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LITERATURE REVIEW

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Evolution of the AO Spine Sacral and Pelvic Classification System: a systematic review

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OBJECTIVE The purpose of this study was to describe the genesis of the AO Spine Sacral and Pelvic Classification System in the context of historical sacral and pelvic grading systems.

METHODS A systematic search of MEDLINE, EMBASE, Google Scholar, and Cochrane databases was performed consistent with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to identify all existing sacral and pelvic fracture classification systems.

RESULTS A total of 49 articles were included in this review, comprising 23 pelvic classification systems and 17 sacral grading schemes. The AO Spine Sacral and Pelvic Classification System represents both the evolutionary product of these historical systems and a reinvention of classic concepts in 5 ways. First, the classification introduces fracture types in a graduated order of biomechanical stability while also taking into consideration the neurological status of patients. Second, the traditional belief that Denis central zone III fractures have the highest rate of neurological deficit is not supported because this subgroup often includes a broad spectrum of injuries ranging from a benign sagittally oriented undisplaced fracture to an unstable “U-type” fracture. Third, the 1990 Isler lumbosacral system is adopted in its original format to divide injuries based on their likelihood of affecting posterior pelvic or spinopelvic stability. Fourth, new discrete fracture subtypes are introduced and the importance of bilateral injuries is acknowledged. Last, this is the first integrated sacral and pelvic classification to date.

CONCLUSIONS The AO Spine Sacral and Pelvic Classification is a universally applicable system that redefines and reorders historical fracture morphologies into a rational hierarchy. This is the first classification to simultaneously address the biomechanical stability of the posterior pelvic complex and spinopelvic stability, while also taking into consideration neurological status. Further high-quality controlled trials are required prior to the inclusion of this novel classification within a validated scoring system to guide the management of sacral and pelvic injuries.

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KEYWORDS classification system; fracture; pelvic; sacral; trauma

ABBREVIATIONS PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses; ROBINS-I = Risk of Bias in Non-Randomized Studies of Interventions.

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The sacrum is a kyphotic structure that acts as the transitional point of weight transference between the spine and pelvis.[1] Sacral fractures exhibit an epidemiological bimodal peak and are usually the consequence of high-energy trauma in young adults or low-energy trauma in the osteoporotic elderly.[2,3] Approximately 25% of patients with sacral fractures experience neurological deficits, ranging from minor neurapraxia to lumbosacral plexus injury and cauda equina transection.[4–6] The lack of a validated classification system has hindered the care for patients with these often neglected injuries, and has also precluded the development of a universally accepted treatment algorithm.

Since Duverney reported the iliac wing fracture in 1751 and Malgaigne introduced the vertical shear fracture in 1876, a bewildering number of pelvic and sacral classifications have been proposed.[7,8] The majority of these attempt to predict fracture stability or death based on mechanism, fracture type, or fracture location.[4,9–46] Few of these systems acknowledge the inextricable relationship between sacral and pelvic ring fractures.[6] Furthermore, existing pelvic classifications are either too broad, such as those of Dalal et al. or Cryer et al., or exceedingly specific, which prohibits effective integration into a sacral classification system.[21–23,25,26,47,48] Similarly, sacral classification systems either are entirely focused on a particular sacral fracture morphology, such as those proposed by Denis et al. or by Roy-Camille et al., or address only an isolated portion of the sacrum, such as the lumbosacral junction system of Isler.[32,39–41] An ideal classification is rationally structured in its introduction of fracture patterns and addresses both mechanical stability and neurological status, as well as being reproducible with high interrater reliability.[46,49,50] We aimed to review all historical classification systems and to demonstrate the value of the pioneering AO Spine Sacral and Pelvic Classification System in comparison.[46]

Methods

Search and Eligibility Criteria

A systematic electronic search of the MEDLINE, EMBASE, Google Scholar, and Cochrane Database of Systematic Reviews from their date of inception to August 2021 was conducted in keeping with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[51] Databases were queried with the following terms combined with various Boolean operators: “sacrum,” “sacral,” “pelvis,” “pelvic,” “fracture,” “injur*,” “classification,” and “system.” Only studies examining human subjects and reported in the English language or with available English translations were included. No registered review protocol exists for this study.

Inclusion and Exclusion Criteria

All abstracts were independently screened by two authors (B.T.S.K. and J.W.T.) before articles suitable for full-text examination were identified. The bibliographies of included studies were also interrogated for further eligible articles. Discrepancies were discussed until consensus was attained. The inclusion criteria were defined as follows: 1) any form of article, whether a randomized or nonrandomized controlled trial, cohort study, case series, case report, or review article, that proposed a new classification system, defined as a method of grading fractures on a rational basis with two or more categories; 2) any article that added a new category to an established classification system (case reports of a single rare fracture morphology subtype were excluded); and 3) human subjects.

Study Selection and Data Extraction

Extraction of data into a preformatted spreadsheet was performed independently by one author (B.T.S.K.) and cross-checked by another (J.W.T.) in accordance with the *Cochrane Handbook for Systematic Reviews*.[52] No authors were contacted for further unpublished data.

Appraisal and Synthesis of Results

The Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tool and Murad et al.’s instrument were applied for included nonrandomized studies and the case studies or case reports, respectively.[53,54] Study quality was independently assessed by two authors (B.T.S.K. and J.W.T.), with consensus attained following discussion. The “Robvis” tool was used to generate a traffic light plot in accordance with Cochrane recommendations.[55]

Results

Study Selection

The primary search retrieved 2925 articles, which were culled to 2060 after duplicates were discarded (Fig. 1). Following screening of abstracts, 107 studies required full-text assessment for eligibility. A total of 49 studies were included in the systematic review, with 40 articles proposing a novel pelvic or sacral classification system and 9 studies describing the reliability of an established system. The most common reasons for exclusion were failure to propose a new classification system or review articles.

Study Quality

Assessment of risk of bias in the included studies was generally low as assessed by the instruments of Murad et al. (Supplementary Table 1) and the ROBINS-I tool for studies on both pelvic (Supplementary Fig. 1) and sacral (Supplementary Fig. 2) classifications.[53,54]

Historical Classification Systems—Pelvic Ring Fracture Classifications

A total of 23 individual pelvic fracture classification systems were identified from 24 studies (Table 1 and Supplementary Table 2).[9–32] The earliest studies classified pelvic fractures by their morphological features to infer the single most likely mechanism by which they occurred. In this era, a common surrogate for biomechanical stability was the ability of patients to bear weight following an injury. Watson-Jones in 1938 dichotomized injuries into those that affected or spared the pelvic ring, which determined in what position the patients should lie while recovering.[9] For example, isolated fractures of the pelvic ring required no positional restrictions in bed, whereas patients with combined fractures produced by lateral compression were advised

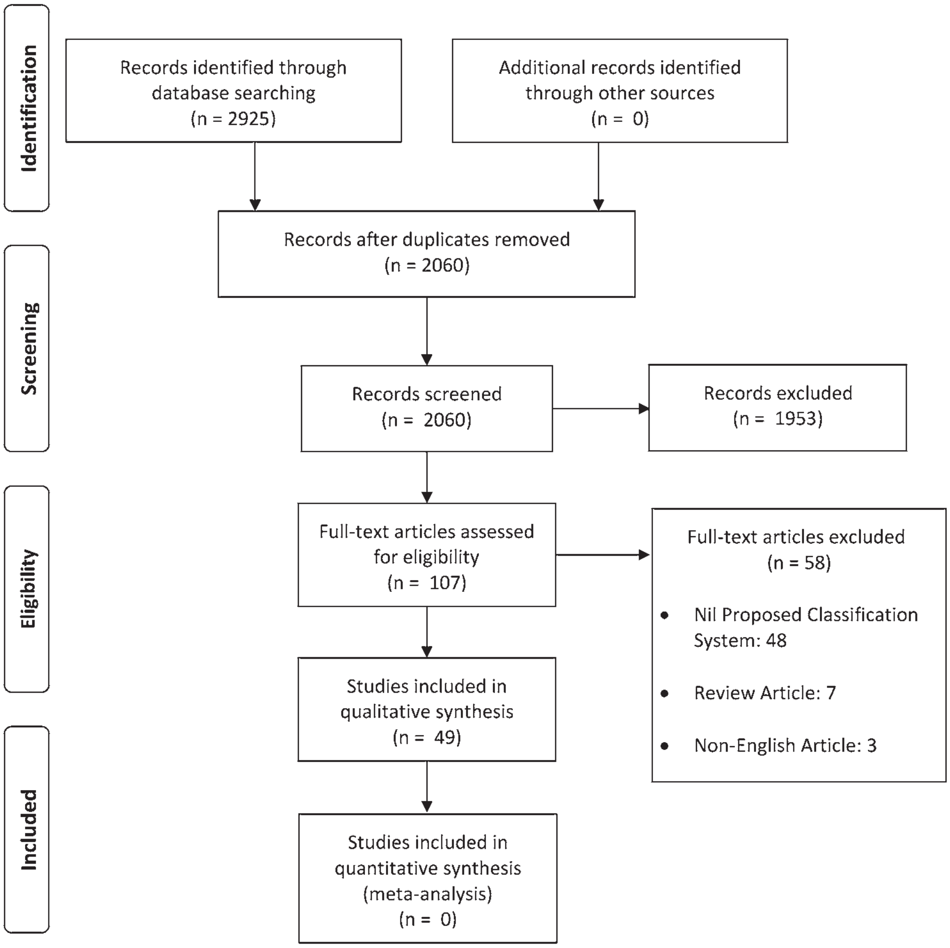

FIG. 1. PRISMA flow diagram. Data added to the PRISMA template (from Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 2009;6[7]: e1000097) under the terms of the Creative Commons Attribution License.

to lie on their back but not on their side.[9] Peltier in 1965 and Conolly and Hedberg in 1969 assisted by identifying fractures that did not affect weight-bearing status, such as avulsion fractures and isolated iliac wing fractures.[10,12] Associated overall systemic injury burden was also used as a clue toward pelvic injury severity.[9,12–15] Indeed, bilateral fractures of the pubic rami suggested a high probability of abdominal visceral injuries, whereas hemipelvic shear injuries often led to crushing soft-tissue damage, as Froman and Stein and Connolly and Hedberg noted.[11,12,16]

With time, understanding of biomechanical stability improved and it became increasingly evident that the integrity of the strong posterior structures including the posterior sacroiliac, sacrotuberous ligaments, and sacrospinous ligaments was crucial to resisting rotational and shear forces.[15,16] Looser and Crombie based their classification system solely on this distinction between anterior and posterior fractures, given the significantly higher rate of neurological injury (0% vs 11.6%) and mortality (8.8% vs 14.0%) for posterior fractures.[15] However, Huittinen and Slatis warned that although the anterior third of the pelvic ring does not participate in any weight transmission in the erect position, anterior ring fractures such as of the pubic rami or pubic symphysis still serve as a vital clue to a combined posterior injury.[13] This was also suspected by Letournel and confirmed by Bucholz, who found that 26 of the 32 cadavers of multitrauma patients they dissected did in fact demonstrate a double vertical break of Malgaigne pattern of pelvic ring injury.[17,18] Moreover, 14 of these patients only had an anterior ring injury radiographically, but on dissection were confirmed to have either a nondisplaced vertical sacral fracture or tearing of the anterior sacroiliac ligament.[17]

In light of this increasingly sophisticated understanding of pelvic fractures, Pennal et al. explored specific vectors of force as a means of classifying injuries.[9,16] This led to the landmark Young-Burgess classification, which is still widely used today.[19,23] The defining characteristic of this system is subdivision of injuries into lateral or anteroposterior compression fractures, which may be rotationally unstable but vertically stable compared to the vertical shear injury, which is grossly multidirectionally unstable.[19,23] Tile introduced the main rival classification system of the Young-Burgess system in 1988, with a divi-

TABLE 1. Integration between AO Spine Sacral and Pelvic Classification System and existing classification systems

	Classification Element Considered					
Authors & Year	Stability	Neurological Deficit	Hierarchical	Consideration of Combined Spinopelvic Stability	Reliability Assessed	Relevance to AO Classification System
Pelvic studies						
Watson-Jones, 1938[9]	Yes	No	Yes	Yes	No	None
Peltier, 1965[10]	Yes	No	Yes	Yes	No	Groups B & C
Froman & Stein, 1967[11]	Yes	No	Yes	No	No	None
Conolly & Hedberg, 1969[12]	Yes	No	Yes	No	No	None
Huittinen & Slatis, 1972[13]	Yes	No	No	No	No	None
Trunkey et al., 1974[14]	Yes	No	Yes	Yes	No	Groups B & C
Looser & Crombie, 1976[15]	Yes	Yes	Yes	Yes	No	Groups B & C
Pennal et al., 1980[16]	Yes	No	Yes	Yes	No	Groups B & C
Bucholz, 1981[17]	Yes	No	Yes	Yes	No	Groups B & C
Letournel, 1981[18]	Yes	No	No	No	No	None
Young et al., 1986[19]	Yes	No	Yes	Yes	No	Groups B & C
Tile, 1988[20]	Yes	No	Yes	Yes	No	Groups B & C
Cryer et al., 1988[21]	Yes	No	Yes	No	No	None
Dalal et al., 1989[22]	No	No	No	No	No	None
Burgess et al., 1990[23]	Yes	No	Yes	No	Yes	None
Hanson et al., 1991[24]	Yes	No	Yes	No	No	None
Tile, 1996[25,26]	Yes	No	Yes	Yes	Yes	Groups B & C
Isler & Ganz, 1996[27]	Yes	No	Yes	Yes	No	Groups B & C
Jones et al., 1997[28]	Yes	No	Yes	No	No	Group B
Rommens & Hofmann, 2013[29]	Yes	No	Yes	Yes	Yes	Groups B & C
Coccolini et al., 2017[30]	Yes	No	Yes	No	No	None
Meinberg et al., 2018[31]	Yes	No	Yes	Yes	No	Groups B & C
Beckmann et al., 2020[32]	Yes	No	Yes	Yes	No	Groups B & C
Sacral studies						
Medelman, 1939[33]	No	No	No	Yes	No	Group B
Bonnin, 1947[34]	No	Yes	No	Yes	No	Groups A & B
Fountain et al., 1977[35]	No	Yes	No	No	No	None
Sabiston & Wing, 1986[36]	No	Yes	No	No	No	Group A
Kaehr et al., 1989[37]	Yes	Yes	Yes	No	No	Groups A–C
Schmidek et al., 1984[38]	No	Yes	No	Yes	No	Group B
Roy-Camille et al., 1985[39]	No	Yes	No	No	No	Group A
Denis et al., 1988[40]	No	Yes	Yes	No	No	Group A
Isler, 1990[41]	Yes	No	Yes	Yes	No	Group B
Gibbons et al., 1990[42]	No	Yes	Yes	No	No	Group B
Strange-Vognsen & Lebach, 1991[43]	No	Yes	No	No	No	Group A
Vaccaro et al., 2004[44]	Yes	No	No	Yes	Yes	Group C
Vaccaro et al., 2004[44]	Yes	Yes	Yes	No	Yes	Groups A–C
Lehman et al., 2012[4]	Yes	Yes	Yes	Yes	No	Group B
Bakker et al., 2018[45]	No	Yes	Yes	No	No	Groups A–C, modifiers
Vaccaro et al., 2020[46]	Yes	Yes	Yes	Yes	Yes	NA

NA = not applicable.

sion of pelvic fractures into 3 discrete groups based purely on perceived rotational and vertical stability rather than mechanism of injury.[20]

The ultimate aim of all of these evolving classification systems was to lower the morbidity and mortality rate of these potentially neurologically devastating injuries. In order to achieve this, Trunkey et al. and later Hanson et al. began correlating pelvic injuries with increasing magnitude of mortality.[14,24] The risk of major hemorrhage associated with pelvic fractures formed the basis of Cryer et al. adapting the Pennal system and succeeding in correlating stability of different fracture subtypes with risk of hemorrhagic shock.[16,21] Furthermore, Dalal et al. observed that certain fracture injury patterns portended specific injuries. Those with anteroposterior compression fractures tended to have intracranial insults, in contrast to patients with lateral compression fractures who experienced crushing intraabdominal injuries.[22]

Sacral fractures were also examined with a more holistic approach by Jones et al., who cautioned about the need to consider whether pelvic fractures were open and at higher risk of sepsis and complication, whereas Rommens and Hofmann raised awareness for fragility fractures of the pelvic ring.[28,29] Recently, the AO/OTA (Orthopaedic Trauma Association) has adapted the Tile classification system, whereas the World Society of Emergency Surgery prefers the Young-Burgess system in making critical decisions based primarily on the hemodynamic stability of acutely unwell patients.[20,25,26,30,31,47] Improved modern imaging has also seen the development of radiological systems for assessing severity of pelvic fractures, but despite this an integrated and validated pelvic and sacral classification system remains lacking.[32]

Historical Classification Systems—Sacral Classifications

A total of 17 proposed sacral classification systems were identified from 16 articles (Table 1 and Supplementary Table 3).[4,33–46] These systems have evolved over time from recognizing basic fracture morphologies and their underlying mechanisms to understanding their stability and propensity to cause neurological injury. In 1939, Medelman recognized the fundamental idea that sacral fractures occurred simultaneously with pelvic injuries in 44% of cases.[33] A simple classification was subsequently devised with 3 distinct groups: longitudinal, oblique, and horizontal.[33] This was developed by Bonnin, who began associating mechanisms of injury with common injury patterns.[34] Classically, traction injuries of the sacrotuberous or sacrospinous ligaments leading to detachment of lateral sacral fragments were relatively stable compared to direct-impact forces causing transverse fractures.[34] These injuries have been incorporated into group A of the AO Spine classification system. From this, Sabiston and Wing began correlating sacral injury patterns with rates of neurological injury and, importantly, established that isolated sacral fractures of the lower segments carried a lower rate of deficit (9.1%) compared to those associated with pelvic fractures (15.8%) or fractures of higher segments (100%).[36]

Similarly, Kaehr et al. divided the sacrum into different anatomical regions guided by the sacral foramina.[37] In their system, type 2 fractures were lateral to the neural foramina, whereas type 3 were transforaminal and type 4 were medial to the neural foramina.[37] This foreshadowed the landmark classification system proffered by Denis et al., which used similar zones, and found a corresponding rise in the rate of neurological deficit in injuries of the alar zone I (5.9%), before moving medially to foraminal zone II (28.4%), and finally to the central zone III (56.7%).[40] These fractures have been adapted into the group B category of injuries of the contemporary AO Spine classification system.

It was not until 1977 that Fountain et al. emphasized the importance of transverse sacral fractures as a separate entity with poor neurological outcomes without surgical decompression of neural elements.[35] Schmidek et al. concurred and their classification emphasized the division between low transverse fractures (S3 and below), likely to be a result of direct trauma, and high transverse fractures of S1 and S2, which were more likely to be secondary to indirect forces.[38] This was formalized by Roy-Camille et al. in 1985, who described 3 types of transverse sacral fractures: type 1 being a simple flexion fracture, and types 2 and 3 were associated with posterior and anterior displacement of the upper fragment, respectively.[39] Finally, in 1991 it was Strange-Vognsen and Lebech who added type 4 as a segmental comminution of S1 as a consequence of axial loading that is generally unstable.[43] These lower sacrococcygeal injuries now occupy the more severe spectrum of group A injuries. With the correlation between sacral fracture patterns and neurological injury established, Gibbons et al. provided a methodological way of grading the severity of such injuries.[42] In particular, the characteristic fracture patterns named for their resemblance to certain letters, such as "U" or "H" type, became independent morphologies that have inspired the group C category of the AO classification.[44]

At last there was bridging of the pelvic and sacral classification systems by Isler's 1990 lumbosacral junction classification, which highlighted the importance of determining whether the fracture line exited proximally lateral or medial to the articular process of S1.[41] Significantly, hemipelvic displacement only compromises the lumbosacral junction if the fracture line passes medial to the articular process of S1. The pioneering AO Spine Sacral Classification System established by Vaccaro et al. thus reorders and integrates all of these individual sacral classification systems into a rational hierarchical system for the first time.[46]

Interobserver Reliability of Existing Pelvic and Sacral Classification Systems

There were 16 independent evaluations of the included classification systems derived from 10 studies (Table 2).[46,56–64] Two studies examined the AO Spine Sacral Classification System, with moderate to strong reliability for fracture type ($\kappa = 0.69–0.83$) and moderate reproducibility for subtype ($\kappa = 0.61–0.71$).[46,56] Six studies interrogated the AO/Tile Pelvic Ring Classification, with variable results.[57–62] Furey et al. ($\kappa = 0.47$) and Berger-Groch et al. ($\kappa = 0.21–0.51$) found weak to moderate interobserver reproducibility, whereas Ansorge et al. found it to be more favorable when assessing by fracture type alone ($\kappa = 0.79$).[58,60,61] A similar result was observed for the Young-Burgess Pelvic Classification System, with Berger-Groch et al. observing poor reliability ($\kappa = 0.28–0.55$), whereas Furey et al. argued that there was moderate reproducibility ($\kappa = 0.61$).[58,60] The Rommens classification for pelvic ring fragility fractures was also moderate in its performance ($\kappa = 0.68–0.72$) when assessed by Krappinger et al., but rather poor in the study by Berger-Groch et al.[60,64]

TABLE 2. Intraobserver and interobserver reliability of existing sacral and pelvic classification systems

Authors & Year	Classification System	No. of Cases Reviewed	No. w/ Fx	Modality Used	Intraobserver Reproducibility	Interobserver Agreement
Vaccaro et al., 2020[46]	AO Sacral Classification System	38	17	CT	κ = 0.83 for Fx severity type κ = 0.71 for Fx subtype	κ = 0.75 for Fx severity type Highest for type A Fxs, κ = 0.95 Lowest for type C Fxs, κ = 0.70 κ = 0.58 for Fx subtype Highest for A2 subtype, κ = 0.81 Lowest for A1 subtype, κ = 0.20
Urrutia et al., 2021[56]	AO Sacral Classification System	80	6	CT	κ = 0.69 (0.63–0.75) for Fx severity type Highest for type A Fxs, κ = 0.71 (0.62–0.80) Lowest for type B Fxs, κ = 0.67 (0.58–0.76) κ = 0.61 (0.56–0.67) for Fx subtype Highest for B2 subtype, κ = 0.70 (0.61–0.79) Lowest for B1 subtype, κ = −0.28 (0.19 to 0.37)	κ = 0.68 (0.63–0.72) for Fx severity type Highest for type A Fxs, κ = 0.79 (0.73–0.85) Lowest for type C Fxs, κ = 0.64 (0.59–0.70) κ = 0.52 (0.49–0.54) for Fx subtype Highest for B2 subtype, κ = 0.70 (0.64–0.75) Lowest for B1 subtype, κ = −0.01 (−0.07 to 0.0)
Koo et al., 2008[57]	AO/Tile Pelvic Ring Classification	30	6	XR & CT	NR	κ = 0.44 (0.29–0.63) for type κ = 0.33 (0.19–0.52) for subtypes
Furey et al., 2009[58]	AO/Tile Pelvic Ring Classification	89	5	XR & CT	κ = 0.47 (0.31–0.64)	κ = 0.46 (0.39–0.52)
Gabbe et al., 2013[59]	AO/Tile Pelvic Ring Classification	187	3	XR & CT	NR	κ = 0.12–0.17 for complete classification κ = 0.10–0.17 for 3 main categories
Berger-Groch et al., 2019[60]	AO/Tile Pelvic Ring Classification	154	4	CT	κ = 0.21–0.51	κ = 0.55 (0.47–0.63) overall κ = 0.64 for main types B/C
Ansorge et al., 2021[61]	AO/Tile Pelvic Ring Classification	86	3	XR & CT	κ = 0.79 (0.66–0.91) for type κ = 0.68 (0.57–0.80) for group κ = 0.62 (0.51–0.73) for subgroup κ = 0.47 (0.37–0.58) for qualification	κ = 0.72 (0.63–0.81) for type κ = 0.48 (0.43–0.53) for group κ = 0.48 (0.44–0.52) for subgroup κ = 0.37 (0.35–0.40) for qualification
Zingg et al., 2021[62]	AO/Tile Pelvic Ring Classification	238	6	CT	NR	κ = 0.44 for group κ = 0.31 for type
Koo et al., 2008[57]	Young-Burgess Pelvic Fracture Classification	30	6	XR & CT	NR	κ = 0.63 (0.49–0.77)
Furey et al., 2009[58]	Young-Burgess Pelvic Fracture Classification	89	5	XR & CT	κ = 0.61 (0.53–0.69) for type κ = 0.72 (0.66–0.78) w/ subtypes	κ = 0.58 (CI 0.45–0.72)
Gabbe et al., 2013[59]	Young-Burgess Pelvic Fracture Classification	187	3	XR & CT	NR	κ = 0.42 for mechanism of injury κ = 0.59 for stable vs unstable κ = 0.38 for complete classification κ = 0.17–0.19 for 4-category classification κ = 0.16–0.21 for stable vs unstable
Berger-Groch et al., 2019[60]	Young-Burgess Pelvic Fracture Classification	154	4	CT	κ = 0.28–0.55	κ = 0.42 (0.33–0.50)

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TABLE 2. Intraobserver and interobserver reliability of existing sacral and pelvic classification systems

Authors & Year	Classification System	No. of Cases Reviewed	No. w/ Fx	Modality Used	Intraobserver Reproducibility	Interobserver Agreement
Cheung et al., 2021[63]	Young-Burgess Pelvic Fracture Classification	369	2	XR & CT	NR	Interobserver agreement on XR: κ = 0.72 for mechanism of injury κ = 0.60 for stable vs unstable κ = 0.55 for complete classification Interobserver agreement on CT: κ = 0.42 for mechanism of injury κ = 0.59 for stable vs unstable κ = 0.38 for complete classification
Ansorge et al., 2021[61]	Young-Burgess Pelvic Fracture Classification	86	3	XR & CT	κ = 0.69 (0.57–0.80)	κ = 0.51 (0.45–0.57)
Krappinger et al., 2019[64]	Rommens Fragility Fractures of Pelvic Ring Classification	100	4	CT	κ = 0.68–0.72 overall	κ = 0.42–0.59 overall
Berger-Groch et al., 2019[60]	Rommens Fragility Fractures of Pelvic Ring Classification	154	4	XR & CT	κ = 0.29–0.55	κ = 0.54 (0.44–0.64)

Fx = fracture; NR = not reported; XR = radiograph.
All values in parentheses represent 95% CIs.

Discussion

The AO Spine Sacral and Pelvic Classification System is revolutionary and challenges existing historical schemes in five novel ways. First, the AO system is a hierarchical system that introduces injury patterns in order of stability, akin to Lehman et al., while simultaneously taking into consideration the degree of neurological deficit, which is reminiscent of Denis et al. and Gibbons et al.[4,40,42,46] The 3 main divisions consist of type A (lower sacrococcygeal), type B (posterior pelvic), and type C (spinopelvic) injuries. Type A injuries have no impact on the stability of the posterior pelvic ring or spine, given their distant location from the weight-bearing axis (Fig. 2). Subtype A1 injuries are coccygeal compression or ligamentous avulsion fractures, which were first identified by Bonnin as traction injuries in 1947.[34] This category also includes subtype A2 nondisplaced transverse sacral fractures below the sacroiliac joint as described by Sabiston and Wing, and subtype A3 displaced fractures below the sacroiliac joint as documented by Schmidek et al.[36,38,46] Importantly, the AO system with its unique set of modifiers takes into account the crucial fact that type A injuries may be mechanically stable but still cause neurological compromise, as exemplified by subtype A3 fractures.[46] Indeed, the subtype A3 fracture is similar to a Roy-Camille type 3 injury, except with reversal of the direction of fragment displacement.[39] This subtle distinction is conveyed by the AO system and enables clinicians to understand that for these injuries, traction is traditionally believed to be helpful but that surgery may still potentially be required in the presence of persistent neurological deficit.[39]

Second, on superficial inspection of type B posterior pelvic injuries within the AO system it would seem that this category merely consists of the familiar unilateral vertical sacral fractures without disruption of the medial aspect of the S1 facet joint (Fig. 3).[41,46] As such, type B injuries disrupt the posterior pelvic complex while preserving spinopelvic stability.[41,44,46] This series of vertical fractures was recognized by Kaehr et al. and refined by Denis et al. in their landmark 1988 study, in which alar zone I fractures (50%) carry a 5.9% risk of neurological deficit manifesting typically as L5 sciatica.[37,40] More severe than this are the foraminal zone II injuries (34%), with a 28.4% rate of deficit usually affecting the L5–S2 nerve roots, followed by the central zone III (16%) fractures, with a devastating 56.7% rate of deficit often affecting bowel and bladder function.[40] What physicians will notice is that the AO system actually challenges this historical system by nominating subtype B1 injuries, previously designated Denis zone III injuries, as those involving the central zone and spinal canal actually as the most stable.[40,46] Following this are subtype B2 transalar fractures, formerly Denis zone I, without involvement of the sacral foramina or spinal canal.[40,46] The last of the type B injuries, transforaminal fractures, which were previously Denis zone II fractures, are labeled as subtype B3 injuries.[40,46]

Furthermore, the evolutionary AO system even seems to contradict contemporary evidence. In fact, Khan et al. examined 1507 consecutive patients with sacral fractures over more than a decade and found that the overall rate of nerve injury was lower today compared to that in 1988

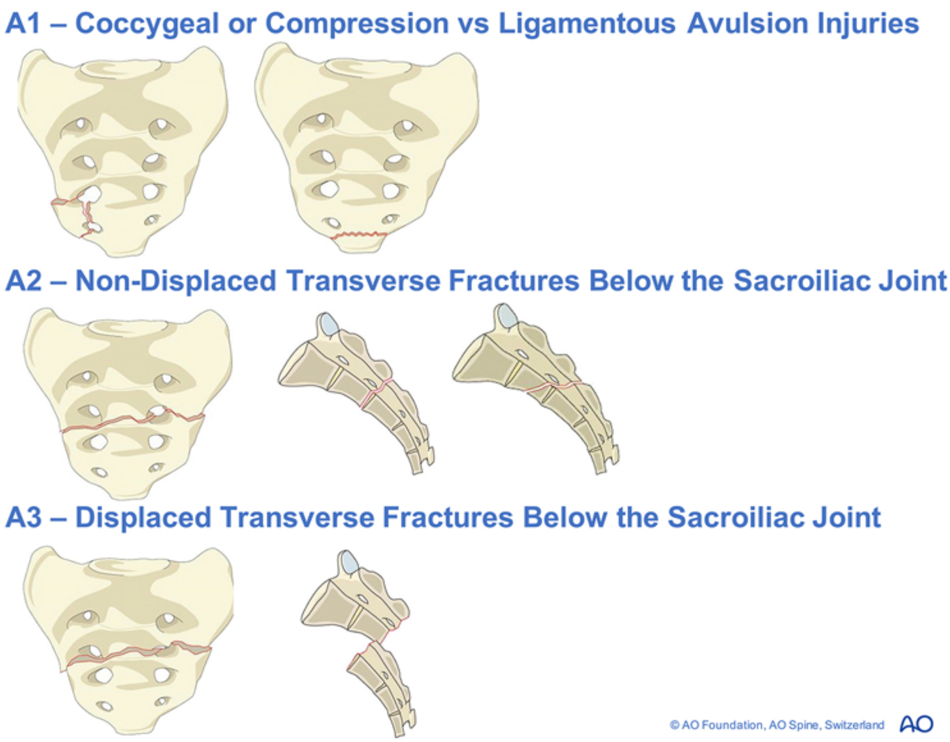

FIG. 2. Type A injuries as designated by the AO Spine Sacral and Pelvic Classification System. Sacral A1 subtype fractures consist of coccygeal or ligamentous avulsion injuries. Sacral A2 subtype fractures are nondisplaced transverse fractures below the level of the sacroiliac joint, whereas sacral A3 subtype fractures are displaced transverse fractures below the level of the sacroiliac joint. © AO Spine, AO Foundation, published with permission. Figure is available in color online only.

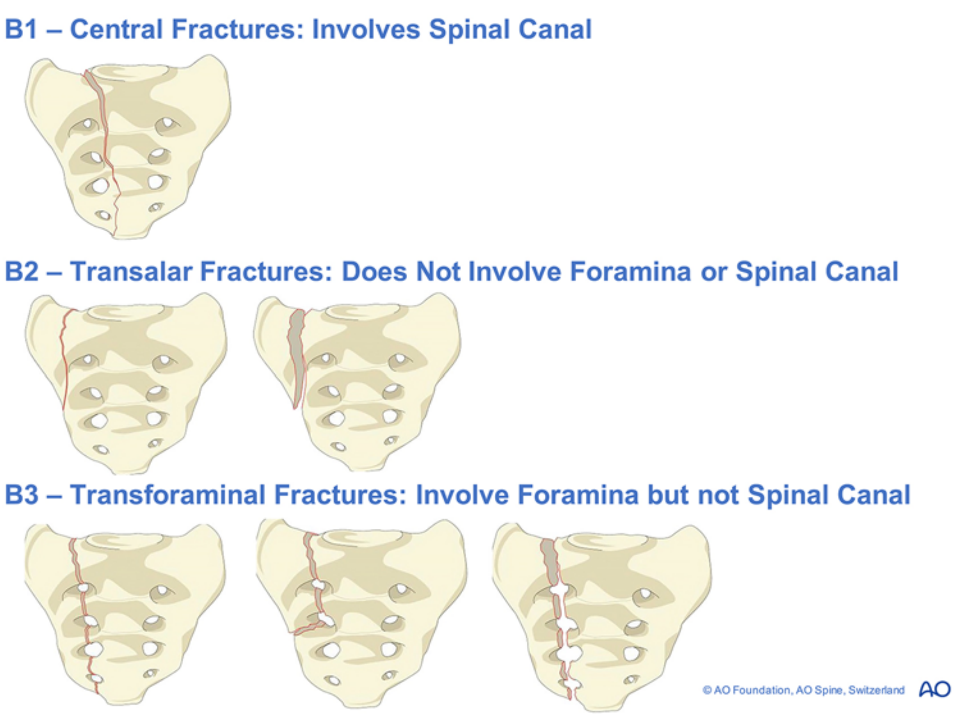

FIG. 3. Type B injuries as designated by the AO Spine Sacral and Pelvic Classification System. Sacral B1 subtype fractures are central fractures that involve the spinal canal. Sacral B2 subtype fractures are represented by transalar fractures, which do not involve the sacral foramina or spinal canal. Sacral B3 subtype fractures are transforaminal in nature but do not involve the spinal canal. © AO Spine, AO Foundation, published with permission. Figure is available in color online only.

during the era of Denis et al. (3.5% vs 21.6%, $p < 0.001$).[40,65] However, the trend of an escalating rate of neurological deficit was maintained across the 3 zones (1.9% for zone I, 5.8% for zone II, and 8.6% for zone III).[40,65] This is probably partially explained by more advanced and high-resolution CT imaging techniques detecting less severe and minimally displaced sacral fractures.[40,65] Ultimately, Schroeder et al. astutely noted that Denis zone III injuries included all injuries ranging from simple vertical undisplaced fractures medial to the foramen to those fractures with a horizontal component and therefore actually included the extremely unstable "U-type" variant proposed by Vaccaro et al. in 2004.[44,49] Bellabarba et al. examined only uncomplicated sagittally oriented sacral fractures and found no neurological deficit in their 10-patient case series, which was in contrast to the greater than 50% chance of deficit observed when there exists a transverse component to the fracture.[66] This is biomechanically explained perhaps by the concurrent displacement of the neural structures within their bony elements with these fracture types. For this reason, 77.8% of spine surgeons concurred with the belief shared by Bydon et al. that the potentially unstable subtype B3 fractures directly compromising the sacral foramina were more likely to cause a deficit than subtype B1 injuries.[2,49] This justifies the dramatic and unprecedented reordering within the type B injury subdivision today.[46,49]

Third, the AO system is novel in truly adhering to the lumbosacral system of facet dislocation proposed by Isler in 1990.[41,46] The original classification scrutinized lumbosacral junction injuries with an associated unstable pelvic fracture and determined that there would be hemipelvic instability if the sacral fracture line passed medial to or through the articular process of S1.[41,46] Isler distinctly classified these injuries in which even the slightest hemipelvic displacement could cause instability into the following categories: type 1 injuries as extraarticular, type 2 as articular involving the L5–S1 facet joint, and type 3 as complex.[41] Intriguingly, the literature often erroneously misquotes this seminal work by Isler as subclassifying fractures according to whether the fracture line passes lateral, through, or medial to the articular facet, despite the original classification being related specifically and exclusively only to fractures passing medial to the facet.[67,68] Fortunately, the AO system adheres to the initial intention of Isler by separating type B fractures as strictly those in which the S1 facet is continuous with the medial sacrum so that only posterior pelvic but not spinopelvic stability is affected.[46] It is unsurprising that an entire category should be dedicated to posterior injuries, given the greater associated mortality and associated injury compared with anterior fractures as established by Looser and Crombie.[15]

The final category of type C unstable spinopelvic injuries was foreshadowed by Denis et al. when they warned that there were two important additional factors to consider when evaluating sacral fractures: axial level of the fracture and bilateral injuries (Fig. 4).[40] This category addresses both. The C0 subtype fracture is a nondisplaced sacral "U" variant, which Vaccaro et al. formalized in 2004, and which was supported for inclusion in the AO system by Schroeder et al.—a feature unique to this classification.[44,49] This is followed by the C1 subtype fracture, in which there is a fracture line medial to the ipsilateral S1 facet, and bilateral complete type B injuries without a transverse component (being represented by a C2 subtype injury). The most unstable fracture pattern is the C3 subtype displaced U-type fracture, which represents a high sacral injury and complete fragment dissociation. It is important to note that bilateral type B vertical injuries, which appear to be a C2 subtype injury, may in fact harbor an unrecognized obscure horizontal component and be either a C0 or C3 subtype injury.[40]

The spinopelvic injuries encapsulated by type C injuries were well described by Helgeson et al. in the setting of blast injuries, in which there is both a vertical and horizontal component to the sacral fracture, resulting in dissociation between the sacrum and pelvis.[69] These are significant injuries, which Robles noted should be suspected if there is fracture of a lower lumbar transverse process, asymmetry of the sacral notch, or irregularity of the arcuate lines in the upper 3 sacral foramina.[70] Morimoto et al. in particular found that an L5 transverse process fracture was significantly associated with sacral fractures.[71] These generally unstable injuries also lead to devastating neurological deficit, with Kempen et al. determining that 62% of patients presented with a posttraumatic lumbosacral plexus injury or cauda equina syndrome.[72] Operative stabilization promoted healing and earlier mobilization, but was associated with a 13% postoperative infection rate, with both Rizkalla et al. and Zelle et al. warning of the need to weigh this perioperative risk against the potential operative difficulty encountered when correcting delayed posttraumatic deformity.[73,74]

The distinguishing final feature of the AO system is its synthesis and integration of historical pelvic and sacral classification systems. It has been interrogated by Schroeder et al. and proven robust, with 86.90% of 474 surgeons agreeing with the progressive arrangement of categories, with moderate reproducibility and interobserver agreement.[46,49,56] Not only does this comprehensive and universally applicable system draw upon early work by Medelman and Bonnin when describing group A injuries, but it also redefines the sacral zones of Denis et al. as well as acknowledging the transverse sacral fracture types popularized by Roy-Camille et al., and later Strange-Vognsen and Lebach in the group B category.[33,34,39,40,43] Moreover, the AO system strictly adheres to the original 1990 Isler classification system between its type B and C categories, while also taking into consideration pelvic stability and redirecting clinicians in the case of type B fractures to consider the stability of the posterior pelvis.[41]

This is not to say that the AO system is beyond improvement. The classification may benefit from a clearer definition of what constitutes displacement or angulation.[56] At present, both the Tile and Young-Burgess systems use the disruption of the symphysis pubis of more than 2.5 cm as a threshold for increasing severity.[19,23,25,26,31,47] It is also generally accepted that more than 1 cm of posterior displacement is a sign of posterior instability.[75] Future validation of the hierarchical system correlating with escalating morbidity and mortality would facilitate integration into a scoring system that guides operative or nonoperative clinical decision-making. At present, physicians seem to rely on the rational

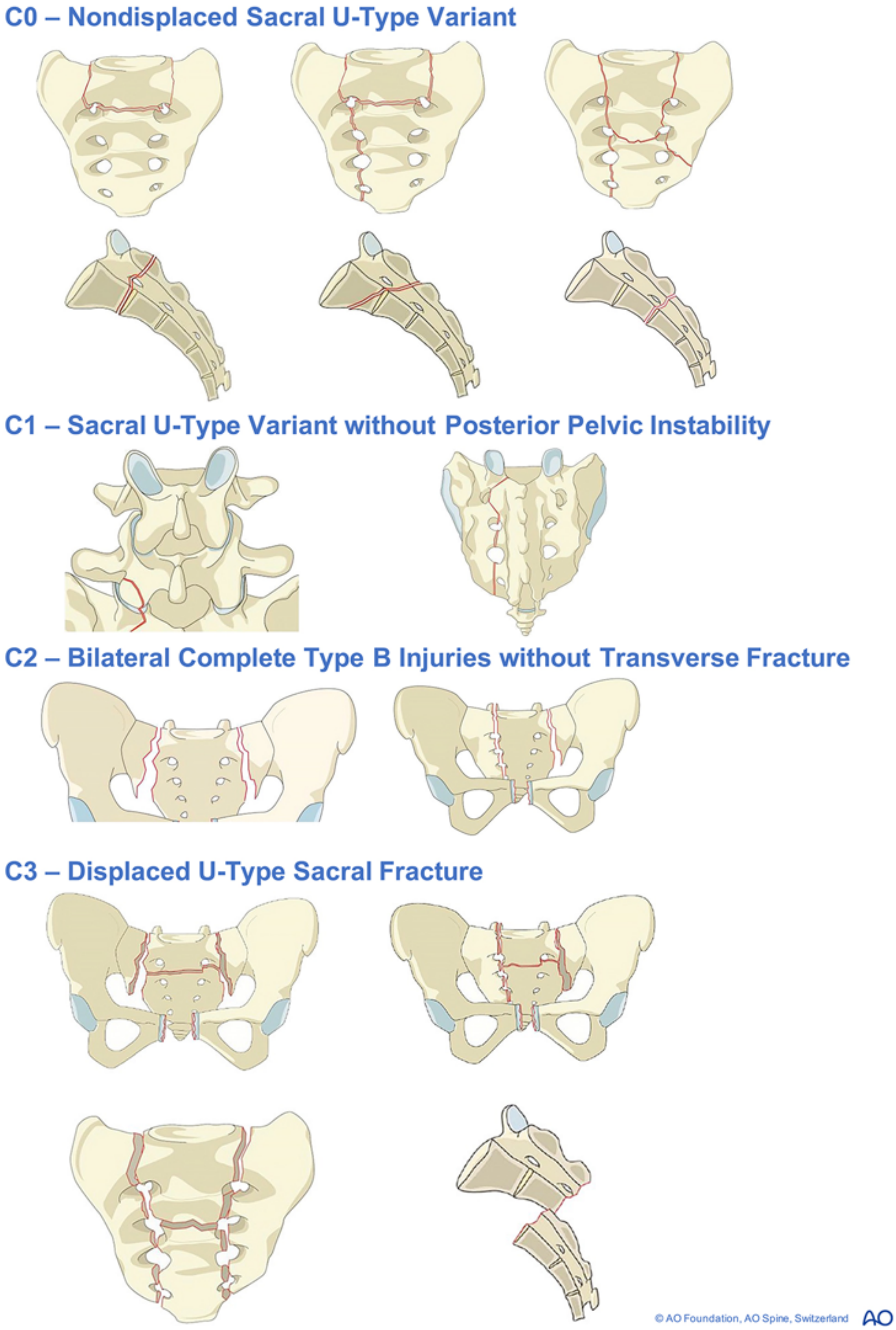

FIG. 4. Type C injuries as designated by the AO Spine Sacral and Pelvic Classification System. Sacral C0 subtype fractures are nondisplaced sacral U-type variants. Sacral C1 subtype injuries are unilateral B subtype injuries in which the ipsilateral superior S1 facet is discontinuous with the medial sacrum. Sacral C2 subtype fractures are bilateral complete type B injuries without a transverse component. Sacral C3 subtype fractures are displaced U-type sacral fractures. © AO Spine, AO Foundation, published with permission. Figure is available in color online only.

principle of bony decompression being performed where there is clear neural compression, and this is followed by a combination of postoperative neurological, radiological, and electrophysiological assessment to determine whether further decompression or stabilization is necessary.[5,44]

Our comprehensive longitudinal and historical systematic review defines the evolution of pelvic and sacral classification systems over time. The AO Spine Sacral and Pelvic Classification System and its evolutionary advancements on historical schemes are considered. This review was limited by the paucity of high-quality randomized controlled evidence available to support the proposed contemporary classification system. Instead, the review derives external validity from the international and multicenter pool of included studies, while a sense of internal validity is imparted by the independent, rigorous testing to which it has been subjected.[4,9–46,56]

Conclusions

The AO Spine Sacral and Pelvic Classification is a universally applicable system that redefines and reorders historical fracture morphologies into a rational hierarchical system. This is the first classification to simultaneously address the biomechanical stability of the posterior pelvic complex and spinopelvic stability, while also taking into consideration neurological status. The consistent use of this novel classification system will facilitate meta-analysis of future high-quality controlled trials to provide evidence-based recommendations in the management of sacral and pelvic fractures.

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Author Contributions

Conception and design: Tee, Kweh. Acquisition of data: Kweh. Analysis and interpretation of data: Tee, Kweh. Drafting the article: Tee, Kweh. Critically revising the article: all authors. Reviewed submitted version of manuscript: Tee, Kweh. Statistical analysis: Kweh. Administrative/technical/material support: Tee, Kweh. Study supervision: Kweh.

Supplemental Information

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