).
- Type 2A are displaced fractures with intact ligaments (Fig. 9.1B).
- Type 2B fractures are displaced occipital condyle fractures with cranio cervical junction instability.

In this context, cranio cervical junction instability is determined via evidence from MRI demonstrating ligamentous injury or CT with coronal reconstructions revealing joint misalignment in the occiput-C1-C2 complex.

Tuli et al proposed that type I fractures be managed without intervention, type 2A fractures be managed with C-collar immobilization, and type 2B fractures require halo traction or surgical immobilization. Contemporary reports advise C-collar immobilization for both type 1 and 2A fractures. At the conclusion of the period of immobilization, flexion-extension views should be obtained to confirm the absence of cranio cervical junction instability.

**Atlanto-Occipital Dislocation**

The recognition of atlanto-occipital dislocation, as with occipital condyle fractures, has increased with the advent of routine CT evaluation of the cervical spine in the trauma survey. Atlanto-occipital (AO) dislocations are high-velocity, high-force injuries. Typically, AO dislocation results from distraction with extreme hyperextension and rupture of the tectorial membrane (the cranial extension of the posterior longitudinal ligament).

Atlanto-occipital dislocation accounts for 8 to 35% of fatalities from motor vehicle accidents and 10% of cervical spine injury fatalities. Classically, AO dislocation was considered fatal. Survival is now common, perhaps related to increased sensitivity of detection during the trauma survey. Twenty percent of survivors have normal neurology; 10% have lower cranial nerve palsies, 34% hemiparesis or hemiplegia, and 38% quadriplegia.

Death from AO dislocation results most commonly from respiratory depression secondary to neurogenic shock. Patients surviving AO dislocation frequently have neurologic deficits secondary to injuries other than the AO dislocation, such as traumatic brain injury (24%), carotid or vertebral artery injury, or brachial plexus injury.

Both type I and type II odontoid fractures increase the risk for AO dislocation due to weakening or rupture of the alar ligament, apical ligaments, or tectorial membrane. The more classic association is with type I odontoid fractures;
in fact, any type I odontoid fracture diagnosis should prompt an evaluation for AO dislocation.

The diagnosis of AO dislocation is frequently delayed or missed in patients who present neurologically intact or with incomplete neurologic syndromes. The radiographic evaluation of AO dislocation involves the calculation of Power’s ratio, Lee’s lines measurements, or Harris’s measurements. Power’s ratio is the distance from the tip of the basion to the posterior arch of C1 (B-C) divided by the distance of from the tip of the opisthion to the tip of the odontoid (O-O). Ratios greater than 1 are consistent with the diagnosis of anterior atlanto-occipital dislocation. For Lee’s lines, two intersecting lines are drawn, one from the tip of the basion to the anterior aspect of the posterior ring of C2 and a second from the tip of the opisthion to the posteroinferior aspect of the C2 body. The first line should pass across the superior-posterior aspect of the odontoid process, and the second should pass just anterior to the posterior portion of the ring of C1. Harris’s measurements involve two calculations: the basion-dens interval (BDI), the distance between the inferior and posterior tip of the basion and the superior tip of the odontoid; and the basion-posterior axial interval (BAI), the distance from the posterior axial line to the inferior and posterior tip of the basion. For both the BDI and BAI, a value greater than 12 mm is indicative of an anterior atlanto-occipital dislocation.

With modern continuous slice acquisition CT and three-dimensional reconstructions of the spine and head, Power’s ratio, Lee’s method, or Harris’s measurements may be employed with reliability and accuracy for evaluation for AO dislocation.

Spontaneous reduction of AO dislocation can occur such that any of the aforementioned measurement techniques no longer detect it. An increased distance between the posterior elements of C1 and C2 may be the only clue on CT, with subsequent magnetic resonance (MR) evaluation revealing substantial ligamentous injury at the craniovertebral junction. Retropharyngeal hematomas occur in all AO dislocations and, if noted on CT or plain film radiographs, should prompt MR evaluation of the cervical spine.

Traynelis and colleagues classified three types of AO dislocations (Table 9.2):

- Type I: anterior displacement of the occiput relative to the atlas
- Type II: longitudinal distraction with separation of the occiput and atlas
- Type III: posterior displacement of the occiput with respect to the atlas

Fig. 9.2 Three methods for measuring atlanto-occipital dislocation are depicted. (A) The Power’s ratio is the ratio of the distance from the tip of the basion to the posterior arch of C1 (B-C) divided by the distance of from the tip of the opisthion to the tip of the odontoid (O-O). Ratios greater than 1 are consistent with the diagnosis of anterior atlanto-occipital dislocation. (B) For Lee’s lines, two intersecting lines are drawn, one from the tip of the basion to the anterior aspect of the posterior ring of C2 and a second from the tip of the opisthion to the posteroinferior aspect of the C2 body. The first line should pass across the superior-posterior aspect of the odontoid process, and the second should pass just anterior to the posterior portion of the ring of C1.

Lee’s method sought to improve the sensitivity of plain film radiographs in the diagnosis of AO dislocation, because proper identification of the midpoint of the posterior arch of C1 for calculation of Power’s ratio can be difficult on lateral x-rays.

Harris’s measurements, or the rule of 12s, involve two calculations: the basion-dens interval (BDI) and the basion-posterior axial interval (BAI) (Fig. 9.2C). The BDI is the distance between the inferior and posterior tip of the basion and the superior tip of the odontoid. To calculate the BAI, a vertical line is drawn along the posterior aspect of the odontoid, extending above the level of the foramen magnum (the posterior axial line). A perpendicular line is drawn from this posterior axial line to the inferior and posterior tip of the basion, and the distance is measured. For both the BDI and BAI, a value greater than 12 mm is indicative of an anterior atlanto-occipital dislocation (hence, the rule of 12s).
Note that Power’s ratio may be falsely negative in detecting type III (posterior) AO dislocations. Patients with AO dislocation should be treated to avoid progression of neurologic deficits due to the highly unstable nature of these fractures. Occipital-cervical fusion is the treatment of choice, although halo ring-vest orthosis is an alternative for patients where occipital-cervical fusion is contraindicated. Early surgical intervention does not increase risk of neurologic worsening or late instability. In most case of AO dislocations, traction results in longitudinal distraction. It would therefore not be indicated in patients whose spinal column was in good alignment and whose primary pathology was longitudinal distraction (type II). For type II AO dislocations, traction is controversial and is associated with a 10% risk of neurologic deterioration because it could increase the distraction distance.18

Table 9.2 Traynelis Atlanto-Occipital Dislocation Classification System

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Stability</th>
<th>Treatment Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Anterior displacement of occiput over atlas</td>
<td>Unstable</td>
<td>• Gentle traction under fluoroscopy may be indicated to realign the spine followed by immediate immobilization with a halo vest if possible, especially if there is a neurologic deficit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Surgical stabilization is indicated when spine is realigned</td>
</tr>
<tr>
<td>II</td>
<td>Distraction with longitudinal separation of occiput and atlas</td>
<td>Unstable</td>
<td>• Gentle traction under fluoroscopy may be indicated to realign the spine followed by immediate immobilization with a halo vest if possible, especially if there is a neurologic deficit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Surgical stabilization is indicated</td>
</tr>
<tr>
<td>III</td>
<td>Posterior displacement of occiput over atlas</td>
<td>Unstable</td>
<td>• Gentle traction under fluoroscopy may be indicated to realign the spine followed by immediate immobilization with a halo vest if possible, especially if there is a neurologic deficit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Surgical stabilization is indicated when spine is realigned</td>
</tr>
</tbody>
</table>

Fig. 9.3 Radiographic images of a patient with anterior atlanto-occipital dislocation. (A) Sagittal CT reconstruction at presentation demonstrates a clear dissociation of bony elements at the cranio cervical junction and a Power’s ratio greater than 1. (B) Sagittal T2-weighted MRI obtained hours later demonstrates interval decrease in the basion-dens interval, indicating spontaneous reduction of the atlanto-occipital (AO) dislocation. However, associated disruption in the posterior ligamentous complex is seen. (C) Axial T2-weighted MRI reveals an epidural hematoma adjacent to the upper cervical spinal cord. The patient had a left hemiparesis.
Isolated C1 Fractures

Isolated fractures of C1 rarely cause neurologic sequelae. Improper management of these fractures, however, can lead to delayed neurologic deficit. Atlas fractures may involve the lateral mass (13–37%), the anterior or posterior ring (31–45%), or a Jefferson fracture of both the anterior and posterior ring (37–51%) (Table 9.3).

The critical clinical feature to discern in isolated C1 fractures is integrity of the transverse ligament. Integrity of the transverse ligament may be assessed on anteroposterior (AP) or open-mouth odontoid plain film radiography or coronal reconstruction CT by measuring the lateral mass displacement. If the cumulative displacement of the lateral masses is ≤ 7 mm, then the transverse ligament is considered incompetent (the rule of Spence). Panjabi's group found that an atlanto-dens interval (ADI) greater than 3.5 mm on flexion radiographs was the most reliable predictor of transverse ligament disruption. Transverse ligament disruption can also be diagnosed on magnetic resonance imaging (MRI).

There is no class I or class II evidence regarding treatment for isolated C1 fractures. Fractures of the C1 lateral mass, which are unlikely to be associated with disruption of the transverse ligament or an increase in the ADI, can be treated with external cervical immobilization. There is no evidence to support the use of a halo orthosis over rigid cervical collars. External immobilization for 8 to 12 weeks is sufficient, and healing should be assessed with flexion-extension plain film radiographs to exclude pseudarthrosis and craniocervical instability. Some clinicians advocate use of a halo orthosis for comminuted lateral mass fractures to increase fusion rates over rigid cervical collar immobilization, but this decision should be multifactorial and take into consideration the overall medical condition, as older patients with significant medical comorbidities do not tolerate external immobilization well.

Fractures of either the anterior or posterior arch should be assessed for concomitant instability or disruption of the transverse ligament. Instability is characterized by an ADI > 3.5 mm, lateral mass displacement > 7 mm, or evidence of transverse ligament avulsion or disruption. Isolated C1 ring fractures of either the anterior or posterior arch may be treated with cervical collar immobilization, sternal occipital mandibular immobilization (SOMI) brace, or halo for up to 3 months. There is no evidence to support the use of one option over the others.

Fractures of both the anterior and posterior arch carry special treatment considerations. Sir Geoffrey Jefferson in 1920 initially described his fracture of the C1 ring as bilateral fractures of the junction of the lateral masses and the anterior and posterior arches. This fracture of both the anterior and posterior arch is also referred to as a C1 burst fracture. Treatment of C1 burst fractures is dictated by the presence or absence of instability, defined as either an ADI > 3.5 mm or lateral mass displacement > 7 mm on CT or disruption of the transverse ligament on MRI. A C1 burst fracture with an intact transverse ligament may be treated with external cervical immobilization (rigid cervical collar or halo vest orthosis) for up to 3 months. An unstable burst fracture may be treated with either a halo device for 3 months or C1-C2 internal fixation and fusion, with postoperative immobilization dictated by the fusion procedure chosen.

Surgical options for C1-C2 fusion for unstable C1 burst fractures include the Harms technique (C1 lateral mass and the C2 pedicle, pars interarticularis or translaminar fixation with cervical polyaxial screws and rods), C1-C2 transarticular screw fixation, or a Brooks, Gallie, or Sonntag posterior wiring fusion. Dickman and Sonntag reported their long-term results for C1-C2 transarticular screw fixation and noted a substantially higher fusion rate for C1-C2 transarticular screws over Brooks, Gallie, or Sonntag posterior wiring techniques. The Harms technique of C1-C2 fixation was described in 2001, but large case series with long-term data are not yet available. However, the Harms C1-C2 fusion has biomechanical advantages over the Magee technique of transarticular screw fixation, is less likely to injure the vertebral artery, does not require structural bone graft or wiring, and is less likely to be contraindicated by anatomy. In addition, Harms and Melcher reported a 100% fusion rate in their initial series of 37 patients. Postoperative external cervical immobilization is not necessary following a Harms C1-C2 fusion, in contradistinction to Sonntag's original description of his modification of the posterior wiring technique, further limiting postoperative morbidity of the Harms C1-C2 fusion.

More recently, Harms described a transoral reduction and C1 osteosynthesis technique for young patients as an alternative function-preserving option for unstable Jefferson fractures.
Isolated C2 Fractures

Approximately 20% of all cervical spine trauma cases involve C2. The spectrum of C2 fractures includes hangman's fractures (bilateral traumatic spondylolisthesis of the atlas), odontoid fractures, and miscellaneous fractures of the C2 vertebral body. The incidence of neurologic deficit in surviving patients is low (7.5% in one series), likely due to the larger spinal canal diameter at this level. C2 fractures are common in the elderly and carry a significant in-hospital mortality rate, perhaps as high as 25%. However, recent evidence suggests that surgical management of C2 fractures among the elderly is associated with acceptable rates of morbidity and lower mortality for this group of fractures, arguing for more routine use of surgical management in appropriate patients in this population.

Odontoid Fractures

Odontoid fractures are the most common traumatic injuries of the axis and account for 7 to 14% of all cervical spine injuries. The most common symptom is high cervical pain, as neurologic deficits are infrequent. However, spinal cord compression may result from subluxation of the fracture dens, and maintenance of spinal alignment must be a primary goal of the evaluation and management of these fractures.

Anderson and D’Alonzo proposed a classification system for odontoid fractures in 1974 that is still in use today (Table 9.4). Type I fractures are oblique fractures

Table 9.4 Anderson and D’Alonzo Classification of Odontoid Fractures

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Stability</th>
<th>Treatment Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Fracture through tip of dens</td>
<td>Stable</td>
<td>C-collar</td>
</tr>
<tr>
<td></td>
<td>In association with atlanto-occipital dislocation</td>
<td>Unstable</td>
<td>Surgical fixation, C-collar, halo</td>
</tr>
<tr>
<td>II</td>
<td>Through base of dens</td>
<td>Often unstable</td>
<td>Surgical fixation, C-collar, halo</td>
</tr>
<tr>
<td>IIA</td>
<td>Through base of dens with comminuted fragments</td>
<td>Unstable</td>
<td>Surgical fixation</td>
</tr>
<tr>
<td>III</td>
<td>Fracture extends through body of C2</td>
<td>Usually stable</td>
<td>C-collar, halo if unstable</td>
</tr>
</tbody>
</table>
through the tip of the odontoid process. Type I fractures are rare, representing less than 1% of odontoid fractures, but may occur during atlanto-occipital dislocation. Type I fractures may lead to os odontoideum due to resorption of the lower dens from avascular necrosis. Type II fractures are those occurring at the base of the odontoid process at the junction with the body of C2. Type III odontoid fractures extend through the dens and into the body of C2. Anderson and D’Alonzo themselves stated that type III odontoid fractures should be considered fractures of the body of C2. In fact, later authors argued that type III odontoid fractures should be treated with posterior atlantoaxial stabilization. The authors defined type IIA fractures as minimally or nondisplaced type II fractures with free fragments of the base of the odontoid. These fractures are termed type IIA fractures. Although rare (only 5% of the Hadley series of type II fractures), the type IIA fracture is unstable, and early surgical intervention is recommended.

The distinction between type II and type III fractures can be difficult because no clear definition exists to distinguish a “high” type III from a “low” type II fracture. Grauer and colleagues proposed an alternative modification to the Anderson and D’Alonzo classification scheme to better define suitability of treatment options such as anterior odontoid placement. The authors defined type IIA fractures as minimally or nondisplaced type II fractures with no comminution, type IIB fractures as displaced fractures extending anterior-superior to posterior-inferior or traverse fractures, and type IIC fractures as fractures extending from anterior-inferior to posterior-superior. The authors report that type IIA fractures can often be managed conservatively, type IIB fractures were suitable for anterior odontoid screw placement, and type IIC fractures are treated with posterior atlantoaxial stabilization.

No treatment intervention is considered inappropriate for any type of odontoid fracture except in extreme circumstances (e.g., age > 100, low Karnofsky score, hospice patients). Type I odontoid fractures, unless in association with atlanto-occipital dislocation, may be managed with cervical collar alone, with fusion rates of 100% reported (Table 9.3).

Type II odontoid fractures are the most common subtype and have presented the greatest treatment dilemmas to the spine surgeon. Nonunion rates for conservative management of type II odontoid fractures are as high as 75%. Risk factors associated with nonunion of type II odontoid fractures include age > 50 and dens displacement ≥ 6 mm. Lennarson and colleagues in Iowa provided class II evidence (case-control study) that substantiates surgical treatment for type II odontoid fractures in patients over age 50. Seybold and Bayley reached a similar conclusion, in that patients over age 60 had high symptomatic nonunion rates (19.5%) and lower cervical range of motion when treating type II and III odontoid fractures with halo immobilization. Pepin et al noted poor halo tolerance in elderly patients and argued for early surgical intervention in older patients with type II odontoid fractures. Andersson and colleagues noted poor union rates in elderly patients treated nonsurgically for type II odontoid fractures and further noted that posterior approaches were superior to anterior odontoid screw in this patient population. Surgical intervention for type II odontoid fractures should also be considered if there is failure to maintain spinal alignment following traction and external immobilization. As mentioned above, type IIA fractures should be treated with early surgical intervention when clinically feasible.

Type III odontoid fractures may be treated with cervical immobilization with a fusion rate over 80%. Although type III (and type II) odontoid fractures have historically been treated with halo vest immobilization, cervical collars are equivalent to halo devices in prevention of late nonunion or late need for surgical stabilization. Surgical fixation for type III odontoid fractures may be reserved for patients with nonunion/late instability following attempted nonsurgical management with cervical immobilization or failure to maintain spinal alignment with external immobilization. Our preference is rigid cervical collar over halo orthosis; however, patient compliance and confounding factors such as smoking history and other traumatic injuries must be considered.

Surgical options for odontoid fractures include posterior atlantoaxial wiring techniques (Brooks, Gallie, or Sonntag methods), the Magerl C1-C2 transarticular screw technique, the Harms C1-lateral mass-C2 pedicle screw technique, or an anterior odontoid screw in certain cases. Posterior C1-C2 fusion procedures result in greater loss of motion of the atlantoaxial joint but higher fusion rates and fewer contraindications than an anterior odontoid lag screw fusion.

Traumatic Spondylolisthesis of the Axis (Hangman’s Fracture)

A hangman’s fracture is the colloquial name given to a fracture of the pedicles or pars interarticularis (isthmus) of the axis (C2 vertebra). Schneider et al coined the term “hangman’s fracture” in 1965 in their series of eight patients whose injuries mimicked the fracture pattern of judicial hanging described by Wood-Jones in the first volume of Lancet in 1913.

Traumatic bilateral spondylolisthesis of the pars interarticularis of the axis is a hyperextension and compression with axial loading that is often seen with motor vehicle accidents, falls, and diving accidents. The classic scenarios are that of an unrestrained occupant in a motor vehicle accident who is thrown forward and hits the windshield, or a swimmer who dives and hits the bottom of a shallow

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pool. In both instances the combined forces of hyperextension and axial compression occur. The fracture seen in trauma is similar to that induced by judicial hangings; however, the true judicial “hangman’s fracture” results from distraction and hyperextension, not compression and hyperextension. There is often anterior subluxation of C2 on C3, and it is usually stable, with neurologic deficits being rare. Instability can usually be identified if there is ≥ 4 mm of subluxation of C2 on C3 or ≥ 50% subluxation of C2 on C3, excessive angulation, or significant motion on flexion-extension films.

Multiple classification systems for traumatic spondylolisthesis of the axis exist, though none is in routine clinical use. Pepin and Hawkins described two types: type I is a nondisplaced fracture of the posterior elements, and type II is a displaced fracture of the posterior elements and the dens. Francis and colleagues described five grades of hangman’s fractures on the basis of displacement of the C2 body (less than or greater than 3.5 mm) and the angulation of C2 on C3 (less than or greater than 11 degrees). Effendi and colleagues described three types on the basis of mechanism of injury (type I, axial loading; type II, hyperextension and rebound flexion; type III, hyperflexion and rebound extension). Levine and Edwards modified the Effendi classification such that type I injuries resulted from a hyperextension-axial loading force, type II injuries from an initial hyperextension-axial loading force followed by severe flexion, type IIa injuries from flexion-distraction, and type III injuries from flexion-compression.

Starr and Eismont drew attention to the atypical hangman’s fracture, defined as canal-compressive traumatic spondylolisthesis of the axis with significant neurologic deficit. Atypical hangman’s fractures occur through the posterior aspect of the vertebral body, with unilateral or bilateral continuity of the posterior cortex or pedicle (Fig. 9.5). These fractures have higher rates of spinal canal subluxation; hence the higher rates of neurologic deficit with the atypical hangman’s fracture.

No class I or II studies have been performed regarding management of traumatic spondylolisthesis of the axis. Multiple large case series (class III evidence) have been published, which report that almost all hangman’s fractures heal with traction, when necessary, followed by 12 weeks of external cervical immobilization with a rigid cervical collar or, more commonly, halo orthosis. Fusion rates with halo orthosis alone are as high as 95%.

Li et al. published a systematic review of 32 papers on the management of hangman’s fractures. The authors recommend that most stable Effendi types I and Levine-Edwards type II injuries be managed with cervical collar, unstable Effendi types I and II and Levine-Edwards type II fractures be managed with traction and external cervical immobilization, Levine-Edwards types IIIa and III fractures be managed with rigid immobilization, and Levine-Edwards types IIa and III fractures with significant dislocation be managed with surgical stabilization (Table 9.5).

Surgery for hangman’s fractures should be reserved for significant C2-C3 disk disruption, failure to induce or maintain reduction, or nonunion following halo immobilization. Though clinicians in most series employed halo ring-vest orthoses, a Philadelphia cervical collar for 12 weeks is likewise effective for nondisplaced traumatic spondylolisthesis of the axis with less device-associated morbidity. When surgery is indicated, options include C2-C3 anterior cervical fusion and C1-C3 posterior fusion techniques. No study has demonstrated the superiority of anterior versus posterior approaches, and an anterior approach does spare rotation at C1-C2.

Figure 9.6 depicts an evidence-based treatment algorithm for management of traumatic spondylolisthesis of the axis. The treatment choice must be weighed in the context of other traumatic injuries, medical comorbidities, and patient preference.
Miscellaneous C2 Fractures

C2 vertebral body fractures occur that are neither odontoid fractures nor a part of traumatic spondylolisthesis of the axis. They represent a diverse group of fractures. Several investigators argue that type III odontoid fractures are misleading and, in fact, belong categorized with other nonodontoid C2 body fractures. In several series of miscellaneous C2 body fractures, all fractures healed with external cervical immobilization (either rigid cervical collar or halo device) with the possible exception of C2 burst fractures. Surgery is reserved for cases of nonunion, the rare C2 burst fractures with spinal cord compromise, or the rare miscellaneous C2 body fracture that fails to reduce with traction.

Combined C1-C2 Injuries

The description of combined fractures of the atlas and axis goes back to the original published series of Jefferson, from which the C1 burst fracture became characterized as Jefferson fractures. Fractures of C1 occur in up to 53% of

Table 9.5 Classification System of Hangman’s Fractures

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Radiology</th>
<th>Mechanism</th>
<th>Stability and Treatment</th>
</tr>
</thead>
</table>
| I    | Vertical pars interarticularis fracture | ≤ 3 mm subluxation of C2 on C3 and no angulation | Axial loading and extension | Stable on flexion and extension x-rays  
Neurologic deficit is rare  
Hard collar is recommended |
| IA   | Fracture lines through the pars interarticularis on each side are not parallel | C2 may be subluxed 2–3 mm on C3 | May be rotational during hyperextension | Know as the “atypical hangman’s fracture” with a 30% incidence of neurologic injury  
Fracture can extend through the foramen transversum |
| II   | Vertical fracture through pars with disruption of C2-C3 disk and posterior longitudinal ligament | Subluxation of C2 on C3 > 3 mm | Axial loading and extension | Usually reduces with traction, and neurologic deficit is rare |
| IIA  | Oblique fracture | Very little subluxation (usually < 3 mm) but can have more angulation of C2 on C3 | Flexion distraction (posterior arch fails in tension) | Traction can make angulation and widening of disk space worse |
| III  | Vertical pars fracture with C2-C3 facet capsules disrupted with anterior longitudinal ligament disruption | C2–C3 facets may be locked or unstable | Unclear (flexion and compression?) | Traction may be dangerous  
Open reduction and stabilization are indicated |

type II or III odontoid fractures. Similarly, odontoid fractures are noted in up to 50% of patients with C1 fractures, and C1 fractures are seen in up to 26% of hangman’s fractures. In a large review of almost 800 patients with upper cervical injuries, the incidence of C1-C2 combination injuries in patients with either a C1 or C2 injury was 27%, and combined C1-C2 fractures represented 4% of all cervical spine injuries. Combined C1-C2 injuries have higher rates of death and neurologic deficit than isolated fractures of C1 or C2, consistent with the presumed higher degrees of force necessary to precipitate combination fractures. The management of C1-C2 combination injuries is dictated principally by the characteristics of the C2 fracture. As such, these injuries fall into four groups: C1–type II odontoid combination fractures, C1–type III odontoid combination fractures, C1–hangman’s combination fractures, and C1–miscellaneous C2 combination fractures. Hence, most C1-C2 combination injuries can be treated with external immobilization as discussed above for the specific C2 injury involved. Surgery for combined C1-C2 injuries is reserved for ADI/H11022 5 mm, C2-C3 angulation greater than 11 degrees, or nonunion after nonsurgical management. In patients requiring surgery, again, the surgical approach is dictated by the appropriate approach for the C2 injury. When the injury to the ring of C1 does not permit instrumentation, occipital-cervical fusion or C1-C2 transarticular screw fixation are viable options.

<table>
<thead>
<tr>
<th>Table 9.6 Combined C1-C2 Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Injury Type</strong></td>
</tr>
<tr>
<td>C1–type II odontoid fracture</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>C1–type III odontoid fracture</td>
</tr>
<tr>
<td>C1–hangman’s fracture</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>C1–miscellaneous C2 fracture</td>
</tr>
</tbody>
</table>

Subaxial Cervical Spine (Based on AO Classification)

Biomechanical Considerations

The two-column concept of the cervical spine was proposed in Holdsworth’s landmark paper in 1963. The anterior column consists of the vertebral body, anterior and posterior longitudinal ligaments, and intervertebral disks, whereas the posterior column consists of the facet joints, capsular ligaments, spinous process, lamina, and interspinous ligament. Holdsworth contended that instability occurs with injury to the posterior ligamentous complex in association with an anterior column injury. The determinants of cervical spinal column injury are the magnitude, vector, and rate of force application sustained by the cervical spine. White and Panjabi defined instability as “loss of the ability of the spine under physiologic loads to maintain its pattern of displacement so that there is no initial or additional neurologic deficit, no major deformity, and no incapacitating pain.” It may result from ligamentous injury with or without associated bony injury.

More recently, the Cervical Spine Injury Severity Score was proposed for measuring stability after cervical spine trauma. The scoring system evaluates the extent of bony and ligamentous disruption in the anterior, posterior, left, and right columns, and the summated score is a valid, reliable indicator of spinal instability. It is validated for injuries from C2 to T1. The system is a useful adjunct in the decision-making process during evaluation and management of the patient with cervical spine trauma.

The most common subaxial cervical level injured is C5-C6, believed to be due to the higher degree of flexion-extension motion at this level compared with the rest of the cervical spine.

Classification

Argenson et al in Nice, France, built upon the schemata of Allen et al and Harris et al to classify subaxial cervical spine injuries on the principal force vectors producing specific patterns of injury. The first of these force vectors is compression injury, which may occur in association with flexion or extension.

Compression Injuries

Pure axial loading as a cause of cervical spine injury is relatively rare below C2, described in only 7% of subaxial injuries in the Nice series. (Axial loading in atlantoaxial injuries was discussed above.) Pure axial compression results...
in comminuted fractures, which may or may not push back into the spinal canal to endanger neural elements. The most common force producing traumatic spinal cord injuries and unstable cervical spinal fractures is compression with flexion (Table 9.8). Force vectors directed in flexion will result in distraction of posterior elements and compression of anterior elements. Clinically, axial loading plus flexion vectors direct force at the anterior column (anterior aspect of the vertebral body and the intervertebral disk). Less severe degrees of axial loading produce wedge fractures, whereas severe forces result in unstable teardrop fractures.

Compression Fractures

True compression (pure axial loading) injuries of the cervical spine can only occur with loss of cervical lordosis. As such, compression or wedge fractures typically result from axial loading in combination with some degree of flexion or extension. Compression fractures, by definition, involve only the anterior column, and there is no retropulsion of bony fragments into the canal. Compression fractures heal with external immobilization alone, with an overall 5% nonunion rate.\(^73,74\)

Burst Fractures

Burst fractures are, like compression fractures, the result of axial loading forces, typically in combination with flexion. Failure of both the anterior and posterior columns occurs, and neurologic injury may result from retropulsion of bony fragments into the canal (Fig. 9.7). Subaxial cervical burst fractures may occur with or without disruption of the posterior ligamentous complex. Burst fractures in patients with normal or incomplete neurologic functioning should be treated with surgical intervention to decompress the neural elements and fuse these unstable injuries. Rigid external immobilization may be considered in patients with complete spinal cord injuries.

<table>
<thead>
<tr>
<th>Type</th>
<th>Injury Mechanism</th>
<th>%</th>
<th>Injury Pattern</th>
<th>%</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Compression injuries</td>
<td>33</td>
<td>II: comminuted fracture</td>
<td>7</td>
<td>Principally bony damage; often associated with flexion forces</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: teardrop fracture</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Flexion/extension/ distraction injuries</td>
<td>28</td>
<td>I: moderate whiplash with neurologic injury</td>
<td>5</td>
<td>Principally disk and ligamentous damage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II: severe whiplash (sprain)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: bilateral facet fracture-dislocation</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Rotation injuries</td>
<td>39</td>
<td>II: fracture separation of the articular pillar</td>
<td>10</td>
<td>Asymmetric lesions; rotation is always associated with lateral flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: unilateral dislocation</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.7 Degrees of Motion in the Cervical Spine

<table>
<thead>
<tr>
<th>Level</th>
<th>Flexion-Extension</th>
<th>Axial Rotation</th>
<th>Lateral Bending</th>
<th>Translation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3-C4</td>
<td>15.2 ± 3.8</td>
<td>4.5 ± 1.1</td>
<td>3.5 ± 1.4</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>C4-C5</td>
<td>17.1 ± 4.5</td>
<td>4.6 ± 1.1</td>
<td>3.3 ± 1.0</td>
<td>0.9 ± 0.3</td>
</tr>
<tr>
<td>C5-C6</td>
<td>17.1 ± 3.9</td>
<td>4.0 ± 1.1</td>
<td>4.3 ± 1.4</td>
<td>0.9 ± 0.2</td>
</tr>
<tr>
<td>C6-C7</td>
<td>18.1 ± 6.1</td>
<td>1.6 ± 1.8</td>
<td>5.7 ± 1.9</td>
<td>0.6 ± 0.3</td>
</tr>
<tr>
<td>Overall</td>
<td>(60 to 75)</td>
<td>134.2 ± 17.1</td>
<td>64.2 ± 6.8</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Translation does not occur in the absence of axial rotation.

Table 9.8 Classification of Subaxial Cervical Spine Injuries

Asymmetric lesions; rotation is always associated with lateral flexion
Teardrop Fractures

Teardrop fractures result from hyperflexion-compression injuries. These fractures can be misleading in that they appear as small chip fractures of the anteroinferior margin of the vertebral body, but true teardrop fractures are biomechanically unstable and frequently associated with devastating neurologic injuries. Instability results from disruption of the disk and anterior and posterior ligaments. MRI demonstrating disk or ligament disruption distinguishes teardrop fractures from simple avulsion fractures.

Teardrop fractures are unstable injuries that require surgical intervention. Teardrop fractures in the absence of canal compromise may be treated via a posterior approach. If canal compromise exists, a combined anterior and posterior approach is usually necessary to decompress neural elements and achieve fusion.

Rotation Injuries

A rotational injury manifests itself clinically in the form of asymmetric lesions such as unilateral locked or fractured facets or fractures of the articular pillar (the facets absorb half of the load resulting from rotational forces applied to the cervical spine). Rotational injuries are designated type C injuries in the Nice classification (Table 9.8). Rotational injury always occurs with lateral flexion vectors superimposed on rotation. Spinal column alignment, in general, is maintained following rotational injuries. Rotational injuries are typically stable, with the exception of the unilateral “perched facet,” in which ligamentous injury (and attendant spinal instability) results from avulsion of ligaments from bony attachments during the rotational event itself.

Unilateral Facet Dislocations

Unilateral facet dislocation is the prototypical asymmetric rotation-flexion injury. The inferior articulating facet of the upper vertebral level becomes perched anterior to the superior articulating facet of the lower vertebra. Anterolisthesis may occur and is typically less than 25% of the diameter of the vertebral body.

Both nerve root and spinal cord injury may occur secondary to unilateral facet dislocations. Treatment is closed reduction with traction followed by halo orthosis or open surgical fixation. Closed reduction, discussed in more detail below, is unsuccessful in up to 26% of cases. If closed reduction fails, open reduction in the operating room is warranted.

Flexion-Extension-Distraction Injuries

The final group of injury force vectors to consider is flexion-extension injuries, the less severe versions of which are commonly known as “whiplash” injuries. These injuries are characterized by disproportionate injury to the spinal ligaments and intervertebral disks compared with the bony elements.

The physiologic movements of flexion and extension are modulated by the posterior longitudinal ligament, which is strong in the cervical spine. Thus, when the posterior longitudinal ligament remains intact after whiplash injury (with mild or moderate force magnitude), the transverse axis of the spine remains intact, and neurologic injury is rare. However, when the posterior longitudinal ligament is disrupted in more severe injuries, often in association with failure of the posterior annulus, unstable spinal lesions are produced (type BII and BIII, Table 9.8). Unstable lesions happen when failure of the posterior...
longitudinal ligament and posterior annulus occurs in combination with anterolisthesis, end-plate angulation > 10 degrees, facet malalignment, or distracted vertebral segments due to posterior ligamentous complex injury.\textsuperscript{75}

**Whiplash**

In mild and moderate flexion-extension injuries, static and dynamic radiographs may be normal, but subclinical ligamentous injury and delayed deformity may arise. This is supported experimentally by work that has demonstrated on microscopic analysis multilevel disk and anterior longitudinal ligament injury in spines that are radiographically normal with exaggerated, though subpathologic, motion at multiple levels on motion segment.\textsuperscript{76}

Management of whiplash injuries is controversial. Patients with persistent neck pain following trauma, despite normal plain films or CT scans of the cervical spine, should be evaluated with MRI. Mild soft tissue injury in the absence of instability may be treated with physical therapy or C-collar immobilization, with meta-analysis indicating more rapid recovery, less pain, and improved cervical range of motion in patients treated with physical therapy without immobilization.\textsuperscript{77} The medicolegal climate in the United States clouds management of whiplash injuries.

**Bilateral Facet Fracture-Dislocations**

Bilateral fracture-dislocation (or jumped facets, Fig. 9.8) occurs when the traumatizing force of distraction with flexion or extension persists in the setting of posterior longitudinal ligament failure and disruption of the posterior ligamentous complex (supra/interspinous ligaments). This ligamentous injury has important implications for clinical management of flexion-compression injuries: traction with larger weights may be dangerous; halo fixation is more likely to fail with ligamentous injury; and anterior approaches may jeopardize the remaining intact anterior ligaments, worsening stability and increasing the likelihood of pseudarthrosis.

Extension-distraction injuries are far less common than flexion-distraction injuries, but their consequences tend to be more severe with spinal instability and neurologic deficit.\textsuperscript{78}

Closed reduction is controversial. The reports of neurologic worsening with closed reduction led to the argument that closed reduction should not be attempted in patients with normal function or incomplete spinal cord injury prior to MR evaluation for herniated disk. Mortality with closed reduction is as high as 7%, although most of these reports were prior to the ready availability of MRI for the trauma patient.\textsuperscript{73,79–81} More modern reports indicate the safety of closed reduction, even in the setting of disk herniation.\textsuperscript{82} Closed reduction is successful in approximately three fourths of facet dislocation cases. When closed reduction fails or is contraindicated, open reduction is almost always successful whether via an anterior or posterior approach. The medicolegal climate and the ready availability of MRI in most major trauma centers in the United States lead a majority of spine surgeons to obtain MRI before attempting closed reduction.

**Fig. 9.8** (A) Coronal and (B) sagittal CT reconstructions of a patient with bilateral facet fracture-dislocations at C6-C7. Degree of anterolisthesis is greater than 50%. (C) T2-weighted sagittal MRI demonstrates distortion of the spinal cord. Patient suffered an incomplete spinal cord injury, American Spinal Injury Association (ASIA) class B.
Bilateral facet dislocation injuries are unstable, and reduction should be followed by internal fixation and fusion. Either anterior or posterior approaches are appropriate, and the presence or absence of disk herniation causing neural element compression may help guide the choice of the surgical approach. Anterior approaches alone have a slightly higher rate of delayed instability (6%) than posterior alone approaches (3%).

Timing of surgery, whether or not early intervention improves outcome, remains controversial.

Cervicothoracic Junction Injuries
The cervicothoracic junction is a transitional zone. The incidence of cervicothoracic junction injury is significantly less than other cervical injuries or thoracolumbar junction injuries. These injuries were frequently missed due to inadequate plain film radiographs (in approximately 25% of all trauma patients, the C7-T1 disk space is not adequately visualized on the three-view x-ray series) but the CT era has improved the detection of cervicothoracic junction trauma.

The cervicothoracic region has unique anatomy where the lordotic, mobile cervical spine transitions to the kyphotic, rigid thoracic spine. Upper thoracic spine rigidity comes from rib articulation with the sternum (the so-called fourth column of the thoracic spine). Recent CT kinematics studies demonstrate the cervicothoracic junction is twice as stiff as compared with its cervical neighbor. However, the angular motion is similar in this region in comparison to the subaxial cervical spine.

The patterns of injury seen in the cervicothoracic junction include rotatory subluxation of C7 on T1, fracture-dislocations, unilateral and bilateral facet dislocations, and burst fractures. Fractures involving T1 through T4 are rare. The incidence of complete spinal cord injury from cervicothoracic junction trauma is high.

The principles of initial intervention involve immediate closed reduction of the fracture and establishing spinal alignment. Dislocations of the cervicothoracic junction require greater traction for prompt reduction, and weights up to 120 lb have been used to achieve closed reduction. Chapman et al. applied traction equal to 60% of the patient’s body weight to achieve reduction. They did not notice any adverse outcome from the increased traction weight. If closed reduction is unsuccessful, then immediate operative reduction should be considered in cases of bilateral locked facets.

The selection criteria for surgical intervention for trauma involving the cervicothoracic junction are not well defined. There is no level I or level II evidence that delineates the selection criteria. Patients with progressive neurologic deficit or incomplete spinal cord injury require immediate closed reduction and realignment. If these measures fail and the patient demonstrates persistent neurologic deficit, then open reduction, decompression, and stabilization are warranted.

The goal of stabilization is to prevent progressive kyphosis and possibly diminish posttraumatic syrinx formation with a view toward preserving function above the level of the injury. Posttraumatic kyphotic deformity can cause spinal cord stretch and progressive neuronal injury to the anterior horn and motor neurons. Recent animal studies show that progressive kyphosis of the cervical spine results in demyelination of nerve fibers and neuronal loss in the anterior horn due to chronic stiffness of the thoracic spine.
compression. As such, realignment remains one of the primary goals when addressing cervicothoracic junction trauma.

Stabilization of the cervicothoracic junction can be difficult, and a variety of techniques and approaches have been described for this procedure. One of the technical challenges has been that instrumentation constructs for the cervical spine are smaller than those for the thoracic region. Newer dual diameter, or tapered, rod systems overcome this issue, allowing the surgeon to use a single rod, while placing the appropriate-sized instrumentation in each segment of the spinal column (Fig. 9.9B).

Cervicothoracic fixation of the unstable spine is challenging due to the transition of cervical lordosis to thoracic kyphosis. Stress and motion are important at the cervical level in contrast to the rigid upper thoracic spine. Rhee et al\(^\text{10}\) compared the stiffness of several posterior fixation constructs. C7 and T1 pedicle screws are stronger than lateral mass screws at C7. This study also demonstrated that extension of the construct to C6 increased construct stiffness; wiring augmentation did not provide increased rigidity.

References
1. Bell C. Surgical observations. Middlesex Hosp J 1817;4:469–470
III Management

86. Pateder DB, Carbone JJ. Lateral mass screw fixation for cervical spine trauma: associated complications and efficacy in maintaining alignment. Spine J 2006;6:40–43

[Q1] Au: you explain what a Power’s ratio of less than 1 or greater than 1 means. Should a ratio equal to 1 be included in one of these two categories? Also, if Power is the person’s name, pls verify that it is spelled correctly (not Powers?).

[Q2] Au: “less than or greater than 3.5 mm” seems to mean that any size of displacement except 3.5 receives a grade, which is very confusing. Please fix, or explain. Do the same for “less than or greater than 11 degrees.”

[Q3] Au: heading has AO classification. Do you mean the “Arbeitsgemeinschaft fur Osteosynthesefragen (AO, Association for the Study of Internal Fixation)” or “atlanto-occipital”? Pls specify.

[Q4] Au: ref 25: What is editor’s initial?

[Q5] Au: ref 70: Please supply volume and pages?

[Q6] Au: Fig. 9.3, verify that the figure parts are correctly labeled and cited in legend.

[Q7] Au: Edited hardcopy not received, plz. suggest.