Innovations in Cervical Spine Trauma: Developing the Next Generation Upper Cervical Spine Injury Classification System

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Abstract

The upper cervical spine not only consists of intricate bony and ligamentous anatomy affording unique flexibility but also has increased susceptibility to injuries. The upper cervical spine trauma can result in a wide spectrum of injuries that can be managed both operatively and nonoperatively. Several existing classification systems have been proposed to describe injuries of the upper cervical spine, many of which rely on anatomic descriptions of injury location. Prior fracture classifications are limited in scope, characterizing fractures restricted to a single region of the upper cervical spine, and fail to provide insight into injury management. The AO Spine Upper Cervical Injury Classification System (AO Spine UCCS) has recently been developed as a comprehensive, yet concise classification scheme to describe all injuries of the upper cervical spine. The AO Spine UCCS represents a significant development in the classification of upper cervical spine injuries, with the potential to serve as a decision-making instrument to aid in patient management.

Keywords: AO spine, classification, fracture, upper cervical

Introduction

The upper cervical spine, often referred to as the craniocervical junction, is defined as the anatomic region extending from the occipital condyles to C2. The upper cervical spine protects the brainstem, spinal cord, upper spinal nerve roots, lower cranial nerves, and vasculature involved in posterior cranial circulation. As such, an injury to this area can result in a wide spectrum of injuries from muscular strain to spinal cord injury and death. Because of its critical location supporting the cranium and its unique anatomy allowing for the largest proportion of the total range of motion in the cervical spine, the upper cervical spine is particularly prone to injuries.[1]

Given the complexity of injury patterns seen in upper cervical spine trauma (UCST), prior classification schemes have restricted themselves to descriptions of fracture patterns limited to subregions of the upper cervical spine. These anatomic descriptions facilitate communication of injuries to other providers but fail to provide the conceptual framework required for injury management. The UCST often necessitates surgical intervention, and therefore a comprehensive upper cervical injury classification should help predict clinical outcomes and help guide surgical decision-making. Taking into consideration the most clinically relevant aspects of UCST, the AO Spine Knowledge Forum Trauma recently developed the AO Spine Upper Cervical Classification System (AO Spine UCCS) as a concise and comprehensive scheme to classify UCST. Building on the work of previous AO Spine Subaxial, Thoracolumbar, and Sacral Injury Classification Systems, the AO Spine UCCS represents a significant step toward the development of treatment algorithms for patients with UCST.[2-5] The purpose of this review is to summarize the previous upper

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cervical fracture classifications and to highlight the newly developed AO Spine UCCS.

Anatomy

The upper cervical spine consists of the occiput, atlas, and axis, their synovial articulations, and a complex network of stabilizing ligamentous structures. The role of the upper cervical spine is to bear the weight of the cranium, protect the housed neurologic structures including the medulla oblongata, lower cranial nerves, and upper cervical spinal nerve roots and cord, and provide the majority of flexion, extension, and rotation of the cervical spine.[1,6] Of the entire cervical spine, the atlantooccipital joint provides the greatest range of motion in the flexion/extension plane, with a total range of motion of approximately 15°–20°, whereas the atlantoaxial complex accounts for the majority of the cervical spine's axial rotation, between approximately 29° and 46° in each lateral direction.[7-11] Given that the weight-bearing load across the upper cervical spine is less than that experienced by the remainder of the spine, vertebral body size and segmental motion are ideal to compensate for the increased range of motion experienced in this region of the skeleton. Stability in this region is achieved through a ligamentous framework rather than bony morphology.[8] As a result, the ligaments of the upper cervical spine are more robust with higher loads to failure when compared with the ligaments of the lower cervical spine.[1] However, this unique flexibility and intricate bony and ligamentous anatomy make the upper cervical spine vulnerable to injuries.

Prior Classification Systems

Existing and historical upper cervical fracture classification systems are detailed in Table 1. Early UCST classification schemas concentrated on anatomic location in describing fracture patterns and failed to incorporate ligamentous injuries, significantly limiting the ability of these classification systems to guide clinical management. Subsequent classifications have served as modifications of early classification systems, incorporating injury morphology, mechanism, and ligamentous status. However, the utility of these systems is limited by their scope addressing only subregions within the upper cervical spine. Accordingly, a new upper cervical injury classification system has been developed to be concise, reproducible, universally applicable throughout the upper cervical spine and ultimately serve as the foundation for clinical decision-making.

New Classification System

AO Spine UCCS

With the ultimate goal of optimizing patient outcomes and standardizing UCST management, the AO Spine Knowledge Forum Trauma has recently developed a classification system for upper cervical spine injuries that has proven to be an encompassing scheme incorporating the most clinically relevant factors of the aforementioned classification systems. The development of the AO Spine UCCS follows a similar methodology to the previously described development of AO Spine Thoracolumbar and Sacral Injury Classification Systems.[5,25,26] Under the guidance of a coordinating methodologist, 10 experienced internationally trained spine trauma surgeons participated in a structured consensus method to develop and refine the AO Spine UCCS. Agreement among surgeons was analyzed using latent class modeling, and the reasons for disagreement were systematically revised iteratively during review meetings until consensus was reached among all surgeons.

Similar to the AO Spine Subaxial, Thoracolumbar, and Sacral Injury Classification Systems, the AO Spine UCCS utilizes an alphanumerical nomenclature based on the injury type and severity.[2,4,5,27] The classification scheme's hierarchical nature allows for prompt stratification of injury severity. In addition to classifying the injury type and location, the AO Spine UCCS also takes into consideration patient-level factors relevant to patient management, as well as neurologic status at the time of presentation.[27-29]

The first node in the classification of the upper cervical spine injury using the AO Spine UCCS is based on the anatomic location of the injury. The three anatomic locations are defined by the condyle/vertebra and its caudal joint. Category I injuries involve the occipital condyle and craniocervical junction. Category II injuries involve the C1 ring and C1–2 joint. Lastly, Category III injuries involve the C2 body and C2–3 joint. From there, injuries are further subclassified by the mechanism of the injury and its inherent instability. Type A injuries represent isolated bony injuries that do not involve injuries of the surrounding soft tissues or intervertebral disc. As a result, these injuries are inherently stable and typically do not require surgery. Type B injuries are defined by tension band and ligamentous injuries with or without bony injury, which may or may not be stable depending on the injury characteristics. Angular deformity injuries that do not involve translation, such as an atypical Hangman's fracture, are classified as Type B, which may or may not require surgical stabilization. Lastly, Type C injuries include translational, rotational, or distraction injuries through the joint or disc space in any direction. These injuries are inherently unstable and require surgical management.

Category I: Occipital Condyle and Craniocervical Junction

Injuries of the occipital condyle and craniocervical junction are least common and are depicted in Figure 1.

Table 1: Summary of prior upper cervical classification systems

Cervical region	System (year)	Basis	Injury types	Utility	Limitations
Occipital condyle	Anderson and Montesano[12] (1988)	Injury mechanism	1. Burst type injury with comminution 2. Direct blow with linear fracture extension 3. Rotational injury with alar ligament avulsion	Early understanding of the severity	Ligamentous stability is not taken into consideration
	Tuli *et al.*[13] (1997)	Displacement and ligament status	1. Nondisplaced 2a. Displaced without ligamentous disruption 2b. Injuries are displaced with ligamentous disruption	Incorporates an MRI-based soft-tissue assessment	
Occipital cervical dislocation	Traynelis *et al.*[14] (1986)	Direction of occiput displacement	1. Anterior displacement 2a. Longitudinal displacement (OCJ distraction) 2b. Significant longitudinal displacement (OCJ and C1-C2 distraction) 3. Posterior displacement	Informs reduction maneuvers	Occiput displacement at the time of imaging does not represent forces at time of injury
	Harborview[15] (2006)	Degree of displacement	1. <2 mm displacement on static and dynamic images 2. >2 mm displacement only on dynamic imaging 3. >2 mm displacement on static imaging	Increases sensitivity in detecting unstable OCJ	Cranial traction in imaging risks injury from overdistraction
Atlas	Jefferson[16] (1919)	Anatomic location	1. Posterior arch only 2. Anterior arch only 3. Anterior and posterior arch involvement 4. Lateral mass(es)	Standardizes fracture terminology	No role in injury management
	Dickman *et al.*[17] (1996)	Incorporated transverse ligament status	1. Purely ligamentous injury 1a. Mid-portion 1b. Avulsion from insertion 2. Bony injury 2a. Tubercle avulsion fracture 2b. Comminuted lateral mass	Distinguishes isolated ligamentous injury from bony involvement	
Axis: Odontoid process	Anderson and D'Alonzo[18] (1974)	Anatomic location	1. Tip 2. Waist 3. Axis body	Insight into nonunion rate by location	Incompletely informs injury stability and severity
	Grauer *et al.*[19] (2005)	Incorporated direction of displacement	2a. Nondisplaced 2b. Displaced transverse or anterior superior to posterior inferior 2c. Comminuted or anterior inferior to posterior superior	Informs surgical management of type 2 fractures	
Axis: Pars interarticularis	Effendi *et al.*[20] (1981)	Mechanism and displacement	1. Isolated nondisplaced from axial loading and hypertension 2. Anterior displacement from further hyperextension and rebound flexion 3. Anterior displacement with facet dislocation from flexion and rebound extension	Early understanding of the mechanism	Fails to incorporate C2-C3 disco-ligamentous complex status
	Levine and Edwards[21] (1985)	Incorporated ligamentous status	1. Minimally displaced without angulation 2. Displaced with angulation 2a. Minimally displaced with severe angulation 3. Facet dislocations	Informs understanding of injury stability	
	Starr and Eismont[22] (1993)	Defined atypical variant	Posterior body with unilateral or bilateral continuity to the posterior cortex or pedicle	Distinguishes a variant associated with neurologic injury	
Axis: Vertebral body	Benzel *et al.*[23] (1994)	Fracture orientation	1. Coronal 2. Sagittal 3. Transverse	Standardized fracture terminology	Fails to address disco-ligamentous disruption
	Fujimura *et al.*[24] (1996)	Incorporated fracture morphology	Avulsion, transverse, burst, or sagittal variants	Informed management by morphology type	

Type IA injuries involve a fracture of the occipital condyle without an associated ligamentous injury or craniocervical dislocation. Type IB injuries involve nondisplaced ligamentous injuries of the craniocervical junction and are the only injury type of the classification that requires MRI to confirm the diagnosis. Lastly, Type IC injuries involve displacement through the craniocervical junction, including both distraction and translational injuries [Figure 1].

Category II: C1 Ring and C1–2 Joint

Injuries of the C1 ring and C1–2 joint include injuries to the bony arch (Type IIA), ligamentous injury of the transverse atlantal ligament (Type IIB), and atlantoaxial instability (Type IIC). Type A injuries are stable and can typically be managed nonoperatively. An injury to the transverse ligament in Type IIB burst injury is indicated by lateral mass overhang visible on both coronal computed tomography (CT) sequences and also on open mouth AP radiographs. Lastly, Type IIC injuries represent significant atlantoaxial instability with a rotational or translational injury with risk of neurologic injury requiring surgical intervention [Figure 2].

Category III: C2 and C2–3 Joint

Injuries of C2 and the C2–3 joint are the most common injuries within the upper cervical spine. Type IIIA injuries include bony injuries of the axis, including the dens, pedicle, pars interarticularis, and lamina. Unlike most Type A injuries (i.e., Type IA and IIA injuries), Type IIIA injuries may need to be managed operatively depending on the fracture pattern, amount of displacement, and patient neurologic status. Type IIIB injuries are defined by disruption of the posterior tension band with associated injury to the intervertebral disc. Important to note, angulation through the C2–3 joint represents Type IIIB injuries, whereas angulation through fractures of the odontoid represents Type IIIA injury. Complete translation occurring through the C2–3 joint represents a Type IIIC injury [Figure 3].

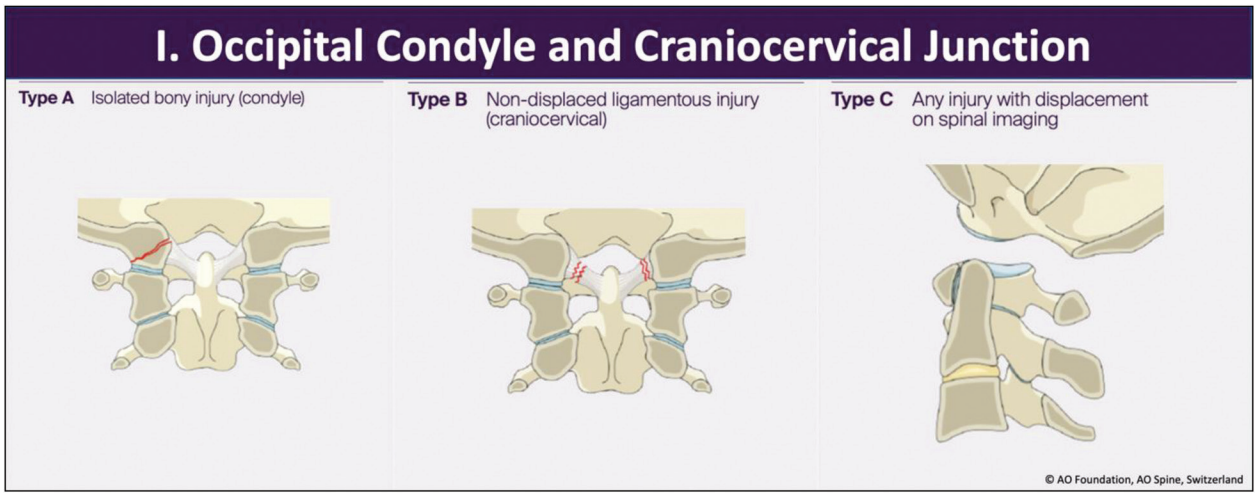

Figure 1: Injuries of the occipital condyle and craniocervical junction

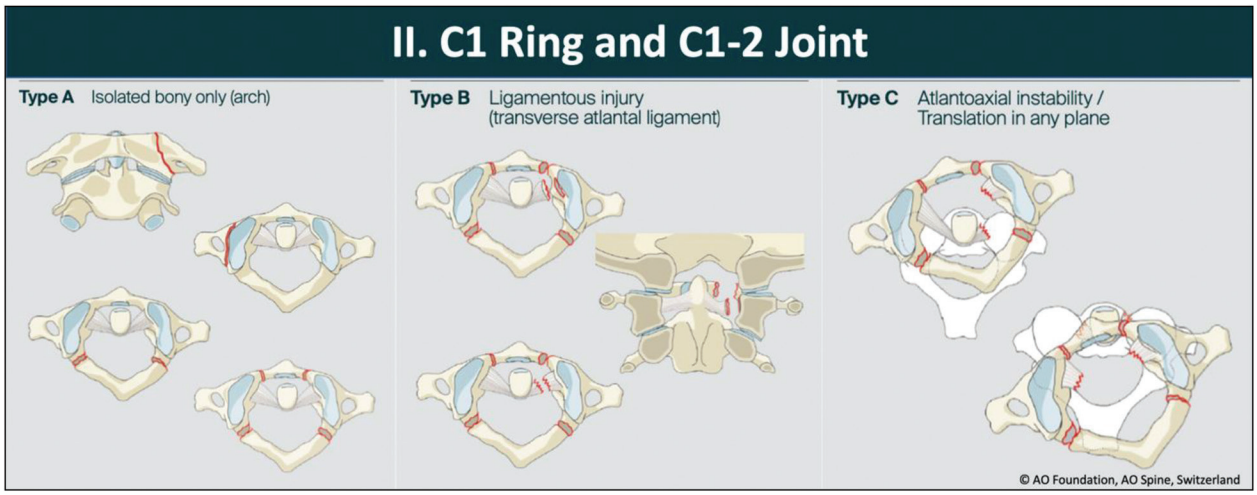

Figure 2: Injuries of the C1 ring and C1–2 joint

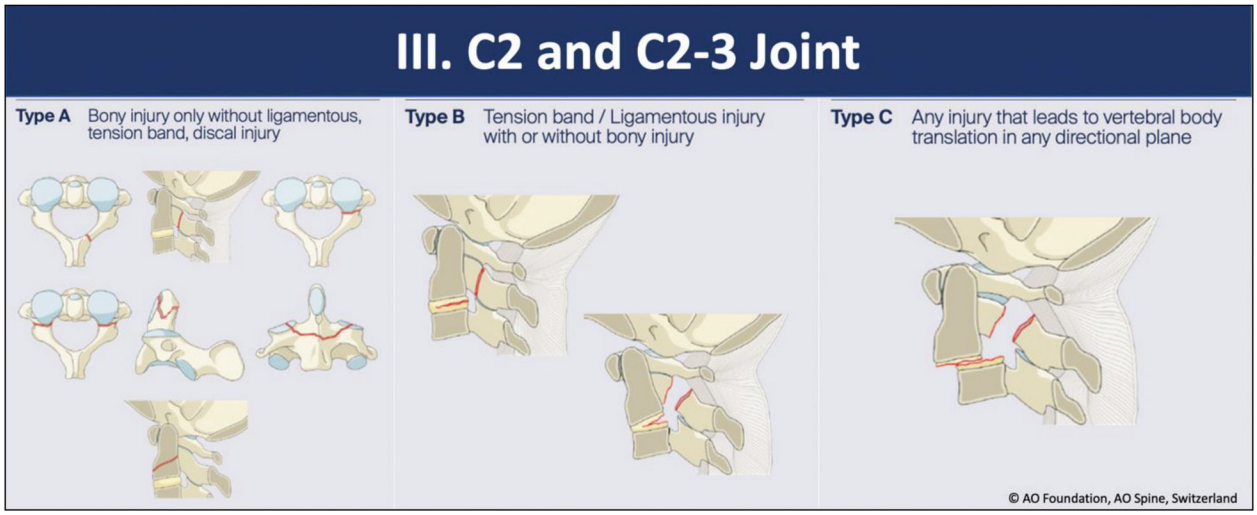

Figure 3: Injuries of C2 and C2–3 joint

Modifiers

Similar to the AO Spine Subaxial, Thoracolumbar, and Sacral Injury Classification systems, the AO Spine UCCS incorporates clinically relevant variables shown to affect patient management and outcomes as patient-specific modifiers.[30] Injuries that are at high risk of nonunion with nonoperative management have the M1 modifier. For example, this would include patients with Type IIIA angulated and displaced fractures through the waist of the odontoid or patients initially treated nonoperatively with subsequent displacement on follow-up imaging. Injuries that are likely to be unstable, such as a displaced C1 unilateral lateral mass fracture, have the M2 modifier.[31] Comorbidities and patient characteristics that pose difficulties for injury management, including age, smoking status, and pertinent medical history such as ankylosing spondylitis, are incorporated using the M3 modifier. Finally, vascular injury or vertebral artery abnormalities that affect treatment are incorporated in the M4 modifier.

Neurology

Neurologic status plays a critical role in the management of spinal trauma patients, where patients with injuries that may be otherwise managed nonoperatively require surgical decompression and stabilization due to neurologic compromise. Accordingly, the AO Spine has used the same neurology classifiers across all subaxial, thoracolumbar, and sacral classifications systems.[2,4,27,28] N0 defines neurologically intact patients. Patients with transient neurologic deficits and those with radicular symptoms are classified as N1 and N2, respectively. Patients with incomplete spinal cord injury are classified as N3, and patients with complete spinal cord injury are classified as N4. Patients who are either obtunded/unconscious or otherwise unable to be examined are considered NX. Lastly, a "+" indicates continued spinal cord compression in patients with neurologic compromise.

Validation

In the only study validating the AO Spine UCCS, "almost perfect" interobserver reliability (k = 0.862/0.884, first/second assessment), as well as intraobserver reproducibility, was found when 32 cases were evaluated by four residents (k = 0.830–0.999) and four senior spine surgeons (k = 0.861–0.999) for fracture sites I, II, and III.[29] For subtype A, B, and C, interobserver reliability was "substantial" (k = 0.660/0.603, first/second assessment), and intraobserver reproducibility ranged from "substantial" to "almost perfect" (k = 0.691–0.920) for residents and "almost perfect" (k = 0.841–0.983) for senior spine surgeons. As is the ultimate goal with any injury classification system, treatment must follow injury categorization. When surveying treatment recommendations based on the AO Spine UCCS classification, reliability ranged from "substantial" (k = 0.679/0.751) for residents to "almost perfect" (k = 0.982/0.963) for spine surgeons. These observed reliability scores lend credence to the AO Spine UCCS as a dependable resource for classification and decision-making with regard to patients with the upper cervical spine injury but require further validation.

Future Directions

The precedent for validation methodology has been previously established in all AO Spine classifications, including the AO Spine Subaxial and Thoracolumbar Classification Systems.[2,3,26,32-36] The aforementioned study of the AO Spine UCCS, while promising, represents a pilot validation examining the reliability of the classification system among a small number of users with various levels of training. Further work is ongoing, including a multicenter agreement study using a large number of representative cases and raters of various levels of expertise globally to complete intermediate validation. Following the results, further refinement and improvement of the classification

system will be performed before proceeding to advanced validation to include injury severity assessment, score assignment, and the development of a surgical algorithm using threshold values.

Conclusion

The AO Spine UCCS represents a significant advancement in the classification of UCST and lays the groundwork for future treatment algorithms. Unlike the numerous existing and overlapping upper cervical classification systems, the AO Spine UCCS is a concise, comprehensive, and reliable classification scheme that is universal to the entire upper cervical spine. Ultimately following advanced validation, an accompanying scoring system with clinically relevant cutoff values will be developed to standardize the treatment of upper cervical injuries and help drive higher-level studies for the management of UCST.

Ethical policy and institutional review board statement

Not applicable.

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Conflicts of interest

There are no conflicts of interest.

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