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Review article

Biomechanics, evaluation, and management of subaxial cervical spine injuries: A comprehensive review of the literature

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ABSTRACT

Study design: Literature review.
Objectives: It has been reported that 2.4–3.7% of all blunt trauma victims suffer some element of cervical spine fracture, with the majority of these patients suffering from C3-7 (subaxial) involvement. With the improvement of first-response to trauma in the community, there are an increasing number of patients who survive their initial trauma and thus arrive at the hospital in need of further evaluation, stabilization, and management of these injuries.
Methods: A comprehensive literature review compiled all relevant data on the biomechanics, imaging, evaluation, and medical and surgical management strategies for subaxial cervical spine fractures.
Results: After review of the current literature on subaxial cervical spine biomechanics, imaging characteristics, evaluation strategies and surgical and orthopedic management techniques, the authors created a comprehensive review and protocol for management of subaxial cervical spine fractures.
Conclusions: The subaxial cervical spine is biomechanically and anatomically unique from the remainder of the spinal axis. Evaluation of subaxial cervical spine injuries is nuanced, and improper management of these injuries can lead to significant patient morbidity and even death. This provides a comprehensive review combining anatomy, imaging characteristics, evaluation strategies, and surgical and orthopedic management principles for subaxial cervical spine fractures.

1. Introduction

A reported 2.4–3.7% of all blunt trauma victims suffer some element of cervical spine fracture, with a 2:3 ratio of occiput-C2 (craniocervical junction) and C3-C7 (subaxial) involvement [1,2]. As with most traumatic injuries, the age distribution is bimodal, with peaks in males during the second and third decade of life, and another peak in those over the age of 65 [3]. As advanced trauma and life support protocols and response-times of emergency medical responders continue to improve, an increasing number of patients are surviving their initial injuries and require evaluation, stabilization, and possible surgical management of other injuries, including cervical spine trauma [4]. Additionally, the widespread adoption and availability of spinal computed tomography (CT) imaging in trauma protocols has improved the early diagnosis of cervical spine injuries and allows the spine surgeon to have early input on the management of cervical spine trauma. The spine surgeon thus plays a critical role in guiding the early management and stabilization of the trauma patient with subaxial cervical spine trauma. This review will focus on those the mechanisms of subaxial spine fractures in addition to the anatomy, evaluation, and management of such injuries. The spine surgeon's awareness of these paradigms is invaluable in all settings of neurosurgical and orthopedic practice and trauma care, as the correct work-up, accurate diagnosis, and effective treatment of subaxial spine fractures has the potential to reduce the associated morbidity and mortality.

2. Mechanisms of injury and classification systems

One of the first widely-accepted standardized classification systems for cervical spine injuries was written by Holdsworth et al. in 1970. In this landmark study, they classified cervical spine injuries into flexion, flexion/rotation, extension, compression, and shear-type injuries [5].

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In 1982, this was further expanded by Allen and Ferguson, who described cervical spine injuries occurring due to compressive flexion, vertical compression, distractive flexion, compressive extension, distractive extension, and lateral flexion. Additionally, they detailed various severities of compression flexion, vertical compression, distractive flexion, compressive extension, and distractive extension to better describe the severity and likelihood of underlying neurological injury [6]. Each category of injury details stages of subaxial cervical spine disruption, with higher stages representing increasingly unstable cervical anatomy.

While the Allen and Ferguson classification system provided an in-depth analysis of injury mechanism and incidence of neurological injury with each subtype, there was low inter- and intra-rater reliability. Although multifactorial, the system's inconsistency in guiding surgical practice is primarily due to its inability to capture the multiple force vectors and complex injury morphology of most real-world cervical spine fractures and therefore has fallen out of favor. Since then, multiple other injury classifications have been published, including the Harris classification system and the AOSpine classification for subaxial spine injuries [7,8]. The Harris system characterizes fractures based on flexion, flexion/rotation, extension/rotation, vertical compression, hyperextension, and lateral flexion mechanisms, predicting damaged structures according to these mechanisms of injury. Similarly, the AOSpine Subaxial Classification system groups fractures categorically into compression injuries, tension band injuries, translation injuries, and facet injuries [9]. These systems produce higher intra- and inter-rater reliability, and their use is, therefore, more widespread amongst the clinical community [10,11].

It is important to recognize, however, that uniplanar injuries are rare, and most cervical spine injuries are due to injuries involving multiple force vectors [12]. The predominant force vector is often revealed in the injury appearance on CT scan, but it is important to recognize that multiple vectors may be involved, as this may impact operative planning and surgical approach.

3. Evaluation

Few traumatic injuries, when missed, can cause as much sudden, catastrophic, and possibly permanent morbidity than an unstable cervical spine fracture. Thus, the importance of systematic and thorough evaluation cannot be overstated. Today, evaluation of cervical spine trauma consists of patient-reported symptoms, a thorough physical exam, and radiographic imaging—primarily with a CT scan (See Figs. 1–3). When available, a thorough history (from either the patient or witnesses) and physical examination can be crucial in raising or lowering the suspicion for unstable cervical spine injury. It is vital to understand that even minor trauma can cause significant cervical spine injury.

3.1. Patient history

If available, a thorough history includes the event surrounding the traumatic accident. For motor vehicle collisions, the mechanism of the collision (head-on, rear-end, side-end), as well as speed, rollover, airbag deployment, seatbelt-use, and extrication time, are all critical to providing an overall gestalt as to the mechanism and severity of any cervical spine injuries. Falls, all-terrain vehicle (ATV) accidents, and others are also part of a wide gamut of mechanisms capable of producing a cervical spine injury, so recollection of the precipitating incident and estimation of force may help with immediate prognostication of the patient. It is also crucial to be aware of other injuries. For example, patients with traumatic head injuries are four times as likely to have also incurred

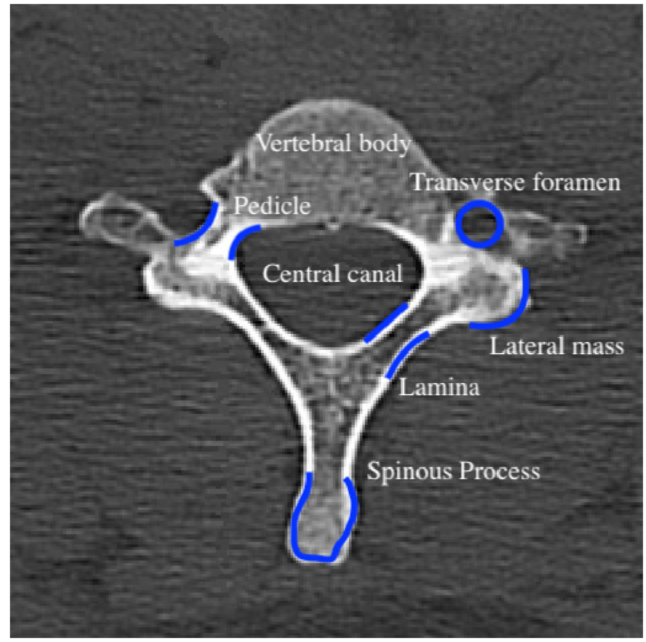

Fig. 1. The typical axial view of the cervical vertebra demonstrating the normal anatomy of a single subaxial vertebra, including the vertebral body, transverse process, and spinous process.

cervical spine trauma [3]. The incidence of head injury in the setting of cervical spine trauma is between 18 and 40% [13].

3.2. Neurological exam

The neurological exam is the next crucial step in evaluating any neurological injury involving either the spinal cord or nerve roots. Besides assessing for the strength and sensation of the patient's extremities, it is important to document pathological reflexes or the absence of reflexes. A thorough baseline neurological exam can be used as a reference for future exam changes, although traumatic injuries to the extremities can prevent a thorough neurological exam. It is advisable to test motor function, sensory function, and anal contraction as well as reflexes such as the bulbocavernosus reflex. These These are summarized in The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) examination [14].

In addition, American Spinal Injury Association (ASIA) score should be documented for patient prognostic information. Palpation of the cervical spine, while not a part of the routine bedside neurological exam in an atraumatic patient, can also reveal any tenderness or bony stepoffs that may indicate fractures or dislocations. Vital signs are another component of the neurological exam, as cord injury at the cervical level is suggested when a patient displays hypotension, bradycardia, and hypothermia (loss of sympathetic response). Bladder scans can reveal urinary retention but should be interpreted with caution in the setting of a critically ill patient who would have other reasons to be unable to void.

3.3. Radiographic evaluation

In the past, there were two widely accepted algorithms used to assess the need for cervical spine imaging in the trauma patient: the NEXUS Low Risk Criteria (NLC) and Canadian C-Spine Rule (CCR) (see Table 1). These two criteria combined clinical and physical exam findings to justify the need for cervical spine radiographs in the assessment for cervical spine trauma. For example, patients who were alert, without posterior midline tenderness, without dis-

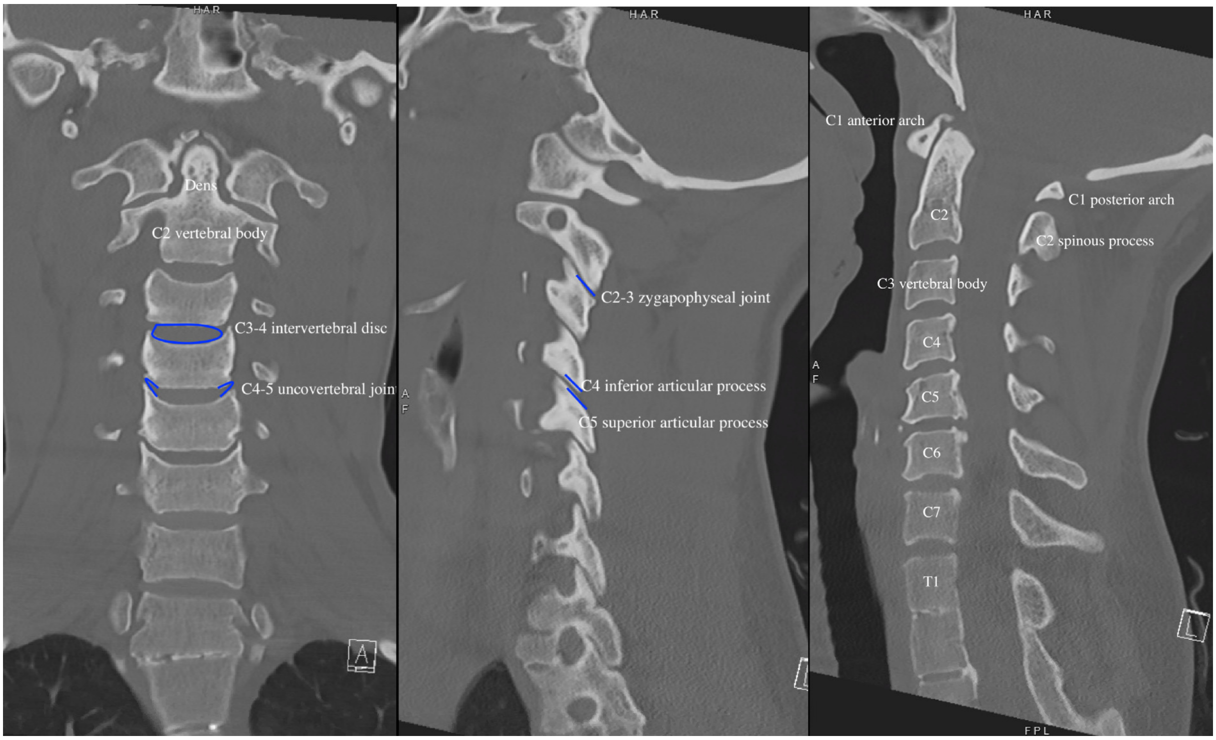

Fig. 2. Cervical spine sagittal and coronal views with critical structures identified.

tracting injuries, and were not intoxicated could be cleared of cervical spine trauma without any additional imaging [15].

Clinically, many, if not most, trauma patients do not meet the criteria established by the NLS and the CCR. Additionally, the criteria themselves have a wide range of interpretations. "Distracting injuries" or "intoxication" or "dangerous mechanism" have non-standard definitions across clinical practice. Additionally, plain radiographs have difficulty imaging the craniocervical and cervicothoracic junctions and are limited to overt fractures or fractures causing gross malalignment [16]. As a result, the false-negative rate of plain films is unacceptably high for them to be the sole imaging modality used in cervical spine trauma evaluation [17]. The wide availability of CT scanners, coupled with their high fidelity for bony anatomy visualization, has made CT imaging the gold standard radiographic tool for evaluating cervical spine fractures [18].

Evaluating cervical spine injuries on CT scans is not without challenges. Fractures can be subtle, and a multitude of image- and patient-related factors can sometimes obscure an otherwise obvious injury. CT slice thickness, axial gantry angle, patient positioning, and hardware artifact can complicate the interpretation of cervical spine imaging, and a systematic method for reviewing CT is critical for minimizing the incidence of missed injuries [19]. A 2014 study by Raniga et al. described a methodical checklist for CT cervical spine evaluation [20]. In their algorithm, systematic anterior to posterior and superior to inferior review of bony, ligamentous, and soft tissue anatomy was key to reducing missed injuries (Tables 2 and 3).

Following interpretation of CT, clinicians must decide on the utility of magnetic resonance (MR) imaging. In the past, MR image acquisition times and scanner availability prevented their widespread adoption; however, thanks to increased availability, MR imaging now plays a more vital role in the acute evaluation of cervical spine trauma [21]. MR imaging, with its superior contrast resolution, is the preferred imaging modality to evaluate soft tissue such as intervertebral disc, spinal cord, ligamentous complexes, and hematoma [22,23].

In general, the indications for MR in cervical spine trauma are summarized by the following criteria as suggested by Saifuddin et al., Hogan et al., and Benzel et al. [24–26]:

Radiographic and/or CT scan findings suggestive of ligamentous injury, such as prevertebral hematoma, spondylolisthesis, asymmetric disc space widening, facet joint widening or dislocations, and inter-spinous space widening.

To look for epidural hematoma or disc herniation before attempting a closed reduction of cervical facet dislocations.

To identify spinal cord abnormalities in patients with impaired neurological status.

To exclude clinically suspected ligamentous or occult bony injuries in patients with negative radiographs.

To determine the stability of cervical spine and assess the need for cervical collar in obtunded trauma patients.

To differentiate between hemorrhagic and non-hemorrhagic spinal cord injuries for the prognostic significance, as the presence of hemorrhage significantly worsens the final clinical outcome.

3.4. Stability

The Denis three-column model has been the benchmark for evaluating spinal stability of the lumbar spine [27]. This model was refuted for use in the cervical spine by other surgeons due to the biomechanical differences between the lumbar and cervical spine. Holdsworth et al. simplified the cervical spine into two columns: one containing the entirety of the vertebral body, and one containing all the posterior elements. In their landmark 1970 paper, fractures were described as stable or unstable based on their injury mechanism and imaging morphology, rather than by simple involvement of one or two columns [5]. Other imaging characteris-

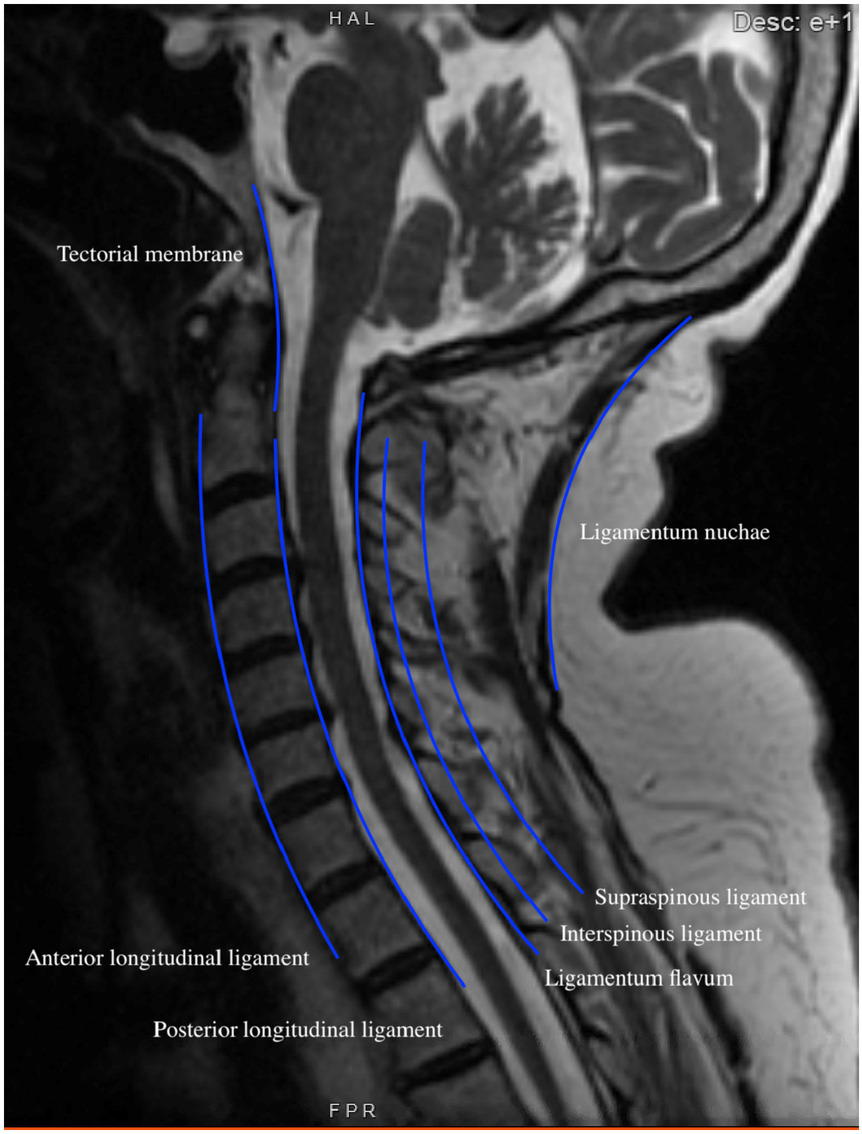

Fig. 3. Sagittal view of the subaxial spine, highlighting the major ligamentous structures of the cervical spine. This figure emphasizes the ligaments of the subaxial cervical spine, including the anterior longitudinal ligament, the posterior longitudinal ligament, the interspinous ligament, and the ligamentum nuchae. *Figures can be printed in black/white.*

tics suggestive of instability include greater than 20 degrees of angulation of one vertebra compared to the adjacent vertebrae, and over 25% anterolisthesis, which can be associated with unilateral or bilateral facet dislocation [28].

Table 1
Nexus and Canadian Criteria.

Nexus Criteria: (any one of the following criteria requires further radiographic evaluation)	1. Focal neurological deficit present 2. Midline spinal tenderness 3. Altered level of consciousness 4. Intoxicated 5. Distracting Injury
Canadian C-Spine Rule (any one of the following criteria requires further radiographic evidence)	1. Age >65 years 2. Extremity paresthesias 3. Dangerous mechanisms 4. High-speed MVC with rollover/ ejection 5. Bicycle collision 6. Motorized recreational vehicle (i.e. ATV)

Punjabi's 1975 landmark study offered additional criteria to indicate cervical spine instability. In this study, >3.5 mm of vertebral body displacement and/or an interspace angle of >11 degrees was indicative of instability [29]. A later manuscript by White and Punjabi in 1990 expanded on these criteria and provided a more detailed point system with cutoffs that were used to evaluate spine stability [30]. A total of five points or more indicated an unstable subaxial spine; factors such as destruction of anterior and posterior elements, cord and root damage, and abnormal disc narrowing are taken into account.

Additional classification systems by Anderson et al. and Vaccaro et al. have each attempted to provide point systems for determining spinal stability [31]. In Anderson's Cervical Spine Injury Severity Score classification system, the spinal column is split into four pillars, an anterior pillar comprising of the vertebral body, two lateral pillars including the facet complexes, and a posterior pillar including the posterior elements. Spinal stability was determined in a non-binary scale, with 0–5 points given to each pillar depend-

Table 2
Subaxial Cervical Spine CT Imaging Checklist [20].

	Anterior Column	Posterior Column
Bone	Vertebral body - Preserved height - Absence of wedging - Smooth cortices - No retropulsion of bone fragment	Neural arch - Intact, absence of fracture - No comminution
Joints	Intervertebral disc - Symmetrical disc space - Absence of focal widening, narrowing, or asymmetry	Facet joint - Normal: congruent, parallel, symmetrical - Absence of articular process fracture
Ligaments	Anterior longitudinal line (ALL)/Posterior longitudinal line (PLL): - Normal integrity inferred from alignment of anterior and posterior vertebral lines	Posterior ligamentous complex (PLC): - Normal alignment of the interspinous - No evidence of focal kyphosis - Interspinous widening
Curvature	Smooth lordosis, absence of focal kyphosis	–
Alignment	Anterior and posterior vertebral body align in the sagittal plane	Spinolaminar and interspinous lines are intact on sagittal plane. Interspinous and articular pillar lines are intact in coronal plane
Measurement	–	Interpeducular, interspinous, and interlaminar distance are less than 2 mm

ing on fracture displacement. A total of 20 points was thus possible, and injuries with greater than 10 points were generally considered a fracture of clinical significance and a high chance of neurological injury.

The Subaxial Injury Classification is based on the morphology, the integrity of the disco-ligamentous complex, and the patient's neurological status [32]. Scores of three or less did not require surgical fixation, while scores of five or greater necessitated surgical fixation. A score of four allowed the surgeon the freedom to decide operative or nonoperative management. Low interrater reliability and the existing presence of well-validated scoring systems has prevented these from being widely adopted.

4. Management

4.1. In the field

Like most ATLS guidelines, airway, breathing, and circulation are the first priorities for Emergency Medical Services (EMS) responders. Any trauma patient, awake or not awake, must be assumed to have a cervical spine injury until proven otherwise [33]. Until cervical spine injury can be ruled out, the trauma patient is typically immobilized on a backboard, has their head secured with rigid blocks, their neck secured in a rigid cervical collar (Philadelphia or Miami J), and their body secured to the backboard with spider straps [34].

These rigid mechanisms allow for safe transport from the field to the hospital, where the aforementioned clinical and radiographic evaluations can take place [35].

For the spine surgeon consultant, evaluation of the cervical spine in the emergency room setting typically abides by the following pathway:

1. Is there a cervical spine injury?
2. Is the cervical spine injury stable or unstable?
3. If there is an injury, does the patient need urgent/emergent operative intervention?
4. If operative intervention is needed, what surgery should they undergo?

Steps 1 and 2 are covered broadly in the previous sections of this manuscript. Patients with unstable injuries can be managed in the Intensive Care Unit (ICU). However, if the patient is cooperative and without risk of rapid respiratory or neurological compromise, he/she can be managed with strict cervical spine precautions and brace-immobilization in experienced step-down units. Patients with spinal cord injuries must have invasive arterial pressure monitoring and mean arterial pressures maintained at higher than 85 mmHg (norepinephrine is preferred at our institution due to its alpha- and beta-receptor agonism) for at least five to seven days, and thus require admission to an ICU for close monitoring and the administration of intravenous vasoactive medications as directed by arterial line data [36]). Most fractures that are unstable will require operative fixation. In select cases, certain unstable cervical spine fractures at the atlantoaxial level can temporarily be managed conservatively (halo collar, etc; however, almost all

Table 3
Potential subaxial cervical spine injuries identifiable on CT scan and preferred viewing plane [20].

	Sagittal	Axial	Coronal
Alignment	Malalignment of: - anterior and posterior vertebral line - spinolaminar line - interspinous lineAnterior and posterior translation	Uncinate process malalignment	Lateral translation of vertebral body Articular pilar alignment Spinous process alignment for rotation
Bone, Fractures	Fractures - Compression fractures; vertebral body compression, wedging - Retropulsion - Articular pillar, articular process fracture - Spinous process fracture	Communitive fracture Sagittal/ coronal split fracturesRetropulsive fracturesPedicle fractureTransverse process fracture	Sagittal split fracture Articular pillar fractureTransverse processOther horizontally oriented fractures
Measurement	Interspinous space widening or narrowing Interlaminar space widening or narrowing	–	Interpedicular space widening Interspinous widening
Joint	Kyphotic angle changes Intervertebral disc Facet joint injury (dislocation, fracture)	Uncinate process malalignment Facet joint injury (dislocation, fracture)	Intervertebral disc asymmetry
Ligaments	ALL and PLL injury	–	–

unstable subaxial spine fractures must be treated with operative intervention unless the patient has a very poor prognosis from other injuries or comorbidities where operative intervention would otherwise be futile.

4.2. Bracing

Bracing can be utilized to immobilize a patient prior to surgery, to provide additional stabilization following surgery, or as a conservative measure in lieu of surgery. Johnson et al. described four general classes of cervical braces: cervical collars, poster braces, cervicothoracic orthoses, and the halo vest [37]. Each has its own uses and pitfalls.

Cervical collars can be further split into rigid (Philadelphia, Necloc, stiffneck) and semirigid (Miami J, Aspen, Malibu) collars. In general, semirigid collars can be used to treat stable cervical fractures, or postoperatively following stabilization of unstable fractures [38]. While the availability of certain collars plays the highest role in selecting which one to use, it is important to understand that each has its biomechanical advantages. In a mechanical study of patients wearing each brace, Evans et al. determined that the Aspen and Philadelphia collars to be superior to all other bracing at restricting rotation, flexion, and extension [39].

Poster braces and cervicothoracic braces provide optimum immobilization of the cervicothoracic junction. The cervico-thoracic-orthosis (CTO) brace is the workhorse of this category and has been shown to provide better lower cervical spine immobilization than the Miami J and Philadelphia collars [40].

The most rigid brace for cervical spine immobilization, however, remains the halo vest. Unfortunately, given the risks of application (i.e. skull fractures, malalignment, displaced pins), limitations from body habitus (i.e. morbidly obese or cachectic patients), and the complications of continued use (i.e. pin loosening, infection), its clinical efficacy remains limited to mainly craniocervical junction fractures and its usage in the geriatric population must be carefully considered [41].

The morbidity of bracing cannot be underestimated, especially in the elderly population. Pressure ulcers, pin site infections, skin erythema, fracture malalignment, patient's ability to follow-up in clinic, development of delayed neurological complications, and high rates of noncompliance must be carefully factored into the decision to brace a patient [42].

4.3. Timing of intervention

The timing of surgical intervention is critical. Typically, patients without neurological injury can undergo surgery less emergently, as long as they are kept under strict cervical spine precautions with rigid immobilization in the interim, while patients with neurological injury or actively worsening neurological status require urgent to emergent intervention. The natural instinct is to operate sooner rather than later, and there is currently a large body of evidence demonstrating that, indeed, early surgical intervention is preferred over delayed intervention. In a study of 43 patients undergoing decompression and stabilization, Mirza et al. demonstrated better neurological recovery and decreased hospitalization time for patients with cervical cord injury and surgical intervention within 72 h [43]. Similarly, in a study of 313 patients undergoing surgical management of acute cervical cord injury, Fehlings et al. also saw improved neurological outcomes for patients undergoing surgery within 24 h when compared to patients undergoing surgery after 24 h [44]. Lastly, another study by Grassner et al. for patients with acute traumatic cervical cord injury showed that surgical management within eight hours resulted in better neurological outcomes than surgery after eight hours, as measured by the Spinal Cord Independence Measure at one year following injury [45].

However, the data from these studies do not universally support better outcomes for early intervention. In a study of 595 subaxial cervical spine trauma patients with cord injury, Liu et al. demonstrated similar neurological outcomes at six-month follow-up between patients undergoing decompressive surgery at <72 h compared to those who underwent surgery at >72 h [46]. In a larger, systematic review of six studies, Wilson et al. concluded that there was no universal recommendation for acute versus delayed intervention, but that patients with incomplete cord injury or central cord injury had better functional outcomes at six-months with early intervention than late intervention. In this study, complication rates were similar between early and late intervention groups for cervical injuries [47]. Given the conflicting data, it is imperative that the spine surgeon use their best clinical judgement when determining the urgency of surgical intervention on a subaxial spine fracture. The timing of intervention may be multifactoral and depend on the patient's medical comorbidities, traumatic injuries to other organs, and availability of the surgeon.

5. Procedural and operative fixation

5.1. Closed reduction and realignment

Currently, there is Level III medical evidence that supports the efficacy of closed reduction for acute traumatic cervical spine fracture-dislocation injuries and a low rate of neurological injury [48–51]. It is currently the gold standard noninvasive intervention for reducing facet fractures and dislocations [52]. Closed reduction is ideally done with the patient awake so that the neurological exam can be actively monitored periprocedurally. However, realistically speaking, it is oftentimes difficult for a patient to tolerate the discomfort associated with these maneuvers. If done in the awake setting, these maneuvers are done with muscle relaxants, sedation, flat-panel fluoroscopy and with close neurological and hemodynamic monitoring in the ICU setting. Alternatively, closed reduction is oftentimes done using Gardner-Wells tongs or halo rings in the operating room under anesthesia with the aid of fluoroscopy and neuromonitoring.

Contraindications to cervical traction are few but include distractive injuries, especially those in the craniocervical junction (atlanto-occipital dissociation) [52]. Additionally, traction reduction of injuries at the cervicothoracic junction may not be technically feasible due to the inability to accurately image the cervicothoracic junction with fluoroscopy as well as the immense amount of force required to obtain adequate traction. A more controversial contraindication to closed reduction is the concurrent presence of a disc herniation. After multiple reports of neurological injury occurring during closed reduction in patients with disc herniations, it was suggested that pre-reduction MR imaging was necessary prior to proceeding with traction [53]. However, in the ensuing years, multiple studies by Doran et al., Rizzolo et al., and Grant et al. showed that cervical disc herniations did not place patients at increased risk for neurological injury following closed reduction [54–56]. Interestingly, a study by Daursaut et al. demonstrated that in addition to reducing cervical spine fractures, closed reduction was able to also reduce disc herniations in 11 of its 17 consecutive subjects [57]. The integrity of the PLL was not commented on in this manuscript. Thus, while MR imaging is certainly preferred prior to attempting closed reduction, its clinical utility is questioned. While unsubstantiated by evidence, the utility of pre-reduction MR imaging in patients with ASIA A spinal injury is also questioned. One additional utility of MR in the trauma setting is evaluation of atlanto-occipital injury. While this can oftentimes be seen on CT, ligamentous disruption and joint fluid signal can be definitively proven on MR.

5.2. Principles of operative management

Operative intervention for subaxial cervical spine fractures typically obeys the following principles:

1. Decompress neurological structures
2. Restore vertebral column integrity
3. Prevent further instability

Unlike thoracolumbar spine surgery, which has anterior, posterior, transforaminal, transpedicular, lateral, and oblique approaches, there are relatively few windows to the cervical spine. While there are fewer surgical approaches, there are no fewer combinations of surgical plans, nor is there universal agreement on the most appropriate instrumentation. In addition to obeying the previous statutes, the individualized approach and surgical solution for each subaxial cervical spine fracture is a culmination of:

1. Surgeon's preference (area of expertise, comfort level)
2. Direction and area of maximum cord compression
3. Extent and location of injury
   a. One vs. two-column injury
4. Any anatomical variants (i.e. ankylosing spondyltitis, rheumatoid arthritis, diffuse idiopathic skeletal hyperotosis (DISH))

5.3. Anterior approach

In general, the anterior approach is recommended for traumatic fractures involving disc herniations and for fractures resulting in near-complete destruction of the vertebral body (where a corpectomy cage can be inserted). Additionally, fractures that preserve the posterior tension band also favor the anterior approach [58]. The hallmark of anterior cervical spine surgery is the anterior cervical discectomy and fusion (ACDF), and anterior cervical corpectomy and fusion. These approaches utilize natural tissue planes and avoid the pain and bleeding associated with posterior muscular dissection. Several studies have demonstrated the overwhelmingly positive results following anterior arthrodesis for subaxial cervical spine trauma, as well as the utility of anterior approaches in restoring cervical lordosis. A study of 19 patients by Woodworth et al. demonstrated an 88% fusion rate and only one case of instrumentation failure following ACDF for subaxial cervical spine fractures. In this series, there were no cases of neurological deterioration or infection [59]. Another study by Kasimatis et al. showed a 90% fusion rate following anterior approach fusion, but also reported a 15% infection rate and 4% revision rate [60]. Reindl et al.'s study of 41 patients with anterior and posterior column disruption and at least one violated facet showed that 31.5% of patients improved at least one Frankel grade at follow-up and 100% of patients achieved successful bony fusion [61]. In a study comparing anterior to posterior approaches for unilateral facet fracture-dislocation, Kwon et al. demonstrated that anterior approach surgery resulted in less pain, lower rates of wound infection, and higher fusion rates than fractures treated with the posterior approach [62].

The anterior approach can also be utilized in patients with isolated facet or lateral mass fractures. Henriques et al. reported a series of 39 patients with ligamentous unilateral and bilateral facet dislocations treated with anterior instrumentation and fusion, where only 11.8% of patients with unilateral injuries lost reduction postoperatively [63]. The loss of reduction in patients with bilateral facet dislocation was higher, at 54%. Additionally, four of their five patients with complete neurological injuries and bilateral facet dislocations had radiographic failure [63].

The rates of radiographic failure and loss of reduction suggest that patients with bilateral facet fractures should undergo both anterior and posterior surgeries. Johnson et al. published a retrospective series of 87 patients with unilateral and bilateral facet injuries treated with anterior approach fusion. Thirteen percent of patients suffered radiographic failure, but none had neurological deterioration. Of these patients, facet fracture, endplate fracture, and lower cervical spine fractures were identified as risk factors for failure to fuse [64]. Common complications for anterior surgery include dysphagia, hoarseness, and cage subsidence.

5.4. Posterior approach cervical spine surgery

Supporters of posterior approach cervical spine surgery argue that posterior fixation provides stronger biomechanical support than anterior-only approaches. In a cadaveric biomechanical study comparing posterior instrumentation to anterior instrumentation, Koh et al. demonstrated a significant improvement in resistance to flexion and extension with posterior instrumentation [65]. In a similar biomechanical study comparing anterior, posterior and anterior-posterior instrumentation for cervical corpectomy, the anterior approach was inferior to anterior-posterior and posterior-only instrumentation with regards to resistance against flexion, extension, lateral bending, and axial rotation [66]. Additionally, supporters of posterior-approach cervical spine surgery argue that open reduction of cervical spine facet fractures is more easily achieved with an open posterior approach. Multiple studies demonstrate a high degree of clinical efficacy achieved with posterior-only surgery, namely with respect to neurological outcomes, rate of instrumentation failure, and need for revision surgery [67–70].

Posterior approach surgery can also be uniquely beneficial for treating neurological compromise that results from the posterior elements. For example, laminar bone fragments impinging on the canal, or displaced facet fragments can be directly decompressed from a posterior approach. Furthermore, the posterior approach allows direct reduction movements that are aimed at spinal realignment, which cannot be accomplished through the anterior approach [71–73]. Contrarily, the posterior approach is relatively contraindicated in patients with anterior cord impingement, either from a herniated disc or from anterior bone fragments, but can be used to supplement anterior surgical constructs if the anterior approach is first used to decompress the neural elements [74]. Additionally, clinically unstable patients may not be able to tolerate the prone position required for posterior approach cervical spine surgery.

5.5. Anterior-Posterior approach cervical spine surgery

It is widely agreed that a combination of anterior and posterior approach surgery offers the greatest biomechanical stability [72,75]. Generally, a combined anterior-posterior approach surgery is used for unstable two-column fractures, or in special cases such as in patients with DISH or significant osteoporosis. There are no relative contraindications for anterior-posterior approach surgery, although the decision to pursue this approach must be weighed against the risks of prolonged surgery and of patient repositioning [58].

Ultimately, anterior, posterior, and anterior-posterior approaches have all been shown to be effective at reducing and stabilizing subaxial spine fractures and decompressing the neural elements. Most authors, through expert opinion, recommend that the surgical approach be guided by the site of maximal spinal cord compression, presence and position of bone fragments, and, perhaps most importantly, surgical expertise [69,72,76]. In order to provide the best care and optimize clinical outcomes, spine surgeons dealing with cervical trauma must be well-versed in all approaches.

6. Conclusion

Subaxial spine fractures are a common traumatic injury that requires a specific, detailed anatomical knowledge and diagnostic skill set. Ideal management of patients with a potential subaxial spine fracture includes a detailed physical examination, accurate imaging evaluation, and the consultation of a spine surgeon. With this information, the spine surgeon can decide on operative and non-operative management of the injury. In determining surgical treatment, spine surgeons must consider the mechanism and extent of injury as well as potential complications of surgery in the context of the patient's clinical status. Consistently, it has been shown that unstable subaxial spine fractures should be managed surgically unless other severe injuries render treatment futile, while stable fractures can be managed with more conservative methods.

Although the literature demonstrates conflicting data regarding the urgency of surgical intervention, unstable patients and patients with cord injuries should receive ICU level care in order to monitor neurological status and hemodynamics and the timing of surgical intervention should be made using the best judgement of the surgeon [36]. Spine surgeons must be well-versed in both the anterior and posterior surgical approaches, as the extent and site of maximum spinal cord compression should be the primary factor in deciding surgical approach.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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