Eur Spine J (2016) 25:2173–2184
DOI 10.1007/s00586-015-3831-3

ORIGINAL ARTICLE

AOSpine subaxial cervical spine injury classification system

Alexander R. Vaccaro · John D. Koerner · Kris E. Radcliff · F. Cumhur Oner · Maximilian Reinhold · Klaus J. Schnake · Frank Kandziora · Michael G. Fehlings · Marcel F. Dvorak · Bizhan Aarabi · Shanmuganathan Rajasekaran · Gregory D. Schroeder · Christopher K. Kepler · Luiz R. Vialle

Received: 29 October 2014 / Revised: 19 February 2015 / Accepted: 19 February 2015 / Published online: 26 February 2015
© Springer-Verlag Berlin Heidelberg 2015

Abstract
Purpose This project describes a morphology-based subaxial cervical spine traumatic injury classification system. Using the same approach as the thoracolumbar system, the goal was to develop a comprehensive yet simple classification system with high intra- and interobserver reliability to be used for clinical and research purposes.
Methods A subaxial cervical spine injury classification system was developed using a consensus process among clinical experts. All investigators were required to successfully grade 10 cases to demonstrate comprehension of the system before grading 30 additional cases on two occasions, 1 month apart. Kappa coefficients (κ) were calculated for intraobserver and interobserver reliability.
Results The classification system is based on three injury morphology types similar to the TL system: compression injuries (A), tension band injuries (B), and translational injuries (C), with additional descriptions for facet injuries, as well as patient-specific modifiers and neurologic status. Intraobserver and interobserver reliability was substantial for all injury subtypes ($\kappa = 0.75$ and 0.64, respectively).
Conclusions The AOSpine subaxial cervical spine injury classification system demonstrated substantial reliability in this initial assessment, and could be a valuable tool for communication, patient care and for research purposes.

Keywords AOSpine · Subaxial · Cervical · Spine · Trauma · Injury · Classification

Introduction

Injury classification is important for communication between providers, patient care as well as for research pur-

A. R. Vaccaro (✉) · J. D. Koerner · K. E. Radcliff · G. D. Schroeder · C. K. Kepler
Rothman Institute, Thomas Jefferson University, Philadelphia, PA, USA
e-mail: alexvaccaro3@aol.com

F. C. Oner
University Medical Center, Utrecht, The Netherlands

M. Reinhold
Department of Orthopaedic and Trauma Surgery, Klinikum Suedstadt Rostock, Suedring 81, 18059 Rostock, Germany

K. J. Schnake
Schön Klinik Nürnberg Fürth, Center for Spinal Surgery, Fürth, Germany

F. Kandziora
Berufsgenossenschaftliche Unfallklinik Frankfurt, Center for Spinal Surgery and Neurotraumatology, Frankfurt, Germany

M. G. Fehlings
University of Toronto Spine Program and Toronto Western Hospital, Toronto, ON, Canada

M. F. Dvorak
University of British Columbia, Vancouver, BC, Canada

B. Aarabi
University of Maryland Medical Center, College Park, MD, USA

S. Rajasekaran
Ganga Hospital, Coimbatore, Tamil Nadu, India

L. R. Vialle
Catholic University of Parana, Curitiba, Brazil

poses. Ideally, classification systems should be simple, reproducible, and highlight the injury characteristics that are relevant for patient care. Classification systems can be useful to accurately and efficiently characterize an injury, which is essential for the transfer of information between caregivers, especially for injuries involving the spine where inaccuracies could lead to devastating outcomes. Numerous classification systems have been developed over the years [1–6], with varying degrees of reliability, accuracy, and clinical relevance. At this time no subaxial cervical spine fracture classification system has been widely accepted by the world community [7]. Moreover, because of the wide spectrum of injuries in the subaxial cervical spine, it is difficult to create a comprehensive classification system that is not cumbersome.

Historical classification systems have been based on the purported mechanism of injury. In an attempt to avoid the overly descriptive terminology used frequently in historical systems, injury morphology was used as the basis for recent algorithm-based systems instead of mechanism of injury. The Spine Trauma Study Group proposed a system (known as the SLIC) based on three main categories: injury morphology, disco-ligamentous complex integrity, and neurologic status [8]. Each injury category was assigned a score, and treatment options were suggested based upon these values. While reliability compared favorably to the Harris and Ferguson & Allen systems, users continued to have difficulty agreeing on injury morphology. With the previous morphologic disagreements in mind, the AOSpine Knowledge forum, a group of international academic surgeons with special interest in spinal trauma, has attempted to develop and validate a user friendly classification system for subaxial cervical spine injuries [9, 10].

The purpose of this project is to describe this new morphology-based subaxial cervical spine traumatic injury classification system. Similar to the effort put towards the thoracolumbar system [11], the goal was to develop a comprehensive yet simple classification system with high intra- and interobserver reliability to be used for clinical and research purposes.

Materials and methods

The AOSpine Classification group has systematically assessed and revised multiple drafts of the subaxial cervical spine classification system using an AO database of spinal trauma cases with CT scans saved as DICOM images to develop a simple, cohesive classification system based on morphology according to the validation concept of Audigé et al. [12]. Multiple sessions were needed to evaluate and refine the reliability and accuracy of the system, and identify areas of disagreement. The system was considered complete only when unanimous consensus within the classification group was achieved.

Validation process

All reviewers for the validation of this system were sent a paper, which overviewed the background and purpose of the system, and described the system with illustrations in a powerpoint presentation. The reviewers then used the system to grade 10 cases to prove competency as compared to a gold standard established by two of the senior authors. The cases selected represent a selection of subaxial cervical spine injuries across all grades of morphology, facet injury, and patient-specific modifiers. The neurological status was described with each case as well. Two authors then reviewed the responses for each of the 10 cases, and returned cases with incorrect responses to the investigators with an explanation, and the cases were then resubmitted for repeat grading. Once the authors confirmed that an individual reviewer had a thorough understanding of the system by correctly classifying the 10 cases, 30 additional cases were sent for evaluation on two separate occasions, 1 month apart. Each case had all pertinent CT images, and if the members of the knowledge forum felt that additional information could be gained from MR imaging, this was provided as well.

Statistical analysis

Kappa coefficient (κ) was utilized to assess the reliability of the classification system among different observers (interobserver agreement) and the reproducibility for the same observer on separate occasions (intraobserver reproducibility). The coefficients were interpreted using the Landis and Koch grading system [13], which defines κ of less than 0.2 as slight agreement or reproducibility, between 0.2 and 0.4 as fair agreement or reproducibility, between 0.4 and 0.6 as moderate agreement or reproducibility, between 0.6 and 0.8 as substantial reliability or reproducibility, and more than 0.8 as excellent reliability or reproducibility. Kappa coefficients were calculated for the most severe injury type (i.e., A, B or C), subtype (e.g., A0, A1, A2, A3 or A4), and facet injury (F1, F2, F3, or F4). Fractures categorized by at least one assessor as an A-type fracture or as a B-type fracture were included in a subgroup analysis for intrarater reproducibility of subtypes for A- and B-type injuries.

Classification system overview

The classification system describes injuries based on four criteria: (1) morphology of the injury, (2) facet injury, (3) neurologic status, and (4) any case-specific modifiers. Each criterion is described below. Injuries are described by their level, followed by the morphologic type of the primary injury. The secondary injuries and modifiers are placed in parentheses (facet injury, neurologic status, and case-specific modifiers).

(1) Morphology: three basic categories (Types) were used in a similar manner to the AO thoracolumbar fracture classification system to describe primary injury morphology [11]. "Type A" injuries are fractures that result in compression of the vertebra with intact tension band. "Type B" injuries include failure of the posterior or anterior tension band through distraction with physical separation of the subaxial spinal elements while maintaining continuity of the alignment of the spinal axis without translation or dislocation. "Type C" includes those injuries with displacement or translation of one vertebral body relative to another in any direction; anterior, posterior, lateral translation, or vertical distraction. Injuries are first classified by their level and either C, B, or A in this order.

Type A: compression injuries: failure of the anterior structures under compression or mechanically insignificant fractures of the spinal processes (e.g., spinous process or lamina fractures). Type A injuries are further divided into 5 subtypes in order of increasing severity:

A0—no bony or minor injury such as an isolated lamina or spinous process fracture, additionally A0 is also used when a patient presents with central cord syndrome without an associated fracture (Fig. 1).

A1—compression fractures involving a single endplate without involvement of the posterior wall of the vertebral body (Fig. 2).

A2—coronal split or pincer fractures involving both endplates without involvement of the posterior aspect of the vertebral wall (Fig. 3).

A3—burst fractures involving a single endplate. These injuries affect a single endplate resulting in bony retropulsion with any involvement of the posterior vertebral wall (Fig. 4).

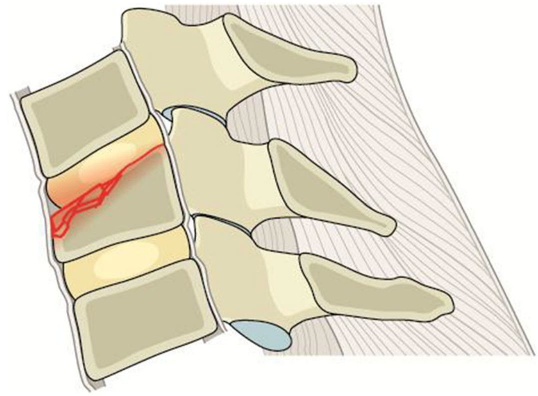

Fig. 2 Subtype A1: compression fractures involving a single endplate without involvement of the posterior wall of the vertebral body

A4—burst fracture or sagittal split injury involving both endplates. These injuries are similar to A3 injuries but involve both endplates. Fractures that split the vertebral body in the sagittal plane involving the posterior vertebral wall are also included in this group (Fig. 5).

Type B: tension band injuries: These injuries either affect the anterior or posterior tension band, and are subdivided into three subgroups. Of note, if any translation is seen with these injury mechanisms, they become classified as type "C" injuries.

B1—posterior tension band injury: (bony) Primary physical separation through fractured bony structures only. These injuries are failures of the posterior tension band extending into the vertebral body. Anterior structures (such as disk or annulus) may also be involved (Fig. 6).

B2—posterior tension band injury: (bony, capsuloligamentous, ligamentous) Complete disruption or separation of the posterior capsuloligamentous or bony capsuloligamentous structures. Anterior structures (such as vertebral body or disk) may also be involved and should be specified separately (Fig. 7).

B3—anterior tension band injury: Physical disruption or separation of the anterior structures (bone/disk) with

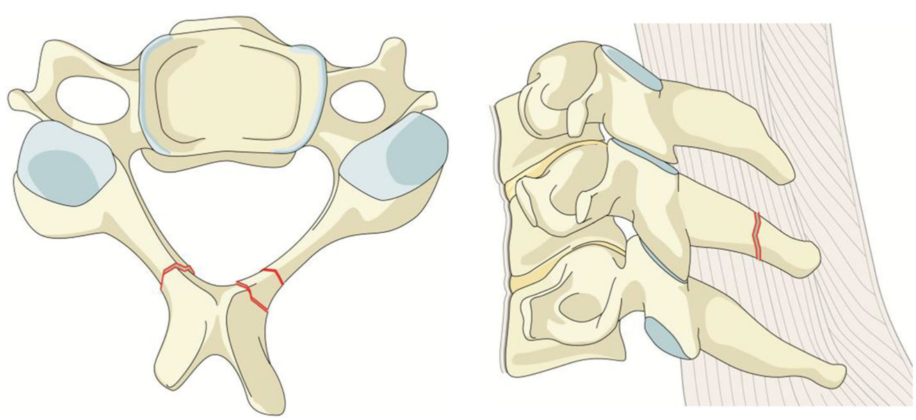

Fig. 1 Subtype A0: no bony or minor injury such as an isolated lamina or spinous process fracture (A0 is also used when a patient presents with central cord syndrome without an associated fracture)

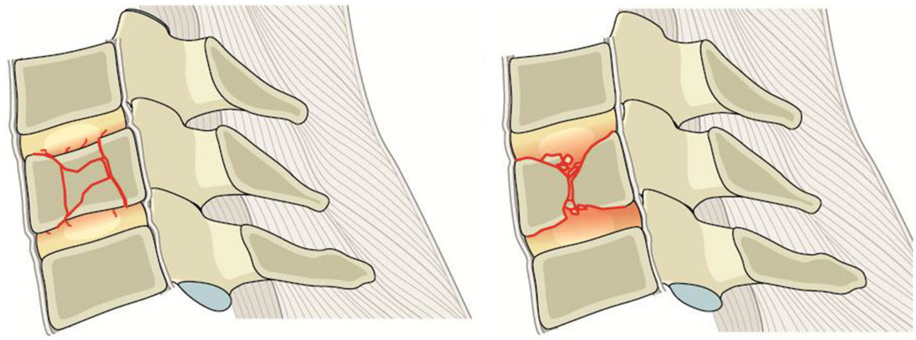

Fig. 3 Subtype A2: coronal Split or pincer fractures involving both endplates without involvement of the posterior of the vertebral wall

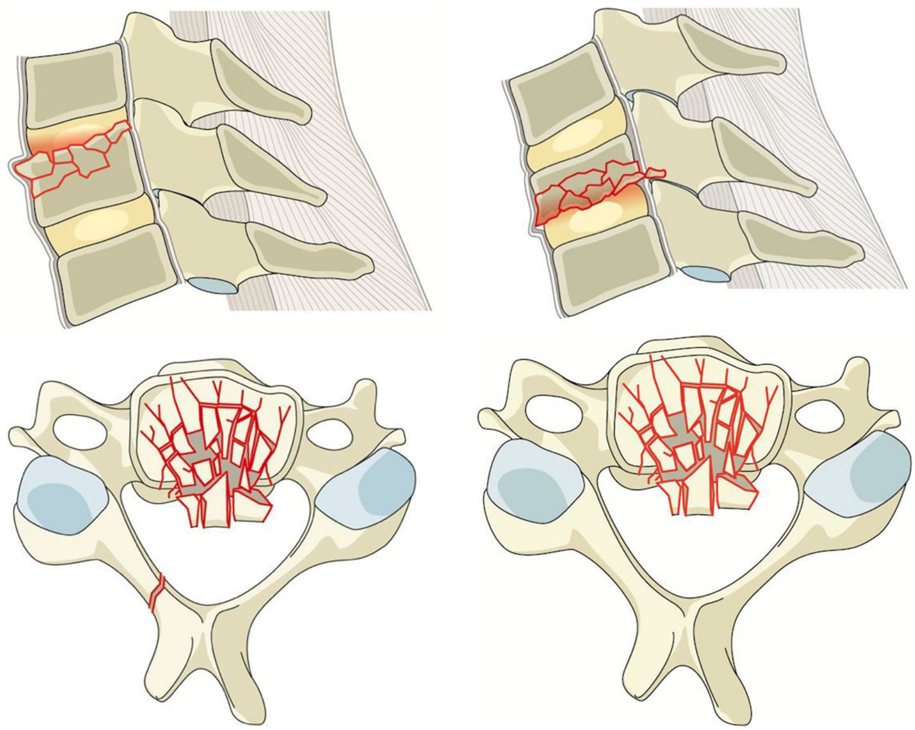

Fig. 4 Subtype A3: burst fractures involving a single endplate

tethering of the posterior elements. These injuries may pass through either the intervertebral disk or through the vertebral body itself (as in the ankylosed spine). An intact posterior hinge will prevent gross displacement (Fig. 8).

Type C: translational injury in any axis: this category includes injuries with displacement or translation of one vertebral body relative to another in any direction. Any associated injury (either a "Type A" or "Type B" injury) should be specified separately as a subtype, after designation as a "Type C" injury. Designation of the subtype ("B") does not necessarily imply mechanism, but by convention is used to confer clarity of the relative position of the spinal elements. Injuries where the anterior and posterior vertebral elements are distracted would be classified as translational injuries (Fig. 9).

(2) Facet injury: a series of descriptors were created to describe a spectrum of injuries to the facet joint complex. If there are multiple injuries to the same facet (for example, a small fracture and dislocation), only the highest level of injury is classified (dislocation). If both facets on the same vertebrae are injured, the right-sided facet injury is listed before the left sided injury if the injuries are of different subcategories. The "Bilateral" (BL) modifier is used if both facets have the same type of injury. If only facet injuries are identified (no A, B, or C injury), they are listed first after the level of injury.

F1—non-displaced facet fracture (either superior or inferior facets): fragment <1 cm, <40 % lateral mass [14] (Fig. 10).

F2—facet fracture with potential for instability (either superior or inferior facets): fragment >1 cm, >40 % lateral mass [14] or displaced (Fig. 11).

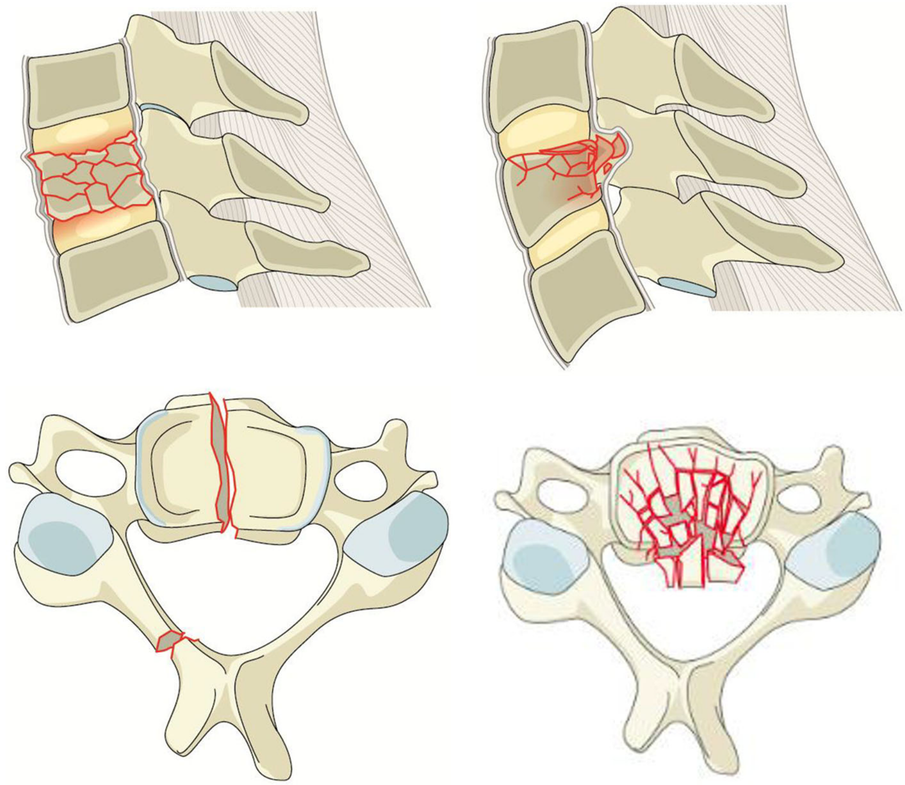

Fig. 5 Subtype A4: burst fracture or sagittal split injury involving both endplates

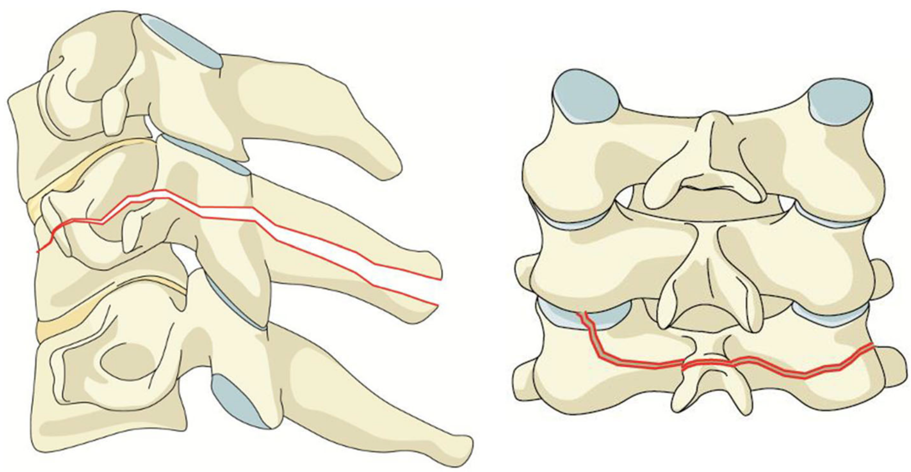

Fig. 6 Subtype B1: bony posterior tension band injury

F3—floating lateral mass: disruption of pedicle and lamina resulting in disconnection of superior and inferior articular processes at a given level or set of levels (Fig. 12).

F4—pathologic subluxation or perched/dislocated facet: injury in which either the tip of the inferior articular process of the cephalad vertebrae rests on the superior tip of the superior articular process of the caudal vertebrae, or an injury resulting in the inferior facet of the cephalad vertebrae translating over the superior articular surface of the caudal vertebrae and remaining ventral to the superior facet of the caudal vertebral body (Fig. 13).

BL—Bilateral—modifier used when the same type of facet injury is observed bilaterally on the same vertebra.

(3) Neurology: neurological status is graded according to a six-part system similar to the system described with the TL classification:

N0—neurologically intact

N1—transient neurologic deficit that has completely resolved by the time of clinical examination (usually within 24 h from the time of injury)

N2—radiculopathy

N3—incomplete spinal cord injury

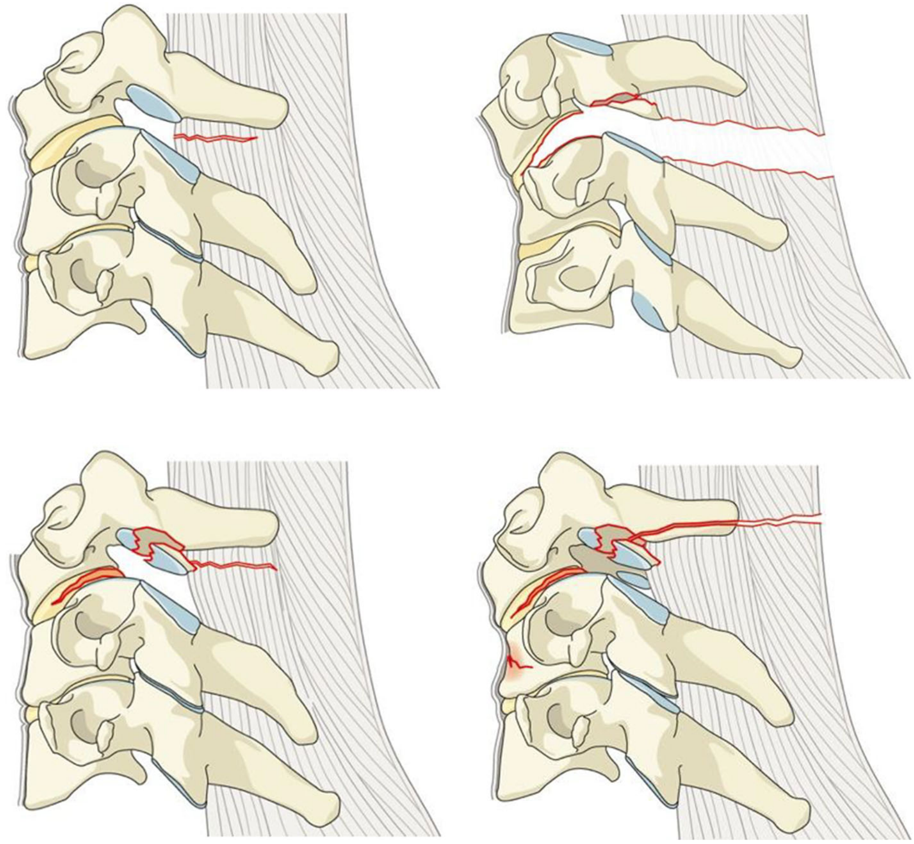

Fig. 7 Subtype B2: complete disruption or separation of the posterior capsuloligamentous or bony capsuloligamentous structures

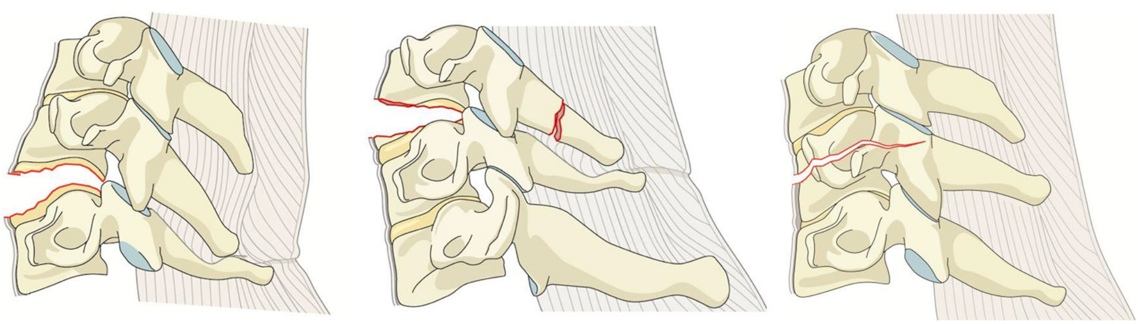

Fig. 8 Subtype B3: anterior tension band injury: physical disruption or separation of the anterior structures (bone/disk) with tethering of the posterior elements

N4—complete spinal cord injury

NX—neurology undetermined—used to designate patients who cannot be examined due to head injury or another condition which limits their ability to complete a neurological examination such as intoxication, multiple trauma, or intubation/sedation.

There is one difference with the system used in the TL classification:

"+" is given in the case of ongoing cord compression in setting of incomplete neurologic deficit or nerve injury

(4) Case-specific modifiers: additional modifiers created to describe unique conditions relevant to clinical decision-making are as follows:

M1—posterior capsuloligamentous complex injury without complete disruption: This modifier designates injuries, which may appear stable from a bony standpoint, but there is some evidence of injury to the posterior ligamentous structures without complete disruption. This is often identified on MRI imaging and associated with very localized posterior tenderness on clinical examination.

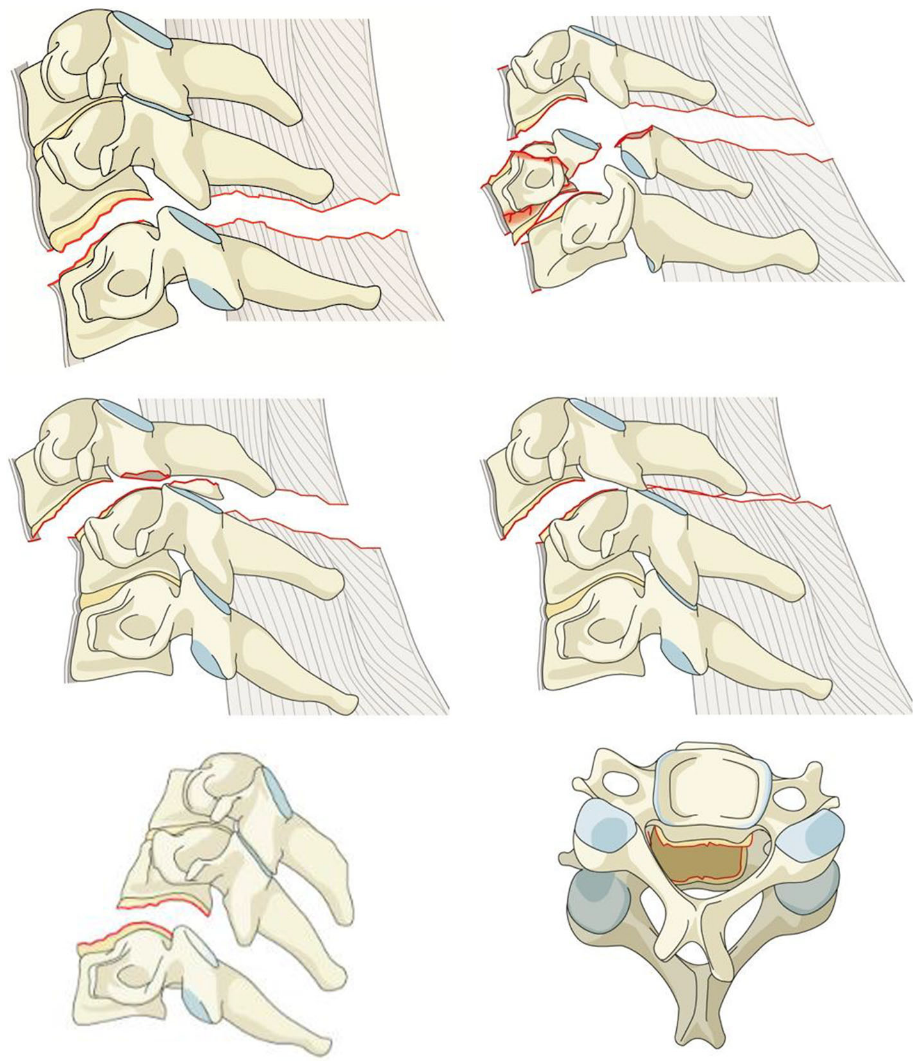

Fig. 9 Type C: translational injury in any axis

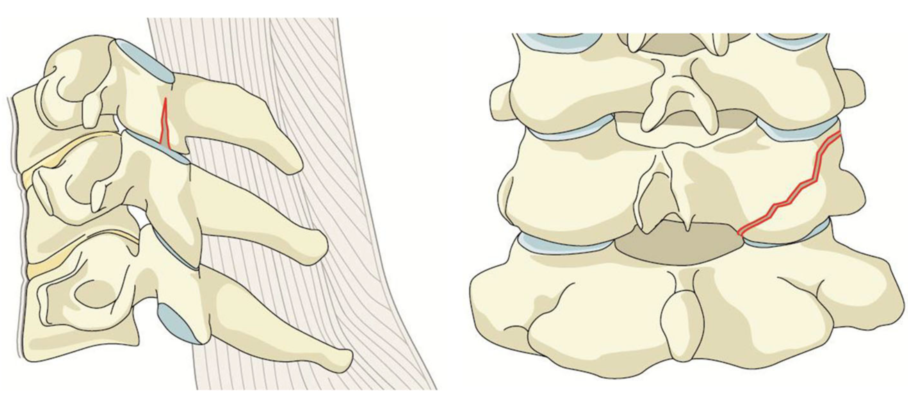

Fig. 10 Subtype F1: nondisplaced facet fracture (either superior or inferior facets): fragment <1 cm, <40 % lateral mass

M2—Critical disk herniation defined by tissue signal intensity that is consistent with nucleus pulposus protruding posteriorly to a vertical line drawn along the posterior border of the inferior vertebral body at the injured level [15].

M3—Stiffening/metabolic bone disease [i.e., Diffuse Idiopathic Skeletal Hyperostosis (DISH), Ankylosing Spondylitis (AS), Ossification of the Posterior Longitudinal Ligament (OPLL) or Ossification of the Ligamentum

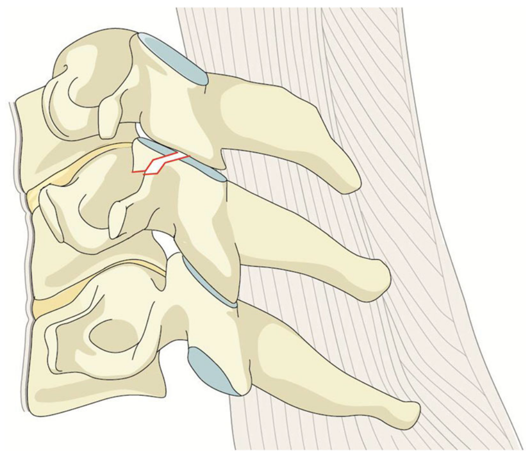

Fig. 11 Subtype F2: facet fracture with potential for instability (either superior or inferior facets): fragment >1 cm, >40 % lateral mass or displaced

Flavum (OLF)]. This modifier describes conditions that may argue either for or against surgery for those patients.

M4—Signs of vertebral artery injury

Results

According to the total number of assessments (600) the most frequent was type C (36.3 %) and the least often reported was type B1 (0.2 %) (Table 1).

Interobserver reliability

The overall interobserver reliability when including individual subtypes of injuries was 0.64, demonstrating

Fig. 12 Subtype F3: floating lateral mass: disruption of pedicle and lamina resulting in disconnection of superior and inferior articular processes at a given level or set of levels

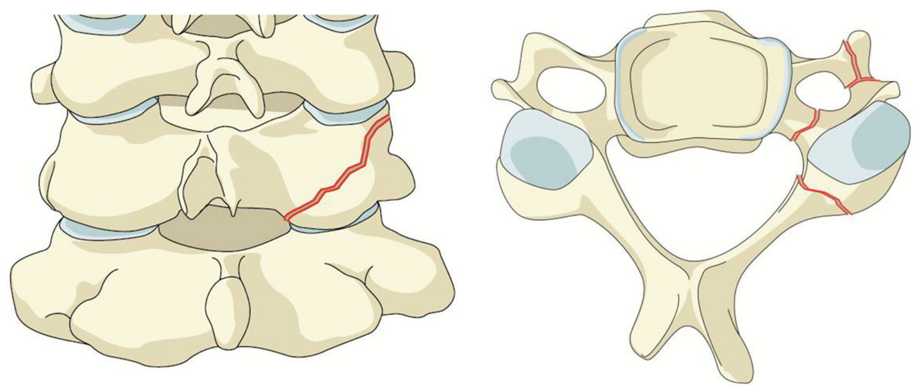

Fig. 13 Subtype F4: pathologic subluxation or perched/ dislocated facet

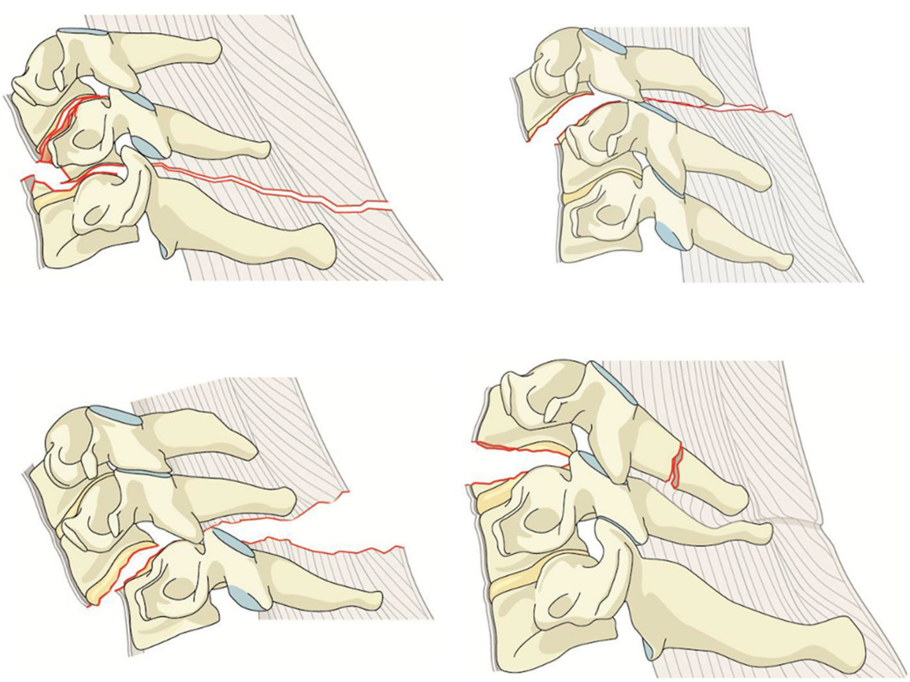

Table 1 Frequency of responses of injury types

Cervical classification	*N*	%
A0	15	2.5
A1	34	5.7
A2	28	4.7
A3	7	1.2
A4	71	11.8
B1	1	0.2
B2	77	12.8
B3	82	13.7
C	218	36.3
F1	6	1.0
F2	30	5.0
F3	24	4.0
F4	7	1.2

Table 2 Interobserver reliability for all subtypes

Cervical classification	Kappa
A0	0.75
A1	0.78
A2	0.72
A3	0.25
A4	0.62
B1	n/a
B2	0.29
B3	0.87
C	0.73
F1	0.00
F2	0.57
F3	0.60
F4	0.06
Combined	0.64

Table 3 Interobserver reliability for combined subgroups

Injury type	Kappa
A	0.66
B	0.54
C	0.73
F	0.66
Combined	0.65

substantial reliability (Table 2). The type B1 was excluded for the calculation of inter-rater agreement, since there was only one investigator who assessed a case as B1. When comparing levels of fracture severity (A/B/C/F), the kappa statistics for overall agreement on severity rating was 0.65 (Table 3), indicating substantial agreement according to the Landis and Koch grading system.

Table 4 Intraobserver reliability

Investigator	Morphology (13 subtypes)	Morphology (4 injury types)
1	0.71	0.72
2	0.91	0.91
3	0.65	0.73
4	0.91	0.90
5	0.60	0.68
6	0.91	0.90
7	0.80	0.77
8	0.58	0.57
9	0.74	0.80
10	0.73	0.77
Average	0.75	0.77

The highest agreement was observed in type B3 ($\kappa = 0.87$). The lowest level of agreement was observed in fractures types A3, B2, F1 and F4. Given that kappa value is strongly influenced by the prevalence of the outcome, in some situations when the prevalence of a given response is very low (e.g., types A3, F1 and F4), interpretation of the kappa statistic may not be meaningful.

Intraobserver reliability

The average Kappa intraobserver reliability value for all subtypes was 0.75. Among the 10 investigators, none had fair reproducibility results ($\kappa < 0.40$) with respect to morphology classification. Excellent reproducibility results ($\kappa > 0.80$) were identified in 3 investigators. On the average, reproducibility of the severity grades (A/B/C/F) was substantial ($\kappa = 0.77$) (Table 4).

Comparison with 'Gold Standard'

In the first round of assessments, out of 30 cases, the range of correctness compared to the 'Gold Standard' was 20–29 cases and in the second round, the range of correctness was 16–29 cases. Nevertheless, it is worth mentioning that 7 out of 10 investigators achieved worse results, according to the gold standard, in the second round of assessments compared to the first round (Table 5).

Discussion

The subaxial cervical spine fracture classification system proposed in this paper characterizes injury morphology, mechanism of injury, integrity of the facets, neurologic status, and additional modifiers thought to be important in the treatment of cervical spinal injuries. In an attempt to

Table 5 Comparison of investigators to the "gold standard"

Investigator	First assessment (% cases in agreement with gold standard) (*n*/30)	Second assessment (% cases in agreement with gold standard) (*n*/30)
1	80 (24/30)	77 (23/30)
2	83 (25/30)	80 (24/30)
3	67 (20/30)	77 (23/30)
4	73 (22/30)	67 (20/30)
5	80 (24/30)	67 (20/30)
6	97 (29/30)	97 (29/30)
7	73 (22/30)	80 (24/30)
8	67 (20/30)	53 (16/30)
9	73 (22/30)	63 (19/30)
10	70 (21/30)	60 (18/30)
Average	75	77

create cohesiveness between systems, the proposed subaxial cervical spine fracture classification system was modeled after the recently developed thoracolumbar system, with important variations and additions that are specific to the subaxial cervical spine. The development process of the AOSpine classification systems are based on evaluation of numerous cases in multiple sessions by a group of investigators and followed a methodological pathway similar to those used in the successful development of the AO pediatric long-bone fracture classification system [7, 16, 17].

While there is currently no universally accepted classification system for subaxial cervical spine injuries, many systems have been developed since the first classification of spinal injuries by Böhler [6], and each have influenced the development of the proposed system. Holdsworth described a system based on mechanism of injury of his observation of over 2000 patients with spinal injuries [3]. While the system did not specifically distinguish between cervical and thoracolumbar injuries, it did focus on the importance of determining "stable" versus "unstable" injuries, as well as the importance of the posterior ligamentous complex, concepts that continue to be crucial in the treatment of spinal injuries. In 1982, Allen and Ferguson presented their classification system, also based on mechanism of injury, which included: compressive flexion, vertical compression, distractive flexion, compressive extension, distractive extension, and lateral flexion [1]. To create this system, the senior author reviewed radiographs of 165 cases of fractures and dislocations, as well as the likely mechanism of injury, which was implied by the history of the injury and recoil position of the spine on plain radiographs. While this system is comprehensive, it lacks clinical relevance, and has poor interobserver reliability [9]. Modifications to this system by Harris changed the mechanisms to include flexion, flexion and rotation, hyperextension and rotation, vertical compression, extension, and lateral flexion, however, this did not change the inherent flaws associated with the Allen and Ferguson classification system [2]. Previous classification systems for spine injuries have also been developed by AO over the years, and are reflected in the currently proposed system [4, 5].

The Spine Trauma Study Group (STSG) developed the Sub-axial Injury Classification (SLIC) and Severity Scale in 2007 in an effort to combine the best parameters from previous systems, as well as the clinical experience of the subcommittee [8]. In the SLIC system, injuries are characterized based on three main categories: injury morphology, disco-ligamentous complex, and neurologic status. Within each category, subgroups are graded based on severity, and a score can be obtained to guide decision-making. While the initial assessment of the SLIC system showed good validity and moderate reliability [8], a recent validation study comprised of 12 surgeons demonstrated poor inter-rater agreement on morphology ($\kappa = 0.29$), and average agreement on the integrity of the disco-ligamentous complex ($\kappa = 0.46$) [10]. The importance of neurological status was introduced in the SLIC system, and continues to be used as a modifier in the proposed system. The degree of neurologic deficit can reflect the severity of injury and amount of energy required to cause the deficit, and in turn influence the decision-making process.

Similar to the thoracolumbar classification system, the morphological characteristics of subaxial cervical spine injuries based on CT scan and radiographs are the foundation of this system. CT is available at most trauma centers, and has been recommended by some to be the initial screening modality for patients with suspected injuries [18, 19]. While CT scan alone is adequate to identify and classify most injuries in this system, MRI can aid in the diagnosis of subtle injuries to the PLC when disruption of the bony structures, such as widening of the spinous processes, is not obvious. However, the integrity of the PLC should not be based on MRI alone [20, 21]. This system also includes a modifier to acknowledge cases in which injury to the PLC is indeterminate, which is applicable in cases where MRI is unavailable, or the images available cannot rule out injury.

Unique to this classification system is the assessment of the facets as a separate descriptor. The spectrum of facet injury varies from non-displaced or displaced fractures to subluxed, perched, or dislocated facets. The facet complex has been demonstrated to be a dominant stabilizer for axial rotation, and overall stability in association with the capsule, disc, and ligamentous structures [22, 23]. The presence of facet dislocation not only suggests an injury of significant energy, but also a mechanism of flexion distraction [24]. In the setting of SCI, patients with facet dislocation present with a significantly worse AIS grade, and less improvement at 1 year [25].

Overall, the interobserver and intraobserver reliabilities for this proposed system were substantial (0.64 and 0.75, respectively). Due to the low frequency of certain injury subtypes (A3, B1, F1, and F4), these injuries may have a low kappa value. It is unknown if the low kappa values for these injuries are due to the low prevalence within the 30 cases, or if these injuries truly represent an area of disagreement. Future studies will hopefully further evaluate this question. Another interesting finding was that 7 out of 10 investigators had worse agreement with the 'Gold Standard' on the second assessment compared to the first assessment. A possible explanation for this finding is that the investigators may have performed the first evaluation soon after reviewing the descriptive introduction to the system as well as the introductory 10 cases, while the second round was completed after 30 days. There was no required "pre-test" prior to the second round of assessment, which may have lowered the number of cases in agreement with the 'Gold Standard'. Investigator fatigue in reviewing 30 cases a second time may have been a factor.

Acknowledgments AOSpine is a clinical division of the AO Foundation—an independent medically guided not for profit organization. The AO has a strong financial independence thanks to the foundations endowment. The annual operating activities are financed through three pillars: Collaboration and support agreements with DePuy Synthes and other industrial partners, return on own financial assets and other third party income (e.g., participant fees, R&D projects, memberships). The AOSpine Knowledge Forums are pathology focused working groups acting on behalf of AOSpine in their domain of scientific expertise. Each forum consists of a steering committee of up to 10 international spine experts who meet biannually to discuss research, assess the best evidence for current practices, and formulate clinical trials to advance their field of spine expertise. Authors are compensated for their travel and accommodation costs. Study support is provided directly through AOSpine's Research department and AO's Clinical Investigation and Documentation unit. There are no other institutional subsidies, corporate affiliations or funding sources supporting this work unless clearly documented and disclosed.

Conflict of interest None.

References

1. Allen BL Jr, Ferguson RL, Lehmann TR, O'Brien RP (1982) A mechanistic classification of closed, indirect fractures and dislocations of the lower cervical spine. Spine 7:1–27
2. Harris JH Jr, Edeiken-Monroe B, Kopaniky DR (1986) A practical classification of acute cervical spine injuries. Orthop Clin North Am 17:15–30
3. Holdsworth F (1970) Fractures, dislocations, and fracture-dislocations of the spine. J Bone Joint Surg Am 52:1534–1551
4. Aebi M, Nazarian S (1987) Classification of injuries of the cervical spine. Der Orthopade 16:27–36
5. Blauth MKA, Mair G, Schmid R, Reinhold M, Rieger M (2007) Classification of injuries of the subaxial cervical spine. In: Aebi MAV, Webb JK (eds) AO spine manual: clinical applications. Thieme, Stuttgart, pp 21–38
6. Bohler L (1951) Die Technik der Knochenbruchbehandlung. Maudrich, Wien
7. van Middendorp JJ, Audige L, Hanson B, Chapman JR, Hosman AJ (2010) What should an ideal spinal injury classification system consist of? A methodological review and conceptual proposal for future classifications. Euro Spine J Off Publ Eur Spine Soc Euro Spinal Deformity Soc Euro Sect Cerv Spine Res Soc 19:1238–1249. doi:10.1007/s00586-010-1415-9
8. Vaccaro AR, Hulbert RJ, Patel AA, Fisher C, Dvorak M, Lehman RA, Anderson P, Harrop J, Oner FC, Arnold P, Fehlings M, Hedlund R, Madrazo I, Rechtine G, Aarabi B, Shainline M, Spine Trauma Study G (2007) The subaxial cervical spine injury classification system: a novel approach to recognize the importance of morphology, neurology, and integrity of the disco-ligamentous complex. Spine 32:2365–2374. doi:10.1097/BRS.0b013e3181557b92
9. Stone AT, Bransford RJ, Lee MJ, Vilela MD, Bellabarba C, Anderson PA, Agel J (2010) Reliability of classification systems for subaxial cervical injuries. Evidence-Based Spine-Care J 1:19–26. doi:10.1055/s-0030-1267064
10. van Middendorp JJ, Audige L, Bartels RH, Bolger C, Deverall H, Dhoke P, Diekerhof CH, Govaert GA, Guimera V, Koller H, Morris SA, Setiobudi T, Hosman AJ (2013) The Subaxial Cervical Spine Injury Classification System: an external agreement validation study. Spine J Off J North Am Spine Soc. doi:10.1016/j.spinee.2013.02.040
11. Vaccaro AR, Oner C, Kepler CK, Dvorak M, Schnake K, Bellabarba C, Reinhold M, Aarabi B, Kandziora F, Chapman J, Shanmuganathan R, Fehlings M, Vialle L, Injury AOSC, Trauma Knowledge F (2013) AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers. Spine 38:2028–2037. doi:10.1097/BRS.0b013e3182a8a381
12. Audige L, Bhandari M, Hanson B, Kellam J (2005) A concept for the validation of fracture classifications. J Orthop Trauma 19:401–406
13. Landis JR, Koch GG (1977) The measurement of observer agreement for categorical data. Biometrics 33:159–174
14. Spector LR, Kim DH, Affonso J, Albert TJ, Hilibrand AS, Vaccaro AR (2006) Use of computed tomography to predict failure of nonoperative treatment of unilateral facet fractures of the cervical spine. Spine 31:2827–2835. doi:10.1097/01.brs.0000245864.72372.8f
15. Vaccaro AR, Falatyn SP, Flanders AE, Balderston RA, Northrup BE, Cotler JM (1999) Magnetic resonance evaluation of the intervertebral disc, spinal ligaments, and spinal cord before and after closed traction reduction of cervical spine dislocations. Spine 24:1210–1217
16. Slongo T, Audige L, Clavert JM, Lutz N, Frick S, Hunter J (2007) The AO comprehensive classification of pediatric long-bone fractures: a web-based multicenter agreement study. J Pediatr Orthop 27:171–180. doi:10.1097/01.bpb.0000248569.43251.f9
17. Slongo T, Audige L, Schlickewei W, Clavert JM, Hunter J, International Association for Pediatric T (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the Pediatric Expert Group of the AO Foundation in collaboration with AO Clinical Investigation and Documentation and the International Association for Pediatric Traumatology. J Pediatr Orthop 26:43–49. doi:10.1097/01.bpo.0000187989.64021.ml
18. Bailitz J, Starr F, Beecroft M, Bankoff J, Roberts R, Bokhari F, Joseph K, Wiley D, Dennis A, Gilkey S, Erickson P, Raksin P, Nagy K (2009) CT should replace three-view radiographs as the initial screening test in patients at high, moderate, and low risk for blunt cervical spine injury: a prospective comparison. J Trauma 66:1605–1609. doi:10.1097/TA.0b013e3181a5b0cc

19. LeBlang SD, Nunez DB, Jr. (1999) Helical CT of cervical spine and soft tissue injuries of the neck. Radiologic clinics of North America 37:515-532, v-vi
20. Vaccaro AR, Rihn JA, Saravanja D, Anderson DG, Hilibrand AS, Albert TJ, Fehlings MG, Morrison W, Flanders AE, France JC, Arnold P, Anderson PA, Friel B, Malfair D, Street J, Kwon B, Paquette S, Boyd M, Dvorak MF, Fisher C (2009) Injury of the posterior ligamentous complex of the thoracolumbar spine: a prospective evaluation of the diagnostic accuracy of magnetic resonance imaging. Spine 34:E841–E847. doi:10.1097/BRS.0b013e3181bd11be
21. Oner FC, Wood KB, Smith JS, Shaffrey CI (2010) Therapeutic decision making in thoracolumbar spine trauma. Spine 35:S235–S244. doi:10.1097/BRS.0b013e3181f32734
22. Nadeau M, McLachlin SD, Bailey SI, Gurr KR, Dunning CE, Bailey CS (2012) A biomechanical assessment of soft-tissue damage in the cervical spine following a unilateral facet injury. J Bone Joint Surg Am 94:e156. doi:10.2106/JBJS.K.00694
23. Rasoulinejad P, McLachlin SD, Bailey SI, Gurr KR, Bailey CS, Dunning CE (2012) The importance of the posterior osteoligamentous complex to subaxial cervical spine stability in relation to a unilateral facet injury. Spine J Off J North Am Spine Soc 12:590–595. doi:10.1016/j.spinee.2012.07.003
24. Ivancic PC, Pearson AM, Tominaga Y, Simpson AK, Yue JJ, Panjabi MM (2007) Mechanism of cervical spinal cord injury during bilateral facet dislocation. Spine 32:2467–2473. doi:10.1097/BRS.0b013e3181573b67
25. Wilson JR, Vaccaro A, Harrop JS, Aarabi B, Shaffrey C, Dvorak M, Fisher C, Arnold P, Massicotte EM, Lewis S, Rampersaud R, Okonkwo DO, Fehlings MG (2013) The impact of facet dislocation on clinical outcomes after cervical spinal cord injury: results of a multicenter North American prospective cohort study. Spine 38:97–103. doi:10.1097/BRS.0b013e31826e2b91