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Traumatic Spinal Injuries Related to Artisanal Mine Collapses in Côte d'Ivoire: A Two-Center Analytical Study of Injury Patterns, Neurological Severity, and Prehospital Management

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Abstract

Background and Objective: Artisanal gold mining, expanding rapidly across West Africa, carries a serious accident burden whose resulting traumatic spinal injuries (TSI) have not been the subject of any analytical study. This work compares the injury pattern, severity, evacuation, and one-year outcome of TSI caused by artisanal mine collapse with those of other mechanisms. **Methods:** Retrospective two-center cohort in Côte d'Ivoire (2019-2024): 120 TSI, including 26 collapses versus 94 other mechanisms. Univariate comparisons were followed by Firth penalized logistic regression for four outcomes: severe injury (ASIA A/B), thoracic location, evacuation without medical support, and one-year death; because the models adjust for presumed mediators, the unadjusted total effect is reported alongside the direct effect. **Results:** Collapse victims more often had a thoracic location, compression or burst-type fractures, and a severe injury (ASIA A/B: 85% vs 45%; unadjusted OR 6.81). After adjustment, collapse remained associated with severe injury (OR 4.29; 95% CI: 1.19 - 15.5) and, suggestively, with thoracic location (OR 2.84). The absence of medically staffed evacuation was the strongest association of the mechanism (96% vs 36%; adjusted OR 37.2). Favorable outcome was rarer (12% vs 48%), with no difference in mortality by mechanism, deaths concentrating on complete injuries (88.6% of ASIA A versus 1.3% of grades B to E). **Conclusion:** Artisanal mine collapse is a distinct, probably under-reported mechanism of TSI, marked by increased severity and a near-absence of medically staffed evacuation; the thoracic predominance requires confirmation. Mortality appears determined by injury completeness rather than by the mechanism itself, and argues for the prevention of mining accidents and the strengthening of prehospital care.

Keywords

Traumatic Spinal Injury, Artisanal Gold Mining, Mine Collapse, ASIA Score, Prehospital Care, West Africa

1. Introduction

Traumatic spinal injuries (TSI)—injuries of the spinal column with or without spinal cord involvement—are a major cause of morbidity, mortality, and lasting disability. According to the Global Burden of Disease 2019 study, there were worldwide about 0.9 million new cases and 20.6 million people living with a spinal cord injury, responsible for 6.2 million years lived with disability, with the absolute number of cases having risen by more than 50% since 1990 [1]. Incidence is particularly high in resource-limited countries, where falls and road traffic accidents predominate [1] [2]. In sub-Saharan Africa, the latter remain the leading cause, but context-specific etiologies are emerging and remain under-documented [3].

Artisanal and small-scale gold mining is expanding rapidly across West Africa, driven by the price of gold and economic precarity. This informal sector is estimated to employ about 45 million people directly [4]; in Côte d'Ivoire, its exact scale remains poorly documented for lack of a census [5]. This often-clandestine activity carries a severe accident burden dominated by the collapse of shafts and galleries [6]-[8]. By collapse, we mean the caving-in of a shaft, gallery, or artisanal mining excavation causing partial or total burial of the worker. While limb injuries and mercury poisoning have been described, TSI related to gold mining remain very little studied, even though they strike a young, working population [9]. To our knowledge, no published study has compared these TSI with other traumatic mechanisms. From a global-neurosurgery perspective, this mechanism could contribute in a growing but still poorly recognized way to the worldwide burden of TSI [1] [3].

We hypothesized that artisanal mine collapse was associated with a thoracic location, increased neurological severity, and a lack of medically staffed evacuation; these associations were then tested in multivariable models tailored to each outcome studied. The objective was to compare the injury pattern, severity, evacuation modalities, and outcome of collapse victims with those of other mechanisms.

2. Patients and Methods

2.1. Setting and Population

This was a retrospective, observational, two-center cohort study conducted at Bouaké

University Teaching Hospital and Treichville General Hospital (Abidjan), in Côte d'Ivoire, from 1 January 2019 to 31 December 2024, in accordance with the STROBE recommendations (**Figure 1**). Cases were ascertained by consecutive screening of the neurosurgery admission and hospitalization records of the two centers over the study period; a traumatic spinal injury was defined as a traumatically induced injury of the spinal column—vertebral fracture, dislocation, or ligamentous injury—with or without neurological involvement, confirmed by clinical examination and spinal imaging (radiography and/or computed tomography, with magnetic resonance imaging when available). All TSI with a complete record were included, with no age limit (n = 120). Of 250 records identified, 130 were not included: incomplete record (82), loss to follow-up before one year (21), non-traumatic origin (12), and missing analysis data (15) (**Figure 1**). The mechanism, recruiting center, and admission ASIA grade of the non-included records—in particular the 21 patients lost to follow-up before one year—could not be systematically retrieved and are therefore not reported; this restricts the assessment of selection related to the outcome and is addressed among the study limitations. Survivors had to have a minimum follow-up of one year, or follow-up until death for patients who died before that time point, so as not to underestimate mortality. The database was frozen on 31 January 2026.

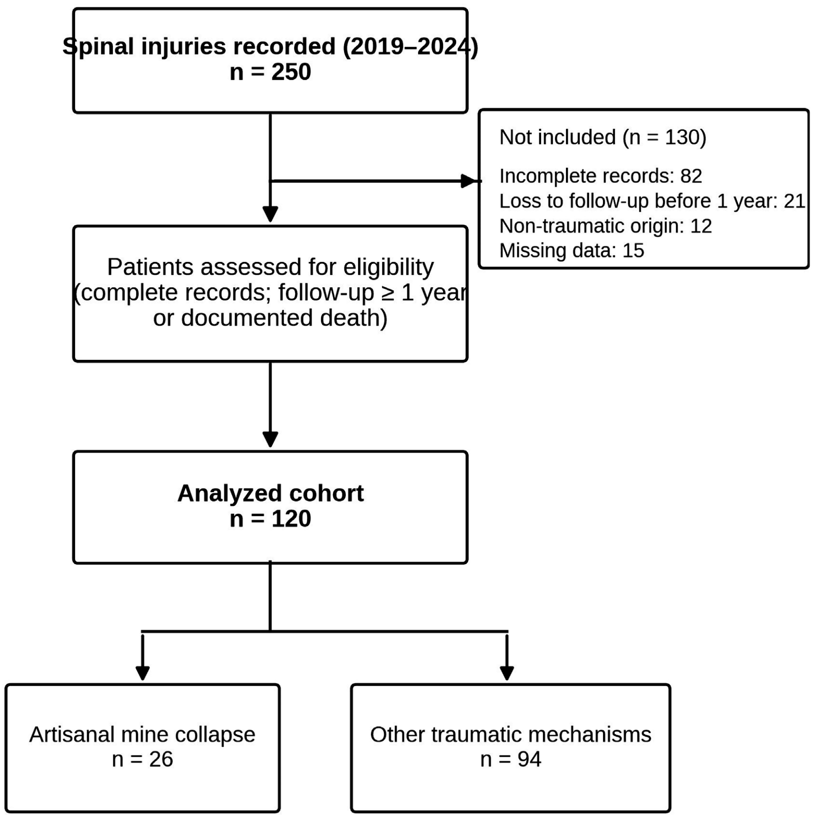

Figure 1. Study flow diagram according to the STROBE recommendations: 250 records identified, 130 not included (incomplete record 82, loss to follow-up before one year 21, non-traumatic origin 12, missing data 15), and 120 patients analyzed.

2.2. Exposure and Variables

The main exposure was the mechanism: artisanal mine collapse (n = 26) versus another mechanism (n = 94), the detail of which appears in Table 1. Occupation (gold miner or not) was recorded separately. Injury location was documented by main spinal segment (cervical, thoracic, lumbar), with the thoracic sub-segment specified (T1 - T4, T5 - T8, T9 - T12) for thoracic injuries in the collapse group only. Other variables included the type of vertebral injury, associated injuries, ASIA grade, mode of evacuation, times (in days) to hospitalization and to surgery, the surgical procedure, and overall one-year outcome. For the binary analysis, evacuation without medical support grouped together transport by third parties and public rescue services lacking an onboard medical team; a single collapse-group patient, transferred secondarily by hospital ambulance after extraction from the site by third parties, was classified as "medically staffed transport", giving a final count of 25/26 evacuations without medical support.

Table 1. Detailed traumatic mechanisms (n = 120).

Mechanism	n (%)
Road traffic accident	78 (65.0)
Artisanal mine collapse	26 (21.7)
Fall from a tree	5 (4.2)
Fall from a wall	3 (2.5)
Fall of a load bag	2 (1.7)
Assault with a bladed weapon	2 (1.7)
Fall into an artisanal shaft	2 (1.7)
Fall from one story	2 (1.7)
Total	**120 (100)**

The patients who fell into an artisanal shaft did so outside a collapse episode and are classified in the comparison group.

The outcome was considered favorable when functional improvement was documented in the record during follow-up—partial neurological recovery, standing or assisted walking, or partial autonomy in activities of daily living; it was classified as "stationary" in the absence of change, or as "death". In the absence of standardized ASIA grading at follow-up, this assessment relied on the clinical data recorded by the referring neurosurgeon. The admission neurological examination was performed by the neurosurgery team on arrival, before or immediately after initial resuscitation, and the ASIA grade was assigned according to the International Standards for the Neurological Classification of Spinal Cord Injury (ISNCSCI). The ASIA grade was available only at admission. A severe neurological injury was defined as an ASIA grade A or B at admission.

2.3. Statistical Analysis

Qualitative variables are expressed as counts (percentages), quantitative variables as median (IQR). Comparisons of proportions used the Fisher exact test, and the Fisher-Freeman-Halton exact test for contingency tables larger than 2 × 2 with low expected counts; continuous variables were compared with the Mann-Whitney test and the ordinal distribution of ASIA grades with a Cochran-Armitage trend test. Effect size was reported systematically (Cramér's V for contingency tables, Cohen's h for comparisons of proportions). Crude odds ratios (OR) and their 95% confidence intervals were estimated by univariate logistic regression, without continuity correction.

Four multivariable Firth penalized logistic regression models—suited to small samples and to separation, which it handles by providing finite estimates—tested the factors associated with: (i) a severe injury (ASIA A or B), adjusted for age, sex, and injury location; (ii) a thoracic location, adjusted for age and sex; (iii) evacuation without medical support, adjusted for age and sex; (iv) one-year death, adjusted for ASIA grade, location, and mode of evacuation. Models (i) and (iv) adjust for variables lying on the presumed causal pathway: they therefore estimate a direct effect and not the total effect of collapse, the latter being reported as the unadjusted OR. No formal mediation analysis was conducted, the sample sizes not lending themselves to it. The number of covariates was limited according to the events-per-variable principle. Sex was not retained in the mortality model, its estimate being unstable.

Two sensitivity analyses were conducted. The first introduced the recruiting center into four models: severity, on mechanism and center only, location being deliberately omitted in order to estimate a total effect adjusted for center, to be compared with the unadjusted OR and not with the direct effect; thoracic location and evacuation without medical support, on mechanism, age, sex, and center; one-year death, on mechanism, ASIA grade, location, mode of evacuation, and center. The second restricted the analysis to gold miners, comparing collapse (n = 22) and road traffic accident (n = 22), in order to distinguish the effect of the mechanism from that of the occupation. Given the exploratory nature and the multiplicity of comparisons, effect sizes were favored; the threshold was set at $p < 0.05$, without adjustment for multiple comparisons. Analyses: Epi Info™ 7.2 (descriptive) and R 4.4.0, logistf package (Firth models).

3. Results

The univariate analyses are presented in **Table 2** and **Table 3**, the independent associations in the multivariable models of **Tables 4-7**.

Table 2. Univariate comparison: artisanal mine collapse (n = 26) versus other mechanisms (n = 94).

Variable	Collapse (n = 26)	Other (n = 94)	Crude OR (95% CI)	p
Age, median (IQR), years	31 (26 - 34)	36 (29 - 45)	—	0.058
Male sex	26 (100)	77 (81.9)	NE	0.022

Continued

Cervical location	10 (38.5)	40 (42.6)	0.84 (0.35 - 2.05)	0.82
Thoracic location	13 (50.0)	24 (25.5)	2.92 (1.19 - 7.16)	0.029
Lumbar location	3 (11.5)	30 (31.9)	0.28 (0.08 - 1.00)	0.048
Compression or burst-type fracture	18 (69.2)	37 (39.4)	3.47 (1.37 - 8.78)	0.008
Severe injury (ASIA A or B)	22 (84.6)	42 (44.7)	6.81 (2.18 - 21.3)	<0.001
Surgical treatment	26 (100)	63 (67.0)	NE	<0.001
Evacuation without medical support	25 (96.2)	34 (36.2)	44.1 (5.7 - 340.2)	<0.001
Favorable outcome at one year	3 (11.5)	45 (47.9)	0.14 (0.04 - 0.51)	<0.001
Death at one year	11 (42.3)	29 (30.9)	1.64 (0.67 - 4.01)	0.35

Counts (percentages) unless otherwise stated. Crude ORs by logistic regression, without continuity correction; p from the Fisher exact test, except for age (Mann-Whitney, without OR). NE: not estimable—the absence of women and the absence of non-operated patients in the collapse group create a null cell; only the exact p is reported. Effect sizes (Cohen's h): thoracic location 0.51; lumbar location 0.51; ASIA A/B 0.87; surgery 1.22; evacuation without medical support 1.46.

Table 3. Distribution of the ASIA grade at admission by mechanism.

ASIA grade	Collapse (n = 26)	Other (n = 94)	Total (n = 120)
A	12 (46.2)	32 (34.0)	44 (36.7)
B	10 (38.5)	10 (10.6)	20 (16.7)
C	0 (0)	12 (12.8)	12 (10.0)
D	0 (0)	14 (14.9)	14 (11.7)
E	4 (15.4)	26 (27.7)	30 (25.0)
Total	**26 (100)**	**94 (100)**	**120 (100)**

Fisher-Freeman-Halton exact test $p < 0.001$. The Pearson χ^2 is not applicable, with three of the ten expected counts being below 5. Cramér's V = 0.39; Cochran-Armitage trend test p = 0.012. No intermediate grade (C or D) in the collapse group.

Table 4. Multivariable Firth penalized logistic regression: severe neurological injury (ASIA A or B).

Variable	Adjusted OR (95% CI)	p
Artisanal mine collapse	4.29 (1.19 - 15.5)	0.026
Thoracic location (ref. cervical)	1.18 (0.42 - 3.31)	0.75
Lumbar location (ref. cervical)	0.09 (0.02 - 0.34)	<0.001
Age (per year)	0.98 (0.94 - 1.03)	0.39
Male sex	1.54 (0.39 - 8.21)	0.56

Model adjusted for age, sex, and injury location. As location is itself a consequence of the mechanism (Table 5), the model estimates the direct effect of collapse; the corresponding total effect is the unadjusted OR of 6.81 (95% CI: 2.18 - 21.3).

Table 5. Multivariable Firth penalized logistic regression: thoracic location.

Variable	Adjusted OR (95% CI)	p
Artisanal mine collapse	2.84 (1.10 - 7.29)	0.030
Age (per year)	0.99 (0.95 - 1.03)	0.67
Male sex	1.67 (0.43 - 7.12)	0.46

Outcome variable: thoracic location (yes/no). Model adjusted for age and sex.

Table 6. Multivariable Firth penalized logistic regression: evacuation without medical support.

Variable	Adjusted OR (95% CI)	p
Artisanal mine collapse	37.2 (6.4 - 214.8)	<0.001
Age (per year)	1.01 (0.97 - 1.06)	0.58
Male sex	1.83 (0.52 - 7.46)	0.35

Outcome variable: evacuation without medical support (yes/no). Model adjusted for age and sex. As almost all collapse victims (25/26) received no medically staffed transport, the estimate is affected by quasi-separation, hence a wide confidence interval; Firth regression provides a finite estimate despite this configuration.

Table 7. Multivariable Firth penalized logistic regression: one-year death (exploratory model).

Variable	Adjusted OR (95% CI)	p
Artisanal mine collapse	1.18 (0.19 - 7.42)	0.86
Complete injury (ASIA A)	194.3 (43.4 - 1875.0)	<0.001
Thoracic location (ref. cervical)	1.21 (0.47 - 3.16)	0.69
Lumbar location (ref. cervical)	0.63 (0.17 - 2.04)	0.45
Evacuation without medical support	1.58 (0.46 - 5.61)	0.47

Finite estimator despite the near-complete separation observed for the ASIA A grade; the p is from the penalized likelihood-ratio test and the very wide interval invites retaining the order of magnitude rather than the point value. Sex, whose estimate was unstable, was not included. This model adjusts simultaneously for ASIA grade, location, and mode of evacuation, all lying on the presumed causal pathway: it estimates a direct effect and not the total effect of collapse, whose unadjusted estimate appears in Table 2 (OR 1.64; 95% CI: 0.67 - 4.01). The limited number of events (40 deaths) makes this model exploratory.

3.1. Place of Gold Mining and Mechanisms

Gold miners were the most represented socio-occupational category (45/120, 37.5%), ahead of farmers (25.8%). Mine collapse was the second traumatic circumstance (26/120, 21.7%), behind road traffic accidents (65%), and occurred predominantly in gold miners (22/26) (Table 1). Among the 45 gold miners, injuries resulted from a collapse in 22 cases and from a road traffic accident in 22 cases, the latter frequently occurring during trips to remote sites; the 45th patient had fallen into an artisanal shaft outside any collapse episode and was therefore classified in the comparison group.

3.2. Injury Pattern—Univariate Analysis

All collapse victims were men (100%), with a median age of 31 years (IQR: 26 - 34) versus 36 years (IQR: 29 - 45) in the comparison group (p = 0.058). Injuries more frequently involved the thoracic spine (50% vs 26%; OR 2.92; 95% CI: 1.19 - 7.16; p = 0.029; Cohen's h = 0.51), whereas lumbar locations were less frequent (12% vs 32%; p = 0.048), with more frequent compression and burst-type fractures (69% vs 39%; p = 0.008) (Figure 2, Figure 3, Table 2). Among the 13 thoracic injuries in the collapse group, the lower T9 - T12 segment was the most frequent location (6 cases, 46.2%; T9 n = 2, T10 n = 1, T11 n = 1, T12 n = 2), ahead of the upper T1 - T4 segment (4 cases, 30.8%) and the middle T5 - T8 segment (3 cases, 23.1%); the sub-segmental distribution was not available for the comparison group.

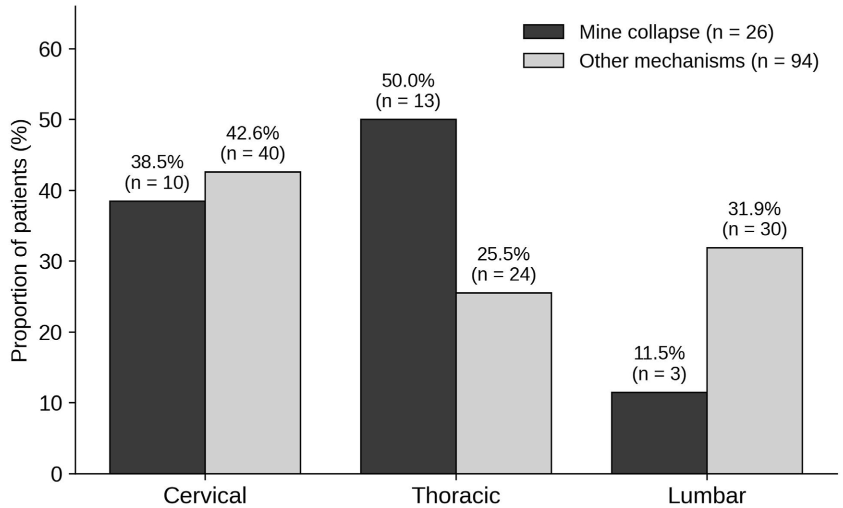

Figure 2. Distribution of injury location (cervical, thoracic, lumbar) by traumatic mechanism, artisanal mine collapse versus other mechanisms.

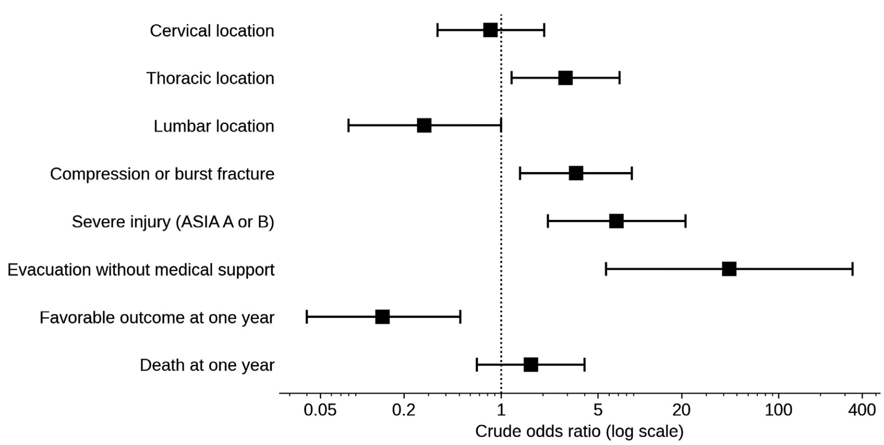

Figure 3. Forest plot of the associations of artisanal mine collapse in univariate analysis (reference: other mechanisms). Crude odds ratios and 95% confidence intervals.

3.3. Neurological Severity

Severity was markedly greater: 85% of injuries were ASIA A or B versus 45% (p <

0.001; Cohen's h = 0.87), with no intermediate grade (ASIA C or D) in the collapse group (**Table 3**; Fisher-Freeman-Halton exact test $p < 0.001$; Cramér's V = 0.39; Cochran-Armitage trend test $p = 0.012$). Conversely, four collapse victims (15%) were free of any neurological deficit (ASIA E) but had radiological vertebral instability: three burst-type fractures with retropulsion of the posterior wall and substantial loss of vertebral height, and one compression fracture associated with injury of the posterior ligamentous complex and progressive kyphosis. All patients in the collapse group underwent surgical treatment (100% vs 67%; $p < 0.001$; h = 1.22).

3.4. Multivariable Analysis

The unadjusted total effect of collapse on neurological severity corresponded to an OR of 6.81 (95% CI: 2.18 - 21.3; $p < 0.001$). After adjustment for age, sex, and injury location—the latter itself a consequence of the mechanism—the direct effect remained significant (ASIA A/B: OR 4.29; 95% CI: 1.19 - 15.5; $p = 0.026$) (**Table 4**). Collapse likewise remained associated with thoracic location after adjustment for age and sex (OR 2.84; 95% CI: 1.10 - 7.29; $p = 0.030$) (**Table 5**) and with evacuation without medical support (OR 37.2; 95% CI: 6.4 - 214.8; $p < 0.001$) (**Table 6**). The total effect of the mechanism on one-year mortality was not significant (unadjusted OR 1.64; 95% CI: 0.67 - 4.01; $p = 0.35$). In a model adjusted for ASIA grade, location, and mode of evacuation—that is, for the whole set of presumed intermediates—no direct contribution of the mechanism was found (OR 1.18; 95% CI: 0.19 - 7.42; $p = 0.86$), mortality being dominated by the presence of a complete injury (**Table 7**). This model, limited by the number of events and by adjustment for intermediate variables, remains exploratory and does not constitute a formal mediation analysis.

3.5. Evacuation, Times, and Outcome

Evacuation was almost always without medical support (25/26, 96% vs 36%; OR 44.1; 95% CI: 5.7 - 340.2; $p < 0.001$; Cohen's h = 1.46). Overall, one-year outcome was markedly less favorable after collapse: only 12% of patients progressed favorably versus 48% ($p < 0.001$), for a mortality of 42% vs 31% ($p = 0.35$). In the absence of standardized ASIA grading at follow-up, neurological recovery could not be quantified more finely.

Cohort mortality was almost entirely concentrated on complete injuries: 39 of the 44 patients classified as ASIA A at admission died within the year (88.6%), versus 1 of the 76 patients with grade B to E (1.3%) (**Table 8**). Deaths occurring after collapse were, according to the records, exclusively attributed to postoperative infection (8/11) and to thromboembolic complications (3/11); the share of deaths attributed to postoperative infection was higher there than in the comparison group (8/11 vs 3/29; $p < 0.001$) (**Table 9**). This comparison, however, is not conditioned on having been operated on, whereas the entire collapse group was, against 67% of the comparison group. The documented times (in days) to hospitalization (median 1 day) and to surgery (median 3 days) did not differ significantly between groups (**Table 10**).

Table 8. One-year mortality by ASIA grade at admission (n = 120).

ASIA grade at admission	Deaths	Survivors	Mortality (%)
A (complete injury), n = 44	39	5	88.6
B to E, n = 76	1	75	1.3
Overall, n = 120	**40**	**80**	**33.3**

Fisher exact test p < 0.001. Firth penalized OR from the multivariable model of Table 7: 194.3 (95% CI: 43.4 - 1875.0).

Table 9. Probable causes of death by mechanism (n = 40 deaths).

Probable cause	Collapse (n = 11)	Other (n = 29)	Total (n = 40)
Postoperative infection	8 (72.7)	3 (10.3)	11
Thromboembolic complication	3 (27.3)	3 (10.3)	6
Pulmonary infection	0 (0)	7 (24.1)	7
Pressure sore and its complications	0 (0)	6 (20.7)	6
Postoperative hematoma	0 (0)	5 (17.2)	5
Cardiorespiratory arrest	0 (0)	5 (17.2)	5
Total	**11 (100)**	**29 (100)**	**40**

Probable causes recorded in the medical files, without independent validation or systematic confirmation (microbiological, imaging, or autopsy). The share of deaths attributed to postoperative infection differed between groups (8/11 vs 3/29; Fisher exact test p < 0.001), but this comparison is not conditioned on having been operated on, whereas the entire collapse group was, against 67% of the comparison group. The registry did not document the non-fatal complications of survivors.

Table 10. Prehospital and therapeutic times (median [IQR], in days).

Time	Collapse (n = 26)	Other (n = 94)	p
Trauma—hospitalization	1 [1 - 2]	1 [1 - 2]	0.74
Admission—surgery (operated only)	3 [2 - 5] (n = 26)	3 [2 - 4] (n = 63)	0.48

No significant difference between groups. Times collected in days (limited granularity); no precise hourly prehospital time was available. Admission-to-surgery time is computed among operated patients only (26/26 in the collapse group and 63/94 in the comparison group); the 31 non-operated patients of the comparison group are excluded from that row. Mann-Whitney test.

3.6. Sensitivity Analyses

Introducing the recruiting center as a covariate altered neither the direction nor the order of magnitude of the main associations: collapse remained associated with severe injury (OR 6.94; 95% CI: 2.24 - 25.88; p < 0.001; a value to be compared with the unadjusted total effect of 6.81, this model not including injury location) and with evacuation without medical support (OR 25.57; 95% CI: 5.90 - 241.54; p < 0.001), and exerted no direct effect on mortality (OR 1.42; 95% CI: 0.11 - 15.89; p = 0.772). The association with thoracic location retained a comparable magnitude but lost precision, its confidence interval including unity (OR 2.55; 95% CI: 0.96 - 6.89; p = 0.061): this result, more fragile than the others, must be regarded as suggestive (Table 11). The analysis restricted to the 44 gold miners recovered the same associations at reduced sample size: severe injury 81.8% vs 45.5% (OR 6.00; 95% CI: 1.54 - 29.16; p = 0.009) and evacuation without medical support 100% vs 50.0% (OR 41.69; 95% CI: 4.02 - 5811.47; p < 0.001) (Table 12). At comparable occupation, the excess severity and the lack of medically staffed evacuation therefore remained associated with collapse in this restricted comparison rather than with membership of the gold-mining sector alone; residual confounding by the accident setting and by differences between collapse and road-traffic injuries cannot, however, be excluded.

Table 11. Effect of collapse after adjustment for the recruiting center.

Outcome	Adjusted OR (95% CI)	p	Model covariates
Severe injury (ASIA A/B)	6.94 (2.24 - 25.88)	<0.001	Mechanism + center
Thoracic location	2.55 (0.96 - 6.89)	0.061	Mechanism + age + sex + center
Evacuation without medical support	25.57 (5.90 - 241.54)	<0.001	Mechanism + age + sex + center
One-year death	1.42 (0.11 - 15.89)	0.772	Mechanism + ASIA grade + location + mode of evacuation + center

Firth regression; each row corresponds to a distinct model. The severity model includes neither location, nor age, nor sex: it estimates a total effect adjusted for center, to be compared with the unadjusted OR of 6.81 and not with the direct effect of Table 4.

Table 12. Analysis restricted to gold miners: collapse versus road traffic accident.

Outcome	Collapse (n = 22)	RTA (n = 22)	OR (95% CI)	p
Severe injury (ASIA A/B)	18 (81.8)	10 (45.5)	6.00 (1.54 - 29.16)	0.009
Evacuation without medical support	22 (100)	11 (50.0)	41.69 (4.02 - 5811.47)	<0.001

Firth regression. The complete absence of medically staffed evacuation in the collapse group produces complete separation: the upper bound of the confidence interval has only indicative value. The 45th gold miner, injured by a fall into an artisanal shaft outside a collapse episode, belongs to neither group.

4. Discussion

4.1. Gold Mining, an Emerging Cause of TSI—A Global-Neurosurgery Perspective

In this cohort, gold mining occupied a major place, being both the most represented socio-occupational category (37.5%) and the second traumatic circumstance (21.7%). This share is rarely reported in African hospital series of TSI [3]. It matches the accident profile of gold mining described in Ghana, Zimbabwe, and Ethiopia, where shaft collapse is the leading cause of serious accidents [6]-[8], as well as the TSI from traditional mine collapses reported in Mali [9]. As informal gold mining spreads across sub-Saharan Africa, the TSI related to it could constitute a growing share of the global burden of spinal cord injury, which justifies their consideration in the global neurosurgery agenda [1] [3] [10] [11].

4.2. A Thoracic Injury Pattern Driven by Axial Compression

The main originality of this work is the identification of a distinct injury pattern, characterized by a predominance of thoracic locations, a high frequency of compression and burst-type fractures, and increased neurological severity. The association with thoracic location was maintained after adjustment for age and sex (OR 2.84; p = 0.030) but lost its precision after adjustment for center: it must be regarded as suggestive. It could be explained by the vertical compressive load of burial: unlike road traffic accidents, which often induce flexion-distraction or hyperextension injuries, the collapse of earth and rock subjects the worker to a massive axial load, resulting in burst-type fractures and severe cord compression [12]. This morphology corresponds to type A fractures of the AO Spine thoracolumbar classification [13], but the absence of systematic grading in the records did not allow this to be verified.

Three reservations, however, limit the scope of this biomechanical interpretation. The sub-segmental distribution was available only in the collapse group, so that the observed predominance of the T9 - T12 segment (6 of 13 cases) rests on no comparator; moreover, the T9 segment does not belong to the thoracolumbar junction in the strict sense (T10 - L2), and nearly a third of the thoracic injuries were located at the upper T1 - T4 segment, which the axial-load model does not explain. Above all, an axial load concentrated on the junction should be accompanied by an excess of high lumbar injuries, whereas lumbar locations were, on the contrary, less frequent after collapse (12% vs 32%). This injury signature, consistent with West and Central African series of thoracolumbar spine trauma [14] [15], suggests that a potentially unstable thoracolumbar injury should be sought in any victim of a mining collapse, but it remains a hypothesis to be confirmed by studies combining standardized radiological analysis with reconstruction of the mechanisms at mining sites.

The proposed conceptual model (**Figure 4**) synthesizes the observed relationships and the plausible pathophysiological mechanisms linking collapse to neurological severity and then to prognosis.

4.3. Increased and Independent Neurological Severity

Collapses were accompanied by higher neurological severity: 85% of injuries were ASIA A/B, with a large effect size (Cohen's h = 0.87). The unadjusted total effect reached an OR of 6.81 (95% CI: 2.18 - 21.3), and the direct effect, after accounting for injury location, remained significant (OR 4.29; p = 0.026). In this model, location strongly modulated severity: lumbar injuries were markedly less severe than cervical ones (OR 0.09; p < 0.001), reflecting involvement of the cauda equina rather than the cord, while thoracic injuries were of a severity comparable to cervical ones. The absence of intermediate grades (ASIA C/D) could reflect a polarized spectrum (**Figure 5**), the energy of burial leading either to minor injuries or to complete injuries [16] [17]; the observation covers 26 patients and calls for caution.

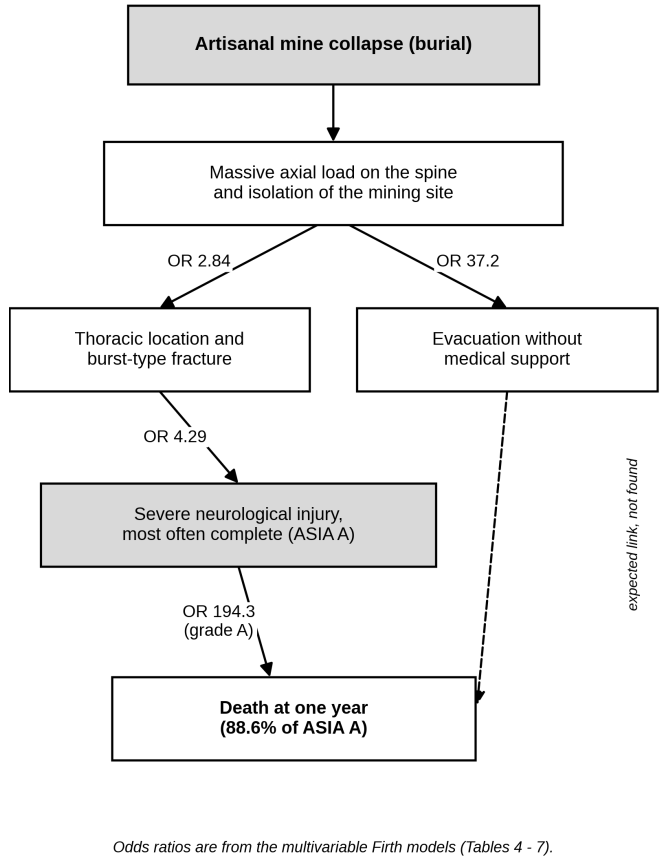

Figure 4. Conceptual model of the proposed pathophysiological sequence, from burial to neurological severity and then to prognosis. The odds ratios shown come from the multivariable Firth models (Tables 4-7). The dashed arrow represents the expected link between the absence of medically staffed evacuation and death, not found in the adjusted model (OR 1.58; 95% CI: 0.46 - 5.61).

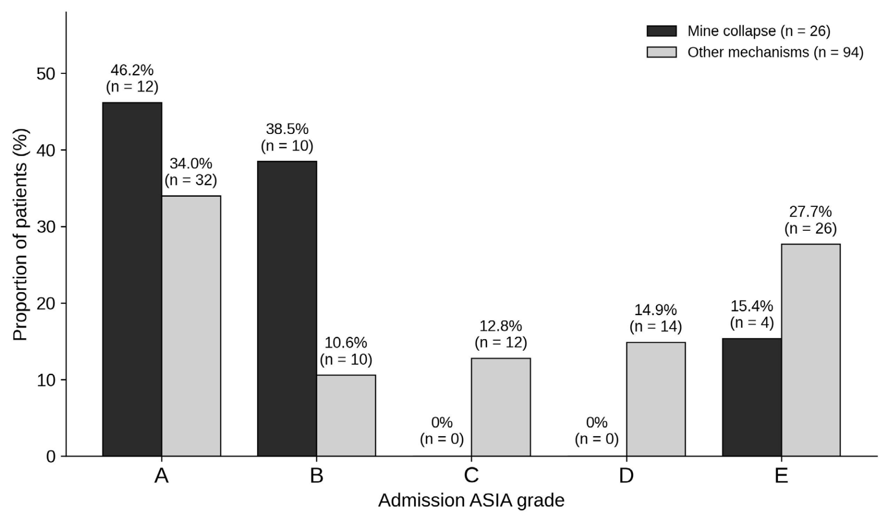

Figure 5. Distribution of the admission ASIA grade (A - E) by traumatic mechanism, artisanal mine collapse (n = 26) versus other mechanisms (n = 94). No intermediate grade (ASIA C or D) was observed in the collapse group (Fisher-Freeman-Halton exact test $p < 0.001$; Cramér's $V = 0.39$; Cochran-Armitage trend test $p = 0.012$).

The prognostic value of the ASIA grade [18] [19] is clearly confirmed here, but the divide runs between grade A and grades B to E, and not between the A/B composite and the rest: almost all deaths occurred in complete patients, mortality of grades B to E remaining marginal. The ASIA A/B composite, relevant for describing initial severity, must therefore not be read as a homogeneous prognostic marker. Our results are compatible with the hypothesis of a prognosis mediated by the high frequency of complete injuries, but they do not establish it: the mortality model adjusts for ASIA grade, that is, for the presumed mediator, which by construction cancels out the share of the mechanism's effect passing through it. A formal mediation analysis, which the current sample sizes do not allow, would be needed to demonstrate it.

4.4. The Lack of Medically Staffed Evacuation

The most concerning public-health finding is the near-total absence of medically staffed evacuation: 25 of the 26 collapse victims (96%) were transported by means without medical support, versus 36% in the comparison group (Cohen's h = 1.46). Among the associations of the mechanism, the one linking it to the absence of medically staffed evacuation had by far the greatest magnitude (adjusted OR 37.2), which designates the isolation of clandestine gold-mining sites and the absence of structured emergency services as major determinants of initial management. It resists adjustment for center and is found among gold miners alone, where all collapse victims, but only half of road-traffic-accident victims, were evacuated without medical means: it therefore relates to the mechanism and the place of the accident more than to the occupation. This finding matches regional data, where more than 90% of the African population has no access to formal emergency services and where prehospital care of the spinal-injured patient remains rudimentary [20]. The World Health Organization has made emergency care systems a priority of universal health coverage [21]; in the most deprived settings, community first-aid programs and alert networks in mining areas constitute a realistic first step [20] [22]. The documented times, collected with a granularity limited to the day, did not differ between groups: the deficiency lies more in the quality of immobilization and transport than in the delay, which prospective studies will have to clarify. The absence of medically staffed evacuation, however, exerted no independent effect on mortality once the ASIA grade was taken into account (OR 1.58; 95% CI: 0.46 - 5.61).

4.5. Lethality of Complete Injuries and Excess Postoperative Infectious Mortality

One-year mortality in this cohort was almost entirely borne by complete injuries: 39 of the 44 patients classified as ASIA A at admission died within the year (88.6%), versus a single one of the 76 patients with grade B to E (1.3%), that is, a penalized OR of 194.3 (95% CI: 43.4 - 1875.0). Lethality of this order exceeds what most sub-Saharan hospital series report and must first be read in the light of recruitment: the exclusion of patients lost to follow-up before one year removes from the cohort subjects whose survival is probable, which mechanically inflates the observed mortality among complete-injury patients. It nonetheless illuminates the distribution of causes of death: in the collapse group, postoperative infection accounted for 8 of the 11 deaths, versus 3 of 29 in the comparison group. Several factors specific to this mechanism may contribute—telluric contamination of wounds during burial, a median delay of three days before surgery, prolonged recumbency, limited resources for surgical-site infection prevention—but the crude comparison does not account for the fact that all collapse-group patients were operated on, versus two-thirds of the comparison group, which alone suffices to raise the expected share of postoperative infections. In the absence of microbiological validation, this hypothesis cannot be tested here; it does, however, designate an actionable target: initial decontamination, antibiotic prophylaxis, and shortening of the time to surgery in burial victims.

4.6. Implications

The concentration of these injuries among men of working age makes them a socioeconomic problem of the first order: beyond the individual disability, often permanent in cases of complete injury, they represent a loss of productivity and a factor of household impoverishment in regions where gold mining is frequently the main source of income. These results argue for a dual strategy: upstream, the prevention of artisanal mining accidents (regulation of gold mining, securing of galleries, protective equipment) and its integration into national policies against serious injury; downstream, the strengthening of prehospital care, spinal immobilization, surgical-site infection prevention, and neurosurgical capacity [17] [23] [24].

4.7. Limitations

The retrospective nature exposes the study to information and selection biases, two of which act in opposite directions: the inclusion of complete records only and the absence of any count of deaths occurring at mining sites or during transport lead to underestimation of the true lethality of collapses, whereas the exclusion of patients lost to follow-up before one year, which bears directly on the outcome, leads on the contrary, to overestimation of the mortality measured in the analyzed cohort. Patients came exclusively from two neurosurgical centers, which limits national representativeness: the most benign forms probably never reach them, hence an overrepresentation of severe forms linked to referral bias. Adjustment for center leaves the associations with severity and evacuation unchanged but renders imprecise the one observed with thoracic location, which correspondingly weakens the biomechanical argument developed above. A gold miner injured by a fall into an artisanal shaft, a mechanism close to burial, appears in the comparison group, which tends to attenuate rather than exaggerate the observed contrasts.

The severity and mortality models adjust for variables lying on the presumed causal pathway: they estimate a direct effect and do not allow the mediation discussed above to be established. The size of the collapse group (n = 26) limits power, particularly for mortality, whose absence of a significant difference by mechanism cannot be read as evidence of equivalence; it also explains the width of several confidence intervals, such as that of the analysis restricted to gold miners for evacuation, where separation is complete, having only indicative value. The multiplicity of comparisons requires cautious interpretation, which is why effect sizes were favored. Neurological outcome could be assessed only globally, in the absence of standardized ASIA grading at follow-up; non-fatal complications of survivors were not recorded; the thoracic sub-segments were available only for the collapse group; the absence of standardized radiological data (AO Spine classification, TLICS score [13]) limits the fine morphological characterization of injuries, and the causes of death, collected from records, received no independent validation. These results, drawn from a referral hospital cohort, are therefore exploratory and hypothesis-generating: based on observational associations, they allow neither estimation of the population incidence of gold-mining-related injuries nor inference of a causal relationship. Multicenter prospective studies incorporating artisanal mining sites and standardized neurological assessments are needed to confirm these results and guide prevention policies.

5. Conclusion

Artisanal mine collapse appears as a distinct, probably under-reported mechanism of severe traumatic spinal injury in the artisanal gold-mining regions of West Africa. It is associated with increased neurological severity and a near-absence of medically staffed evacuation, two associations that resist adjustment for the recruiting center as well as restriction to gold miners alone; the predominance of thoracic locations, more fragile, requires confirmation. Mortality appears determined by injury completeness rather than by the mechanism itself, a hypothesis compatible with our models but which this design does not allow to be demonstrated. Recognition of this distinct traumatic mechanism is a necessary step toward improving prevention, the organization of rescue, and access to specialized care in artisanal mining regions.

Ethics Approval

The study was conducted in accordance with the principles of the Declaration of Helsinki (2013 revision) [25] and received the approval of the Institutional Ethics Committee of Bouaké University Hospital (approval no. CEI/CHU-BKE/107/2026 of 15 June 2026). Individual consent was not required given the retrospective and anonymized nature of the analysis.

Use of Artificial Intelligence

During the preparation of this work, the authors used a generative AI tool to assist with reference formatting and verification and with manuscript layout. The tool was not involved in data collection, coding, or interpretation. The authors reviewed and edited all content and took full responsibility for the content of the publication.

Consent for Publication

Not applicable: the manuscript contains no individual data allowing a patient to be identified.

Cohort Overlap

The 120 patients analyzed here constitute the same cohort as that of a second manuscript by the same authors, devoted to genitosphincteric disorders after traumatic spinal injury (manuscript submitted). The two works address distinct questions, exposures, and outcomes; no result is duplicated.

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Data Availability

The anonymized individual data and the analysis code are available from the corresponding author on reasonable request and subject to the agreement of the participating institutions.

Author Contributions

All authors commented on the successive versions and approved the submitted version.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Safdarian, M., Trinka, E., Rahimi-Movaghar, V., Thomschewski, A., Aali, A., Abady, G.G., *et al.* (2023) Global, Regional, and National Burden of Spinal Cord Injury, 1990-2019: A Systematic Analysis for the Global Burden of Disease Study 2019. *The Lancet Neurology*, **22**, 1026-1047. https://doi.org/10.1016/s1474-4422(23)00287-9

[2] Lu, Y., Shang, Z., Zhang, W., Pang, M., Hu, X., Dai, Y., *et al.* (2024) Global Incidence and Characteristics of Spinal Cord Injury Since 2000-2021: A Systematic Review and Meta-Analysis. *BMC Medicine*, **22**, Article No. 285. https://doi.org/10.1186/s12916-024-03514-9

[3] Jesuyajolu, D., Ayantayo, T., Oyesiji, E., Bakare, S., Madeleine, O., Adewale, O., *et al.* (2023) Burden of Traumatic Spinal Cord Injury in Sub-Saharan Africa: A Scoping Review. *World Neurosurgery*, **179**, 216-221.e2. https://doi.org/10.1016/j.wneu.2023.08.096

[4] World Bank (2024) Achieving Sustainable and Inclusive Artisanal and Small-Scale Mining (ASM): A Renewed Framework for World Bank Engagement. World Bank. http://hdl.handle.net/10986/42156

[5] Ngom, N.M., Baratoux, D., Bolay, M., Dessertine, A., Abass Saley, A., Baratoux, L., *et al.* (2022) Artisanal Exploitation of Mineral Resources: Remote Sensing Observations of Environmental Consequences, Social and Ethical Aspects. *Surveys in Geophysics*,

44, 225-247. https://doi.org/10.1007/s10712-022-09740-1

[6] Kyeremateng-Amoah, E. and Clarke, E. (2015) Injuries among Artisanal and Small-Scale Gold Miners in Ghana. *International Journal of Environmental Research and Public Health*, **12**, 10886-10896. https://doi.org/10.3390/ijerph120910886

[7] Singo, J., Isunju, J.B., Moyo, D., Bose-O'Reilly, S., Steckling-Muschack, N. and Mamuse, A. (2022) Accidents, Injuries, and Safety among Artisanal and Small-Scale Gold Miners in Zimbabwe. *International Journal of Environmental Research and Public Health*, **19**, Article 8663. https://doi.org/10.3390/ijerph19148663

[8] Abebil, F., Tefera, Y., Tefera, W., Kumie, A., Mulugeta, H. and Kassie, G. (2023) Non-fatal Occupational Injuries among Artisanal and Small-Scale Gold Mining Workers in Ethiopia. *Environmental Health Insights*, **17**, 1-8. https://doi.org/10.1177/11786302231171809

[9] Traoré, I. (2021) Traumatismes vertébro-médullaires secondaires aux éboulements de mines traditionnelles au CHU de Kati [Traumatic Spinal Injuries Secondary to Traditional Mine Collapses at Kati University Hospital.] Doctoral Thesis, University of Sciences, Techniques and Technologies of Bamako.

[10] Park, K.B., Johnson, W.D. and Dempsey, R.J. (2016) Global Neurosurgery: The Unmet Need. *World Neurosurgery*, **88**, 32-35. https://doi.org/10.1016/j.wneu.2015.12.048

[11] Garcia, R.M., Shlobin, N.A., Baticulon, R.E., Ghotme, K.A., Lippa, L., Borba, L.A., *et al.* (2024) Global Neurosurgery: An Overview. *Neurosurgery*, **95**, 501-508. https://doi.org/10.1227/neu.0000000000003109

[12] Denis, F. (1983) The Three Column Spine and Its Significance in the Classification of Acute Thoracolumbar Spinal Injuries. *Spine*, **8**, 817-831. https://doi.org/10.1097/00007632-198311000-00003

[13] Lambrechts, M.J., Schroeder, G.D., Tran, K., Li, S., Huang, A., Chu, J., *et al.* (2023) Validation of the AO Spine Thoracolumbar Injury Classification System Treatment Algorithm: Should It Be Used to Guide Fracture Management? *Spine*, **48**, 994-1002. https://doi.org/10.1097/brs.0000000000004693

[14] Shu, P.C., Motah, M., Massi, D.G., Ngunyi, Y.L., Budzi, N.M. and Mefire, A.C. (2023) Thoracolumbar Spine Injury in Cameroon: Etiology, Management, and Outcome. *BMC Musculoskeletal Disorders*, **24**, Article No. 386. https://doi.org/10.1186/s12891-023-06481-z

[15] Hima-Maïga, A., Kpelao, E., Kelani, A.B., Abdoulwahab, I., Gaye, M., Diop, A., *et al.* (2021) Les traumatismes du rachis dorsolombaire de l'adulte au Niger [Thoracolumbar Spine Injuries in Adults in Niger.] *Health Sciences and Disease*, **22**, 72-76. https://www.hsd-fmsb.org/index.php/hsd/article/view/2777

[16] Ahuja, C.S., Wilson, J.R., Nori, S., Kotter, M.R.N., Druschel, C., Curt, A., *et al.* (2017) Traumatic Spinal Cord Injury. *Nature Reviews Disease Primers*, **3**, Article No. 17018. https://doi.org/10.1038/nrdp.2017.18

[17] Alizadeh, A., Dyck, S.M. and Karimi-Abdolrezaee, S. (2019) Traumatic Spinal Cord Injury: An Overview of Pathophysiology, Models and Acute Injury Mechanisms. *Frontiers in Neurology*, **10**, Article 282. https://doi.org/10.3389/fneur.2019.00282

[18] Kirshblum, S.C., Burns, S.P., Biering-Sorensen, F., Donovan, W., Graves, D.E., Jha, A., *et al.* (2011) International Standards for Neurological Classification of Spinal Cord Injury (Revised 2011). *The Journal of Spinal Cord Medicine*, **34**, 535-546. https://doi.org/10.1179/204577211x13207446293695

[19] Rupp, R., Biering-Sørensen, F., Burns, S.P., Graves, D.E., Guest, J., Jones, L., *et al.* (2021) International Standards for Neurological Classification of Spinal Cord Injury.

Topics in Spinal Cord Injury Rehabilitation, **27**, 1-22. https://doi.org/10.46292/sci2702-1

[20] Eisner, Z.J., Delaney, P.G., Widder, P., Aleem, I.S., Tate, D.G., Raghavendran, K., *et al.* (2021) Prehospital Care for Traumatic Spinal Cord Injury by First Responders in 8 Sub-Saharan African Countries and 6 Other Low- and Middle-Income Countries: A Scoping Review. *African Journal of Emergency Medicine*, **11**, 339-346. https://doi.org/10.1016/j.afjem.2021.04.006

[21] World Health Organization (2019) Emergency Care Systems for Universal Health Coverage: Ensuring Timely Care for the Acutely Ill and Injured (Resolution WHA72.16). WHO.

[22] Marchesini, N., Demetriades, A.K., Alves, O., Dange, R.M., Choco, H.M., Lozada, E.D., *et al.* (2025) Bootstrap-Sci: Beyond One Option of Treatment for Spinal Trauma and Spinal Cord Injury: Consensus-Based Stratified Protocols for Pre-Hospital Care and Emergency Room (Part I). *Brain and Spine*, **5**, Article ID: 104251. https://doi.org/10.1016/j.bas.2025.104251

[23] Wahle, C.F., Samuels, C., Kakulamarri, S., Adejuyigbe, B., Tee, T., Gomez Alvarado, F., *et al.* (2025) Spine Trauma Resource Priorities in Sub-Saharan Africa: A Delphi Approach. *Global Spine Journal*, **16**, 1501-1508. https://doi.org/10.1177/21925682251383510

[24] Zileli, M., Osorio-Fonseca, E., Konovalov, N., Cardenas-Jalabe, C., Kaprovoy, S., Mlyavykh, S., *et al.* (2020) Early Management of Cervical Spine Trauma: WFNS Spine Committee Recommendations. *Neurospine*, **17**, 710-722. https://doi.org/10.14245/ns.2040282.141

[25] World Medical Association (2013) World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. *JAMA*, **310**, 2191-2194.

List of Abbreviations

AO Spine: AO Spine Thoracolumbar Injury Classification System;
ASIA: American Spinal Injury Association;
CI: confidence interval;
IQR: interquartile range;
OR: odds ratio;
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology;
TLICS: Thoracolumbar Injury Classification and Severity Score;
TSI: traumatic spinal injury.