The Management of Unstable Cervical Spine Injuries

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\textbf{ABSTRACT:} Injuries to the cervical spine can cause potentially devastating morbidity and even mortality. In this review we discuss the anatomy and biomechanics of the cervical spine. The evaluation and treatment of cervical spine injuries begins with the prompt immobilization of suspected injuries in the field. Once an assessment of the patient’s neurological status is made, imaging studies are obtained, which can include X-rays, CT, and MRI. Careful scrutiny of the imaging studies for bony and/or ligamentous injury allows the physician to determine the mechanism of injury, which guides treatment. The ultimate treatment plan can consist of non-operative or operative management, and depends on patient specific factors (medical condition and neurological status), the mechanism of injury, and the resultant degree of instability. With prompt diagnosis and appropriate management, the morbidity of these injuries can be minimized.

\textbf{KEYWORDS:} C-spine, trauma, unstable fractures

\textbf{INTRODUCTION:} Injuries to the spine are common worldwide; in the United States, more than 50,000 spinal fractures occur yearly with 75\% of those injuries occurring in the cervical spine.\textsuperscript{1} Approximately 20\% of these fractures are accompanied by spinal cord injury.\textsuperscript{1} Because of the potential for tremendous morbidity and even mortality, prompt diagnosis and appropriate management of an unstable cervical spine injury is critical. This begins in the pre-hospital setting with empiric immobilization of any patient suspected to have a spinal injury. In the emergency room setting, all patients should receive timely and frequent clinical exams including radiographic examination with X-rays, CT, and/or MRI when indicated. The specific injury pattern will be dictated by patient specific factors (age, sex, bone quality, pre-existing cervical spine disease) in addition to injury factors (mechanism, high vs. low energy). Finally, after identification of the specific injury, definitive treatment may consist of non-operative or operative management. In this review we will discuss the anatomic and biomechanical factors important for understanding these injuries, followed by a discussion of their management in the pre-hospital, hospital, and operating room settings.

\textbf{BACKGROUND:} Anatomy & biomechanics. The cervical spine consists of 7 cervical vertebrae that can be subdivided into the axial cervical spine (C1–C2) and the subaxial cervical spine (C3–C7). These vertebrae are smaller than those in the thoracic and lumbar spine, and the 1st, 2nd, and 7th vertebrae have unique anatomic features. In addition to the bony anatomy, the contribution of the intervertebral discs, anterior and posterior longitudinal ligaments (ALL & PLL, respectively), and other supporting ligamentous structures (ligamentum flavum, ligamentum nuchae) to the overall structure and function of the cervical spine is important in understanding injury patterns. It is also important to remember that children younger than 12 years old have more ligamentous laxity and a larger head size relative to their body size. This predisposes them to injuries at the occipitocervical junction, as well as injuries that can occur without radiographic abnormality. We will begin...
by discussing the bony anatomy followed by the other critical supporting structures of the cervical spine.

**Bony anatomy.**

Occiput. The occiput articulates with the atlas (C1) and forms the occipitocervical articulation between the skull and the axial cervical spine. The occiput articulates with the atlas at the inferiorly projecting occipital condyles, which lie at the anterolateral aspect of foramen magnum, the opening for the brainstem and upper cervical spinal cord. Important landmarks in the occiput are the basion (the anterior aspect of foramen magnum), the opisthion (the posterior aspect of foramen magnum), and the clivus (the bony shelf extending anteriorly from the basion). The clivus and the basion are important anatomic landmarks because they can be readily identified on plain radiographs and can be used to determine occipitocervical alignment.

Atlas. The atlas, or C1, is a uniquely shaped bony element of the spine. It lacks a vertebral body and a spinous process, and consists only of two lateral masses that articulate with the occipital condyles, connected by anterior and posterior arches forming a ring. The atlanto-occipital joint allows for 50% of neck flexion and extension. There are several tubercles that serve as attachment points for various structures. There is an anterior tubercle that serves as an attachment point for the paired longuscolli muscles. There are also tubercles located on the inner surfaces of the lateral masses for attachments of the transverse atlantal ligament. Posterior to the anterior arch is a fovea, which articulates with the dens of C2. The posterior arch has a groove on its cranial surface, where the vertebral artery and the first cervical nerve lie, that can be injured in C1 fractures. The posterior arch provides a bony restraint to occiput extension.

Axis. The axis, or C2, has a unique and complex structure. It contains the dens, or odontoid process, which forms part of the atlanto-axial articulation and provides for approximately 50% of neck rotation. The dens articulates on its anterior surface with the fovea of C1 and posteriorly is contained by the transverse ligament. The dens connects to the body of C2, which extends laterally into the lateral masses of C2, which also articulate with C1 (Figs. 1A and 1B). The pedicles of C2 connect the lateral masses to the posterior inferior articulating processes of C2, which form a facet joint with C3.

Subaxial cervical spine (C3–C7). When compared to osseous anatomy in the thoracic and lumbar spine, unique features of the cervical vertebrae are the presence of the foramen transversarium, which contain the vertebral arteries. C6 has a palpable tubercle on its anterior surface (carotid tubercle or tubercle of Chassaignac), which can be a useful intraoperative landmark. C7 is also called “vertebra prominens” due to its large, easily palpable posterior spinous process.

**Ligamentous anatomy.**

Craniocervical ligaments. The craniocervical ligaments help to stabilize the occipitocervical junction and the upper cervical spine, and injury to these ligaments can cause significant cervical spine instability. These can be split into external craniocervical ligaments, which lie outside the spinal canal, and internal craniocervical ligaments.

External craniocervical ligaments. Ligamentum nuchae is the most robust of these ligaments and extends from the external occipital protuberance down to the C2 spinous process, and continues distally down to the C7 spinous process. The anterior longitudinal ligament (ALL) runs along the anterior aspect of the vertebral bodies from the occiput down to the sacrum. Anteriorly and posteriorly, there are thin fibrous elastic bands, termed the occipitoatlantal membranes, that are located between foramen magnum and the anterior and posterior arches of C1. Similar structures called the atlantoaxial membranes connect C1 and C2. Given their small caliber, these membranes provide little stability to the upper cervical spine. Importantly, the upper cervical spine

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**Figure 1.** (A) Open mouth odontoid view showing the relationship of the odontoid process to the lateral masses of C1. (B) Annotated image highlighting the relationship of the dens, superior articulating processes of C2 and the ring of C1.
lacks intervertebral discs or ligamentum flavum. The annulus in the lower cervical spine, coupled with the ALL, acts as an anterior tension band limiting extension of the cervical spine.

Internal craniocervical ligaments. Although the ligamentum nuchae is robust and provides significant stability as a posterior tension band, the internal craniocervical ligaments provide most of the stability to the occipitocervical junction and upper cervical spine. These ligaments are located anterior to cord, and consist of 3 layers. The most anterior ligaments are the apical ligament and the alar ligaments. The apical ligament connects the basion to the tip of the odontoid and provides little structural stability. The alar ligaments are thicker, and connect the lateral aspect of the odontoid tip to the anteromedial surface of the occipital condyles. The cruciate ligament comprises the next layer, of which the transverse atlantal ligament is the most substantial component. The transverse atlantal ligament extends from the medial aspect of the lateral masses of C1 and runs posterior to the dens. This ligament provides the most important ligamentous constraint to anterior translation at the atlantoaxial articulation. The most posterior layer is the tectorial membrane, which helps to limit hyperflexion. It is a continuation of the posterior longitudinal ligament (PLL) and attaches proximally to the anterior aspect of foramen magnum.

**Patient evaluation.** All patients with injury to the head and/or neck should be treated as if they have an unstable cervical spine until definitely ruled out by clinical exam with imaging as needed. In the field, emergency medical service (EMS) providers must adhere to strict immobilization techniques with patients log rolled onto a spine board with the head immobilized in neutral position in a rigid cervical collar and head blocks. Pediatric patients, due to the large size of their head relative to their body, should be immobilized on a backboard with the head repressed or on a standard backboard with the torso elevated to prevent positioning in cervical flexion. Patients should be immediately transferred to a hospital with initial treatment and evaluation adhering strictly to Advanced Trauma Life Support (ATLS) guidelines. If the airway needs to be secured via intubation, manual in-line stabilization should be maintained at all times. Spinal evaluation should consist of careful log roll followed by palpation of the entire spine from occiput to sacrum for tenderness or stepoff. A detailed neurological examination should be completed according to the International Standards for Neurological Classifications of Spinal Cord Injury (ISNCSCI) guidelines. Injuries to the occipital condyles and occipitocervical (OC) junction can result in injury to the lower cranial nerves, which should be noted. Specifically, the spinal accessory nerve (CN XI) and hypoglossal nerve (CN XII) can be assessed by motor examination.

**Imaging.** Standard radiographic evaluation in patients with suspected unstable cervical spine injuries includes antero-posterior (AP), lateral, and open-mouth odontoid views. The lateral view must include the cervicothoracic junction. Radiographic evaluation of the cervical spine may be limited, however, by body habitus or overlying lines and tubes from resuscitation. Typically, trauma patients with head and neck injuries will receive a computed tomography (CT) scan of the head, and along with this should also receive a CT of the cervical spine with 2 mm slice thickness. If an isolated CT of the cervical spine is done it should extend rostrally through the occipital condyles and caudally through the cervicothoracic junction. Any patient with abnormal or inconclusive findings on plain radiography also should be further evaluated with a CT scan.

Evaluation of upper cervical spine imaging should begin with careful scrutiny of the X-rays. Plain radiographs should provide clear views of the OC junction; if they do not then a CT scan should be obtained. The soft tissues should be carefully examined for swelling as retropharyngeal soft tissue swelling is commonly seen in upper cervical spine injury. As measured on CT scan, normal values for the thickness of the soft tissue anterior to the vertebral bodies are 8.5 mm, 6 mm, 7 mm, 18 mm, and 18 mm at C1, C2, C3, C6, and C7, respectively. The thickness anterior to C4 and C5 is less reliable due to the variable position of the esophagus and larynx. The most commonly missed injuries are OC dislocations and odontoid fractures, so these should be looked for and specifically ruled out. A useful measurement to evaluate OC alignment is Power’s ratio, which is the ratio between the distance from the basion to the posterior arch of C1, to the distance between the opisthion to the anterior arch of C1 (Fig. 2). A ratio greater than 1 suggests an anterior occipitocervical dissociation. Other measurements for OC dissociation are the basion-dens interval (BDI), which is a measurement from the basion to the tip of the dens, and the basion-axial interval (BAI), which is a measurement from the basion to a line drawn up along the posterior aspect of the dens. Both BDI and BAI should be <12 mm in a normal OC relationship. The BAI and BDI are more sensitive than Power’s ratio in detecting OC dissociation. In addition to looking for fractures, continuity of the spinolaminar line between C1 and C3 should be assessed. The location of the spinolaminar point of C2 should lie within 2 mm of that connecting C1 and C3. The anterior atlanto-dens interval (ADI) should be measured, with normal values being <3 mm in adults and <5 mm in children under 8 years old. C1 fractures, odontoid fractures, and atlantoaxial subluxations can be visualized on high-quality open mouth views of the upper cervical spine. The C1 lateral masses should be inspected for symmetry and should be equal in distance from the dens.

Evaluation of the subaxial cervical spine should also proceed systematically. The soft tissue in front of C3 should be examined for swelling, as there is a sensitivity of 66% for cervical spine fracture or dislocation when this tissue measures >4 mm. The anterior vertebral line, posterior vertebral line, and spinolaminar line should all be smooth and continuous. Findings that may suggest instability are facet joint widening, tear drop fractures, angulation more than 11 degrees between...
adjacent segments, translation of greater than 3.5 mm, spinous process widening or malalignment, facet rotation, or vertebral body tilting.

Magnetic resonance imaging (MRI) can also be obtained in the acute setting to evaluate for injury to the cord, disc, or ligaments, as well as to exclude other fractures, and is the imaging modality of choice in patients with ankylosing spondylitis. It is also indicated in patients with neurologic deficits when other imaging studies do not clearly show a cause for the deficit. Ligamentous injuries will be readily apparent on fluid-sensitive sequences such as T2 or STIR. MRI may also be useful to evaluate for disc herniations prior to attempting closed reduction in a patient with a facet dislocation.

Assessment & Treatment of Specific Injuries
Injuries to the upper and lower cervical spine can occur through a variety of mechanisms. When evaluating a patient with a potential or confirmed cervical spine injury, consideration of the mechanism can help classify the injury, assess its stability, and predict associated injuries.

Occipital Condyle Fractures
Occipital condyle fractures were first reported in 1817 by Sir Charles Bell based on autopsy findings, and were first described radiographically in the early 1960s, followed by a CT-based description in the early 1980s. Occipital condyle fractures occur primarily by three mechanisms: compression, distraction, or lateral bending or rotation. These fractures were classified by Anderson and Montesano based on morphology on CT scan and the potential for instability. Type I injuries occur via a compression mechanism and cause impaction of the occipital condyle into the lateral mass of the atlas, resulting in a comminuted, usually stable, fracture pattern. A Type II injury is an occipital condyle fracture associated with a basilar skull fracture, usually from a direct impact. These are unstable when the entire condyle is separated from the occiput. Type III injuries occur via a lateral bending or rotation mechanism causing an avulsion fracture from the pull of the alar ligament, with the fragment fragment displacing medially into foramen magnum; these injuries are unstable and require posterior occiput-C1 fusion.

Occipitocervical Instability
Instability at the occipitocervical junction is a frequently missed diagnosis due to the subtle radiographic findings unless there is frank atlanto-occipital dislocation. A frequently used classification scheme for occipitocervical instability is based on the direction of instability. Anterior displacement and posterior displacement of the occiput with respect to the atlas are type I and type III injuries, respectively. Type II injuries occur via distraction—traction should be avoided in this injury mechanism as this can worsen the deformity. Type IIa involves displacement between the occiput and the atlas, while type IIb involves displacement between the atlas and the axis. Children are at particularly high risk for occipitocervical instability due to their large head size relative to their body. Type I and type III injuries can be treated with initial traction and halo vest immobilization for approximately 3 months, with subsequent dynamic radiography to assess stability. Type II injuries usually require occiput-C1 fusion.

Atlas Fractures
Fractures of C1 are common, representing 10% of all cervical spine fractures. They commonly occur in conjunction with other injuries, such as those to the occipital condyle or C2. Neurologic compromise is rare presumably because the mechanism of injury usually involves some component of an axial load that results in a burst configuration with expansion of the size of the canal. There are several commonly described fracture patterns of the atlas. The most common is a posterior arch fracture, which occurs at the junction of the arch with the lateral masses, and results from a hyperextension mechanism. In isolation these are typically stable, but can be unstable if associated with an anterior teardrop fracture or traumatic spondylolisthesis of C2 (Hangman’s fracture). Another pattern is a...
fracture anterior to the lateral mass on one side with a fracture posterior to the lateral mass on the contralateral side, creating an unstable “floating” lateral mass. The Jefferson fracture is a burst fracture resulting from an axial load with involvement of both the anterior and posterior ring. Displacement of the lateral masses greater than 6.9 mm in a Jefferson’s fracture suggests disruption of the transverse atlantal ligament and is an unstable injury.13 Horizontal fractures through the anterior tubercle can be caused by forceful contraction of the superior portion of the longuscolli muscle. Lastly the transverse process of C1 can fracture through a lateral bending mechanism. Most C1 fractures can be treated non-operatively using a rigid cervical orthosis or a halo fixator.12 When C1 fractures are associated with other injuries to the upper cervical spine resulting in instability, operative intervention is indicated. Jefferson’s fractures with disruption of the transverse atlantal ligament can be treated with early C1–2 arthrodesis.

Odontoid Fractures

Odontoid fractures represent 9–15% of cervical spine fractures in the adult population.13,14 These injuries occur in a bimodal distribution with younger patients suffering more high-energy mechanisms and older patients often suffering fractures from low-energy ground level falls. Although there have been several recent modifications, Anderson and D’Alonzo devised a classification scheme in 1974 that is still widely used today.15 Type I fractures involve an avulsion near the tip of the odontoid, type II fractures occur at the base of the odontoid, while type III fractures extend into the body of C2. Type I fractures are caused by an avulsion by the attached alar ligament, and therefore may be associated with occipitocervical instability. These are thought to be stable injuries as long as the contralateral alar ligament is intact and the transverse atlantal ligament is intact. Stable type I fractures can be treated with immobilization in a hard cervical collar unless there are other concomitant injuries. In cases of associated occipitocervical instability, the recommended treatment is occiput-C2 fusion.

Of particular interest are type II fractures because these have a historically high rate of non-union, from 26% to 85%.16–18 Ekong and colleagues reported that risk factors for non-union were age >40 years, posterior displacement >5 mm, angulation >11°, concomitant neurologic deficit, and significant comminution.19 Treatment is controversial as both non-operative and operative outcomes are associated with poor outcomes and high complication rates. Some authors have recommended surgical stabilization of all type II odontoid fractures in patients >50 years of age due to the very high rate of morbidity and mortality associated with rigid halo-vest immobilization in this population.20 Younger patients with minimally displaced fractures at low risk of non-union can be treated non-operatively in a halo-vest orthosis. In those patients at high risk for non-union, surgical treatment is recommended with either an anteriorly placed odontoid screw, or posterior C1–C2 fusion. In patients with irreducible odontoid fractures with canal compromise, a C1 laminectomy can be done with occiput to C2 fixation.21

Type III fractures have a better prognosis than type II fractures because of the larger fracture surface area with an adequate vascular supply for healing. Stable type III fractures can be treated in a rigid collar or a halo-vest orthosis with healing rates of 92% or greater.22–24 Factors that may be associated with instability in type III fractures are vertical instability with >5 mm distraction, high type III fractures that involve the waist of the odontoid, and significant anterior or posterior displacement.25

Transverse Atlantal Ligament Insufficiency

C1–C2 instability can be caused by disruption of the transverse atlantal ligament from a variety of causes, including trauma, infection, inflammatory arthropathies, or congenital etiologies.26 An ADI >3 mm in adults or >5 mm in children suggests disruption of this ligament. Children can sometimes be treated non-operatively in halo fixation for 2 to 3 months, but adults are generally treated with C1–C2 arthrodesis.

Hangman’s Fracture

The hangman’s fracture is a result of forced hyperextension and axial compression that leads to a bilateral fracture through the pars interarticularis causing a traumatic anterior spondylolisthesis of C2 on C3. The resulting fracture rarely results in neurologic deficit because of the large diameter of the canal at this level, and the fracture itself tends to increase the size of the canal. Type I fractures occur through the base of the pedicle, and have <3 mm of translation and no angulation at the fracture site. These can generally be treated in a rigid cervical orthosis. Type II fractures are characterized by >3 mm of translation and significant angulation at the fracture site. There may also be a compression injury to the anterosuperior aspect of the C3 body as the C2 body subluxates onto it, as well as injury to the C2–3 disc. The mechanism of injury in this fracture pattern involves an initial hyperextension and axial loading followed by hyperflexion. This fracture type is typically managed with reduction via traction followed by halo immobilization, unless the fracture pattern suggests a flexion-distraction mechanism, in which case traction would be contraindicated. Type III fractures include facet dislocations at C2–3 in addition to the displaced pars fracture of C2. These injuries have a higher rate of neurologic injury and usually need open reduction of the facet dislocation followed by C2–3 fusion.

Subaxial Cervical Spine Injuries & Mechanisms

A mechanistic classification was first described by Allen and colleagues in 1982 with regards to injury to the subaxial spine, and included six categories of injury based on the presumed position of the cervical spine at the time of injury, and the initial principal mechanism of load to failure. These included flexion compression, flexion distraction, vertical compression, extension compression, extension distraction, and lateral flexion.27
Extension Compression
These injuries can involve multiple contiguous levels and are therefore generally more severe.

Stage 1—Unilateral posterior arch fracture, also usually accompanied by failure of the anterior portion of the disc in tension. These injuries have shown poor results with non-operative treatment and are treated optimally with anterior or posterior instrumented fusion.

Stage 2—Bilaminar fractures with no evidence of failure of anterior structures. Neurologic injury is rare with this type of injury, and immobilization in a rigid cervical orthosis or a halo orthosis usually leads to uneventful healing.

Stages 3 through 5—Progressively worsening disruption of both anterior and posterior columns with stage 5 injuries being true fracture-dislocations involving a posterior arch fracture and greater than 100% displacement of the vertebral body. Given the extensive bony and soft tissue injury, combined anterior and posterior fusion with instrumentation is indicated.

Flexion Compression
These injuries comprise approximately 20% of all subaxial cervical spine fractures. The force vector is directed anteriorly and inferiorly. There are several subtypes which correspond to the energy imparted at the time of injury and the resultant radiographic appearance.

Stage 1—Blunting at the anterosuperior aspect of the vertebral body
Stage 2—Beaklike appearance of the vertebral body anteroinferiorly. These can usually be treated in a rigid orthosis.
Stage 3—Vertebral body fracture with the pathognomonic “teardrop” fragment. These can be treated in a halo vest if minimally displaced with minimal focal kyphosis.
Stage 4—Similar to stage 3 accompanied by less than 3 mm of posterior displacement of the vertebral body into the canal.
Stage 5—Characterized by failure of the posterior ligamentous tension band with interspinous widening and more severe vertebral body displacement.

Stage 4 and 5 injuries can best be treated by anterior decompression and fusion with instrumentation. In severe injuries with significant disruption of the posterior tension band, consideration should be given to performing an anterior and posterior arthrodesis.

Extension Distraction

Flexion Distraction
These injuries account for approximately 10% of subaxial cervical spine injuries. The force vector is directed anteriorly and superiorly.

Stage 1—Failure of the posterior ligamentous complex. Radiographically, this is characterized by facet subluxation and interspinous widening only evident in flexion films, with neutral radiographs often being normal.
Stage 2—Unilateral facet dislocation that may be associated with a pedicle or articular process fracture.
Stage 3—Bilateral facet dislocation with up to 50% anterior vertebral body displacement.
Stage 4—Bilateral facet dislocation usually with 100% or even greater anterior vertebral body displacement.

Facet dislocations can often be reduced by closed means using tongs and traction, especially in an awake, cooperative, and neurologically intact patient. Pre-reduction MRI should be obtained in the situation of an intubated and anesthetized patient to evaluate the degree of cord compression and the possibility of disc fragments impinging on the cord. After reduction, definitive stabilization and fusion is required using either posterior or anterior instrumented techniques.

Vertical Compression
These injuries are the result of an axial compression force with a direct blow to the vertex of the skull, and thus commonly associated with concomitant head injury.

Stage 1—Central cupping of one vertebral end plate. These are usually treated with a rigid cervical orthosis.
Stage 2—Disruption of both vertebral end plates. When there is no neurologic deficit these can be treated in a halo vest for 2–3 months.

Stage 3—Burst injury to the vertebral body with posterior displacement of fracture fragments into the canal. These are best approached with corpectomy for canal decompression followed by strut grafting and anterior reconstruction using instrumentation.

Lateral Flexion

These injuries are a result of a lateral bending moment on the head and neck resulting in ipsilateral injury to the anterior and posterior columns.

Stage 1—Isolated ipsilateral injury involving the body, pedicle, lamina, and/or articular processes. These can often be treated in a rigid cervical orthosis or a halo vest. Stage 2—Stage 1 injury plus contralateral bony or ligamentous failure in tension. These injuries often require traction for reduction followed by surgical stabilization.

Conclusion

Injuries to the cervical spine have the potential to cause serious morbidity and mortality. All patients with suspected head or neck trauma should be evaluated and treated as if they have an unstable cervical spine injury until proven otherwise. Imaging studies should be used liberally to obtain a full understanding of the extent of injury. The optimal management of these patients begins in the pre-hospital setting with the subsequent treatment being based on mechanism of injury in addition to patient-specific factors. With careful understanding of the injury pattern and the forces involved, these fractures can be managed successfully using a combination of non-operative and operative modalities.

Author Contributions

Conceived the concept: VMN and HJK. Wrote the first draft of the manuscript: VMN. Contributed to the writing of the manuscript: VMN and HJK. Jointly developed the structure and arguments for the paper: VMN and HJK. Made critical revisions and approved final version: VMN and HJK.

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