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Clinical Study

AO Spine upper cervical injury classification system: a description and reliability study

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Abstract

BACKGROUND CONTEXT: Prior upper cervical spine injury classification systems have focused on injuries to the craniocervical junction (CCJ), atlas, and dens independently. However, no previous system has classified upper cervical spine injuries using a comprehensive system incorporating all injuries from the occiput to the C2−3 joint.

PURPOSE: To (1) determine the accuracy of experts at correctly classifying upper cervical spine injuries based on the recently proposed AO Spine Upper Cervical Injury Classification System (2) to determine their interobserver reliability and (3) identify the intraobserver reproducibility of the experts.

STUDY DESIGN/SETTING: International Multi-Center Survey.

PATIENT SAMPLE: A survey of international spine surgeons on 29 unique upper cervical spine injuries.

OUTCOME MEASURES: Classification accuracy, interobserver reliability, intraobserver reproducibility.

METHODS: Thirteen international AO Spine Knowledge Forum Trauma members participated in two live webinar-based classifications of 29 upper cervical spine injuries presented in random order, four weeks apart. Percent agreement with the gold-standard and kappa coefficients (ƙ) were calculated to determine the interobserver reliability and intraobserver reproducibility.

RESULTS: Raters demonstrated 80.8% and 82.7% accuracy with identification of the injury classification (combined location and type) on the first and second assessment, respectively. Injury classification intraobserver reproducibility was excellent (mean, [range] ƙ=0.82 [0.58-1.00]). Excellent interobserver reliability was found for injury location (ƙ = 0.922 and ƙ=0.912) on both assessments, while injury type was substantial (ƙ=0.689 and 0.699) on both assessments. This correlated to a substantial overall interobserver reliability (ƙ=0.729 and 0.732).

CONCLUSIONS: Early phase validation demonstrated classification of upper cervical spine injuries using the AO Spine Upper Cervical Injury Classification System to be accurate, reliable, and reproducible. Greater than 80% accuracy was detected for injury classification. The intraobserver reproducibility was excellent, while the interobserver reliability was substantial.

Keywords: AO Spine; Cervical spine; Atlas; Dens; Occipital condyle; Craniovertebral junction; Reliability

Introduction

The AO Spine injury classification systems divide the spinal column into four regions based on their respective biomechanical responsibilities and inherent stability of the spinal segment: upper cervical, subaxial cervical, thoracolumbar, and sacral. The upper cervical spine is heavily reliant on ligamentous attachments for its stability due to the unique anatomy required to provide flexion at the craniocervical junction (CCJ) and rotation at the atlantoaxial joint. The stability of the CCJ is mainly attributed to the articulation between the occipital condyle and superior articular process of the atlas, but the alar ligaments, tectorial membrane, capsular joint ligaments, and anterior and posterior atlanto-occipital membranes provide secondary restraint to dislocation [1,2]. The atlantoaxial joint predominantly obtains its stability during physiologic load through the transverse atlantal ligament and longitudinal ligaments [3,4]. The last joint in the upper cervical spine, the C2−3 joint, can be thought of as a transitional zone between the upper cervical and subaxial spine.

AO Spine classifications pertaining to the cervical spine are based on functional requirements of the spinal segment, with the upper cervical spine further subcategorized into three regions: (I.) Occipital condyle and craniocervical articulation, (II.) C1 ring and C1−2 joint, and (III.) C2 vertebrae and C2−3 joint. One of the strengths of classifying the upper cervical spine by the bone/vertebra and its caudal joint is its ease of understanding, descriptive nature, and proven reliability in classifying injuries as stable (isolated bony injury), potentially unstable (tension band injuries or ligamentous disruption without displacement of the vertebral body), or unstable (ligamentous or disc injuries with translation of the vertebral body). Further, it allows for a simple, comprehensive, and management-driven classification system where stable injury patterns are managed nonoperatively and unstable injuries require operative management. There are some exceptions to this rule, and these are qualified within the modifiers of the AO Spine Upper Cervical Injury Classification System. Although previous upper cervical spine classification systems have been adopted, most focus solely on the occipital condyles [5,6], the craniocervical articulation [7,8], atlas [9], dens [10], C2 ring [11], or C2−3 joint independently [12], which requires knowledge of many classification systems. Further, they are predominantly descriptive without algorithmic guidance for injury management.

As physicians have transitioned from sharing knowledge on a local to a global platform, it is prudent to have a singular and internationally comprehensive classification system. Previous validation studies by the AO Spine [13,14] and independent parties [15−21] have shown a high level of inter- and intraobserver reliability of the AO Spine classification systems. In this study, we perform an early phase validation of the AO Spine Upper Cervical Injury Classification System using an international group of surgeons within the AO Spine Knowledge Forum Trauma. We hypothesize that the AO Spine Upper Cervical Injury Classification System will demonstrate a high level of intraobserver reproducibility and interobserver reliability, which are both necessary to be clinically used and scientifically accepted.

Methods

The AO Spine Knowledge Forum Trauma has created a comprehensive classification of upper cervical spine injuries after evaluation of a database of upper cervical spinal trauma cases, which were viewable in a digital imaging and communications in medicine (DICOM) database. The creators of the classification system underwent multiple iterations of classification design based on Knowledge Forum Trauma feedback. This allowed for classification reliability and reproducibility optimization and minimized classification complexity.

Once the Knowledge Forum Trauma reached unanimous agreement on the final version of the classification system, illustrative material to describe each item of the classification was provided to each member. After that, a compilation of 34 upper cervical spine trauma cases with CT scans from the DICOM database were analyzed. Each validation case analyzed by the Knowledge Forum Trauma was a unique case, which had not been previously utilized in compiling the classification system. Five of these cases were used in an instructional video to demonstrate accurate application of the AO Spine Upper Cervical Injury Classification System and these cases were excluded from the final validation, leaving a total of twenty-nine cases. The AO Spine Upper Cervical Injury Classification System describes injuries primarily based on anatomic location, injury type, injury specific modifiers, and neurologic status consistent with previous AO Spine injury classifications [13,14,22].

Overview of the classification system

Anatomic location and injury type

Injury location is divided into one of three upper cervical spine segments: (I.) occipital condyle and craniocervical junction (atlanto-occipital joint), (II.) C1 ring and C1−2 joint, and (III.) C2 and C2−3 joint. Within these three upper cervical segments, the injury type is assigned as A (isolated bony fractures − stable injuries), B (ligamentous disruption or tension band injury − indeterminate stability or potentially unstable), or C (translation of the entire vertebrae − unstable). Because the classification is based on CT scans, type B injuries were identified as either tension band or ligamentous avulsion injuries because nondisplaced purely ligamentous injuries cannot be identified on CT alone.

For location I injuries, (A) is designated to isolated occipital condyle fractures, (B) is reserved for nondisplaced craniocervical ligamentous injuries or avulsion fracture of the craniocervical ligaments, and (C) requires subluxation or dislocation of the occiput from the atlanto-occipital joint. For location II injuries, (A) is an isolated atlas fracture, (B) is a non-displaced transverse atlantal ligament injury or avulsion fracture of the transverse atlantal ligament, and (C) requires translation of the entire atlas in any plane. Finally, for location III injuries, (A) is an injury to the axis without a soft tissue injury (no discal or ligamentous injury), (B) is a non-displaced soft tissue injury with or without a bony fracture, and (C) requires displacement of the entire C2 ring in any direction or C2−3 subluxation (Figure). Utilization of these injury designations was guided by previous AO Spine injury classifications, which have consistently produced high intraobserver reproducibility and interobserver reliability scores [13,14,22].

Injury modifiers and neurologic status

The injury classification modifiers are based on specific injury characteristics. M1 is used for injuries at high risk of non-union without operative management, M2 injuries are at high risk for instability, M3 is used for patient specific characteristics, which may affect management, and M4 is used for any vascular injury, which may affect management (Figure). A neurologic scale, concordant with all prior AO Spine injury classification schemes, is used to further aid in injury management and classification. If no neurologic deficit is present, the injury is an N0. If a neurologic injury resolves it is an N1. A patient with continued radicular symptoms is given an N2 status. An incomplete spinal cord injury is an N3 and a complete spinal cord injury is designated as N4. If the patient cannot be examined due to additional injuries, they are assigned an Nx (Figure).

Study protocol

Nineteen participants were involved in the study. Six members comprised a “gold standard” committee and were tasked with obtaining unanimous agreement on each case before case distribution. The gold standard committee consisted of three original creators of the classification system (all orthopedic spine surgeons). The remaining three members included one orthopedic spine surgeon, one neurosurgeon, and one orthopedic spine fellow. They had an average post-fellowship surgeon experience of 13.8± 10.9 years. Although the gold standard committee was used to evaluate validation study members’ classification accuracy, they did not participate in the validation. Thus, they

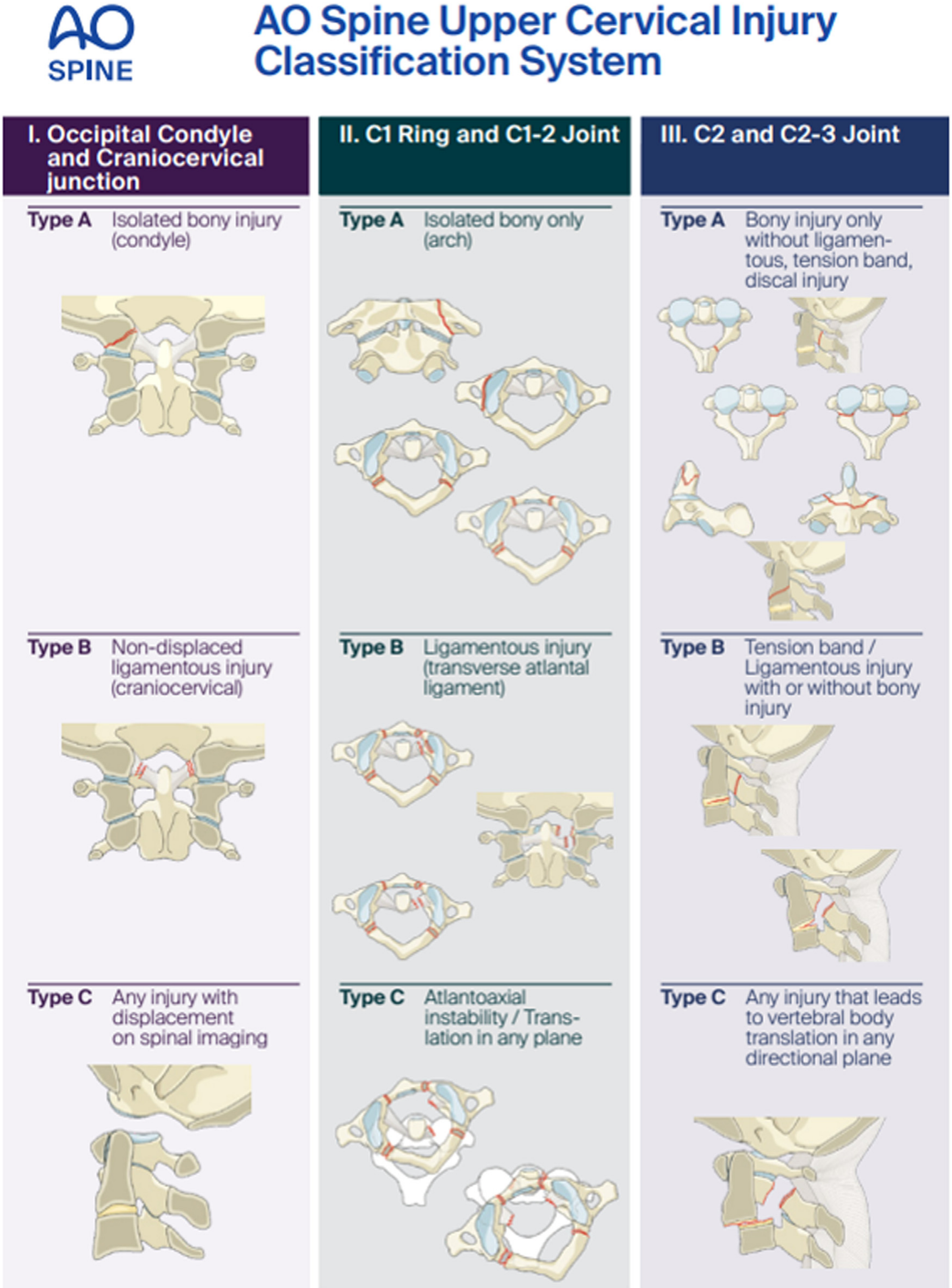

Figure. Depiction of the AOSpine Upper Cervical spine injury classification. The injury classification is determined by the injury location (occipital condyle and craniocervical junction, C1 ring and C1−2 joint, and C2 and C2−3 joint) and the injury type (bony, tension band, ligamentous). Permission to use this figure was granted by the AO Foundation, AO Spine, Switzerland.

were not assigned reliability and reproducibility scores. The remaining thirteen participating members of the validation study graded cases with their answers counting towards the classification systems' reliability and reproducibility. The average experience of the validation members was 17.4± 7.0 years.

During the live webinar-based reliability study, 29 cases with key images were provided, while CT scans played at a rate of two frames/second. An online survey was used to capture the rater's classification of injury location and injury type. Four weeks was allotted between the first and second assessments and cases were presented in randomized order. Neither the neurologic status, nor the modifiers, were assessed because no patient related information was provided to the study participants.

Statistics

Absolute and relative frequencies of raters' agreement with the gold standard injury classifications for anatomic location (I, II, or III), type of injury (A, B, or C), and combined assessment of location and type were tabulated. Fleiss' Kappa coefficient (ƙ) was calculated to obtain anatomical location, injury type, and overall classification agreement between validation members (interobserver reliability) and consistency of the validation members' repeated ratings made one month apart (intraobserver reproducibility). Descriptive summary statistics were calculated across the individual raters' intraobserver reproducibility coefficients. In the interpretation of reliability and reproducibility results, the Landis and Koch convention was used to categorize 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) [23].

Results

The distribution of injuries evaluated by members of the AO Spine Knowledge Forum Trauma is shown in Table 1. Overall, the validation members had an 80.8% accuracy with overall classification on assessment 1 and an 82.7% accuracy on assessment 2. The accuracy of classifying anatomic location was 96.8% and 97.1% on assessment 1 and 2, respectively, while accuracy of characterizing injury type was 83.5% and 84.8%. Additionally, Type B injuries were the most difficult injury type to accurately identify on both assessment 1 and 2 (71.2%, 72.8%) compared with type A (93.5%, 94.2%) and type C injuries (81.2%, 82.9) (Table 2).

Table 1
Distribution of injury types assigned to our validation members. The injury classification was determined by unanimous agreement from our "gold standard" committee

Injury classification	Distribution (%)
IA	2/29 (6.9)
IB	0/29 (0)
IC	2/29 (6.9)
IIA	5/29 (17.2)
IIB	4/29 (13.8)
IIC	2/29 (6.9)
IIIA	5/29 (17.2)
IIIB	4/29 (13.8)
IIIC	5/29 (17.2)

Table 2
Percent of validation members who correctly identified the injury classification, injury location, and injury type based on the first and second assessments

Injury classification	Correct on first assessment (%)	Correct on second assessment (%)
Globally	**303/375 (80.8)**	**311/376 (82.7)**
IA	**22/26 (84.6)**	**25/26 (96.2)**
IC	**25/26 (96.2)**	**23/26 (88.5)**
IIA	**59/64 (92.2)**	**62/65 (95.4)**
IIB	**36/52 (69.2)**	**35/51 (68.6)**
IIC	**11/26 (42.3)**	**17/26 (65.4)**
IIIA	**61/64 (95.3)**	**57/65 (87.7)**
IIIB	**38/52 (73.1)**	**39/52 (75)**
IIIC	**51/64 (78.5)**	**53/65 (81.5)**
Injury location	**Correct on first assessment (%)**	**Correct on second assessment (%)**
Globally	363/375 (96.8)	365/376
I	51/52 (98.1)	49/52 (94.2)
II	132/142 (93)	138/142 (97.2)
III	180/181 (99.4)	178/182 (97.8)
Injury type	**Correct on first assessment (%)**	**Correct on second assessment (%)**
Globally	313/375 (83.5)	319/376 (84.8)
A	144/154 (93.5)	147/156 (94.2)
B	74/104 (71.2)	75/103 (72.8)
C	95/117 (81.2)	97/117 (82.9)

Interobserver reliability

The interobserver reliability was classified as substantial on assessment 1 (ƙ=0.729) and on assessment 2 (ƙ=0.732) (Table 3). Sub-stratifying by injury location yielded

Table 3
Interobserver reliability between validation members on the first and second assessment. The reliability was calculated for injury classification with substratification into injury location and type

Injury classification	Interobserver reliability on first assessment	Interobserver reliability on second assessment
Globally	0.729	0.732
IA	0.814	0.957
IC	0.880	0.829
IIA	0.749	0.729
IIB	0.533	0.570
IIC	0.292	0.537
IIIA	0.862	0.768
IIIB	0.668	0.623
IIIC	0.772	0.819
Injury location	**Interobserver reliability on first assessment**	**Interobserver reliability on second assessment**
Globally	0.922	0.912
I	0.934	0.933
II	0.904	0.898
III	0.933	0.915
Injury type	**Interobserver reliability on first assessment**	**Interobserver reliability on second assessment**
Globally	0.689	0.699
A	0.739	0.720
B	0.509	0.565
C	0.792	0.793

excellent interobserver reliability on assessment 1 (ƙ=0.922) and assessment 2 (ƙ=0.912), while agreement on injury type was substantial on assessment 1 (ƙ=0.689) and assessment 2 (ƙ=0.699). Similar to percent agreement, the interobserver reliability for classifying type B injuries was lower on assessment 1 and 2 (ƙ=0.509, ƙ=0.565) compared with type A (ƙ=0.739, ƙ=0.720) and type C (ƙ=0.792, ƙ=0.793) injuries (Table 3).

Intraobserver reproducibility

The overall injury classification intraobserver reproducibility was excellent (mean, [range] ƙ=0.82 [0.58−1.00]) with excellent intraobserver reproducibility for injury location ƙ=0.93 [0.78−1.00] and substantial intraobserver reproducibility for injury type (ƙ=0.80 [0.547−1.00])

This resulted in ten of thirteen participants demonstrating overall injury classification reproducibility in the excellent range, which improved to twelve of thirteen excellent scores when grouping by injury location, but dropped to eight of thirteen when assessing injury type (Table 4).

Discussion

The AO Spine Upper Cervical Injury Classification System categorizes injuries by anatomic location and injury type to provide a simple-to-use classification system. Previous upper cervical spine classifications have either lacked comprehensiveness [5,7] leading to suboptimal management algorithms or have a narrowed scope focusing on a single anatomic region within the upper cervical spine [6,8,10−12]. The results of our validation study demonstrated high overall accuracy when classifying injuries using the AO Spine Upper Cervical Injury Classification System, with greater accuracy associated with identifying injury location compared with injury type. Additionally, excellent and substantial interobserver reliability was demonstrated for injury location and injury type, respectively.

Table 4
Intraobserver reproducibility of members based on injury classification, injury location, and injury type

Injury classification intraobserver reproducibility	Distribution (%)
Slight (<0.2)	0
Fair (0.21−0.4)	0
Moderate (0.41−0.6)	1 (7.7)
Substantial (0.61−0.8)	2 (15.4)
Excellent (0.81 − 1.0)	10 (76.9)
Injury location Intraobserver Reproducibility	Distribution (%)
Slight (<0.2)	0
Fair (0.21−0.4)	0
Moderate (0.41−0.6)	0
Substantial (0.61−0.8)	1 (7.7)
Excellent (0.81 − 1.0)	12 (92.3)
Injury type Intraobserver Reproducibility	Distribution (%)
Slight (<0.2)	0
Fair (0.21−0.4)	0
Moderate (0.41−0.6)	1 (7.7)
Substantial (0.61−0.8)	4 (30.8)
Excellent (0.81 − 1.0)	8 (61.5)

The AO Spine Upper Cervical Injury Classification System is a relatively new classification scheme. However, four senior-level attendings and four neurosurgery residents have previously performed an independent examination of the interobserver reliability and intraobserver reproducibility [17]. They found the classification system can be applied with a high level of intraobserver reproducibility for fracture location when categorized by residents (ƙ=0.830 −0.999) and attendings (ƙ=0.861−0.999). Further, the results demonstrated excellent interobserver reliability for injury site (ƙ=0.862 on first assessment, 0.883 for second assessment) and substantial reliability for injury type (ƙ=0.660 on first assessment, 0.603 for second assessment) [17]. These results are encouraging as surgeons early in their training were able to demonstrate high levels of interobserver reliability and intraobserver reproducibility within the classification system.

One of the main benefits of this classification system is its simplicity. Although the classification is similar to the AO Spine Subaxial Injury Classification System, the absence of facets in the upper cervical spine minimizes classification complexity and improves its reliability and reproducibility as demonstrated by members of the AO Spine Knowledge Forum Trauma and two separate independent validation teams [14−16]. It should be noted that injury types (A, B, C injuries) are similar between the upper cervical and subaxial cervical classification systems and both classification systems have demonstrated high levels of injury type reliability and reproducibility [14,17]. Moreover, the AO Spine Upper Cervical Injury Classification System also benefits from its reliance on computed tomography (CT) scans rather than magnetic resonance imaging (MRI), which allows for easier adoption of the classification globally. Intended to be a global and universal tool to ultimately help guide the management of upper cervical injuries, using MRI would inherently limit its applicability as MRI scans are inaccessible in certain regions of the world [24]. Even in high-income countries, the accessibility of CT scans far outweighs access to MRI machines [25]. However, MRI is certainly advantageous when it is readily available, especially in obtunded patients. Previous literature suggests that MRI identifies cervical spine injuries in an additional 12% of obtunded patients when compared with isolated CT scans, albeit only 6% of those patients have altered treatment plans based on the additional information [26]. Therefore, while the validation was performed without MRIs, the addition of MRI may improve the classification reliability, especially for “gray-zone injuries,” which are commonly classified as type B injuries. Future studies are indicated to understand how the addition of MRIs impacts the classification accuracy and reliability.

Type B injuries merit further discussion due to their lower classification reliability and reproducibility and the uncertainty in future injury management. However, before further discussion on type B injury management, it should first be noted that classification system reliability studies should be performed in a systemic fashion, through iterations based on performance and feedback. As is the case with this study, early phase studies are performed by a small group of experts in the field. If such study demonstrates poor classification reliability or reproducibility, the classification requires alteration before large-scale implementation [27]. If an early phased reliability analysis performed by experts in the field finds that a classification has a high level of reproducibility and reliability, an international validation of the classification by participants' naïve to the schema is performed [28]. If after this validation, the classification continues to perform with high reliability and reproducibility, injury severity scores can be determined through a modified Delphi approach, which can aid in producing a treatment algorithm, such as has previously been performed for the thoracolumbar spine [29,30]. Often, even after the treatment algorithm is produced, a subset of injuries are treated based on surgeon preference [30]. In these cases, additional information from MRI (if available, to determine if the injury is an isolated ligamentous injury) or upright radiographs in a hard collar, can provide additional clues on the stability of the fracture. In instances where a type B injury appears stable after further imaging with MRI or dynamic radiographs, flexion-extension radiographs in clinic can be performed once the pain from the injury has resolved, which will limit inaccuracies due to splinting [31].

Some limitations to this study warrant additional discussion. Although this pilot study demonstrated substantial to excellent reliability and reproducibility overall, there were zero type IB fractures in our database, so these injuries were not evaluated. This is a significant limitation of the study given that type B fractures were the most frequent incorrectly categorized injury and potential catastrophic consequences can occur if these injuries are missed or treated inappropriately. Therefore, future studies should closely examine participant's ability to accurately classify type IB injuries to confirm the generalizability of this fracture classification. This will likely require future research targeted at advanced classification validation via inclusion of hundreds of potential classification users who are naïve to the classification system, but who will ultimately be using the classification as a tool for fracture management. Additionally, although the current study identified high classification reliability and reproducibility, it may actually be underestimated given that participants were only allowed to view each CT video once at a rate of two frames/second. Although this limits some clinical applicability, it is the same methodology used for validation of an international group of classification naïve users. Therefore, the methodology will allow for direct comparisons to this study. Ultimately, the results from these studies will provide the foundation for using the classification schema as a tool to guide injury management through a detailed treatment algorithm.

Conclusion

Our expert panel classified upper cervical spine injuries using the AO Spine Upper Cervical Injury Classification system with accuracy greater than 80%. The intraobserver reproducibility was excellent and the interobserver reliability was substantial. These results indicate the AO Spine Upper Cervical Injury Classification provides a simple, comprehensive, and reliable tool to be used in the classification of upper cervical spine injuries. Further, the classification has similar reliability as previous classification systems, but with the added benefit of combining all upper cervical spine segments into a singular classification system. Additional international validation studies are required to further confirm the reliability of this classification system.

Declarations of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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