Spine Publish Ahead of Print
DOI:10.1097/BRS.0000000000004429

OPEN

Global Validation of the AO Spine Upper Cervical Injury Classification

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Financial Disclosures: None

Level of Evidence: IV

Acknowledgements:

The authors of the manuscript would like to thank Olesja Hazenbiller for her assistance in developing the methodology and providing support during the validation. We would also like to thank Hans Bauer, senior biostatistician at Staburo GmbH for his assistance with the statistical analysis.

This study was organized and funded by AO Spine through the AO Spine Knowledge Forum Trauma, a focused group of international Trauma experts. AO Spine is a clinical division of the AO Foundation, which is an independent medically0guided not-for-profit organization. Study support was provided directly through the AO Spine Research Department.

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Key Points

1) The AO Spine Upper Cervical Injury Classification System has substantial intraobserver reproducibility (ƙ=0.70).
2) The AO Spine Upper Cervical Injury Classification System demonstrated substantial interobserver reliability on assessment one (ƙ=0.63) and assessment two (ƙ=0.61).
3) Injury location has higher interobserver reliability on assessment one (ƙ = 0.85) and two (ƙ= 0.83) than injury type (ƙ=0.59 and ƙ=0.57, respectively).
4) Accurate classification of Type B injuries (71.2% accuracy on assessment one and 72.1% accuracy on assessment two) is more difficult than Type A and Type C injuries.

Structured Abstract:

Study Design: Global Cross Sectional Survey

Objective: To determine the classification accuracy, interobserver reliability, and intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System based on an international group of AO Spine members

Summary of Background Data:

Previous upper cervical spine injury classifications have primarily been descriptive without incorporating a hierarchical injury progression within the classification system. Further, upper cervical spine injury classifications have focused on distinct anatomical segments within the upper cervical spine. The AO Spine Upper Cervical Injury Classification System incorporates all injuries of the upper cervical spine into a single classification system focused on a hierarchical progression from isolated bony injuries (type A) to fracture dislocations (type C).

Methods: A total of 275 AO Spine members participated in a validation aimed at classifying 25 upper cervical spine injuries via computed tomography (CT) scans according to the AO Spine Upper Cervical Classification System. The validation occurred on two separate occasions, three weeks apart. Descriptive statistics for percent agreement with the gold-standard were calculated and Pearson's chi square test evaluated significance between validation groups. Kappa coefficients (ƙ) determined the interobserver reliability and intraobserver reproducibility.

Results: The accuracy of AO Spine members to appropriately classify upper cervical spine injuries was 79.7% on assessment 1 (AS1) and 78.7% on assessment 2 (AS2). The overall intraobserver reproducibility was substantial (ƙ=0.70), while the overall interobserver reliability for AS1 and AS2 was substantial (ƙ=0.63 and ƙ=0.61, respectively). Injury location had higher interobserver reliability (AS1: ƙ = 0.85 and AS2: ƙ= 0.83) than the injury type (AS1: ƙ=0.59 and AS2: 0.57) on both assessments.

Conclusion: The global validation of the AO Spine Upper Cervical Injury Classification System demonstrated substantial interobserver agreement and intraobserver reproducibility. These results support the universal applicability of the AO Spine Upper Cervical Injury Classification System.

Introduction:

Attempts at classifying upper cervical spine injuries started in 1919 when Jefferson identified potential injury mechanisms and fracture patterns of the atlas.[1] Numerous additional upper cervical spine classifications have since been proposed, but they have narrowed focus to isolated portions of the upper cervical spine.[2-9] Additionally, previous injury classifications of the occipital condyles,[2,3] craniocervical junction,[4,5] atlas and transverse atlantoaxial ligament,[1,6,7] C2 peg and ring,[8-10] and C2-3 joint[11] have predominantly been descriptive with minimal ability to guide fracture management. Therefore, an upper cervical spine injury classification that is descriptive and incorporates each level of the upper cervical spine would be beneficial.

Similar to previous AO Spine classifications, the AO Spine Upper Cervical Injury Classification System follows the validation concept outlined by Audigé.[12] In short, classification systems first have experts determine the classification reproducibility and reliability. If a high reliability and reproducibility is achieved, the classification undergoes widespread international validation, which is the current step of the validation process. Subsequently, if global validation demonstrates a high degree of reliability and reproducibility, consideration then focuses on obtaining injury severity scores[13,14] to determine if the classification system can guide injury management via a treatment algorithm.[15]

Effective classification schema will result in highly accurate injury film interpretation with subsequent correct categorization of the fracture. Understanding limitations of the classification prior to global implementation is imperative in order for the classification to achieve widespread adoption. A lack of reliability and reproducibility from classification users signals the classification requires alterations prior to proceeding to the next phase of validation.[12]

Therefore, the purpose of this study was to determine the international interobserver reliability and intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System.

Methods

A Brief Description of the Classification

The AO Spine Upper Cervical Injury Classification System first divides injuries based on anatomical location. Three anatomically distinct segments are present in the upper cervical spine (I.) the occipital condyle and craniocervical junction; (II.) the C1 ring and C1-2 joint; and (III.) the C2 body, odontoid process, and C2-3 joint. Injury types are presented within each upper cervical anatomical segment. Type A injuries are predominantly bony injuries and are typically stable injury patterns. In most instances they are treated non-operatively, but in certain circumstances they may require operative management, especially if the fracture is unlikely to heal, as is the case for dens fractures at the watershed line. Type B injuries involve a bony and/or ligamentous injury with no vertebral body translation respective to the caudal and cephalad vertebrae. These injuries are identified on CT scans as a ligamentous avulsion or tension band failure. They may be stable or unstable and usually require additional imaging with dynamic radiographs or magnetic resonance imaging (MRI) to determine if operative management is indicated. Type C injuries involve either a ligamentous or bony injury that results in translation of the proximal and distal parts of the injured spinal column in any plane. These injuries are inherently unstable and frequently require operative stabilization (**Figure 1**).

Classification Validation

An open call to the AO Spine community was issued to identify members willing to participate in the AO Spine Upper Cervical Injury Classification System validation. A total of

275 validation members were identified. Each participant watched a tutorial video (https://www.youtube.com/watch?v=KyUYfa_JMb4) describing the classification system and was given examples of different upper cervical spine injuries. The participants were then allowed to ask questions regarding the classification system to the supervisor (a member of the original design team of the classification system) before participating in a sample validation of three upper cervical spine injuries. Each injury was classified by the AO Spine Knowledge Forum Trauma (the gold-standard committee) and unanimous agreement was reached prior to circulation of the injury films.

Based on consultation with our statistician, we attempted to provide participants with three unique injuries for each classification subtype (IA, IB, IIA, etc.) although this was not always feasible due to time constraints and an inadequate number of injury subtypes in our database. The official validation of the AO Spine Upper Cervical Injury Classification System consisted of a live, online webinar (conducted in English) with 25 unique cases showing axial, sagittal, and coronal CT videos played once at a rate of 2 frames/second as previously described.[16] Radiographic key images of the injuries were also provided for reference. Only injury films with a single injury were evaluated to ensure participants evaluated the correct injury, but in clinical practice if multiple injuries are present then the secondary injury should be described in parenthesis. Further, for Type B injuries, only tension band and ligamentous avulsion injuries can be evaluated with CT scan; whereas isolated ligamentous injuries without vertebral body translation require MRI or dynamic radiography for accurate classification and thus were not evaluated in this validation. An online REDCap survey captured the members' classification grades. Three weeks were allotted between the first and second assessments and the cases were re-randomized prior to the second assessment.

Statistics

Relative frequencies were tabulated based on the percent agreement between validation members and the gold-standard committee. The percent agreement was calculated for anatomic location (I, II, or III), injury type (A, B, or C), and the combination of anatomic location and injury type. Differences in relative frequencies between groups of raters were screened for potentially relevant associations with chi-square tests in case of sufficiently large cell counts and with Fisher's exact test otherwise. Kappa coefficients (ƙ) were calculated based on the agreement between different validation members (interobserver reliability) and the consistency with which validation member groups chose the same classification after a three-week interval (intraobserver reproducibility). Interobserver reliability and intraobserver reproducibility were calculated for anatomical injury location, injury type, and overall classification. All of the reported kappa values utilized Fleiss' Kappa coefficient, which allows for missed ratings and comparisons between more than two validation members.[17] Interpretation of the reliability and reproducibility were based on the Landis and Koch convention, which categorized Kappa values as "slight" (<0.2), "fair" (0.2 - 0.4), "moderate" (0.41 - 0.60), "substantial" (0.61 - 0.8), and "excellent" (0.81-1.0).[18]

Results

After an open invitation to all AO Spine members, 275 members with varying levels of experience from each AO world region agreed to participate. A complete list of the validation members' demographics can be found in **Table 1**. Of the 25 cases with CT evaluations reviewed, the most commonly tested injuries were of the C1 vertebrae or C1-2 joint (N=10) and the C2 vertebrae or C2-3 joint (N=11), while the most common injury types were Type A (N=10) and Type C (N=8) (**Supplemental Digital Content 1, http://links.lww.com/BRS/B896**). A description of each evaluated injury film, the associated AO Upper Cervical Spine Injury Classification, and the historical injury classification are provided in **Supplemental Digital Content 2, http://links.lww.com/BRS/B897**.

Gold-Standard Agreement

When assessing the agreement between validation members and the gold-standard committee, the overall classification agreement was 79.7% on assessment one (AS1) and 78.8% on assessment two (AS2). Validation members were more accurate at identifying the injury location (95.1% on AS1 and 94.1% on AS2) than the injury type (82.4% on AS1 and 82% on AS2). Although the accuracy of identifying injury location was similar regardless of anatomical location, Type B injuries (AS1: 71.2, AS2: 72.1%) were accurately identified at a much lower rate than type A (AS1: 85%, AS2: 85.7%) or type C injuries (AS1: 89.1%, AS2: 86.1%) (**Table 2**).

Interobserver Reliability

The overall interobserver reliability for AS1 and AS2 was substantial (ƙ=0.63 and ƙ=0.61, respectively). The individual injuries that had the lowest reliability were IIB (AS1: ƙ=0.48 and ƙ=0.45) and IIC injuries (AS1: ƙ=0.45 and ƙ=0.47). IIA (AS1: ƙ=0.59 and ƙ=0.60) and IIIB injuries (AS1: ƙ=0.53 and ƙ=0.53) were the only other injuries that did not reach at least substantial reliability (**Table 3**). After sub-stratifying the injuries, injury location (AS1: ƙ=0.85 and ƙ=0.83) had a greater interobserver reliability than injury type on AS1 and AS2. When evaluating injury type, type A (AS1: ƙ=0.60; AS2: ƙ=0.59) reached moderate reliability, type B had slight/moderate reliability (AS1: ƙ=0.41; AS2: ƙ=0.39), while type C injuries demonstrated substantial reliability (AS1: ƙ=0.73; AS2: ƙ=0.72) (**Supplemental Digital Content 3, http://links.lww.com/BRS/B898**).

Intraobserver Reproducibility

The overall intraobserver reproducibility was substantial (mean ƙ=0.70). Most validation members had either excellent (38.8%) or substantial classification reproducibility (38.4%), but 15.5% had moderate reproducibility with the remainder of participants demonstrating either fair or slight reproducibility. Although 84% of validation members reached excellent intraobserver reproducibility when evaluating injury location, there was more heterogeneity for injury type. Only 33% and 35.4% of validation members reached excellent and substantial intraobserver reproducibility, respectively. An additional 22.8% of validation members demonstrated moderate reproducibility (**Table 4**).

Discussion

Validation of the AO Spine Upper Cervical Injury Classification System demonstrated substantial interobserver reliability and intraobserver reproducibility. Nearly 80% of all injuries were correctly classified on both assessments when compared to the gold-standard, although there was a greater accuracy at identifying injury location compared to injury type. The interobserver reliability for injury location was deemed excellent, while reliability of the injury type was moderate. Sub-analysis of the injury subtypes (IA, IC, IIA, IIB, etc) demonstrated that most injuries reached at least substantial interobserver reliability; however, all injuries to the atlas and C2 type B injuries demonstrated moderate reliability. We speculate the lower reliability for C2 type B injuries may be related to injury complexity; therefore, we discuss potential ways to distinguish Type B injuries from Type A and Type C injuries.[10]

An independent validation of the AO Spine Upper Cervical Injury Classification System was previously performed by surgeons at a single tertiary referral trauma center.[19] Similar to our results, excellent resident (range: ƙ=0.83-0.99) and attending surgeon (range: ƙ=0.86-0.99) intraobserver reproducibility was identified for injury location, while injury type demonstrated substantial to excellent reproducibility for residents (range: ƙ=0.69-0.92) and excellent reproducibility for attendings (range: ƙ=0.85-0.98). Consistent with our results, excellent interobserver reliability was identified for injury type (range: ƙ=0.86-0.88), but slightly higher interobserver reliability was demonstrated for injury type in the Maeda et al[19] study (AS1: ƙ=0.66; AS2: ƙ=0.60) compared to the results of our study (AS1: ƙ=0.59; AS2: ƙ=0.57). Interestingly, the results of both Maeda et al[19] and our study appear to indicate no "learning effect" occurs from repeat validation attempts or from additional years of surgical experience.[20] However, it should be noted the participants in the Maeda et al[19] study were all neurosurgeons, which may impart a benefit in classification accuracy when compared to non-spine surgeons. This was demonstrated by the approximate 80% classification accuracy of neurosurgeons and orthopaedic spine surgeons compared to ~ 63% accuracy for non-spine surgeons.

Although the overall interobserver reliability and intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System was substantial, injuries to the atlas (IIA, IIB, and IIC) were identified as having lower reliability and reproducibility when compared to other injury types. Previous atlas fracture classifications have been proposed, but they have primarily been designed for descriptive purposes.[1,6] Recently, Laubach et al.[21] found the Gehweiler classification had moderate interobserver reliability (ƙ=0.50) when evaluated by 20 members of the German Society for Spine Surgeons, which was similar to the interobserver reliability obtained in our study when evaluating the AO Spine Upper Cervical Injury Classification (range: ƙ=0.45-0.60 for type IIA-IIC injuries on AS1 and AS2). Therefore, it appears plausible the complexity of atlas injuries account for the moderate classification reliability regardless of the classification schema applied to these injuries.[22]

Similar to C1 ring injuries, C2 type B injuries received moderate classification reliability. These injuries have historically been labeled "atypical hangman's fractures". Unlike typical hangman's fractures, described by Levine-Edwards,[11] atypical variants are infrequently documented in the literature and have variable fracture presentation including C2 vertebral body coronal shear fractures and oblique fractures through the vertebral body, lamina, and/or pars.[23-25] These complex C2 coronal fracture variants were further described and categorized based on injury mechanisms by Benzel et al.[10] Multiple injury mechanisms were described (hyperextension with axial load, flexion with axial load, and flexion distraction) and they often result in AO Spine Type C injuries, based on translation of the vertebral body in either the axial or sagittal plane due to intervertebral disc injuries or avulsion fractures of the anterior or posterior longitudinal ligaments. However, the extension with axial load variant is commonly described as an atypical hangman's fracture, which is frequently classified as a Type B injury due to the tension band failure. Unfortunately, no high quality validations of the Levine-Edwards Classification or Benzel's classification exist to compare reliability and reproducibility scores to the AO Spine Upper Cervical Injury Classification System. Similar to atlas injuries, it seems plausible classification inaccuracies of C2 injuries are due to injury complexity when compared to simple dens fractures (Type A).[26]

It is important to note that the AO Spine Upper Cervical Injury Classification System utilizes CT scans to classify all upper cervical spine injuries. This allows for minimization of the global inequality gaps in accessing magnetic resonance imaging (MRI).[27,28] Although CT scans are quicker and more accessible than MRIs, CT scans are often limited to major trauma centers in low-income countries.[29] This may result in a persistent inability for some spine surgeons to have routine access to any advanced imaging options. In those instances, emergency departments may follow the Canadian C-Spine Rule for determining the necessity of cervical spine imaging.[30] If concerning radiographic findings are present, or if the patient is obtunded and there is concern for a cervical spine injury, patients should be transported to the nearest advanced imaging center. Although the AO Spine classification schema is based on CT evaluation, diligent use of MRI is encouraged in cases where concern for ligamentous instability exists since CT is inadequate for detecting isolated ligamentous injuries. In particular, MRI may ultimately decide whether operative or conservative management is appropriate for Type B injuries when there is questionable injury to an intervertebral disc or ligamentous complex.

There are multiple limitations inherent to the validation of this fracture classification. First, the validation was performed by AO members, which could have inflated the overall classification accuracy, reliability and reproducibility compared to surgeons not familiar with AO classification systems. Second, the study was conducted in English and differences in fluency could have altered the validation members' ability to understand the classification system, which may have resulted in global variations in classification accuracy. Classification of the different injury types were limited to available CT scans in the AO database. Since no type IB injuries were available, they could not be evaluated by validation members which may have artificially improved the overall interobserver reliability and intraobserver reproducibility of the classification given the lower accuracy of classifying type B injuries. Finally, further attention should be given to the effect of regional variability and the influence of surgeons work setting (academic institution or level I trauma center) on the accuracy of correctly classifying injuries based on the AO Spine Upper Cervical Injury Classification System.

Conclusion

The international validation of the AO Spine Upper Cervical Injury Classification System demonstrated substantial interobserver reliability and intraobserver reproducibility, with excellent interobserver reliability for injury location and moderate reliability for the injury type. Although all atlas injuries demonstrated moderate interobserver reliability, this is consistent with the interobserver reliabilities of previous atlas fracture classifications. Future research targeted at understanding the reliability and reproducibility of Type IB injuries is imperative given that these injury types were not evaluated during this validation.

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Table 1. Demographics of surgeons who participated in the AO Spine Upper Cervical Injury Classification

Survey Demographics		**N (%)**
AO Region	*# of participants*	275 (100)
	Africa	16 (5.8)
	Asia	73 (26.5)
	Central/South America	36 (13.1)
	Europe	105 (38.2)
	Middle East	18 (6.5)
	North America	27 (9.8)
Subspecialty	*# of participants*	275 (100)
	Neurosurgery	100 (36.4)
	Orthopaedic Spine Surgery	168 (61.1)
	Other	7 (2.5)
Surgical Experience	*# of participants*	275 (100)
	< 5 years	71 (25.8)
	5-10 years	77 (28)
	11-20 years	82 (29.8)
	> 20 years	45 (16.4)
Work Setting	*# of participants*	275 (100)
	Academic	120 (43.6)
	Hospital Employed	120 (43.6)
	Private Practice	35 (12.7)
Trauma Center Level	*# of participants*	275 (100)
	Level I	192 (69.8)
	Level II	49 (17.8)
	Level III	17 (6.2)
	Level IV	12 (4.4)
	No Trauma	5 (1.8)

Table 2. AO Spine validation members percent agreement with the gold-standard committee based on overall accuracy, injury location accuracy, and injury type accuracy

AO Spine Upper Cervical Injury Classification	***Percent Agreement with Gold-Standard (%)***	
	Assessment 1	Assessment 2
Overall (Injury Location and Type)	79.7	78.8
Overall (Injury Location)	95.1	94.1
I	96.7	94.6
II	93.6	93.3
III	95.9	94.7
Overall (Injury Type)	82.4	82.0
A	85	85.7
B	71.2	72.1
C	89.1	86.1

Table 3. Interobserver Reliability of AO Spine Validation Members based on Overall Classification and Injury Subtype

AO Spine Upper Cervical Injury Classification	**Kappa (ꝁ)**	
	Assessment 1	Assessment 2
Overall	0.63	0.61
IA	0.75	0.70
IC	0.86	0.84
IIA	0.59	0.60
IIB	0.48	0.45
IIC	0.45	0.47
IIIA	0.69	0.67
IIIB	0.53	0.53
IIIC	0.80	0.76

Table 4. Intraobserver agreement for the AO Spine members' based on the overall classification, injury location, and injury type. Level of agreement is based on the Landis and Koch interpretation.

AO Spine Upper Cervical Injury Classification System#	***Intraobserver reproducibility (κ)***		
	Overall classification	**Injury Location**	**Injury Type**
Mean Kappa Values (std)	0.70 (0.19)	0.88 (0.19)	0.67 (0.22)
Level of Agreement	***Absolute number and percent of intraobserver agreement N (%)***		
	Overall classification	**Injury Location**	**Injury Type**
Slight (<0.2)	5 (2.4)	4 (1.9)	8 (3.9)
Fair (0.20-0.40)	10 (4.9)	2 (1.0)	10(4.9)
Moderate (0.41-0.60)	32 (15.5)	10 (4.9)	47 (22.8)
Substantial (0.61-0.80)	79 (38.4)	17 (8.3)	73 (35.4)
Excellent (0.81-1.0)	80 (38.8)	173 (84.0)	68 (33)

Based on 206 validation members who participated in both assessments

Figure 1. Depiction of the AO Spine Upper Cervical Injury Classification. The classification is based on injury location (occipital condyle and craniocervical junction, C1 ring and C1-2 joint, and C2 and C2-3 joint) and injury type (bony, tension band, ligamentous). Permission to use this figure was granted by the AO Foundation©, AO Spine, Switzerland.