Injury 53 (2022) 3248–3254

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

The AO spine upper cervical injury classification system: Do work setting or trauma center affiliation affect classification accuracy or reliability?

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ARTICLE INFO

Article history:
Accepted 14 August 2022

Keywords:
AO spine
Classification
Upper cervical spine
Reliability
Atlas
dens

ABSTRACT

Purpose: To assess the accuracy and reliability of the AO Spine Upper Cervical Injury Classification System based on a surgeons' work setting and trauma center affiliation.
Methods: A total of 275 AO Spine members participated in a validation of 25 upper cervical spine injuries, which were evaluated by computed tomography (CT) scans. Each participant was grouped based on their work setting (academic, hospital-employed, or private practice) and their trauma center affiliation (Level I, Level II or III, and Level IV or no trauma center). The classification accuracy was calculated as percent of correct classifications, while interobserver reliability, and intraobserver reproducibility were evaluated based on Fleiss' Kappa coefficient.
Results: The overall classification accuracy for surgeons affiliated with a level I trauma center was significantly greater than participants affiliated with a level II/III center or a level IV/no trauma center on assessment one ($p_1 < 0.0001$) and two ($p_2 = 0.0003$). On both assessments, surgeons affiliated with a level I or a level II/III trauma center were significantly more accurate at identifying IIIB injury types ($p_1 = 0.0007$; $p_2 = 0.0064$). Academic surgeons and hospital employed surgeons were significantly more likely to correctly classify type IIIB injuries on assessment one ($p_1 = 0.0146$) and two ($p_2 = 0.0015$). When evaluating classification reliability, the largest differences between work settings and trauma center affiliations was identified in type IIIB injuries.
Conclusion: Type B injuries are the most difficult injury type to correctly classify. They are classified with greater reliability and classification accuracy when evaluated by academic surgeons, hospital-employed surgeons, and surgeons associated with higher-level trauma centers (I or II/III).

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https://doi.org/10.1016/j.injury.2022.08.030

Introduction

Upper cervical spine trauma occurs at a disproportionally high rate in geriatric patients.[1] Typically, the injury mechanism is low-energy trauma with the most commonly identified fracture being a sagittally-oriented odontoid fracture [1]. Atlas fractures are increasingly recognized in elderly patients with a reported 700% increase in injury rate during the last 20 years [2].

Given that most upper cervical spine injuries in geriatric patients are caused by ground level falls, and greater than 70% of upper cervical spine injuries result in no neurologic deficit, many of these patients will initially be evaluated at low acuity trauma centers [3]. Current evidence points to no difference in patient mortality based on whether a spine fracture is transferred to a high-level (level I or II) trauma center or if it is managed at a low-level center [4]. Thus, the work setting (academic, hospital employed or private practice) and trauma center affiliation (levels I, II, III, etc.) of a surgeon may not affect their ability to accurately identify simple atlas or dens injuries given their frequent presentation.

Upper cervical spine trauma is seen in a bimodal distribution with younger patients presenting to high-level trauma centers predominantly after falls from height or motor vehicle collisions [5]. C2 fractures, and more specifically odontoid fractures, remain the most common upper cervical spine injuries evaluated in younger trauma patients [5]. However, less common fracture presentations including craniocervical junction dislocations and atypical hangman's fractures are almost exclusively seen with motor vehicle collisions or falls from height [6,7]. Thus, these patients are predominantly evaluated at high-level trauma centers. The greater number of Type B and C injuries evaluated by surgeons' affiliated with level I trauma centers, may provide them an advantage when attempting to classify a variety of upper cervical spine injuries based on the AO Spine Upper Cervical Injury Classification System. Therefore, the purpose of our study was to determine if a surgeons' work setting or trauma center affiliation affected their classification accuracy, interobserver reliability, or intraobserver reproducibility.

Methods

Injury classification description

A detailed description of this fracture classification has previously been provided [8]. In brief, injuries are assigned a roman numeral based on their injury location (I. Craniovertebral junction and occipital condyles; II. Atlas and C1-C2 joint; III. Dens, C2 ring, and C2-C3 joint). The injury is then grouped based on its stability (Type A — Stable, purely bony injuries; Type B — Tension band failures or ligamentous injuries without evidence of instability; Type C — Vertebral body translation consistent with a fracture subluxation or dislocation). Neurologic status is classified in the same manner as previous AO Spine injury classifications and injury modifiers are assigned when the injury could potentially alter management decisions. However, neither neurologic status nor injury modifiers were evaluated during this classification (Fig. 1).

Classification validation

A total of 275 AO Spine members participated in an international validation of the AO Spine Upper Cervical Injury Classification System. Each participant reviewed a tutorial video in English prior to the validation (https://www.youtube.com/watch?v=KyUYfa_JMb4). All participants then completed a sample validation of three cases with feedback from the instructor, who was an original creator of the classification system. After training completion, the official validation was conducted via a live, online webinar format [9]. The validation consisted of 25 computed tomography (CT) videos, which consisted of axial, sagittal, and coronal cuts of upper cervical spine injuries. The video was viewed once by each participant who was provided with associated radiographic key images. An online REDCap survey stored all answers for statistical analysis. Three weeks were given between the first and second assessment. Prior to the second assessment, the cases were re-randomized.

Table 1
Demographics of the participants in the AO Spine Upper Cervical Injury Classification.

Survey Demographics		N (%)
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 center	5 (1.8)

Gold standard committee

Members of the AO Spine Knowledge Forum Trauma, which included original creators of the classification system, formed the gold standard committee. All injury classifications reached unanimous consensus from the committee prior to distribution to the study participants. Any injury without consensus agreement was resolved through live webinar meetings where a discussion was held to achieve unanimous agreement.

Statistics

Each study participant was grouped based on their work setting (academic, hospital-employed, or private practice) and their trauma center affiliation (Level I, Level II or III, and Level IV or no trauma center). Each study participant was then evaluated based on the percentage of injuries they correctly classified.

Kappa coefficients (κ) were calculated based on the classification agreement between study participants (interobserver reliability) and the same participant (intraobserver reproducibility). All kappa values used Fleiss' Kappa coefficient, which allows for missed ratings and comparisons between multiple validation members [10]. Interpretation of the reliability and reproducibility was based on the Landis and Koch convention, which categorizes Kappa values as "slight" (0–0.2), "fair" (>0.2 - 0.4), "moderate" (>0.4 - 0.60), "substantial" (>0.6 - 0.8), and "excellent" (>0.8–1.0) [11]. Pearson's chi square test or Fisher's exact test was utilized to screen for potentially relevant associations.

Results

The validation consisted of 25 upper cervical spine injuries, which were evaluated by 275 study participants. Most study participants worked in an academic environment ($N = 120$, 43.6%) or were hospital-employed ($N = 120$, 43.6%), while the remainder worked in private practice ($N = 35$, 12.7%). Additionally, most participants were affiliated with level I trauma centers ($N = 192$, 69.8%), but 66 (24%) were affiliated with level II/III center and 17 (6.2%) were affiliated with either a level IV trauma center or no trauma center (Table 1). Each injury subtype was validated a minimum of two times with the exception of IB injuries, which could not be evaluated since they were not included in the AO Spine imaging database (Supplemental Data 1).

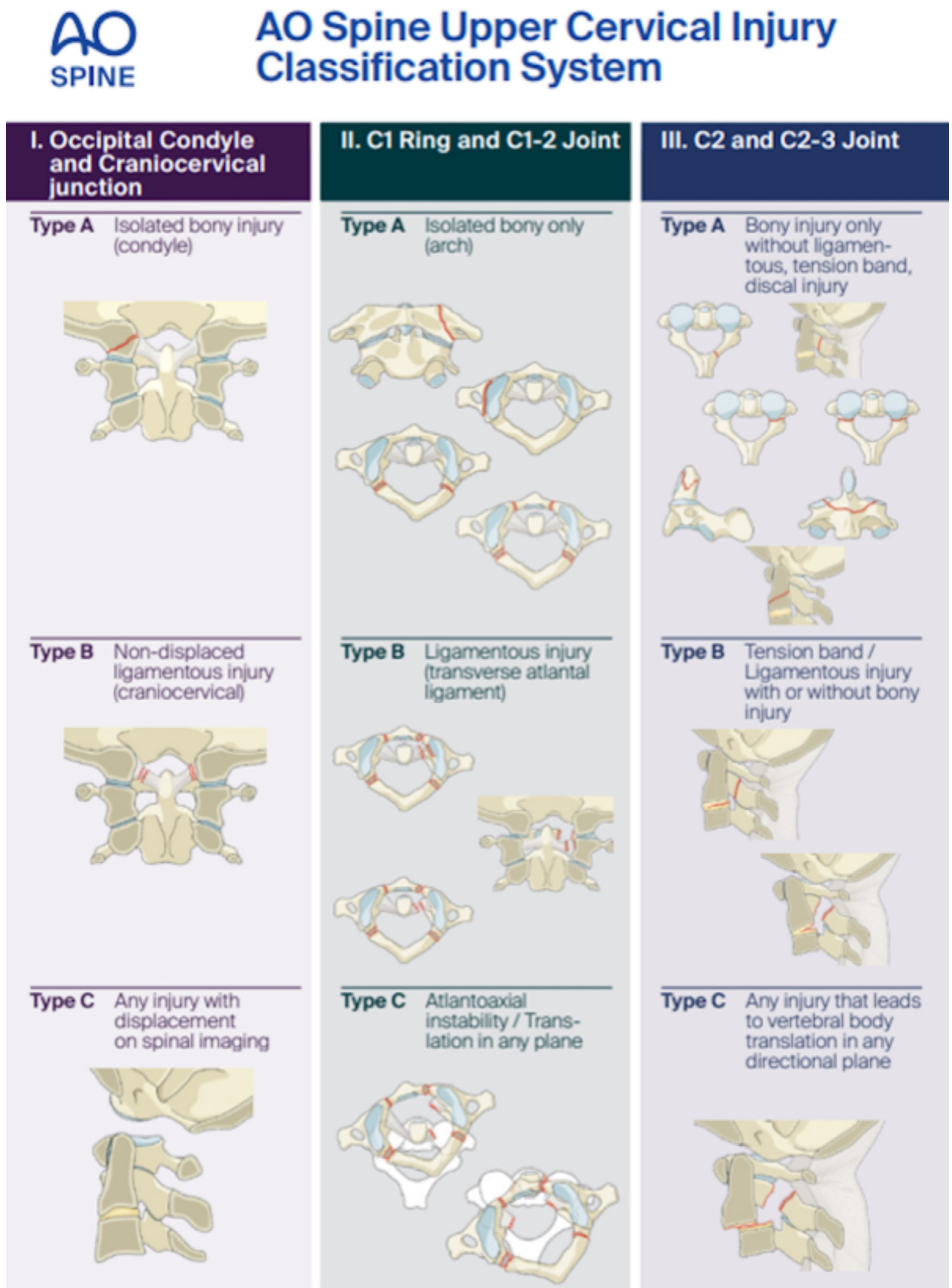

Fig. 1. Pictorial representation of the AO Spine Upper Cervical Injury Classification. The classification is based on injury location (occipital condyle and craniocervical junction, C1 ring and C1–2 joint, and C2 and C2–3 joint) and injury type (bony, tension band, ligamentous with translation). Permission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

Classification accuracy

When evaluating work setting, study participants affiliated with an academic practice or working in a hospital were significantly more likely to correctly classify type IIIB injuries on assessment one (p_1=0.0146) and assessment two (p_2=0.0015), compared to those in a private practice. Broader differences emerged when evaluating classification accuracies based on trauma center affiliation. The overall classification accuracy for participants affiliated with a level I trauma center was significantly greater than participants affiliated with a level II/III center or a level IV/no trauma center on assessment one (p_1<0.0001) and assessment two (p_2=0.0003). On both assessments, surgeons affiliated with a level I or a level II/III trauma center were significantly more accurate at identifying IIIA (assessment 1: p_1=0.0138; assessment 2: p_2=0.0008) and IIIB injury types (p_1=0.0007; p_2=0.0064) when compared to surgeons affiliated with a level IV/no trauma center. Although there were statistically greater classification accuracies for level I affiliated spine surgeons when assessing type IC injuries (p_1=0.0251) and type IIB injuries (p_1=0.0016) on assessment one, these did not persist on assessment two (p_2=0.3420 and p_2=0.0715, respectively) (Table 2).

When stratifying by injury location alone and by injury type alone, work setting did not significantly affect the classification accuracy for injury location (p_1=0.2435l) or injury type (p_1=0.1322) in assessment 1. However, significant differences in injury location accuracy were found on assessment two (p_2<0.0001) between groups due to the lower accuracy of private practice surgeons abil-

Table 2
Proportion and percent of correctly classified injuries based on the surgeons work affiliation and trauma center setting.

First Assessment								
Work Setting					**Trauma Center**			
Injury Classification	*Academic C/N (%)*	*Hospital Employed C/N (%)*	*Private Practice C/N (%)*	*P-value*	*Level I C/N (%)*	*Level II/III C/N (%)*	*Level IV/ No trauma C/N (%)*	*P-value*
Overall	2268/2811 (80.7)	2098/2646 (79.3)	570/740 (77.0)	0.0741	3515/4318 (81.4)	1137/1491 (76.3)	284/388 (73.2)	**<0.0001***
IA	184/227 (81.1)	177/210 (84.3)	54/59 (91.5)	0.1454	289/345 (83.8)	99/120 (82.5)	27/31 (87.1)	0.8232
IC	210/225 (93.3)	194/213 (91.1)	53/60 (88.3)	0.4065	324/346 (93.6)	107/120 (89.2)	26/32 (81.2)	**0.0251***
IIA	357/446 (80.0)	333/425 (78.4)	93/116 (80.2)	0.8039	549/689 (79.7)	186/236 (78.8)	48/62 (77.4)	0.8922
IIB	318/453 (70.2)	287/424 (67.7)	83/120 (69.2)	0.7237	503/694 (72.5)	147/240 (61.2)	38/63 (60.3)	**0.0016***
IIC	146/226 (64.6)	139/213 (65.3)	30/59 (50.8)	0.1080	227/347 (65.4)	71/120 (59.2)	17/31 (54.8)	0.2856
IIIA	382/450 (84.9)	358/422 (84.8)	97/120 (80.8)	0.5222	597/690 (86.5)	192/239 (80.3)	48/63 (76.2)	**0.0138***
IIIB	242/336 (72.0)	222/317 (70.0)	50/89 (56.2)	**0.0146***	376/517 (72.7)	116/179 (64.8)	22/46 (47.8)	**0.0007***
IIIC	429/448 (95.8)	388/422 (91.9)	110/117 (94.0)	0.0625	650/690 (94.2)	219/237 (92.4)	58/60 (96.7)	0.3981
Second Assessment								
Injury Classification	**Work Setting**				**Trauma Center**			
	Academic C/N (%)	*Hospital Employed C/N (%)*	*Private Practice C/N (%)*	*P-value*	*Level I C/N (%)*	*Level II/III C/N (%)*	*Level IV/ No trauma C/N (%)*	*P-value*
Overall	1921/2368 (81.1)	1795/2295 (78.2)	543/741 (73.3)	**<0.0001***	2980/3725 (80.0)	1034/1335 (77.5)	245/344 (71.2)	**0.0003***
IA	155/190 (81.6)	149/185 (80.5)	46/60 (76.7)	0.7043	243/299 (81.3)	87/108 (80.6)	20/28 (71.4)	0.4542
IC	173/189 (91.5)	163/184 (88.6)	52/60 (86.7)	0.4685	270/298 (90.6)	92/107 (86.0)	26/28 (92.9)	0.3420
IIA	317/377 (84.1)	295/366 (80.6)	96/118 (81.4)	0.4462	492/593 (83.0)	178/214 (83.2)	38/54 (70.4)	0.0623
IIB	265/381 (69.6)	247/366 (67.5)	71/117 (60.7)	0.2010	418/598 (69.9)	130/211 (61.6)	35/55 (63.6)	0.0715
IIC	122/190 (64.2)	120/183 (65.6)	31/59 (52.5)	0.1820	187/298 (62.8)	69/107 (64.5)	17/27 (63.0)	0.9501
IIIA	328/378 (86.8)	297/365 (81.4)	96/119 (80.7)	0.0884	504/595 (84.7)	181/212 (85.4)	36/55 (65.5)	**0.0008***
IIIB	220/285 (77.2)	203/278 (73.0)	52/90 (57.8)	**0.0015***	333/449 (74.2)	118/162 (72.8)	24/42 (57.1)	0.0604
IIIC	341/378 (90.2)	321/368 (87.2)	99/118 (83.9)	0.1455	533/595 (89.6)	179/214 (83.6)	49/55 (89.1)	0.0693

Abbreviations: Correct (C) – total number of correct responses; (N) - total number of injury films evaluated.
* Indicates statistical significance with $P<0.05$.

ity to correctly classify location I (p_2=0.0038), II (p_2=0.0002), or III (p_2=0.003) injuries. Private practice surgeons also had a lower classification accuracy when evaluating injury type (p_2=0.0029) predominantly due to lower accuracy when classifying type B injuries (p_2=0.012). When evaluating trauma centers, surgeons affiliated with level I centers were most likely to correctly identify the injury based on its location (p_1=0.0104; p_2=0.0006) and injury type ($p_1<0.0001$; p_2=0.0280), although the effect sizes were mostly rather small. (Supplemental Data 2).

Interobserver reliability

Surgeons in an academic practice had substantial interobserver reliability on both assessments (κ_1=0.644; κ_2=0.650), while private practice surgeons had moderate reliability on both assessments (κ_1=0.593; κ_2=0.515). Hospital-employed physicians had substantial reliability on assessment one (κ_1=0.624) and moderate reliability on assessment two (κ_2=0.599). When evaluating injury subtypes based on work setting, the largest differences between academic and private practice work settings was identified for type IIIB injuries. When analyzing surgeons' interobserver reliability based on their trauma center affiliation, surgeons affiliated with level I centers had substantial reliability on both assessments (κ_1=0.655; κ_2=0.630), while surgeons affiliated with a level II/III (κ_1=0.578; κ_2=0.589) or level IV/no trauma center (κ_1=0.556; κ_2=0.494) had moderate reliability. Similar to our findings based on work setting, the largest differences in reliability for surgeons based on their trauma center affiliation was for type IIIB injuries (Table 3).

When sub-analyzing the injuries based on injury location and injury type, academic surgeons (κ_1=0.862; κ_2=0.860) and hospital employed surgeons (κ_1=0.855; κ_2=0.829) had excellent reliability for injury location on both assessments, while private practice surgeons had excellent reliability on assessment one (κ_1=0.819) and substantial reliability on assessment two (κ_1=0.706). On analysis of injury types, each group had moderate reliability on assessment 1 with only academic surgeons reaching substantial reliability on assessment two (κ_1=0.605) (Supplemental Data 3). Some differences emerged when evaluating trauma center affiliation, with only surgeons at level I (κ_1=0.870; κ_1=0.842) or level II/III (κ_1=0.825; κ_1=0.807) centers having excellent reliability when classifying injury location. When evaluating injury type, only level I trauma center affiliated surgeons reached substantial reliability on assessment one (κ_1=0.616), while all groups achieved moderate reliability on assessment two (Supplemental Data 3).

Intraobserver reproducibility

Injury classification reproducibility was on average substantial for academic surgeons (κ=0.73 ± 0.18), hospital employed surgeons (κ=0.69 ± 0.20), and private practice surgeons (κ=0.67 ± 0.21). Reproducibility was also on average substantial for surgeons affiliated with a level I trauma center (κ=0.73 ± 0.17) and level II/III center (κ=0.66 ± 0.25), but it was moderate for surgeons at a level IV/no trauma affiliation (κ=0.60 ± 0.15). When assessing the amount of surgeons who obtained excellent intraobserver reproducibility, academic surgeons (p = 0.0445) and surgeons affiliated with a level I trauma center (p = 0.0324) were the most likely to achieve excellent reproducibility (Table 4).

Discussion

An ideal injury classification should be reliable and reproducible, although underlying demographics may alter the classification reliability. The frequency at which a surgeon evaluates spine injuries, and their associated exposure to upper cervical spine injuries, may be one factor that impacts classification reliability. Improving our understanding of how demographic factors affect clas-

Table 3
Interobserver reliability of the AO Spine Upper Cervical Injury Classification System based on the surgeons work setting and trauma center affiliation.

First Assessment						
Injury Classification	**Work Setting**			**Trauma Center Level**		
	Academic (κ)	*Hospital Employed (κ)*	*Private Practice (κ)*	*I (κ)*	*II/III (κ)*	*IV/No Trauma (κ)*
Overall	0.644	0.624	0.593	0.655	0.578	0.556
IA	0.732	0.760	0.778	0.755	0.755	0.674
IC	0.873	0.860	0.802	0.889	0.798	0.773
IIA	0.591	0.572	0.618	0.610	0.544	0.528
IIB	0.484	0.469	0.453	0.514	0.393	0.340
IIC	0.469	0.444	0.367	0.472	0.407	0.301
IIIA	0.703	0.689	0.625	0.713	0.639	0.633
IIIB	0.565	0.531	0.380	0.578	0.439	0.360
IIIC	0.831	0.781	0.730	0.812	0.751	0.790
Second Assessment						
Injury Classification	**Work Setting**			**Trauma Center Level**		
	Academic (κ)	*Hospital Employed (κ)*	*Private Practice (κ)*	*I (κ)*	*II/III (κ)*	*IV/No Trauma (κ)*
Overall	0.650	0.599	0.515	0.630	0.589	0.494
IA	0.728	0.699	0.631	0.725	0.707	0.493
IC	0.877	0.829	0.757	0.852	0.822	0.781
IIA	0.634	0.575	0.539	0.620	0.579	0.444
IIB	0.480	0.434	0.355	0.471	0.386	0.399
IIC	0.472	0.493	0.351	0.472	0.468	0.377
IIIA	0.710	0.653	0.577	0.681	0.670	0.508
IIIB	0.590	0.531	0.360	0.562	0.508	0.343
IIIC	0.822	0.762	0.614	0.782	0.734	0.710

Table 4
Intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System based on surgeon work setting and trauma center affiliation.

Level of Agreement	Work Setting				Trauma Center Level			
	AcademicN (%)	Hospital EmployedN (%)	Private PracticeN (%)	P-value	IN (%)	II/IIIN (%)	IV/No TraumaN (%)	P-value
Slight (<0.2)	1 (1.1)	3 (3.5)	1 (3.9)	0.4358	2 (1.4)	3 (5.8)	0	0.2799
Fair (0.2–0.40)	4 (4.3)	5 (5.8)	1 (3.9)	0.8931	7 (5.0)	2 (3.9)	1 (7.7)	0.7411
Moderate (>0.40–0.60)	14 (15.1)	14 (16.1)	4 (15.4)	0.9815	14 (9.9)	13 (25.0)	5 (38.5)	**0.0023***
Substantial (>0.60–0.80)	30 (32.3)	35 (40.2)	14 (53.9)	0.1206	57 (40.4)	16 (30.8)	6 (46.2)	0.3954
Excellent (>0.80–1.0)	44 (47.3)	30 (34.5)	6 (23.1)	**0.0445***	61 (43.3)	18 (34.6)	1 (7.7)	**0.0324***

* Indicates statistical significance with $P<0.05$.

sification accuracy and reliability may provide an opportunity to provide global education, thereby, improving classification generalizability. The results of our study suggest that academic surgeons and hospital-employed surgeons generate high classification accuracies with greater interobserver reliability than private practice surgeons. Additionally, surgeons affiliated with a high-level trauma center (I or II/III) have the greatest interobserver reliability and classification accuracy. Type IIIB injuries are the most difficult injuries to accurately and reliably classify.

When evaluating a surgeon's work setting and trauma center affiliation, granular analysis of specific injury types demonstrated that IIIB injuries resulted in the most disparity in classification accuracy and surgeon reliability. These injury types are visualized on CT scans as complex C2 coronal fractures with variable extension into the pars or lamina depending on the mechanism of injury as depicted by Benzel [6]. In this classification, the fracture characteristics are linked to the mechanism of injury, which includes an extension with axial load variant. This is more commonly labeled an atypical hangman's fracture (IIIB injury as classified by the AO Spine Upper Cervical Injury Classification System due to a tension band failure mechanism). The remaining injury mechanisms described by Benzel include flexion with axial load, flexion distraction, and hyperextension with axial load injuries, which predominantly result in AO Spine Type C injuries, due to vertebral body translation resulting from either intervertebral disk ruptures or avulsion fractures of the longitudinal ligaments [6]. Since nearly all IIIB injuries are the result of high energy mechanism trauma (motor vehicle collisions or falls from height), these injury types are unlikely to be encountered by a private practice surgeon or surgeons without a high-level trauma center affiliation, likely resulting in their lower classification accuracy and reliability [6]. IIIA injuries were also commonly incorrectly classified by surgeons affiliated with low-level trauma centers, although this is likely because they were frequently classified as IIIB injuries.

The accuracy and reliability of applying the AO Spine Upper Cervical Injury Classification System to atlas injuries was lower than occipital condyle/craniovertebral junction or C2 vertebrae injuries, even though the injury incidence of atlas fractures is increasing [2]. Although this may be partially due to the inherent complexity of atlas fractures given that the reliability of the Gehweiler classification (a descriptive classification for atlas injuries) was recently demonstrated as moderate ($k = 0.50$), our study suggests that minimal differences in classification accuracy or reliability exist for IIA or IIC injuries [12]. Instead type IIB injuries, which can be treated with divergent management pathways (conservative versus operative), may be uncommonly encountered and require additional trauma experience or tailored education to optimize classification accuracy [13]. Additionally, if surgeons choose to supplement CT scans with magnetic resonance imaging (MRI), additional information may be obtained which could improve the classification accuracy [14]..

Although the goal of AO Spine is to improve accessibility of the injury classification to an international group of spine surgeons, some of which have limited access to MRI, an MRI may supplement the CT scan and improve injury diagnosis and potentially classification accuracy [14–16]. In the event that MRI scans become more accessible to low income global regions, MRI scans may be a useful supplement to CT scans, without requiring any alteration to the AO Spine Upper Cervical Injury Classification System since the current classification accounts for ligamentous disruption. However, in order to standardize the assessment across all international regions, MRI scans were not provided during this validation assessment.

Some additional limitations were present that merit discussion. First, study participants were solely comprised of AO Spine members who may have a better understanding of AO Spine principles than the non-AO spine surgeons. Second, type IB injuries were not included in the assessment because this injury type was not available in the AO Spine imaging database. Additional differences in classification accuracy and reliability based on surgeons' work settings and trauma center affiliation may exist for this injury type. Finally, the training session was limited to English so differences in fluency may have altered the validation accuracy and reliability.

Conclusion

Type B injuries may be more complex injury patterns that are more often correctly categorized when evaluated by academic surgeons, hospital-employed surgeons, and surgeons associated with higher-level trauma centers (I or II/III). Additional education on how to correctly classify complex injury types (Type B and C injuries) may improve the overall classification accuracy, reliability, and generalizability of the AO Spine Upper Cervical Injury Classification System, especially for surgeons who do not frequently encounter these injury types.

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Elizabeth Boudreau	Gabriel Lacerda	Paterakis Konstantinos
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Devi Prakash Tokala	Hossein Elgafy	Ketan Badani
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Declaration of conflict of interest

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 medically guided not-for-profit organization. Study support was provided directly through the AO Spine Research Department.

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 medically guided not-for-profit organization. Study support was provided directly through AO Network Clinical Research.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2022.08.030.

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