Update on Upper Cervical Injury Classifications

The New AO Upper Cervical Spine Classification System

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Abstract: The upper cervical spine accounts for the largest proportion of cervical range of motion afforded by a complex system of bony morphology and ligamentous stability. Its unique anatomy, however, also makes it particularly vulnerable during both low and high energy trauma. Trauma to this area, referred to as upper cervical spine trauma, can disrupt the stability of the upper cervical spine and result in a wide spectrum of injury. Numerous upper cervical injury classification systems have been proposed, each of which have distinct limitations and drawbacks that have prevented their universal adoption. In this article, we provide an overview of previous classifications, with an emphasis on the development of the new AO Spine Upper Cervical Classification System (AO Spine UCCS).

Key Words: upper cervical spine, trauma, AO Spine, fracture classification

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The upper cervical spine, composed of the occipital condyles, atlas, and axis, is a system of unique bony morphology and tethering capsuloligamentous structures that provide stability to a region of the spine whose segments account for the largest proportion of the total cervical range of motion.[1] To facilitate flexion/extension, as well as axial rotation, the upper cervical spine relies heavily on a complex design of ligamentous structures, rather than on bony stability as seen elsewhere in the vertebral column. The balance of the heavy cranium on the narrow pedestal of the upper cervical spine makes this region particularly vulnerable to trauma. Trauma to this area, referred to as upper cervical spine trauma (UCST), can disrupt the stability of the upper cervical spine and result in a wide spectrum of injury ranging from muscular neck pain to significant spinal cord injury and death.

Despite being a common site of injury, there is a relative paucity of literature evaluating the incidence of UCST. Upper cervical spine injuries comprise 64% of all cervical injuries in the elderly population.[2] However, patients in their fourth decade of life comprise the largest proportion (22.8%) of patients with UCST.[3] In young adults (18−64 y), high-energy hyperextension injury is the most frequent cause of upper cervical spine injury. In the healthy cervical spine, C4−C7 is the most mobile segment

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and is therefore most prone to injury.[4] However, spondylosis and associated stiffening of the lower cervical spine seen with aging results in the translation and dissipation of forces during injury in the mobile upper cervical spine, accounting for the greater incidence observed in older patients.[4] Accidental falls (28.1%–48.7%) and motor vehicle accidents (34.4%–37.6%) are the most common causes of injury.[5,6] C2 fractures are ~3 times more common than C1 fractures, with a higher proportion of C2 injuries seen in elderly patients.[5,7] Injuries of the occipital condyles are relatively rare, with various reports establishing an incidence of around 0.3%–0.7% in patients presenting after trauma.[8–11] Previous investigations have shown that in patients with UCST, 34.5% presented with an associated spinal cord injury, with single C1 fractures accounting for ~23% and single C2 fractures for 32% of these injuries. Of patients fatally injured with cervical spine trauma, 23% and 31% had a fracture at C1 and C2, respectively.[12]

Instability associated with UCST often necessitates surgical management. However, the lack of an appropriate conceptual framework in classifying UCST continues to impede the standardization of management of upper cervical injuries. A comprehensive classification system should lend itself towards communication, prognostication, and management. Numerous upper cervical injury classification systems have been proposed, each of which have distinct limitations and drawbacks, and none of which have been universally adopted.[13] Previous classification schemes are descriptive, limited to a single anatomic region of the upper cervical spine, and generally provide little insight into injury management. This has led to a dearth of high-level evidence regarding the management and outcomes of patients with UCST. In this article, we provide an overview of previous classifications, with an emphasis on the development of the new AO Spine Upper Cervical Classification System (AO Spine UCCS).

OCCIPITAL CONDYLE FRACTURES

Anderson and Montesano[14] were the first to develop a widely accepted occipital condyle fracture classification system. They presented a 3-part scheme distinguishing fracture type based on mechanism of injury: type 1-impaction type injury with comminution, type 2-direct blow with linear fracture extension from the occiput into a respective condyle, and type 3-rotational injury associated with alar ligament avulsion.[14] The authors considered type 1 and 2 injuries to be stable and amenable to nonoperative management, while type 3 injuries were potentially unstable often indicating surgical intervention. Unfortunately, the validity of this system is compromised by its methodologic basis on a total of 6 patients, only one of which had a type 3 injury. Furthermore, it was first proposed in 1988 before the widespread availability of magnetic resonance imaging (MRI) and therefore lacks insight into the ligamentous stability of the injury. With the understanding that soft tissue assessment was necessary for occipital condyle injuries, Tuli et al[11] proposed a new classification evaluating fracture displacement and ligamentous stability. In this system, type 1 injuries are nondisplaced, type 2a injuries are displaced without ligamentous disruption, and type 2b injuries are displaced with ligamentous disruption. A succinct and easily comprehensible system, the Tuli classification represented a significant step forward in utilizing classification systems to help guide patient management (specifically operative intervention in unstable type 2b injuries).[11] However, the classification's utility is limited in scope pertaining to only one specific region of the upper cervical spine.

Occipital Cervical Dislocations

Traynelis et al[15] devised an early classification of atlanto-occipital dissociations focused on the direction of displacement of the occiput relative to the cervical spine. Three directions including anterior (I), longitudinal (II), and posterior (III) were defined. While this directional classification was intended to help with prognostication and inform reduction maneuvers, it failed to consider rotational injuries or that cranial positioning is often dependent on the forces applied at the time of imaging rather than at the time injury. Furthermore, the Traynelis system has no basis in patient management as all atlanto-occipital dissociations represent highly unstable injuries requiring operative management. The more recent Harborview classification for craniocervical injuries assesses injury by quantifying displacement at the craniocervical junction.[16] The results of static and dynamic MRIs inform 3 junctional injury patterns, where stage 1 is <2 mm displacement on static and dynamic images, stage 2 is >2 mm displacement on only dynamic imaging, and stage 3 is >2 mm displacement on static imaging.[16] This classification is useful for the detection of subtle but life-threatening occipitocervical disruptions and has therapeutic implications based upon staging of the injury. However, the requirement for cranial traction risks overdistraction and subsequent worsening of neurological injury. In addition, stage 2 by definition has borderline radiographic distraction findings which may limit classification reproducibility.

Atlas Fractures

The first atlas injury classifications pioneered by Jefferson and later Gehweiler then Landells describe the anatomic location of the fracture (anterior arch, posterior arch, lateral mass, transverse process, and Jefferson fracture involving the anterior and posterior arch).[17–19] Anatomic classification, although useful to standardize terminology, does not provide insight into injury severity, operative urgency, or patient prognosis. Understanding these limitations, Levine and Edwards[20] attempted to classify atlas fractures based on severity but failed to account for the transverse axial ligament, a crucial stabilizer of the atlantoaxial joint. In response, Dickman et al[21] devised a system to assess the status of the transverse ligament and corresponding osseous injury. In this revised system, type 1 represents a purely ligamentous injury

(1a: mid-portion, 1b: avulsion from insertion) and type 2 constitutes a bony injury (2a: tubercle avulsion fracture, 2b: comminuted lateral mass). The authors concluded that all type 1 injuries should be managed operatively, while type 2 injuries may be followed with nonoperative management.[21] While Dickman classification may help guide management, it only considers ligamentous injury limiting its ability to serve as a comprehensive system.

Axis Fractures

Odontoid Process

The first and most ubiquitous odontoid fracture classification proposed by Anderson and D'Alonzo[22] is anatomic in nature. Fracture location is described from cranial to caudal where type 1 is an oblique fracture of the odontoid tip, type 2 is a horizontal fracture of the odontoid waist, and type 3 is a horizontal fracture outside the odontoid within the axis body. The Anderson and D'Alonzo classification is limited by its basis in anatomy rather than severity or stability. Specifically, the system does not incorporate assessment of ligamentous structures and lacks granularity on the various type 2 injury patterns which affect the union rate associated with nonoperative management. Subsequently, Grauer and colleagues, Hadley and colleagues, and Aebi and Nazarian individually attempted to subclassify type 2 fractures based on orientation, displacement, and comminution.[23–25] Although these modifications clarified odontoid base fracture severity and informed treatment approach, an updated and comprehensive odontoid fracture classification is yet to be developed.

Vertebral Body

Benzel et al[26] created a fracture classification for the C2 body proper, using the orientation (type 1: coronal, type 2: sagittal, type 3: horizontal) of the fracture line in a 3-part classification scheme. Fujimura et al[27] subsequently devised a similar classification also incorporating comminuted and avulsion fractures. Of note, the horizontal axis body fracture described by Fujimura et al[27] is equivalent to Anderson and D'Alonzo type 3 odontoid fracture. The failure of the aforementioned classification schemes to account for fracture displacement, angulation, and degree of discoligamentous disruption limit their usefulness in guiding clinical management.

Pars Interarticularis

Effendi developed the first well-recognized classification of bilateral C2 pars fractures, commonly known as "hangman fractures." The classification focused on mechanism of injury and fracture displacement, however lacked discernment of the C2−C3 discoligamentous complex in intermediate fracture patterns.[28] Mechanistic descriptions of fractures have been shown to be inaccurate and speculative.[29–31] This limitation drove modification by Levine and Edwards[32] to clarify the degree of fracture displacement, angulation, and resultant intervertebral disk and posterior longitudinal ligament disruptions. The Levine and Edwards[32] classification included minimally displaced fractures without angulation (type I), displaced fractures with angulation (type II), minimally displaced fractures with severe angulation (type IIa), and facet dislocations (type III). Although the classification hierarchy informs injury stability and treatment approach, it fails to account for atypical fracture variants with increased risk for neurological injury. Starr and Eismont[33] defined "atypical hangman" fractures as a posterior axis body fracture with unilateral or bilateral continuity to the posterior cortex or pedicle. Separation of this atypical variant from previous fracture patterns was necessary due to its association with spinal canal narrowing.[33]

AO Spine UCCS

In an attempt to succeed where other classifications systems have failed, the AO Spine Knowledge Forum Trauma created a concise, reproducible, and comprehensive scheme for all UCST. The development of the AO Spine UCCS, including the pathway and process, follows a similar methodology to previously described development of AO Spine Thoracolumbar and Sacral Injury Classification Systems.[34–36] On the basis of published literature and Knowledge Forum Trauma discussions, the general characteristics of injury patterns as modes of mechanical failure of the upper cervical spine were defined: type A isolated bony injury, type B-ligamentous and tension band injury, and type C-displacement or translation through disk or joint. Under the guidance of a coordinating methodologist, 10 experienced spine trauma surgeons from across the world followed a structured consensus process to develop and refine the AO Spine UCCS. Agreement among surgeons was analyzed using latent class modeling. The reasons for disagreement were examined systematically during review meetings and at each iterative step, the system was revised until consensus was reached among all surgeons.

The goal of the AO Spine UCCS is to facilitate communication, research, and education to optimize patient outcomes and standardize management. Using similar language to previous AO Spine Subaxial, Thoracolumbar, and Sacral Classification Systems, the AO Spine UCCS follows the familiar A/B/C nomenclature based on injury morphology (Supplemental Fig. 1, Supplemental Digital Content 1, http://links.lww.com/CLINSPINE/A194).[35,37,38] As such, it follows the recognizable a hierarchical system based on the stability of the injury and lends itself as a future tool for surgical decision making. Further distinguishing the AO Spine UCCS from prior classification systems is its comprehensive nature encompassing the entire upper cervical spine, allowing for one scheme to describe all UCST.

The AO Spine UCCS is separated into 3 anatomic categories based on the condyle/vertebra involved and its caudal joint: (I) occipital condyle and craniocervical junction, (II) C1 ring and C1−C2 joint, and (III) C2 and C2−C3 joint. Similar to previous AO classification systems, injuries in each of these anatomic areas has been distilled in A, B, and C subtypes. As described above, type A injuries represent isolated bony injuries (Fig. 1). As a result, they are the most stable injury subtype and are often amenable to nonoperative management. Type IA fractures include fractures through the occipital condyle without associated craniocervical dislocation. Type IIA

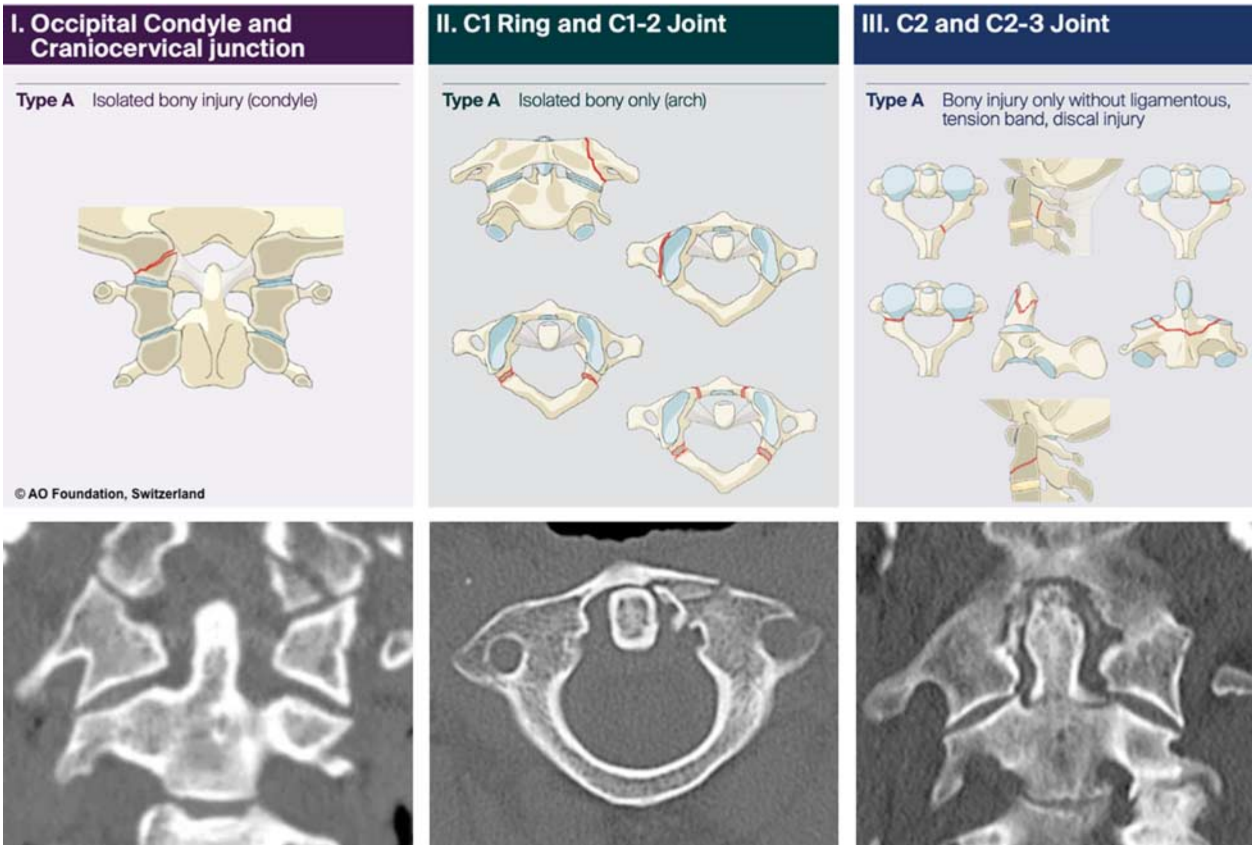

FIGURE 1. AO Spine Upper Cervical Classification System type A injuries. Copyright AO Foundation, Switzerland. All permission requests for this image should be made to the copyright holder. full color online

fractures include 1 or more fractures involving the bony C1 arch, lateral mass, or transverse process regardless of location with an intact transverse ligament. Lastly, type IIIA fractures include 1 or more fractures of the C2 dens, body, pedicle, or posterior arch without associated ligamentous or discal injury.

Type B injuries consist of ligamentous or tension band injuries, which may be stable or unstable depending on the injury specifics, and therefore may be managed operatively or nonoperatively (Fig. 2). In these injuries anatomic integrity remains intact, meaning complete separation at the involved joint has not occurred. Type IB injuries represent a nondisplaced ligamentous injury at the craniocervical junction and often requires advanced imaging in the form of MRI for diagnosis. If stress testing reveals instability, such an injury is classified as a type IC injury (defined below). Type IIB fractures include 1 or more fracture types such as a burst type injury of the C1 ring with associated transverse ligament injury resulting in lateral mass overhang. Lastly, type IIIB injuries represent a tension band injury often caused by a flexion/distraction mechanism resulting in significant angular instability through disruption of the intervertebral disk and posterior longitudinal ligaments.

Type C injuries are composed of vertebral or junctional rotational or translational injuries in any direction as indicated by separation of anatomic integrity (Fig. 3). These injuries are unstable and frequently necessitate operative stabilization. Type IC injuries involve any pathologic separation or displacement at the craniocervical junction whereas type IIC injuries represent pathologic rotational or displacement involving the atlantoaxial joint. Lastly, type IIIC injuries are defined by pathologic translation of the C2 body on C3 with injury involving the intervertebral disk. Within type C injuries, it is important to distinguish anatomic separation through an isolated bony injury, such as a displaced odontoid fracture (type A), versus anatomic separation through a joint or disk (type C). Only pathologic separation and translational injuries through a joint or disk constitutes type C injuries. Angular deformities without translation, such as an atypical hangman fracture, represent ligamentous tension band injuries (type B). The description of subtypes underscores the hierarchical nature of the classification system, where stability decreases from A to C and conversely operative indication increases from A to C, allowing for quick stratification of patient injuries. If an injury involves multiple regions of the upper cervical spine all injuries can be described.

Patient specific modifiers have been incorporated into the AO Spine UCCS, as with all AO Spine classification systems, to provide granularity based on the most relevant clinical variables shown to affect patient outcomes.[39] This alpha-numeric supplement allows for patient specific

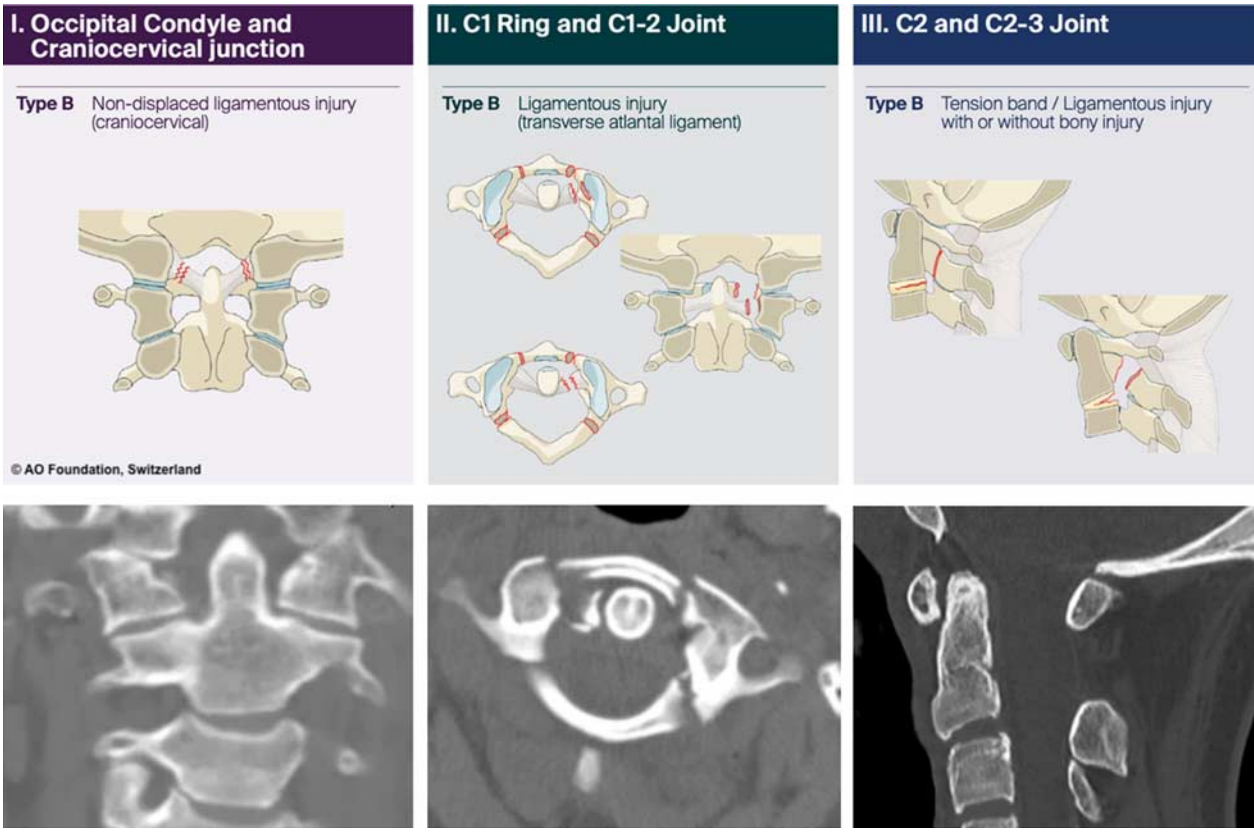

FIGURE 2. AO Spine Upper Cervical Classification System Type B injuries. Copyright AO Foundation, Switzerland. All permission requests for this image should be made to the copyright holder. full color online

application and decision making within a more universal and comprehensive system. An M1 modifier is used to describe injuries that are at high risk of nonunion with nonoperative treatment, such as a fracture through the waist of the odontoid with significant angulation or displacement. An M2 modifier describes injuries with a significant potential for instability, such as a midsubstance injury to the transverse ligament or significant displacement (> 6.9 mm) of the C1 lateral masses in the coronal plane.[40] An M3 modifier is used to incorporate patient specific factors affecting treatment such as age, comorbidities, smoking status, and pertinent medical history. Lastly, an M4 modifier describes a vascular injury or abnormality of the vertebral artery that may affect immediate management.

The neurological status of the patient is an important parameter that influences patient outcomes and surgical decision making.[41] Patients' neurological status at the time of presentation is classified using the same Neurological classification system utilized in all AO Spine fracture classification systems. N0 represents patients who are neurologically intact. N1 is used for patients with transient neurological deficits, such as paresthesias, that have completely resolved by the time of examination. N2 describes patients with radicular symptoms. N3 and N4 describe patients with incomplete and complete spinal cord injuries, respectively. In some cases, patients are obtunded/unconscious or unable to be examined and, in this scenario, NX is applied. Lastly, in patients with neurological compromise, a "+" is used to indicate continued spinal cord compression.

The value of a classification system is centered around its clinical significance in prognosticating and guiding management. However, a classification system must be validated before it can be applied in practice to ensure its accuracy and reliability. Validation is essential, as a poorly validated system will be a biased predictor of patient outcomes.[42] More so, application of a nonvalidated classification system can result in biased scientific research, which relies on accurate, reliable, and objective injury categorization. The AO Spine UCCS has completed a pilot agreement validation study using a cohort of 32 patients evaluated by 4 senior spine surgeons and 4 senior-level neurosurgery residents, demonstrating excellent reliability.[6] For fracture site (I, II, and III), "almost perfect" interobserver reliability ($\kappa = 0.862/0.884$ first/second assessment) as well as intraobserver reproducibility for both residents ($\kappa = 0.830-0.999$) and senior spine surgeons ($\kappa = 0.861-0.999$) was achieved. The interobserver reliability for reported for subtype (A, B, and C) was "substantial" ($\kappa = 0.660/0.603$ first/second assessment) and intraobserver reproducibility ranged from "substantial" to "almost perfect" ($\kappa = 0.691-0.920$) for residents and "almost perfect" ($\kappa = 0.841-0.983$) for senior spine surgeons. Lastly, when evaluating the recommended treatment based on

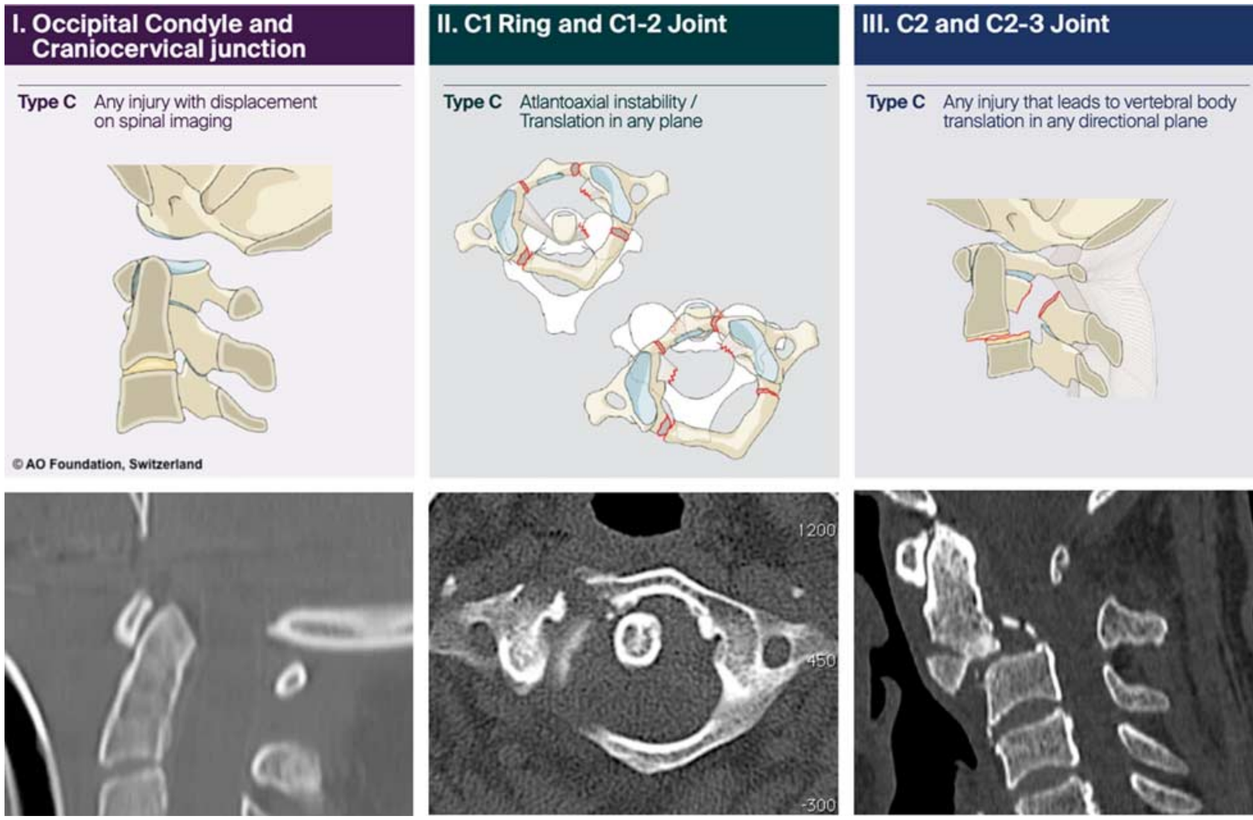

FIGURE 3. AO Spine Upper Cervical Classification System Type C injuries. Copyright AO Foundation, Switzerland. All permission requests for this image should be made to the copyright holder. full color online

classification, reliability ranged from "substantial" (κ = 0.679/0.751) to "almost perfect" (κ = 0.982/0.963) for both residents and spine surgeons, respectively. This pilot validation has demonstrated the ability of surgeons of all levels of experience to both reliably and accurately use the AO Spine UCCS.

Although promising, these results must be verified in the broader clinical context using a multi-institution validation study incorporating surgeons around the world to evaluate generalizability. Depending on the results, further classification refinement may be necessary before the perceived severity of fracture subtypes can be assessed. From this, an accompanying scoring system can be created as an important first step in developing a classification system that will be used to standardize the treatment of UCST. Such a scoring system can help mitigate variation in management by allowing objective data to drive treatment and facilitate higher-level studies.

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