Effect of surgical experience and spine subspecialty on the reliability of the AO Spine Upper Cervical Injury Classification System

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OBJECTIVE The objective of this paper was to determine the interobserver reliability and intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System based on surgeon experience (< 5 years, 5–10 years, 10–20 years, and > 20 years) and surgical subspecialty (orthopedic spine surgery, neurosurgery, and "other" surgery).

METHODS A total of 11,601 assessments of upper cervical spine injuries were evaluated based on the AO Spine Upper Cervical Injury Classification System. Reliability and reproducibility scores were obtained twice, with a 3-week time interval. Descriptive statistics were utilized to examine the percentage of accurately classified injuries, and Pearson's chi-square or Fisher's exact test was used to screen for potentially relevant differences between study participants. Kappa coefficients (κ) determined the interobserver reliability and intraobserver reproducibility.

RESULTS The intraobserver reproducibility was substantial for surgeon experience level (< 5 years: 0.74 vs 5–10 years: 0.69 vs 10–20 years: 0.69 vs > 20 years: 0.70) and surgical subspecialty (orthopedic spine: 0.71 vs neurosurgery: 0.69 vs other: 0.68). Furthermore, the interobserver reliability was substantial for all surgical experience groups on assessment 1 (< 5 years: 0.67 vs 5–10 years: 0.62 vs 10–20 years: 0.61 vs > 20 years: 0.62), and only surgeons with > 20 years of experience did not have substantial reliability on assessment 2 (< 5 years: 0.62 vs 5–10 years: 0.61 vs 10–20 years: 0.61 vs > 20 years: 0.59). Orthopedic spine surgeons and neurosurgeons had substantial intraobserver reproducibility on both assessment 1 (0.64 vs 0.63) and assessment 2 (0.62 vs 0.63), while other surgeons had moderate reliability on assessment 1 (0.43) and fair reliability on assessment 2 (0.36).

CONCLUSIONS The international reliability and reproducibility scores for the AO Spine Upper Cervical Injury Classification System demonstrated substantial intraobserver reproducibility and interobserver reliability regardless of surgical experience and spine subspecialty. These results support the global application of this classification system.

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KEYWORDS AO Spine; upper cervical spine; reproducibility; orthopedic spine surgeon; neurosurgeon; reliability; trauma

Upper cervical spine fractures are most commonly identified in two age categories: patients aged 20 to 45 years with high-energy trauma and elderly patients older than 65 years with low-energy injuries.[1] As the proportion of our population becomes older, upper cervical spine injuries will continue to rapidly increase, highlighted by the twofold jump in C2 fractures between 1997 and 2014.[2] Thus, the need for a simple, reliable, and comprehensible classification for upper cervical spine injuries has become paramount.

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Currently, numerous classification systems exist based on each anatomical segment of the upper cervical spine.[3–12] However, memorization and application of each of these schemata are impractical, and few of them provide treatment guidelines. Although descriptive classifications can provide injury designations for research purposes, they often lack the ability to guide injury management, and thus have minimal utility for spine surgeons.[4–11] Therefore, an upper cervical spine classification system that has utility, reliability, and reproducibility for surgeons irrespective of surgical experience and surgical subspecialty would be of great value.

The AO Spine Upper Cervical Injury Classification System is based on identifying the upper cervical spine injury location and determining the injury severity based on injury hierarchy (Fig. 1). Three anatomically distinct regions of the upper cervical spine are present: I) the occipital condyle and craniocervical junction, II) the atlas and C1–2 joint, and III) the axis and C2–3 joint. Progressive injury types are presented within each anatomical segment. Type A injuries only include bony fractures and are thus typically stable injuries. Type B injuries can include avulsion fractures or ligamentous disruption, but no vertebral body translation is present. These injuries may be stable or unstable, but initial conservative treatment may be a practical option. Type C injuries are completely unstable injuries with translation of the entire vertebral body in any plane and require prompt surgical stabilization.

Although this tiered approach to classifying injuries appears practical, the reliability and reproducibility of the classification based on surgical subspecialty and surgeon experience levels are unknown. Therefore, the purpose of this study was to obtain classification accuracy and reliability scores for the AO Spine Upper Cervical Injury Classification System focusing on an international group of surgeons with varying levels of experience and surgical subspecialty training.

Methods

Classification Analysis

The AO Spine Knowledge Forum Trauma created a simple classification for upper cervical spine injuries after scrutinizing a database of upper cervical spine injuries. All injuries were viewable in a de-identified DICOM database. The creators of the classification sought to create a simple classification based on CT scans so the classification could be implemented globally in the event that certain global regions had no access to MRI. Once injuries were assigned in a hierarchical fashion (that could potentially later be used to guide injury management), the classification underwent multiple iterations of classification design based on Knowledge Forum Trauma feedback and internal classification reliability scores.

The methodology behind obtaining reproducibility and reliability scores for an international group of classification-naive users has previously been outlined.[13] For this study specifically, all AO Spine members were solicited to participate in an international reliability and reproducibility study of the AO Spine Upper Cervical Injury Classification System. A total of 275 study participants from open call to 6500 active members agreed to participate. Immediately prior to the study, each participant watched a tutorial video detailing the principles of the AO Spine Upper Cervical Injury Classification System to better understand the classification schema. Subsequently, all participants were provided with three types of upper cervical spine injuries as a "training" set. The participants were first asked to classify the training injuries, and they were then allowed to ask questions to the proctor (one of the original creators of the AO Spine Upper Cervical Injury Classification System) prior to the official study.

The official study consisted of a live, online webinar and included 25 unique CT scan videos that were not previously circulated to AO Spine members. Key images of the injuries were concurrently provided to participants while the CT image was displayed. The CT videos consisted of axial, sagittal, and coronal scans. Each video was played once at a rate of 2 frames/sec. An online REDCap survey captured each member's classification grades. The study participants were grouped into categories based on their surgical experience (< 5 years, 5–10 years, 11–20 years, and > 20 years) and surgical subspecialty (orthopedic spine surgery, neurosurgery, and "other" surgery). The other surgery group composed a combination of orthopedic generalists and orthopedic trauma surgeons who treat spinal injuries. There was a 3-week break after the first assessment, and then the second assessment was administered. The order of presentation of these same 25 unique cases was rerandomized prior to the second assessment to minimize participant recall bias.

Gold Standard Committee

The gold standard committee was composed of members of the AO Spine Knowledge Forum Trauma, which included all of the original creators of the classification system. All injury classifications reached unanimous consensus from the committee. Any classification without initial consensus required live webinar meetings during which a debate could be held prior to unanimous agreement on the classification.

Statistical Analysis

Absolute and relative frequencies of agreement between study participants and the gold standard committee were compared for anatomical location (I, II, or III), injury type (A, B, or C), and combined assessment of location and type. For categorical comparisons between groups (< 5 vs 5–10 vs 10–20 vs > 20 years of experience) or surgical subspecialty (orthopedic spine surgery vs neurosurgery vs other surgery), Pearson's chi-square test or Fisher's exact test was used to screen for potentially relevant associations. Statistical significance was set at $p < 0.05$. Kappa coefficients (κ) were determined based on study participants' agreement with other members (interobserver reliability) or with themselves after a 3-week time interval (intraobserver reproducibility). Intraobserver reproducibility and interobserver reliability were calculated for the overall classification and for anatomical injury location and injury type. All kappa values were based on Fleiss' kappa coefficient, which allows for missed ratings and

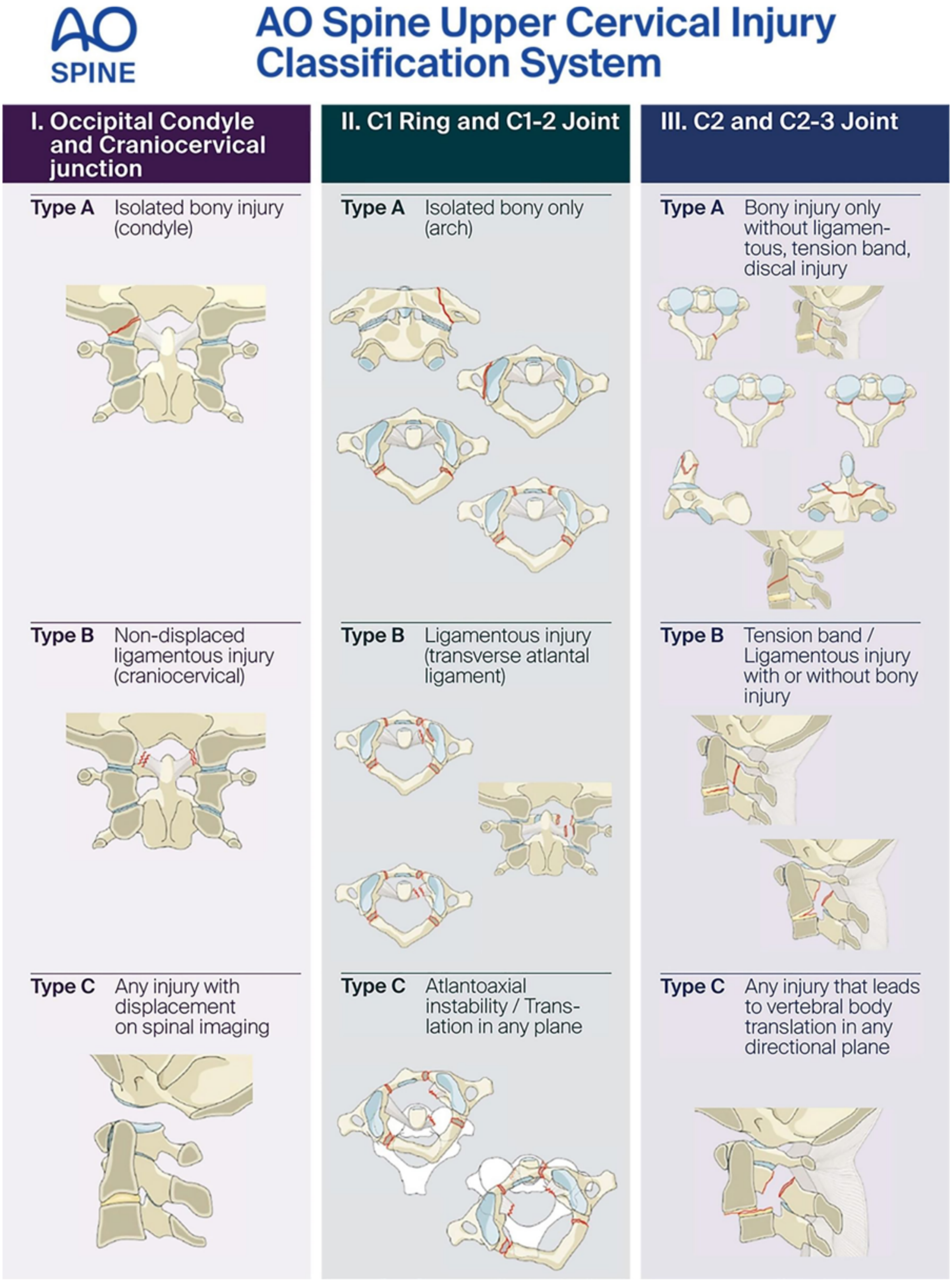

FIG. 1. Depiction of the AO Spine Upper Cervical Injury Classification. The classification is based on injury location (occipital condyle and craniocervical junction, C1 ring and C1–2 joint, and C2 and C2–3 joint) and injury type (bony, tension band, and ligamentous). © 2020 AO Foundation, AO Spine, published with permission. CC BY-NC-ND (https://creativecommons.org/licenses/by-nc-nd/4.0/).

TABLE 1. Total number of upper cervical spine injuries evaluated as categorized by the AO Spine Upper Cervical Injury Classification System

Classification	No. of Validation Cases
Injury location	
I	4
II	10
III	11
Injury type	
A	10
B	7
C	8
Injury subtype	
IA	2
IB	0
IC	2
IIA	4
IIB	4
IIC	2
IIIA	4
IIIB	3
IIIC	4

comparisons between study participants.[14] Interpretation of the reliability and reproducibility results was based on the Landis and Koch convention as follows: slight (< 0.2), fair (0.2–0.4), moderate (0.41–0.60), substantial (0.61–0.8), and excellent (0.81–1.0).[15]

Results

A total of 275 AO Spine members comprising 168 (61.1%) orthopedic surgeons, 100 (36.4%) neurosurgeons, and 7 (2.5%) other surgeons were included in the reliability and reproducibility study for the AO Upper Cervical Spine Injury Classification, which resulted in 6197 and 5404 case assessments during the first and second assessments, respectively. Of the 275 participants, 264 (96.0%) fully completed the survey, while 11 (4.0%) participants only partially completed the survey. In total, 71 (25.8%) participants were in practice for < 5 years, 77 (28%) between 5 and 10 years, 82 (29.8%) between 11 and 20 years, and 45 (16.4%) > 20 years. Of the 25 CT scan videos, there were 10 type A injuries, 7 type B injuries, and 8 type C injuries, with the most commonly evaluated region being the C2 peg/ring and C2–3 joint (Table 1). Each injury film evaluated was described and classified according to previous upper cervical spine injury classifications in Supplemental Appendix A.

Comparison to the Gold Standard—Surgical Experience

When evaluating the effect of surgical experience (< 5 years, 5–10 years, 11–20 years, and > 20 years) on percentage agreement to the gold standard, surgeons with < 5 years of experience exhibited a slightly greater percentage agreement (82.8% vs 79.3% vs 78.4% vs 78.5%, p < 0.03) on assessment 1, but not assessment 2 (p = 0.53) (Table 2).

When substratifying the injuries by anatomical location and injury type, a surgeon's number of years of experience resulted in similar percentage agreement with the gold standard for anatomical location on assessment 1 (p = 0.07) and assessment 2 (p = 0.73), although surgeons with < 5 years and > 20 years of experience had slightly greater percentage agreement with the gold standard for injury type on assessment 1 (84.7% vs 82.3% vs 81.3% vs 81.2%, p = 0.036), but not on assessment 2 (p = 0.67) (Table 3).

Comparison to the Gold Standard—Surgical Subspecialty

There was no significant difference in classification accuracy between orthopedic spine surgeons or neurosurgeons on assessment 1 (80.5% vs 79.2%, p = 0.26) or assessment 2 (79.7% vs 78.5%, p = 0.33). However, there was a significant and large difference between spine surgeons' and nonspine surgeons' classification accuracy on assessment 1 (80% vs 64.8%, p < 0.001) and assessment 2 (79.3% vs 62.7%, p < 0.001) (Table 2).

Interobserver Reliability—Surgical Experience

Regardless of surgical experience (< 5 years, 5–10 years, 11–20 years, and > 20 years), the interobserver reliability was substantial on assessment 1 (κ = 0.67, 0.62, 0.61, and 0.62, respectively), and only study participants with > 20 years of experience did not reach the threshold for substantial agreement on assessment 2 (κ = 0.62, 0.61, 0.61, and 0.59, respectively) (Table 4).

Subanalysis to identify the effect of surgical experience on injury location and injury type determined that the interobserver reliability was excellent for injury location on both assessment 1 (κ = 0.87, 0.85, 0.83, and 0.88, respectively) and assessment 2 (κ = 0.81, 0.83, 0.82, and 0.84, respectively). However, for injury type, only surgeons with < 5 years of surgical experience reached substantial interobserver reliability on assessment 1 (κ = 0.63, 0.58, 0.56, and 0.57, respectively), while each group established moderate reliability on assessment 2 (κ = 0.58, 0.57, 0.57, and 0.56, respectively) (Table 5).

Interobserver Reliability—Surgical Subspecialty

The overall interobserver reliability was substantial for both orthopedic spine surgeons and neurosurgeons on assessment 1 (κ = 0.64 and 0.63) and assessment 2 (κ = 0.62 and 0.63), but the reliability was only moderate for nonspine surgeons on assessment 1 (κ = 0.43) and assessment 2 (κ = 0.36) (Table 4).

When substratifying the interobserver reliability into injury location, orthopedic surgeons and neurosurgeons had excellent interobserver reliability on assessment 1 (κ = 0.84 and 0.88) and assessment 2 (κ = 0.81 and 0.88), but nonspine surgeons only achieved moderate (κ = 0.70) and fair interobserver reliability (κ = 0.49). Although injury type had lower interobserver reliability than injury location, moderate reliability was identified on assessment 1 (κ = 0.60 and 0.58) and assessment 2 (κ = 0.59 and 0.57) for orthopedic spine surgeons and neurosurgeons. Nonspine surgeons, however, only generated moderate reliability on

TABLE 2. Absolute and relative frequencies of study participants' agreement with the gold standard committee

	Surgical Experience					Surgical Subspecialty				
	<5 yrs	5–10 yrs	11–20 yrs	>20 yrs	p Value	Orthopedic Spine Surgery	Neurosurgery	p Value	Other Surgery	p Value*
Assessment 1										
Global	1303 (82.8)	1406 (79.3)	1440 (78.4)	787 (78.5)	**0.03**	3019 (80.5)	1825 (79.2)	0.26	92 (64.8)	**<0.001**
IA	105 (84.0)	125 (88.7)	119 (80.4)	66 (80.5)	0.23	258 (85.7)	151 (82.1)	0.35	6 (54.5)	**0.017**
IC	117 (91.4)	125 (88.0)	137 (92.6)	78 (97.5)	0.10	280 (93.3)	168 (90.3)	0.30	9 (75.0)	0.05
IIA	210 (82.7)	219 (77.4)	223 (76.6)	131 (82.4)	0.20	485 (81.2)	286 (77.9)	0.24	12 (52.2)	**<0.001**
IIB	182 (71.4)	202 (70.9)	201 (67.9)	103 (64)	0.36	425 (70.5)	250 (67.4)	0.34	13 (56.5)	0.25
IIC	86 (67.2)	89 (62.7)	93 (62.8)	47 (58.8)	0.66	194 (64.7)	116 (62.4)	0.68	5 (41.7)	0.26
IIIA	230 (90.9)	230 (80.7)	247 (83.7)	130 (81.8)	**0.01**	511 (85.2)	312 (84.6)	0.87	14 (60.9)	**0.007**
IIIB	134 (70.2)	161 (75.6)	144 (66.1)	75 (62.5)	0.05	309 (68.5)	192 (70.1)	0.72	13 (76.5)	0.73
IIIC	239 (95.2)	255 (90.1)	276 (94.5)	157 (97.5)	**0.01**	557 (92.8)	350 (95.6)	0.10	20 (95.2)	0.20
Assessment 2										
Global	1000 (79.9)	1214 (79.1)	1310 (78.5)	735 (77.4)	0.53	2620 (79.7)	1545 (78.5)	0.33	94 (62.7)	**<0.001**
IA	77 (75.5)	108 (87.8)	107 (79.9)	58 (76.3)	0.08	210 (79.2)	132 (83.5)	0.34	8 (66.7)	0.26
IC	93 (92.1)	106 (86.9)	119 (88.8)	70 (92.1)	0.53	241 (91.3)	139 (88.5)	0.45	8 (66.7)	**0.020**
IIA	163 (82.3)	200 (81.3)	219 (82.6)	126 (82.9)	0.97	439 (83.9)	253 (80.6)	0.25	16 (66.7)	0.06
IIB	136 (68.0)	171 (70.7)	181 (67.0)	95 (62.5)	0.41	365 (69.8)	206 (65.0)	0.17	12 (50.0)	0.06
IIC	64 (64.6)	78 (63.9)	79 (58.5)	52 (68.4)	0.51	168 (63.9)	100 (63.7)	1.00	5 (41.7)	0.29
IIIA	171 (85.9)	202 (81.8)	228 (86.4)	120 (78.9)	0.15	441 (83.8)	267 (85.6)	0.57	13 (54.2)	**<0.001**
IIIB	119 (77.8)	134 (72.4)	147 (73.1)	75 (65.8)	0.19	304 (76.4)	158 (66.7)	**0.01**	13 (72.2)	**0.029**
IIIC	177 (88.5)	215 (87.0)	230 (86.8)	139 (91.4)	0.50	452 (86.1)	290 (92.1)	**0.01**	19 (79.2)	**0.014**

The classification accuracy of injury location and injury type for all members pooled together is 79.7% agreement for assessment 1 and 78.8% agreement for assessment 2. The classification was subsequently stratified by years of surgical experience and surgical subspecialty. Values are given as number of cases (%) unless otherwise indicated. Not all surgeons completed every question, so denominators vary. Boldface type indicates statistical significance ($p < 0.05$).
* Comparison of other surgeons with orthopedic surgeons and neurosurgeons.

assessment 1 ($\kappa = 0.43$) and fair reliability on assessment 2 ($\kappa = 0.37$) (Table 5).

Intraobserver Reproducibility—Surgical Experience and Surgical Subspecialty

The overall mean intraobserver reproducibility was substantial ($\kappa = 0.74$, 0.69, 0.69, and 0.70) irrespective of time in practice (< 5 years, 5–10 years, 10–20 years, and > 20 years, respectively). The mean intraobserver reproducibility was also substantial irrespective of surgical subspecialty ($\kappa = 0.71$, 0.69, and 0.68) for orthopedic spine surgeons, neurosurgeons, and other surgeons, respectively (Table 6).

Furthermore, there was no significant difference in the proportion of study participants who obtained excellent (49% vs 37.3% vs 31.8% vs 40%, p = 0.32), substantial (32.7% vs 39.0% vs 44.4% vs 34.3%, p = 0.59), moderate (12.2% vs 18.7% vs 14.3% vs 17.1%, p = 0.81), fair (4.1% vs 0% vs 8.0% vs 8.6%, p = 0.83), or slight (2.0% vs 5.1% vs 1.6% vs 0%, p = 0.57) intraobserver reproducibility based on their years of surgical experience (< 5 years, 5–10 years, 10–20 years, or > 20 years). Similarly, when evaluating the intraobserver reproducibility between orthopedic spine surgeons and neurosurgery providers there was no difference in the proportion of observers who had excellent (43.5% vs 32.5%, p = 0.16), substantial (33.9% vs 44.2%, p = 0.19), moderate (13.7% vs 18.2%, p = 0.51), fair (5.7% vs 3.9%, p = 0.74), or slight (3.2% vs 1.3%, p = 0.65) reproducibility (Table 7).

Discussion

Successful classification systems should provide users with a highly reliable and reproducible classification schema. In order for the classification to be widely accepted, a structured and rigorous evaluation of the system must be undertaken as outlined by Audigé et al.[16] The current phase of evaluating the AO Spine Upper Cervical Injury Classification System relied on obtaining reliability and reproducibility scores from an international group of classification-naïve surgeons. In general, our study suggests that the AO Spine Upper Cervical Injury Classification System could be applied with similar accuracy, reliability, and reproducibility, irrespective of surgical experience or spine subspecialty.

When evaluating surgeons based on surgical experience (< 5 years, 5–10 years, 10–20 years, and > 20 years), those with < 5 years of surgical experience exhibited an improved classification accuracy on assessment 1 (predominantly because of greater injury-type accuracy), but the greater classification accuracy did not persist on assessment 2. Interestingly, instead of the remaining groups

TABLE 3. Percentage agreement with the gold standard for injury location and injury morphology

	Surgical Experience					Surgical Subspecialty				
	<5 yrs	5–10 yrs	11–20 yrs	>20 yrs	p Value	Orthopedic Spine Surgery	Neurosurgery	p Value	Other Surgery	p Value*
Assessment 1										
Global (location)	1520 (95.9)	1685 (95.0)	1729 (94.2)	961 (95.9)	0.07	3554 (94.7)	2214 (96.1)	**0.014**	127 (89.4)	**<0.001**
I	247 (97.6)	272 (96.1)	283 (95.6)	159 (98.1)	0.37	578 (96.2)	363 (98.1)	0.13	20 (87.0)	**0.008**
II	602 (94.5)	668 (94.1)	678 (92.2)	376 (94.0)	0.32	1402 (93.5)	871 (94.3)	0.48	51 (87.9)	0.15
III	671 (96.5)	745 (95.4)	768 (95.4)	426 (96.8)	0.44	1574 (95.3)	980 (97.1)	**0.029**	56 (91.8)	**0.020**
Global (injury type)	1343 (84.7)	1460 (82.3)	1836 (81.3)	814 (81.2)	**0.036**	3124 (83.3)	1881 (81.7)	0.12	104 (73.2)	**0.004**
A	559 (88.4)	602 (84.9)	606 (82.6)	337 (84.2)	**0.023**	1295 (86.4)	773 (84.0)	0.11	36 (63.2)	**<0.001**
B	326 (73.1)	371 (74.5)	359 (69.8)	182 (64.8)	**0.022**	756 (71.7)	454 (70.4)	0.59	28 (70.0)	0.83
C	458 (90.3)	487 (85.9)	527 (89.6)	295 (91.9)	**0.023**	1073 (89.4)	654 (88.6)	**<0.001**	40 (88.9)	**<0.001**
Assessment 2										
Global (location)	1172 (93.6)	1448 (94.4)	1568 (94.0)	899 (94.6)	0.73	3074 (93.5)	1889 (96.0)	**<0.001**	124 (82.7)	**<0.001**
I	186 (91.6)	231 (94.3)	258 (96.3)	146 (96.1)	0.13	495 (93.6)	307 (97.5)	**0.019**	19 (79.2)	**<0.001**
II	459 (92.4)	576 (94.4)	621 (92.7)	357 (93.9)	0.46	1216 (92.9)	747 (94.8)	0.10	50 (83.3)	**0.002**
III	527 (95.5)	641 (94.4)	689 (94.4)	396 (94.7)	0.82	1363 (94.1)	835 (96.6)	**0.008**	55 (83.3)	**<0.001**
Global (injury type)	1039 (83.0)	1257 (81.9)	2368 (82.0)	769 (80.9)	0.67	2731 (83.1)	1595 (81.1)	0.07	107 (71.3)	**<0.001**
A	431 (86.4)	539 (85.9)	572 (86.3)	318 (83.7)	0.65	1139 (86.7)	671 (85.6)	0.52	40 (66.7)	**<0.001**
B	262 (74.2)	312 (73.1)	342 (72.6)	178 (66.9)	0.20	1139 (74.8)	375 (67.7)	**0.004**	30 (71.4)	**0.013**
C	346 (86.5)	416 (84.7)	454 (85.0)	273 (89.8)	0.18	903 (85.8)	549 (87.3)	0.45	37 (77.1)	0.13

The classification accuracy of injury location for all members pooled together is 95.1% agreement for assessment 1 and 94.1% agreement for assessment 2. The classification accuracy of injury type for all members pooled together is 82.4% agreement for assessment 1 and 82.0% agreement for assessment 2. The classification was subsequently stratified by years of surgical experience and surgical subspecialty. Values are given as number of cases (%) unless otherwise indicated. Not all surgeons completed every question, so denominators vary. Boldface type indicates statistical significance ($p < 0.05$).

* Comparison of other surgeons with orthopedic surgeons and neurosurgeons.

improving their classification accuracy after the first assessment, surgeons with < 5 years of experience actually "dropped back" toward the accuracy of the remaining groups. Although speculative, the improved classification accuracy for surgeons with < 5 years of experience was likely due to type I error since their improved accuracy was not substantiated on the second assessment and it barely reached statistical significance on the first assessment ($p = 0.03$). Although it is possible that the raters suffered from classification "fatigue" on the second assessment, both assessments were performed in the same fashion, with no differences in key images provided or time differences allotted for injury film evaluation.

A previously published reliability analysis attempted to document the effect of surgeon experience on the interobserver reliability and intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System and found excellent intraobserver reproducibility for injury location based on responses from both the residents (range $\kappa = 0.83–0.99$) and attending surgeons (range $\kappa = 0.86–0.99$) participating in the study.[17] Similarly, there was minimal difference between the intraobserver reproducibility for residents (range $\kappa = 0.69–0.92$) and that for attending surgeons (range $\kappa = 0.85–0.98$).[17] Therefore, it is possible that the cause for the difference in classification accuracy on assessment 1 was due to a type I error as opposed to a true difference in classification ability between surgical experience levels. Alternatively, less-experienced surgeons may be more familiar with the most recent AO Spine cervical, thoracolumbar, and sacral classifications, which are the basis for the upper cervical classification.

When evaluating reliability by surgical subspecialty, the classification accuracy and interobserver reliabilities were similar between neurosurgeons and orthopedic spine surgeons overall. However, once the classification was substratified into injury location and injury type, differences did emerge between neurosurgeons and orthopedic spine surgeons. Although neurosurgeons exhibited greater interobserver reliability and significantly greater injury location accuracy than orthopedic spine surgeons, orthopedic spine surgeons showed a greater classification accuracy on assessments 1 and 2 when identifying injury type, albeit the difference did not reach significance (assessment 1: $p = 0.12$; assessment 2: $p = 0.07$). Intuitively, this result is not surprising. Neurosurgeons typically have a higher spine procedure volume during residency, while orthopedic surgeons learn the principles of AO fracture classification and management during residency.[18] Therefore, the AO principles that are applied for management of long bone injuries, including tension band failure and ligamentous avulsion-type injuries, may aid orthopedic surgeons in having slightly improved accuracy when classifying spine bony fractures (especially type B injuries).[19] Interestingly, nonspine surgeons had a substantially lower classification accuracy compared with orthopedic spine surgeons and neurosurgeons when attempting to identify injury location

TABLE 4. Interobserver reliability of the AO Spine Upper Cervical Injury Classification System based on years of surgical experience and surgical subspecialty

	Surgical Experience				Surgical Subspecialty		
	<5 yrs	5–10 yrs	11–20 yrs	>20 yrs	Orthopedic Spine Surgery	Neurosurgery	Other Surgery
Assessment 1							
Global	0.67	0.62	0.61	0.62	0.64	0.63	0.43
IA	0.76	0.80	0.70	0.73	0.77	0.73	0.31
IC	0.85	0.83	0.86	0.91	0.88	0.83	0.61
IIA	0.63	0.54	0.56	0.62	0.60	0.59	0.31
IIB	0.51	0.48	0.45	0.43	0.50	0.47	0.27
IIC	0.50	0.46	0.42	0.38	0.44	0.48	0.13
IIIA	0.76	0.67	0.66	0.66	0.69	0.69	0.40
IIIB	0.58	0.56	0.49	0.49	0.53	0.54	0.47
IIIC	0.84	0.77	0.80	0.77	0.78	0.82	0.83
Assessment 2							
Global	0.62	0.61	0.61	0.59	0.62	0.63	0.36
IA	0.63	0.79	0.71	0.64	0.69	0.75	0.38
IC	0.86	0.82	0.82	0.86	0.86	0.85	0.43
IIA	0.59	0.58	0.61	0.59	0.61	0.61	0.31
IIB	0.47	0.47	0.43	0.40	0.47	0.43	0.23
IIC	0.49	0.49	0.40	0.49	0.46	0.48	0.27
IIIA	0.69	0.65	0.70	0.62	0.67	0.70	0.38
IIIB	0.59	0.51	0.54	0.48	0.56	0.53	0.48
IIIC	0.74	0.76	0.77	0.80	0.74	0.83	0.52

The pooled reliability is 0.63 for assessment 1 and 0.61 for assessment 2. Values are given as kappa coefficients.

TABLE 5. Identification of interobserver reliability for injury location and injury morphology based on years of surgical experience and surgical subspecialty

	Surgical Experience				Surgical Subspecialty		
	<5 yrs	5–10 yrs	11–20 yrs	>20 yrs	Orthopedic Spine Surgery	Neurosurgery	Other Surgery
Assessment 1							
Global (location)	0.87	0.85	0.83	0.88	0.84	0.88	0.70
I	0.86	0.88	0.86	0.93	0.88	0.90	0.72
II	0.85	0.82	0.80	0.85	0.81	0.86	0.63
III	0.89	0.86	0.85	0.88	0.85	0.90	0.77
Global (injury type)	0.63	0.58	0.56	0.57	0.60	0.58	0.43
A	0.65	0.61	0.55	0.59	0.62	0.60	0.32
B	0.46	0.42	0.39	0.38	0.44	0.40	0.23
C	0.77	0.71	0.73	0.70	0.72	0.74	0.73
Assessment 2							
Global (location)	0.81	0.83	0.82	0.84	0.81	0.88	0.49
I	0.79	0.86	0.86	0.85	0.83	0.90	0.41
II	0.79	0.80	0.79	0.79	0.77	0.85	0.49
III	0.85	0.85	0.83	0.87	0.83	0.90	0.53
Global (injury type)	0.58	0.57	0.57	0.56	0.59	0.57	0.37
A	0.59	0.59	0.60	0.55	0.61	0.60	0.25
B	0.44	0.39	0.39	0.35	0.43	0.36	0.33
C	0.70	0.72	0.71	0.75	0.71	0.75	0.54

The pooled injury location reliability is 0.85 for assessment 1 and 0.83 for assessment 2. The pooled injury type reliability is 0.59 for assessment 1 and 0.57 for assessment 2. Values are given as kappa coefficients.

TABLE 6. Intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System based on years of surgical experience and surgical subspecialty

	Surgical Experience				Surgical Subspecialty		
	<5 yrs	5–10 yrs	11–20 yrs	>20 yrs	Orthopedic Spine Surgery	Neurosurgery	Other Surgery
Overall classification	0.74 (0.17)	0.69 (0.22)	0.69 (0.19)	0.70 (0.16)	0.71 (0.22)	0.69 (0.15)	0.68 (0.13)
Injury location	0.90 (0.12)	0.87 (0.24)	0.89 (0.22)	0.90 (0.13)	0.87 (0.22)	0.89 (0.14)	0.89 (0.08)
Injury type	0.70 (0.20)	0.65 (0.25)	0.67 (0.22)	0.66 (0.18)	0.68 (0.24)	0.66 (0.18)	0.62 (0.14)

Values are given as kappa coefficient (SD).

and injury type. This indicates that frequent viewing of spine CT scans may be an integral component for accurately classifying upper cervical spine injuries, signifying that the current classification requires that surgeons have dedicated training in the treatment of spine injuries. This is even more relevant when evaluating rare upper cervical spine injuries such as C1 and C2 ring injuries, which can be highly complex injuries that require accurate pattern recognition.[20]

Furthermore, discussion on atlas injuries and C2 type B injuries is warranted given the moderate interobserver reliability when evaluated by orthopedic spine surgeons and neurosurgeons (the remaining injury subtypes received substantial or excellent interobserver reliability). Although the goal of an injury classification is to optimize its interobserver reliability (providing a framework for facilitating future research, clinical discussion of injury patterns, and injury management guidance), the inherent rarity of certain injuries can make this challenging. The most commonly used classification for fractures of the atlas is the Gehweiler classification.[12] Even though the system is predominantly descriptive, the classification demonstrated moderate interobserver reliability ($\kappa = 0.50$), which is similar to the reliability of the AO Spine Upper Cervical Injury Classification System (range $\kappa = 0.43–0.61$).[20] Given that the AO Spine Upper Cervical Injury Classification System only has three injury types for atlas injuries compared with the five injury types for the Gehweiler classification, the AO Spine Upper Cervical Injury Classification System may be simpler to implement into practice. Further, the moderate reliability of both schemata indicates that atlas fractures may be inherently complex injuries to

TABLE 7. Intraobserver reproducibility of the AO Spine Upper Cervical Injury Classification System based on years of surgical experience and surgical subspecialty

	Surgical Experience					Surgical Subspecialty			
Agreement	<5 yrs	5–10 yrs	11–20 yrs	>20 yrs	p Value	Orthopedic Spine Surgery	Neurosurgery	p Value*	Other
Overall classification									
Slight	1 (2.0)	3 (5.1)	1 (1.6)	0	0.57	4 (3.2)	1 (1.3)	0.65	0
Fair	2 (4.1)	0	5 (8.0)	3 (8.6)	0.83	7 (5.7)	3 (3.9)	0.74	0
Moderate	6 (12.2)	11 (18.7)	9 (14.3)	6 (17.1)	0.81	17 (13.7)	14 (18.2)	0.51	1 (20)
Substantial	16 (32.7)	23 (39.0)	28 (44.4)	12 (34.3)	0.59	42 (33.9)	34 (44.2)	0.19	3 (60)
Excellent	24 (49.0)	22 (37.3)	20 (31.8)	14 (40.0)	0.32	54 (43.5)	25 (32.5)	0.16	1 (20)
Injury location									
Slight	0	2 (3.4)	2 (3.2)	0	0.55	3 (2.4)	1 (1.3)	1.0	0
Fair	0	1 (1.7)	1 (1.6)	0	1.0	2 (1.6)	0	0.53	0
Moderate	2 (4.1)	2 (3.4)	4 (6.4)	2 (5.7)	0.86	7 (5.6)	3 (3.9)	0.74	0
Substantial	6 (12.2)	3 (5.1)	6 (9.5)	2 (5.7)	0.55	10 (8.1)	6 (7.8)	1.0	1 (20)
Excellent	41 (83.7)	51 (86.4)	50 (79.4)	31 (88.6)	0.61	102 (82.3)	67 (87.0)	0.49	4 (80)
Injury type									
Slight	2 (4.1)	2 (3.4)	3 (4.8)	1 (2.9)	1.0	7 (5.6)	1 (1.3)	0.16	0
Fair	1 (2.0)	5 (8.5)	3 (4.8)	1 (2.9)	0.53	5 (4.0)	5 (6.5)	0.51	0
Moderate	9 (18.4)	12 (20.3)	14 (22.2)	12 (34.3)	0.34	19 (15.3)	25 (32.5)	**0.007**	3 (60)
Substantial	19 (38.8)	19 (32.2)	25 (39.7)	10 (28.6)	0.63	48 (38.7)	24 (31.2)	0.35	1 (20)
Excellent	18 (36.7)	21 (35.6)	18 (28.6)	11 (31.4)	0.78	45 (36.3)	22 (28.6)	0.33	1 (20)

Agreement is indicated as follows: slight (< 0.2), fair (0.2–0.4), moderate (0.41–0.60), substantial (0.61–0.8), and excellent (0.81–1.0). Values are given as number of surgeons evaluated (%) unless otherwise indicated. Both surveys were completed by 206 surgeons. Boldface type indicates statistical significance ($p < 0.05$).
* Comparison between orthopedic surgeons and neurosurgeons.

classify, and the "lower" reliability for C1 injuries may not be a shortcoming of the injury classification system itself. For example, detailed understanding of the attachment points of the transverse atlantal ligament is a prerequisite in understanding whether an isolated unilateral or bilateral anterior arch injury should be classified as a C1 type A (stable bony injury) or a C1 type B (avulsion fracture or ligamentous injury with uncertain injury stability) injury.

Difficulties with identifying certain injury patterns are further illustrated when examining C2 type B injuries (atypical hangman's fractures). Historically, hangman's fractures and isolated sagittal oriented dens fractures with minimal obliquity have been the focus of C2 injuries.[10] Recently, increased attention has been given to atypical hangman's fractures, which are tension band–type injuries.[21,22] However, even with attempts to provide fracture classifications for these injuries, no well-established treatment algorithms exist, which is likely in part due to the relative rarity of this injury. Since both of these injuries are rare and have varying injury presentations (coronal shear or oblique dens fracture with contralateral involvement of the lamina or pars), the complexity of the injury may make fracture categorization difficult regardless of the simplicity of the fracture classification system used.[21,22] While this may be one source of criticism for the currently proposed classification, we believe that this instead highlights the need for additional descriptions of injury types and how the current classification compares to previous classifications. Therefore, all injury classifications evaluated by the AO Spine members are described and classified in Supplemental Appendix A.

In order for an injury classification to gain widespread acceptance, users must identify the classification to be usable on an international scale, irrespective of spine surgeon subspecialty training. If a subset of users struggle with accurately classifying injuries, modifications may need to be made to the classification or additional training should be implemented before injury severity scores are applied to the classification. Injury severity scores are the first step in assigning a treatment algorithm that allows a classification system to be used for management purposes, as has previously been performed for the AO Spine Thoracolumbar Injury Classification.[23,24] The current study is an important step in clarifying whether spine surgeons (neurosurgeons or orthopedic spine surgeons) are equally accurate and reliable when using this classification to grade injury types. While there may be other demographic deficiencies with the classification (work setting, geographic location, etc.), the training for orthopedic spine surgeons and neurosurgeons appears sufficient for them to accurately apply this classification. This is especially important since AO started as an orthopedic organization. Our study found that even though the principles of bony fractures (like tension band injuries) are learned extensively during orthopedic residency, neurosurgeons appear similarly adept at identifying and classifying these injuries in the spine.

Multiple limitations inherent within our study design require further discussion. First, all participating members of the AO Spine Upper Cervical Injury Classification System were AO members, which may artificially elevate the accuracy and reliability of the classification due to the members' baseline knowledge of AO Spine classification principles. While our study was intended to evaluate classification-naïve users, this was not an exclusion criterion, nor was it assessed on our demographic questionnaire.[13] Thus, any member incorporating the classification into their spine practice may have more accurately classified the upper cervical spine injuries. Second, although nonspine specialists had substantially lower interobserver reliability and classification accuracy compared with spine specialists, this may be due to a type I error since spine surgeon classification attempts (assessment 1: 6055; assessment 2: 5254) greatly outweighed nonspine surgeons' classification attempts (assessment 1: 142; assessment 2: 150). However, the AO Spine Upper Cervical Injury Classification System will likely be predominantly utilized by spine surgeons, and it is possible that spine-specific training is required in order for upper cervical spine injury films to be accurately classified. Third, all CT scans were compiled from the AO Spine database, and any injury patterns not available in the database could not be included in the injury reproducibility and reliability study; therefore, no type IB injuries were evaluated. Since type B injuries had lower classification accuracy and interobserver reliability than type A and C injuries, this may have artificially increased the accuracy and reliability of the classification system. Therefore, this injury classification should undergo additional reliability assessments (potentially by independent institutions) to clarify the classification reliability for type IB injuries. Fourth, partial survey completion responses were included to allow participants to leave the study for a brief amount of time and then resume once ready. Finally, although not a direct limitation of this study, injury severity scores and a treatment algorithm are future areas of study to determine if the AO Spine Upper Cervical Injury Classification System can be accepted on an international level as a tool to guide injury management.

Conclusions

The AO Spine Upper Cervical Injury Classification System demonstrated substantial interobserver reliability and intraobserver reproducibility regardless of surgical experience level or spine subspecialty (orthopedic spine surgeons vs neurosurgeon). Nonetheless, neurosurgeons were significantly better at identifying injury location, while orthopedic surgeons demonstrated a better injury-type classification accuracy. Overall, the AO Spine Upper Cervical Injury Classification System is universally applicable regardless of surgical experience or spine subspecialty.

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Appendix

AO Spine Upper Cervical Injury Classification International Members

Dewan Asif; Sachin Borkar; Joseph Bakar; Slavisa Zagorac; Welege Wimalachandra; Oleksandr Garashchuk; Francisco Verdu-Lopez; Giorgio Lofrese; Pragnesh Bhatt; Oke Obadaseraye; Axel Partenheimer; Marion Riehle; Eugen Cesar Popescu; Christian Konrads; Nur Aida Faruk Senan; Adetunji Toluse; Nuno Neves; Takahiro Sunami; Bart Kuipers; Jayakumar Subbiah; Anas Dyab; Peter Loughenbury; Derek Cawley; René Schmidt; Loya Kumar; Farhan Karim; Zacharia Silk; Michele Parolin; Hisco Robijn; Al Kalbani; Ricky Rasschaert; Christian Müller; Marc Nieuwenhuijse; Selim Ayhan; Shay Menachem; Sarvdeep Dhatt; Nasser Khan; Subramaniam Haribabu; Moses Kimani; Olger Alarcon; Nnaemeka Alor; Dinesh Iyer; Michal Ziga; Konstantinos Gousias; Gisela Murray; Michel Triffaux; Sebastian Hartmann; Sung-Joo Yuh; Siegmund Lang; Kyaw Linn; Charanjit Singh Dhillon; Waeel Hamouda; Stefano Carnesecchi; Vishal Kumar; Lady Lozano Cari; Gyanendra Shah; Furuya Takeo; Federico Sartor; Fernando Gonzalez; Hitesh Dabasia; Wongthawat Liawrungrueang; Lincoln Liu; Younes El Moudni; Ratko Yurak; Héctor Aceituno; Madhivanan Karthigeyan; Andreas Demetriades; Sathish Muthu; Matti Scholz; Wael Alsammak; Komal Chandrachari; Khoh Phaik Shan; Sokol Trungu; Joost Dejaegher; Omar Marroquin; Moisa Horatiu Alexandru; Máximo-Alberto Diez-Ulloa; Paulo Pereira; Claudio Bernucci; Christian Hohaus; Miltiadis Georgiopoulos; Annika Heuer; Ahmed Arieff Atan; Mark Murerwa; Richard Lindtner; Manjul Tripathi; Huynh Hieu Kim; Ahmed Hassan; Norah Foster; Amanda O'Halloran; Koroush Kabir; Mario Ganau; Daniel Cruz; Amin Henine; Jeronimo Milano; Abeid Mbarak; Arnaldo Sousa; Satyashiva Munjal; Mahmoud Alkharsawi; Muhammad Mirza; Parmenion Tsitsopoulos; Fon-Yih Tsuang; Oliver Risenbeck; Arun-Kumar Viswanadha; Samer Samy; David Orosco; Gerardo Zambito-Brondo; Nauman Chaudhry; Luis Marquez; Jacob Lepard; Juan Muñoz; Stipe Corluka; Soh Reuben; Ariel Kaen; Nishanth Ampar; Sebastien Bigdon; Damián Caba; Francisco De Miranda; Loren Lay; Ivan Marintschev; Mohammed Imran; Sandeep Mohindra; Naga Raju Reddycherla; Pedro Bazán; Abduljabbar Alhammoud; Iain Feeley; Konstantinos Margetis; Alexander Durst; Ashok Kumar Jani; Rian Souza Vieira; Felipe Santos; Joshua Karlin; Nicola Montemurro; Sergey Mlyavykh; Brian Sonkwe; Darko Perovic; Juan Lourido; Alessandro Ramieri; Eduardo Laos; Uri Hadesberg; Andrei-Stefan Iencean; Pedro Neves; Eduardo Bertolini; Naresh Kumar; Philippe Bancel; Bishnu Sharma; John Koerner; Eloy Rusafa Neto; Nima Ostadrahimi; Olga Morillo; Kumar Rakesh; Andreas Morakis; Amauri Godinho; P. Keerthivasan; Richard Menger; Louis Carius; Rajesh Bahadur Lakhey; Ehab Shiban; Vishal Borse; Elizabeth Boudreau; Gabriel Lacerda; Paterakis Konstantinos; Mubder Mohammed Saeed; Toivo Hasheela; Susana Núñez Pereira; Jay Reidler; Nimrod Rahamimov; Mikolaj Zimny; Devi Prakash Tokala; Hossein Elgafy; Ketan Badani; Bing Wui Ng; Cesar Sosa Juarez; Thomas Repantis; Ignacio Fernández-Bances; John Kleimeyer; Nicolas Lauper; Luis María Romero-Muñoz; Ayodeji Yusuf; Zdenek Klez; John Afolayan; Joost Rutges; Alon Grundshtein; Rafal Zaluski; Stavros I. Stavridis; Takeshi Aoyama; Petr Vachata; Wiktor Urbanski; Martin Tejeda; Luis Muñiz; Susan Karanja; Antonio Martín-Benlloch; Heiller Torres; Chee-Huan Pan; Luis Duchén; Yuki Fujioka; Meric Enercan; Mauro Pluderi; Catalin Majer; Vijay Kamath.

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Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

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