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Brian A. Karamian
Thomas Jefferson University

Gregory D. Schroeder
Thomas Jefferson University

Mark J. Lambrechts
Thomas Jefferson University

Jose A. Canseco
Thomas Jefferson University

Emiliano N. Vialle

See next page for additional authors

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Authors
Brian A. Karamian, Gregory D. Schroeder, Mark J. Lambrechts, Jose A. Canseco, Emiliano N. Vialle, Frank Kandziora, Lorin M. Benneker, Rajasekaran Shanmuganathan, F. Cumhur Öner, Klaus J. Schnake, Christopher K. Kepler, and Alexander R. Vaccaro

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OPEN

Validation of the Hierarchical Nature of the AO Spine Sacral Classification and the Development of the Sacral AO Spine Injury Score

Brian A. Karamian, MD, Gregory D. Schroeder, MD,* Mark J. Lambrechts, MD,* Jose A. Canseco, MD, PhD,* Emiliano N. Vialle, MD,† Frank Kandziora, MD, PhD,‡ Lorin M. Benneker, MD,§ AO Spine Sacral Classification Group Members, Rajasekaran Shanmuganathan, PhD,∥ F. Cumhur Öner, MD, PhD,¶ Klaus J. Schnake, MD,# Christopher K. Kepler, MD, MBA,* and Alexander R. Vaccaro, MD, PhD, MBA**

Study Design: Global cross-sectional survey.

Objective: The objective of this study was to validate the hierarchical nature of the AO Spine Sacral Classification System and develop an injury scoring system.

Summary of Background Data: Although substantial interobserver and intraobserver reliability of the AO Spine Sacral Classification System has been established, the hierarchical nature of the classification has yet to be validated.

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From the *Rothman Institute at Thomas Jefferson University, Philadelphia, PA; †Department of Orthopaedics, Catholic University of Parana, Curitiba, Brazil; ‡Center for Spine Surgery and Neurotraumatology, BG Unfallklinik Frankfurt am Main, Frankfurt, Germany; §Spine Service, Orthopaedic Department, Sonnenhofspital, Bern, Switzerland; ∥Department of Orthopaedics, Trauma, and Spine Surgery, Ganga Hospital, Coimbatore, Tamil Nadu, India; ¶University Medical Center, Utrecht, The Netherlands; and #Center for Spinal Surgery, Erlangen, Germany.

AO Spine Sacral Classification Group Members: Aaron Hockley, Abdelgawad Nasser, Akbar Jaleel Zubairi, Alecio Barcelos, Alex Del Arco, Alexander Weening, Alexander Z.E. Durst, Alfredo Guiroy, Ali Haghnegahdar, Ali Madawi, Ali Öner, Alqatub Ahmed, Alsammak Wael, Alvin Pun, Amit Bhandutia, Andrei F Joaquim, Andrés Felipe Gonzalez Arias, Ashraf El Naga, Bruno Saciloto, Bruno Santos, Chang Hwa Hong, Changqing LI, Charalampidis Anastasios, Christina Cheng, Chun-Hao Tsai, Ciccioli Nicolas, Claudio Bernucci, Daniela Linhares, Dave Anthony Dizon, David Bludovsky, David Glassman, Davletgaleev, Giovanni De Falco, Dewan Shamsul Asif, Dihan Aponso, Elias Enmanuel Javier Martinez, Enrico Pola, Enrique Casco, Enzo Mantelli, Frank Lyons, Gabriel Baroffio, Ganau Mario, Gonçalves, Gupta Anuj, Gururaj Gururaj, Gustavo Alonso de Jesús Navarro Cueva, Hai Nie, Hamouda Waeel, Hector Roldan, Heiller Torres Valencia, Henine Amin, Ichiro Okano, Ignacio Fernández Bances, Igor Paredes, Jacob Hoffmann, Janardhana Aithala Parampalli, Jeronimo Milano, Jorge Alves, Juan Esteban Muñoz Montoya, Juan Lourido, Jun Zhang, Khatri Manoj, Kimmatkar Nitin, Konstantinos Margetis, Kumar Vineet, Leandro Badalassi, Lozano C Lady, Maarten de Boer, Mahmoud Shoaib, Manish Vaish, Martin Holas, Matias Pereira Duarte, Matta Javier, Máximo-Alberto Diez-Ulloa, Medina Matías, Michel Triffaux, Mohamed Kandil, Mohammad El-Sharkawi, Morakis Andreas, Mostafa Abdelhafez, Nasser Khan, Nicassio Nicola, Nicholas Kruger, Nishanth Ampar, Norberto Fernandez, Nuno Neves, Olga Morillo, Olger Alarcon, Onuminya John, Oscar González Guerra, Osundina Ahmad, Panchu Subramanian, Pang Hung Wu, Patronis Dimitrios, Pedro Bazán, Pershin Andrey, Peter Ferlic, Peter Loughenbury, Philippe Bancel, Popescu Eugen Cezar, Purnajyoti Banerjee, Rabindra Pradhan, Rafael Lindi Sugino, Rajesh Bahadur Lakhey, Ramieri Alessamdro, Rian Vieira, Ricky Rasschaert, Russo Fabrizio, Saleem Muhammad, Samer Samy, Sathish Muthu, Sbaffi Pier Filippo, Scholz Matti, Sebastián Anibal Kornfeld, Sergio Zylbersztejn, Sícoli Alfredo, Siegmund Lang, Sinan Kahraman, Stipe Corluka, Subbiah Jayakumar, Subramaniam Macherla haribabu, Sudhir Ganesan, Taha Karimjee, Tarek Elhewala, Tejeda Martin, Thami Benzakour, Toluse Adetunji, Triki Mohamed Amine, Tsuyoshi Okudaira, Tulio Rangel, Ullrich Bernhard, Umit Guler, Vijay Kumar Loya, Vineesh Mathur, Vishwajeet Singh, Wael Chaaban Tarabay, Yetkin Söyüncü, Zacharia Silk, Zagorac Slavisa, Zdenek Klezl.

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Reprints: Mark J. Lambrechts, MD, Rothman Orthopaedic Institute at Thomas Jefferson University, 925 Chestnut Street, 5th Floor, Philadelphia, PA 19107 (e-mail: mark.lambrechts@rothmanortho.com).

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Methods: Respondents numerically graded each variable within the classification system for severity. Based on the results, a Sacral AO Spine Injury Score (AOSIS) was developed.

Results: A total of 142 responses were received. The classification exhibited a hierarchical Injury Severity Score (ISS) progression (A1: 8 to C3: 95) with few exceptions. Subtypes B1 and B2 fractures showed no significant difference in ISS (B1 43.9 vs. B2 43.4, $P=0.362$). In addition, the transitions A3→B1 and B3→C0 represent significant decreases in ISS (A3 66.3 vs. B1 43.9, $P<0.001$; B3 64.2 vs. C0 46.4, $P<0.001$). Accordingly, A1 injury was assigned a score of 0. A2 and A3 received scores of 1 and 3 points, respectively. Posterior pelvic injuries B1 and B2 both received a score of 2. B3 received a score of 3 points. C0, C1, C2, and C3 received scores of 2, 3, 5, and 6 points, respectively. The scores assigned to neurological modifiers N0, N1, N2, N3, and NX were 0, 1, 2, 4, and 3, respectively. Case-specific modifiers M1, M2, M3, and M4 received scores of 0, 0, 1, and 2 points, respectively.

Conclusions: The results of this study validate the hierarchical nature of the AO Spine Sacral Classification System. The Sacral AOSIS sets the foundation for further studies to develop a universally accepted treatment algorithm for the treatment of complex sacral injuries.

Level of Evidence: Level IV—Diagnostic.

Key Words: AO Spine, classification, validation, injury severity, injury score, spine trauma, sacral fracture, pelvic fracture

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Sacral fractures are associated with significant morbidity and present in a bimodal distribution resulting from high-energy traumatic injuries in young patients and low-energy insufficiency fractures in elderly patients.[1,2] The incidence of sacral fractures for both populations is increasing.[1,3] Notwithstanding, the lack of an appropriate conceptual framework in classifying sacral fractures continues to impede the conception of standardized treatment protocols and evaluation of outcomes. Previously described sacral fracture classification schemas are descriptive, lack reliability, and have no clinical correlations regarding the prognosis or management of patients.[4–11] This has led to a dearth of high-quality evidence regarding the management of sacral fractures. As a result, the treatment of these injuries is currently determined on a case-by-case basis subject to the discretion of the surgeon.[2]

In an attempt to overcome these limitations, the AO Spine Knowledge Forum Trauma partnered with pelvic trauma experts from AO Trauma to develop the AO Spine Sacral Classification System, a concise and comprehensive scheme facilitating the communication, education, research, and standardized treatment of sacral fractures (Fig. 1).[12] This classification uses the basic AO Spine Trauma Classification system, which separately evaluates 3 items: (1) morphology of the injury, (2) neurological status, and (3) clinical modifiers. Fracture morphology consists of 3 subtypes: type A (lower sacrococcygeal injuries), type B (posterior pelvic injuries), and type C (spinopelvic injuries). It is a hierarchical system in which each morphologic type is subdivided into increasing numerical subtypes based on the energy of injury, with higher numbers ascribed to increased injury severity. The same neurological classification is used throughout the entire spinal column: N0—neurologically intact, N1—transient neurological deficit, N2—radicular symptoms, and N3—incomplete spinal cord injury or any degree of cauda equina syndrome, N4—complete spinal cord injury, and NX—patients that cannot be examined due to secondary causes. However, N4 is not anatomically relevant in the setting of sacral fractures and therefore not applicable. Case-specific clinical modifiers include M1—soft tissue injury, M2—metabolic bone disease, M3—anterior pelvic ring injury, and M4—sacroiliac (SI) joint injury.

Although substantial interobserver and intraobserver reliability of the AO Spine Sacral Classification System has been established, the hierarchical nature of the classification has yet to be validated.[12] Establishing the perceived severity of fractures by surveying spine and trauma surgeons of all types from around the world who represent a diverse array of practice patterns is essential to developing a universally adopted instrument that will drive clinical decision-making. From the severity scores, an accompanying scoring system can then be created as an important first step in developing a classification system that will be used to standardize the treatment of complex sacral injuries. Such a scoring system can help mitigate variation in management by allowing objective data to drive treatment facilitating higher level studies.

The purpose of this is study is to describe surgeons' perceptions of injury severity for fracture categories and modifiers included in the AO Spine Sacral Classification system, and to understand how surgeon region, experience, and subspeciality affect the perception of injury severity. From this data, the Sacral AO Spine Injury Score (Sacral AOSIS) is developed to accompany the classification system. This will set the stage for forthcoming studies to investigate surgical thresholds to establish a treatment algorithm for sacral fractures.

METHODS

Data Collection

A survey was sent to 164 AO Spine members from 6 different world regions (Europe, North America, South America, Africa, Asia, and the Middle East). The respondents' surgical subspecialty and number of years in practice was collected. Respondents were presented with individual unlabeled figures adapted from the AO Spine Sacral Classification System poster (Fig. 1) representing each fracture subtype in randomized order. Each depiction was numerically graded for the severity of injury on a scale of 0–100. A grade of 0 was defined as a minimal injury that would not warrant surgical intervention, whereas a grade of 100 represented the most severe injury in need of urgent surgical stabilization. In addition, the components of the sacral spine classification system including neurological status and patient-specific modifiers were also graded on a scale of 0–100. Surgeon's responses were used to generate a perceived Injury Severity Score (ISS).

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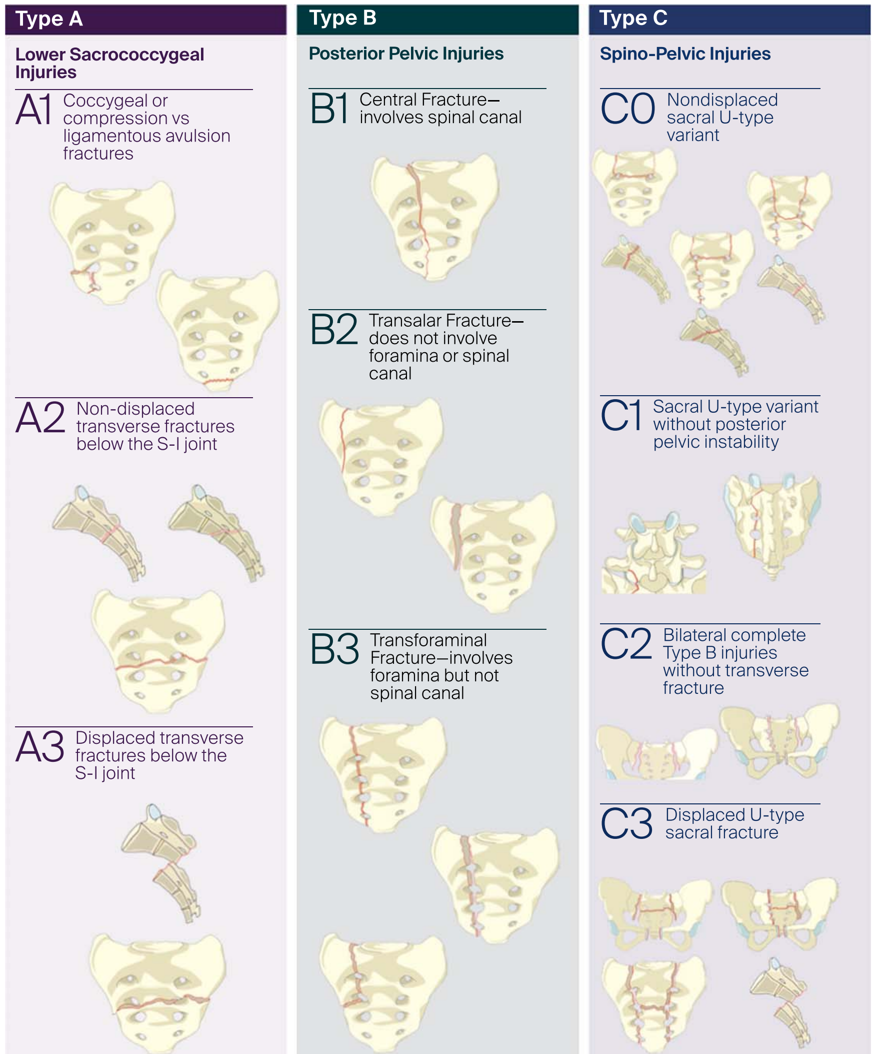

FIGURE 1. The AO Spine Sacral Classification System. Permission to use this figure was granted by the AO Foundation, AO Spine, Switzerland. Copyright AO Foundation, AO Spine, Switzerland, Davos, Switzerland. All permission requests for this image should be made to the copyright holder.

The survey results and ISSs were synthesized to develop a relative hierarchy of sacral spine injury severity with an accompanying point system, described as the Sacral AOSIS. The Sacral AOSIS employed an integer-based point system for each variable, as noninteger values would be impractical for clinical application. Following the initial interpretation of survey results, the AO Spine Knowledge Forum Trauma provided limited input to ensure certain aspect of clinical practice would be captured into the scoring system. Accordingly, if point designations proportionally deviated from the corresponding difference in ISS (ΔISS) between components of the classification scheme, such designation was justified in detail.

Statistics

The sacral ISS was summarized for all respondents and stratified by surgeon demographics of geographic region (Europe and Americas), years of practice experience (< 5, 5–10, 11–20, > 20), and subspecialty (orthopedics and neurosurgery). Descriptive statistics were performed to provide mean and SD. Mean ISS within a fracture subtype was compared across geographic regions and surgical subspecialties with a Wilcoxon rank-sum test and across years of experience with a Kruskal-Wallis test. Pairwise post hoc analysis compared mean ISS across classification system hieratical variables. Statistical significance was defined at 0.05. The analysis was performed using the statistical software SAS, version 9.4 (SAS Institute).

RESULTS

Evaluation of Perceived Severity

Of the 164 surgeons invited to participate, 142 responded to the survey (Table 1). The overall ISS are summarized by fracture subtype, neurological status, and clinical modifier in Figure 2. When ISSs were stratified by

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TABLE 1. Demographics

Category	Characteristic	Respondent [n (%)]
Geographic region	North America	12 (8.5)
	Central and South America	28 (19.7)
	Europe	52 (36.6)
	Africa	8 (5.6)
	Asia	27 (19.0)
	Middle East	15 (10.6)
No. years in practice	< 5 y	28 (19.7)
	5–10 y	32 (22.5)
	11–20 y	51 (35.9)
	> 20 y	31 (21.8)
Surgical subspecialty	General orthopedics	4 (2.8)
	Orthopaedic spine surgery	93 (65.5)
	Orthopaedic trauma surgery	12 (8.5)
	Neurosurgeon	33 (23.2)

orthopedic versus neurosurgeons, there were significant differences across fracture subtypes and case modifiers, but not neurological status (Table 2). The subtypes with significant subspecialty ISS differences included A3 (displaced transverse below SI joint, $P=0.016$), B2 (transalar, $P=0.020$), C0 (nondisplaced U type, $P=0.044$), C2 (bilateral complete type B, $P=0.031$), and C3 (displaced U type, $P=0.022$) with neurosurgeons perceiving all the aforementioned fracture subtypes as more severe than orthopedic surgeons. Within clinical modifiers, only M2 (metabolic bone disease) was perceived as more severe by neurosurgeons than orthopedic surgeons ($P=0.019$). Further ISS subgroup analysis did not yield significant differences in injury severity for fracture subtypes (except for A1, $P=0.011$), case modifiers, or neurological modifiers based on surgeon world region or years of experience (Table 2).

Overall, the results demonstrate a hierarchy with increased ISS for fracture subtypes, neurological status, and clinical modifier categories (Table 2). However, the perceived injury severity does deviate from stepwise hierarchical progression in particular instances. Sequential fracture subtypes are sometimes equivalent in severity, and the transition between morphology types is sometimes associated with a decrease in ISS. For example, within the posterior pelvic injury morphology category B, no significant difference in ISS was found between subtypes B1 (central) and B2 (transalar) fractures (B1 43.9 vs. B2 43.4, $P=0.362$). Furthermore, the transitions from A3 (displaced transverse below SI joint) to B1 (central fracture), and B3 (transforaminal) to C0 (nondisplaced U type), represent statistically significant decreases in perceived fracture severity (A3 66.3 vs. B1 43.9, $P<0.001$; B3 64.2 vs. C0 46.4, $P<0.001$). Despite these granular differences, the substantial

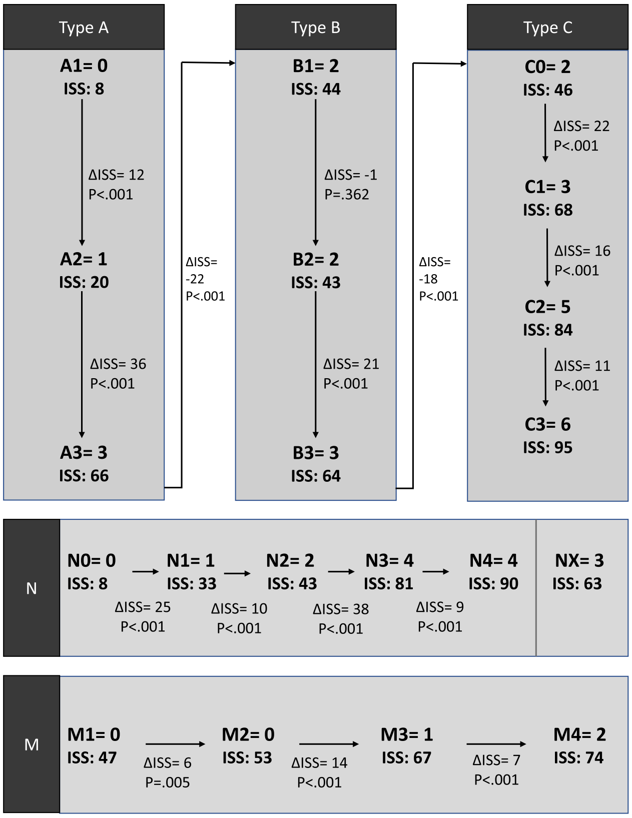

FIGURE 2. The assigned point value of the Sacral AO Spine Injury Score (AOSIS) is listed beside each fracture subtype, neurological status, or clinical modifier. The average perceived Injury Severity Score (ISS) is listed below each fracture subtype, neurological status, or clinical modifier. ΔISS—difference in average ISSs between fracture subtypes, associated *P*-value indicates statistical significance; N—neurological status; M—clinical modifier.

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TABLE 2. Perceived Injury Severity Score

	World region			Years of experience					Surgical subspecialty			Total
	Europe	Americas		< 5 y	5–10 y	11–20 y	> 20 y		Orthopedics	Neurosurgery		
Sacral fracture classification	n = 52 (A–C), n = 51 (N, M)	n = 40 (A, B1–B2, C), n = 39 N1–N4, M), n = 38 (NX)	P	n = 28 (A–C, N1–N4, M), n = 27 (NX)	n = 32 (A, B1–B2, C), n = 31 (B3, N, M)	n = 51 (A–C, N, M)	n = 31 (A–C), n = 30 (N, M)	P	n = 93 (A, B1–B2, C), n = 92 (B3, N1–N4, M), n = 91 (NX)	n = 33 (A–C), n = 32 (N, M)	P	n = 142 (A, B1–B2, C), n = 141 (B3), n = 140 (N0–N4), n = 139 (NX)
A1	8.5	6.0	0.011*	6.4	9.2	8.6	6.2	0.272†	7.6	8.5	0.669*	7.8 (6.7)
A2	19.6	16.8	0.116*	16.1	23.0	21.6	15.5	0.056†	18.5	22.7	0.164*	19.5 (14.4)
A3	68.8	62.6	0.236*	61.1	70.5	66.4	66.5	0.423†	63.1	74.2	**0.016***	66.3 (23.0)
B1	42.1	47.3	0.158*	44.3	48.8	44.2	38.1	0.111†	42.0	47.3	0.221*	43.9 (17.7)
B2	42.1	42.8	0.780*	43.4	43.5	45.2	40.2	0.776†	40.8	48.0	**0.020***	43.4 (16.9)
B3	61.8	63.3	0.537*	65.5	67.3	64.0	60.4	0.261†	62.4	67.2	0.083*	64.2 (15.7)
C0	46.3	47.8	0.830*	48.6	47.7	43.2	48.6	0.632†	43.7	53.2	**0.044***	46.4 (23.3)
C1	68.8	67.0	0.923*	67.7	68.1	68.5	65.8	0.920†	66.9	68.8	0.477*	67.7 (15.1)
C2	82.6	85.8	0.119*	85.4	81.7	82.5	85.8	0.520†	82.1	88.2	**0.031***	83.6 (13.6)
C3	95.5	97.2	0.327*	96.2	94.1	95.0	95.9	0.932†	94.8	97.1	**0.022***	95.2 (8.2)
N0	6.2	7.9	0.774*	6.1	12.7	7.5	6.6	0.373†	7.5	10.5	0.233*	8.2 (17.3)
N1	34.9	30.4	0.372*	28.6	38.4	32.0	32.3	0.418†	32.8	34.7	0.931*	32.8 (19.1)
N2	43.9	44.2	0.938*	42.5	46.3	38.2	47.0	0.204†	42.7	44.2	0.601*	42.7 (20.3)
N3	81.5	82.8	0.360*	84.5	84.2	77.1	80.2	0.290†	80.5	83.3	0.277*	80.8 (16.7)
N4	91.9	91.7	0.651*	90.5	93.8	86.7	87.3	0.612†	88.6	90.6	0.192*	89.2 (19.4)
NX	61.9	65.1	0.843*	59.4	66.9	60.7	66.5	0.691†	62.0	68.6	0.297*	63.1 (28.9)
M1	48.9	45.5	0.534*	48.9	46.9	46.7	44.2	0.950†	44.3	44.1	0.979*	46.6 (24.8)
M2	51.2	52.2	0.856*	45.1	53.7	55.1	56.0	0.107†	50.8	60.3	**0.019***	53.0 (19.4)
M3	66.7	71.3	0.315*	69.5	67.3	66.0	67.0	0.897†	65.0	73.6	0.071*	67.2 (18.6)
M4	71.9	74.6	0.431*	77.4	74.2	73.9	71.5	0.706†	74.8	69.4	0.155*	74.2 (19.2)

Mean Injury Severity Score is represented. SD is reported for total surveyed cohort.
Bold signifies $P < 0.05$
*Means are compared with Wilcoxon rank-sum test.
†Kruskal-Wallis test.
N indicates neurological status; NX, not possible; M, clinical modifier.

increase in injury severity from A1 to C3 (ISS: 8 to ISS: 95, respectively) validates the hierarchical nature of the AO Spine Sacral Classification System.

Development of the Sacral AOSIS

Based on the ISS progression, AO sacral injury subtypes were assigned integer point values beginning with A1, the least severe fracture pattern, defined as zero (Fig. 2, Table 3). Following the severity hierarchy, A2 was assigned 1 point considering it is a nondisplaced sacral fracture. A3 was assigned 3 points given the ΔISS of 36 from A2, likely secondary to the concern for instability and neurologialc injury in a displaced transverse pattern. The points assigned for posterior pelvic injuries B1 and B2 are both 2, given similar severity to one another ($P = 0.362$) and greater stability compared with the A3 pattern. B3 was assigned 3 points given the ΔISS of 21 from B2. C0 was designated as 2 points because it represents a nondisplaced, low-energy spinopelvic injury. A C1 injury, which may result in spinopelvic instability, was assigned 3 points. C2 and C3 morphologies were assigned 5 and 6 points, respectively, due to the ΔISS of 11 points between a C2 and C3 injury. Both injuries are unstable bilateral injuries associated with a high likelihood of neurological disruption, which resulted in a large increase of the ISS compared with C1 injuries.

Neurological status and clinical modifiers were also graded on an integer point system (Fig. 2, Table 3). With respect to neurological injury, there was an uneven stepwise progression, with large severity change, between N2 (radicular symptoms) and N3 (cauda equina) classifications. Consequently, the points assigned to N0 (neurology intact), N1 (transient deficit), N2 (radicular), and N3 (cauda equina) modifiers were 0, 1, 2, and 4, respectively. In the scenario where a neurological examination was not possible (NX), a score of 3 was selected because severe neurological injury cannot be ruled out.

The clinical modifiers of soft tissue injury (M1) and metabolic bone disease (M2) were of similar severity relative to one another and were assigned 0 points since neither injury has robust evidence supporting an increased likelihood for operative intervention. These scores were then set as the baselines for modifier injuries. Given the ΔISS increase of 14 between an M2 and M3 injury, an anterior pelvic ring (M3) injury was assigned 1 point. The resultant additional ΔISS of 7 between an M3 and M4 resulted in these injuries being assigned a score of 2 points (Fig. 2, Table 3).

DISCUSSION

The AO Spine Sacral Classification System was developed as a comprehensive schema to classify complex sacral injuries to facilitate communication, education, re-

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TABLE 3. Point Allocation

Sacral fracture injury type	Classification	Points
Lower sacrococcygeal	A1	0
	A2	1
	A3	3
Posterior pelvic	B1	2
	B2	2
	B3	3
Spinopelvic	C0	2
	C1	3
	C2	5
	C3	6
Neurological status	N0	0
	N1	1
	N2	2
	N3	4
	NX	3
Patient-specific modifiers	M1	0
	M2	0
	M3	1
	M4	2

search, and appropriate evidence-based treatment of patients. The substantial reliability of the classification system has already been established.[12] The current study validates the hierarchical nature of the scheme's organization by querying the perceived severity of sacral fracture subtypes and classification modifiers from surgeons worldwide. The logical progression of the schema sets the framework for categorizing patients based on the severity of their injury. And while the nomenclature of the schema alone allows for the general understanding of injury severity (ie, morphology: C > B > A; subtype: A3 > A2 > A1), to develop an algorithm for the treatment of sacral trauma, an accompanying scoring system is required. The ISS data, in conjunction with the clinical expertise of the AO Spine Knowledge Forum Trauma, was used to develop the Sacral AOSIS. In this situation, expert consensus and opinion was used to develop the point system given that randomized treatment of patients with sacral fractures would be unethical in patients with, or at risk of, neurological injury.

The current study describes the variation in perceived severity of sacral fractures and classification modifiers by surgeons' geographic region, years of experience, and subspeciality. Geographic region and years of experience were not found to have any significant impact on the perceived severity of fracture subtypes and modifiers, underscoring the generalizability of the classification scheme globally. While classification and management of spine trauma has been shown to vary based on these factors, the results demonstrate that the interpretation of severity is not confounded by regional or cultural preferences.[13–18] Interestingly, there were significant differences in perceived severity of both fracture subtypes and classification modifiers when evaluating by subspeciality. Specifically, neurosurgeons assigned a higher ISS for A3, B2, C0, C2, and C3 fracture types, as well as the M2 case modifier compared with orthopedic surgeons. This may result from the varying levels of experience surgical specialties have in treating sacral fractures. Orthopedic surgeons receive comprehensive instruction in the treatment of pelvic ring injuries during their training, which are often associated with sacral fractures and spinopelvic instability.[19] Despite this, all subspecialties reached a consensus regarding the hierarchical nature of the classification system.

The results of the ISS determined the Sacral AOSIS point values. Utilizing the consensus of a large group of diverse surgeons worldwide with gentle input from a small group of expert surgeons allowed for the creation of a point system bereft of treatment biases. Surgeon bias, risk aversion, treatment costs, access to care, and cultural tolerance of disability all contribute to treatment biases in the care of patients with spinal trauma.[13,17,20–23]

Although fracture morphology was based solely on the consensus ISSs, both neurological and case-specific modifiers were scaled down from the ISS in order to limit the weighting of the modification system relative to the fracture morphology. Therefore, even though the transition from N2 to N3 represented a ΔISS of 38 and a clinically significant distinction in patient presentation, an increase of only 2 points was assigned to prevent neurological modifiers from dictating management independently of future clinical algorithms. Controversy ensues regarding the point value assigned to patients who are unable to be examined due to secondary causes (NX). Given the devastating consequences of unstable spinal injuries and the often associated polytraumatic setting in these scenarios, NX was assigned a point value just below that of cauda equina syndrome which is in accord with the consensus of surgeons.

Analysis of the modifiers resulted in deviations from the absolute ISS scores to place increased emphasis on fracture morphology. While both soft tissue injuries (M1) and metabolic bone disease (M2) were associated with high ISS scores, these modifiers by themselves do not necessitate operative management. With respect to soft tissue injuries, soft tissue trauma overlying the sacral fracture may result in watchful waiting to allow the soft tissues to stabilize. Alternatively, severe soft tissue trauma including Morel-Lavallee injuries, along with an unstable sacral injury, may lead to either minimally invasive fixation strategies or surgical management of the Morel-Lavallee injury during fracture fixation.[24] However, fracture fixation in this setting results in a high infection risk and there is poor evidence to guide appropriate management at this time.[25] When assessing the effect of metabolic bone disease on injury severity, these injuries may alter fixation strategies, but injuries in this patient population are often minimally displaced and typically result in a primary trial of nonoperative management.[26] If nonoperative treatment fails, and metabolic bone disease is severe, this may lead to more robust fixation.[27] However, metabolic bone disease alone rarely increases the likelihood of treating a patient operatively. Therefore, both soft tissue injury and metabolic bone disease modifiers were given an ISS score of 0. M3 and M4 scores were then based off M1 and M2 scores as a baseline, which resulted in scores of 1 and 2 points, respectively.

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Future studies utilizing the Sacral AOSIS will establish thresholds for operative management. In a similar process to the current study, surgeons in the global community will be surveyed regarding their treatment preferences of various clinical scenarios. Taking into consideration both AOSIS point values and variations in practice patterns based on both region and surgeon experience, clinically relevant cutoff values will be designated to guide management of complex sacral injuries. The ultimate goal will be to use these surgical thresholds as the framework for higher level studies in hopes of establishing a body of literature that standardizes treatment and optimizes patient outcomes.

This study is not without limitations. Given that this study is a survey of surgeons worldwide, it represents consensus and expert opinion on the topic of sacral injuries. However, several widely adopted severity scales have used similar methodology including the Abbreviated Injury Scale, the ISS, and the Glasgow Coma Scale.[28–30] Furthermore, the surgeons completing the survey were not evaluated on their knowledge of sacral trauma. However, surveying numerous surgeons globally mitigates the influence any single less experienced surgeon may have on the results. Granular data regarding experience in treating sacral fractures based on subspeciality would help understand further the significant differences in severity perceived by orthopedic and neurosurgeons. Moreover, the surgeons surveyed represent an uneven geographic distribution and therefore may not accurately represent the opinion of surgeons from underrepresented regions. Some regions were excluded in the regional analysis due to a low response rate. Last, a single integer value was assigned to fracture subtypes and modifiers based on the stepwise perception as defined by ISS with few exceptions. However, the absolute point value assigned is somewhat arbitrary to the severity of the injury. Prospective studies utilizing the Sacral AOSIS are necessary to determine if further refinement of the point system is required.

CONCLUSION

The results of this study validate the hierarchical nature of the AO Spine Sacral Classification System. Following a logical progression, the severity associated with each fracture subtype and modifier are independent of surgeon region and experience. The development of Sacral AOSIS sets the foundation for further studies to develop a universal treatment algorithm for the clinical management of complex sacral injuries.

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REFRENCES

1. Bydon M, De la Garza-Ramos R, Macki M, et al. Incidence of sacral fractures and in-hospital postoperative complications in the United States. *Spine*. 2014;39:E1103–E1109.
2. Rodrigues-Pinto R, Kurd MF, Schroeder GD, et al. Sacral fractures and associated injuries. *Global Spine J*. 2017;7:609–616.
3. Wagner D, Ossendorf C, Gruszka D, et al. Fragility fractures of the sacrum: how to identify and when to treat surgically? *Eur J Trauma Emerg Surg*. 2015;41:349–362.
4. Strange-Vognsen HH, Lebech A. An unusual type of fracture in the upper sacrum. *J Orthop Trauma*. 1991;5:200–203.
5. Denis F, Davis S, Comfort T. Sacral fractures: an important problem. Retrospective analysis of 236 cases. *Clin Orthop Relat Res*. 1988;227:67–81.
6. Isler B. Lumbosacral lesions associated with pelvic ring injuries. *J Orthop Trauma*. 1990;4:1–6.
7. Roy-Camille R, Saillant G, Gagna G, et al. Transverse fracture of the upper sacrum. *Spine*. 1985;10:838–845.
8. Lehman RA, Kang DG, Bellabarba C. A new classification for complex lumbosacral injuries. *Spine J*. 2012;12:612–628.
9. Bonnin JG. Sacral fractures and cauda equina lesions. *Med World*. 1947;67:140–144.
10. Tile M. Pelvic ring fractures: should they be fixed? *J Bone Joint Surg Br*. 1988;70-B:1–12.
11. Khan JM, Marquez-Lara A, Miller AN. Relationship of sacral fractures to nerve injury: is the denis classification still accurate? *J Orthop Trauma*. 2016;31:181–184.
12. Vaccaro AR, et al. Description and reliability of the AOSpine Sacral Classification System. *J Bone Joint Surg*. 2020;102: 1454–1463.
13. Canseco JA, Schroeder GD, Patel PD, et al. Regional and experiential differences in surgeon preference for the treatment of cervical facet injuries: a case study survey with the AO Spine Cervical Classification Validation Group. *Eur Spine J*. 2020;30: 1–7.
14. Rajasekaran S, Kanna RM, Schroeder GD, et al. Does the spine surgeon's experience affect fracture classification, assessment of stability, and treatment plan in thoracolumbar injuries? *Global Spine J*. 2017;7:309–316.
15. Schroeder GD, Kepler CK, Koerner JD, et al. Is there a regional difference in morphology interpretation of A3 and A4 fractures among different cultures? *J Neurosurg Spine*. 2016;24: 332–339.
16. Schroeder GD, Kepler CK, Koerner JD, et al. A worldwide analysis of the reliability and perceived importance of an injury to the posterior ligamentous complex in AO type A fractures. *Global Spine J*. 2015;5:378–382.
17. Pishnamaz M, Curfs I, Uhing D, et al. Two-nation comparison of classification and treatment of subaxial cervical spine fractures: an internet-based multicenter study among spine surgeons. *World Neurosurg*. 2019;123:e125–e132.
18. Schroeder GD, Kurd MF, Kepler CK, et al. The development of a universally accepted sacral fracture classification: a survey of AOSpine and AOTrauma Members. *Global Spine J*. 2016;6: 686–694.
19. Gutierrez-Gomez S, Wahl L, Blecher R, et al. Sacral fractures: an updated and comprehensive review. *Injury*. 2020;52:366–375.
20. Kepler CK, et al. The thoracolumbar AOSpine Injury Score. *Global Spine J*. 2015;6:329–334.
21. Kepler CK, Vaccaro AR, Koerner JD, et al. Reliability analysis of the AOSpine thoracolumbar spine injury classification system by a worldwide group of naïve spinal surgeons. *Eur Spine J*. 2016;25: 1082–1086.
22. Ngoya PS, Muhogora WE, Pitcher RD. Defining the diagnostic divide: an analysis of registered radiological equipment resources in a low-income African country. *Pan Afr Medical J*. 2016; 25:99.
23. Volpi G. Radiography of diagnostic imaging in Latin America. *Nucl Med Biomed Imaging*. 2016;1:10–12.
24. Shen C, Peng JP, Chen XD. Efficacy of treatment in peri-pelvic Morel-Lavallee lesion: a systematic review of the literature. *Arch Orthop Trauma Surg*. 2013;133:635–640.
25. Rodrigues-Pinto R, Kurd MF, Schroeder GD, et al. Sacral fractures and associated injuries. *Global Spine J*. 2017;7: 609–616.

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26. Wilson DGG, Kelly J, Rickman M. Operative management of fragility fractures of the pelvis–a systematic review. *BMC Musculoskelet Disord*. 2021;22:717.
27. Wagner D, Ossendorf C, Gruszka D, et al. Fragility fractures of the sacrum: how to identify and when to treat surgically? *Eur J Trauma Emerg Surg*. 2015;41:349–362.
28. Teasdale G, Jennett B. Assessment of coma and impaired consciousness: a practical scale. *Lancet*. 1974;304:81–84.
29. Rating the severity of tissue damage: I. The Abbreviated Scale. *JAMA*. 1971;215:277–280.
30. Baker SP, O'neill B, Haddon W, et al. The Injury Severity Score. *J Traumae*. 1974;14:187–196.

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