Modern Combat Spinal Trauma: A Systematic Review of the Top-Cited Evidence

SRMDM. 2025, 102 (2): 20-34; https://doi.org/10.71838/zy3f-x512

Keywords: Spinal fractures; Military medicine; Blast injuries; Spinal cord injury

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Conflict of Interest:
There are no conflicts of interest.

Abstract

Das moderne Wirbelsäulentrauma im Kampfeinsatz ist eine eigenständige klinische Entität. Die Behandlung erfordert einen Ausgleich zwischen der chirurgischen Indikation für eine frühzeitige Dekompression und der logistischen Notwendigkeit einer schnellen strategischen Evakuierung. Wir haben die einflussreichsten Literaturquellen zusammengefasst, um die Epidemiologie, die Behandlung und die Ergebnisse zu charakterisieren und den operativen Versorgungsstandard in Einsatzgebieten zu definieren. Wir haben eine zitiergewichtete Auswertung der Literatur zu Wirbelsäulentraumata im Kriegseinsatz (2000–2025) durchgeführt. Die 30 meistzitierten Primärstudien wurden gesichtet, um klinische Kohorten mit extrahierbaren Daten zu identifizieren. Wir haben diese einflussreichen Quellen zusammengefasst, um die Epidemiologie der Verletzungen, den Zeitpunkt der Operation und die perioperativen Komplikationen zu charakterisieren. Neunzehn Publikationen mit insgesamt 31.409 Verletzten erfüllten die Einschlusskriterien. Die Gesamtkohorte war jung (Durchschnittsalter 25,4 Jahre) und männlich (96,6 %). Bei 27,6 % der auswertbaren Population trat eine traumatische Rückenmarksverletzung auf. Explosionen waren für 79,1 % der Verletzungen verantwortlich, wobei vorwiegend die Lendenwirbelsäule betroffen war (65,5 % der Patienten).

Bei 40,7 % der Patienten wurde ein chirurgischer Eingriff vorgenommen. Die durchschnittliche Zeit bis zur ersten Wirbelsäulenoperation betrug 2,9 Tage. Von den dokumentierten Eingriffen wurden 20,3 % in vorwärts stationierten Einrichtungen durchgeführt, während die übrigen nach der Evakuierung zu definitiven Versorgungsknotenpunkten erfolgten. Die durchschnittliche gemeldete Sterblichkeitsrate betrug 7,4 %. Zusammenfassend kann festgehalten werden, dass kampfbedingte Wirbelsäulentraumata eine eigenständige Entität darstellen, die durch Explosionsmechanismen und thorakolumbale Frakturen definiert ist und bei deren Behandlung eine schnelle Evakuierung einer frühzeitigen Dekompression vorzuziehen ist. Die hier angegebenen Zeitintervalle spiegeln ein logistisches Best-Case-Szenario wider, das auf Luftüberlegenheit basiert. Auf zukünftigen umkämpften Schlachtfeldern wird aufgrund verlängerter chirurgischer Verzögerungen die Neuroprotektion während längerer Transporte von grösster Bedeutung sein.

Modern combat spinal trauma is a distinct clinical entity. Management requires balancing the surgical indication for early decompression against the logistical mandate for rapid strategic evacuation. We synthesized the most influential literature to characterize the epidemiology, management, and outcomes, and to define the operational standard of care in deployed settings. We performed a citation-weighted review of the combat spine literature (2000–2025). The 30 most-cited primary studies were screened to identify clinical cohorts with extractable data. We synthesized these high-impact sources to characterize injury epidemiology, surgical timing, and perioperative complications. Nineteen publications representing 31,409 casualties met inclusion criteria. The aggregate cohort was young (mean 25.4 years) and male (96.6%). Traumatic spinal cord injury occurred in 27.6% of the evaluable population. Explosions accounted for 79.1% of injuries, with a predominantly lumbar anatomical burden (65.5% patient prevalence). Surgical intervention was performed in 40.7% of patients. The mean time to the first spinal operation was 2.9 days. Of recorded procedures, 20.3% were performed at forward-deployed facilities, while the remainder occurred after evacuation to definitive care nodes. The average reported mortality rate was 7.4%. Combat spine trauma presents as a distinct entity defined by blast mechanisms and thoracolumbar fractures, where management favors rapid evacuation over early decompression. The intervals reported here reflect a best-case logistical scenario reliant on air superiority. In future contested battlefields, extended surgical delays will make neuroprotection during prolonged transport paramount.

List of Abbreviations AIS: Abbreviated Injury Scale; ASIA American Spinal Injury Association; DVT Deep Vein Thrombosis; GSW Gunshot Wound; IQR Interquartile Range; MAP Mean Arterial Pressure; MVC Motor Vehicle Collision; NASCIS National Acute Spinal Cord Injury Studies; PE Pulmonary Embolism; PMC PubMed Central Surgical Timing in Acute; STASCIS Surgical Timing in Acute Spinal Cord Injury Study; SCI Traumatic Spinal Cord Injury.

Introduction

Spinal injuries are now a stable component of modern combat casualty care. Analyses from Iraq and Afghanistan show that spinal column trauma occurred in roughly one in ten evacuated combat casualties, is largely fracture-driven, and contributes substantially to long-term disability and death in wounded service members [1-3]. Within these cohorts, explosions – particularly improvised explosive devices and underbody blasts – predominate, and injury patterns are shifted toward thoracolumbar and lumbosacral segments, with low lumbar burst fractures repeatedly described in protected vehicle occupants [4, 5]. These patterns have emerged in a survivorship landscape reshaped by modern body armor and forward resuscitation: ceramic plates, tourniquets, and hemostatic resuscitation allow service members to live through high-energy blasts that would previously have been uniformly fatal, but they also shift part of the energy burden away from the thoraco-abdominal viscera and onto the axial skeleton. Registry and autopsy series from these conflicts report a higher incidence of spinal trauma and war-related traumatic spinal cord injury (tSCI) than in earlier wars, with thoracic, thoracolumbar, and lumbosacral levels over-represented [1-4].

In parallel, the civilian and mixed-system tSCI literature has moved toward earlier decompression. The multicenter Surgical Timing in Acute Spinal Cord Injury Study (STASCIS) cohort associated decompression within 24 hours with higher odds of meaningful neurological improvement after cervical tSCI [6]. Subsequent AO Spine guidelines first suggested early surgery within 24 hours as a treatment option for acute tSCI on the basis of low-quality observational data [7] and have now upgraded this to a recommendation for decompression within 24 hours whenever medically feasible, supported by moderate-quality evidence from updated systematic reviews [8].

In deployed practice, however, timing is constrained by echeloned care. Contemporary military trauma systems move casualties along a Role 1–4 chain: point-of-injury resuscitation and limited damage-control capability at the forward end, damage-control surgery and early specialist input at Role 2/3, and definitive multidisciplinary reconstruction at Role 4 after strategic evacuation [9, 10]. This architecture, matured through the Joint Trauma System, has delivered measurable survival gains by emphasizing rapid stabilization, standardized protocols, and efficient evacuation while concentrating complex surgery at higher-capability nodes [11, 12]. As a result, the deployed surgeon operates under a structural tension: every hour spent on in-theater decompression is an hour the patient is not moving toward definitive safety, whereas every hour spent in transit is a delay against the ischemic «clock» of the injured cord.

The clinical literature from recent conflicts can be read as a series of attempts to navigate this tension, but it is scattered across large registry analyses, autopsy series, and focused surgical cohorts. There is no concise quantitative synthesis of what the most influential primary studies actually report about epidemiology, early management, and short-term outcomes in combat-related spinal trauma.

Research question and objective. Because high citation counts in this space often track clinical influence and doctrinal weight, we asked: across the most cited primary studies of combat-related spine trauma from modern conflicts, what are the epidemiology, early management patterns, and short-term outcomes? The primary outcome was early management, defined as the proportion of patients undergoing surgery and the reported timing of their index spinal operation. Secondary outcomes were mechanism distributions, anatomic injury levels, concomitant injuries, and early complications.

Methods

Design and identification of evidence. We performed a systematic, citation-weighted review of primary clinical studies on combat-related spinal trauma using a custom algorithmic screening script written in Python (Version 3.12; Python Software Foundation, Wilmington, DE, USA) utilizing the Biopython library to interface with the NCBI E-utilities API. Using PubMed/MEDLINE, we searched for English-language original research published between 1 January 2000 and 1 October 2025 that reported acute spinal column injuries (vertebral fractures and/or tSCI) in military or war-related settings. We combined terms for spinal trauma with conflict-related keywords (for example Iraq, Afghanistan, OIF/OEF, blast, improvised explosive device, Role 2/3). We restricted the search to human clinical studies of case series level of evidence or higher with an abstract and excluded clearly non-trauma topics (such as chronic low-back pain, ergonomics, and animal or cadaver models), as well as non-systematic reviews, editorials, and conference abstracts. For each remaining paper we obtained its PubMed Central citation count and then ranked and screened the 30 most-cited articles as the group most likely to influence clinical practice.

Eligibility and abstraction. We reviewed the top 30 papers and included clinical cohorts or case series of acute combat related spinal column injury in deployed personnel or war casualties treated within a military trauma system. Studies required a clear denominator for at least one early care or outcome variable. We excluded narrative reviews, guidelines, autopsy series without a linked clinical cohort, purely civilian trauma series, animal/cadaver studies, and non-trauma topics (e.g., chronic pain, ergonomics); however, systematic reviews containing unique, extractable data were retained. Data were entered into a standardized spreadsheet, recording study design, conflict years, patient numbers, mechanism (explosion, gunshot, MVC, other), injury levels, and associated injuries. For management, we captured surgical location (deployed vs. definitive), proportion operated within 24 and/or 72 hours, and median time to first operation. Mortality and major complications (pneumonia, wound infection, venous thromboembolism) were recorded as reported; no values were inferred.

Synthesis. For each study we calculated proportions using the denominators reported by the original authors. We then pooled studies by summing the number of events and the number of patients for each variable (for example, the total number of patients with tSCI divided by the total number of patients in all cohorts that reported tSCI). For segment-level injury distributions, where many patients had injuries at multiple levels and some large registries reported only partial coding, we also present the unweighted mean (uw-mean) of the study-level percentages so that large and small cohorts contribute equally. Given the heterogeneity in conflicts, case mix, and follow-up windows, we did not perform a formal meta-analysis; all percentages are presented as descriptive summaries of what these influential series report. Each publication was treated as an independent cohort acknowledging that several large datasets come from the same conflicts and time periods and likely include overlapping patients that could not be de-duplicated. Primary outcomes were patterns of early spine management – whether surgery was performed, the echelon of care at which the index spine operation occurred, and the reported time from injury to that operation – while secondary outcomes captured mechanism profiles, anatomic injury distributions, associated injuries, and early complications.

Results

Studies and designs. Nineteen publications met inclusion criteria. Designs were predominantly retrospective cohort studies (n=15), supplemented by two systematic reviews, one case-control study, and one case series (Figure 1). Observation periods spanned 1975–2021. Study sample sizes ranged from 13 to 27,897 patients (median 65; uw-mean 1,653), yielding a total of 31,409 combatants with spine injuries and 36,100 recorded spinal injuries (Figure 2, Table 2). Across the full dataset, this corresponds to 1.15 spinal injuries per patient, while at the study level the median reported ratio was 1.22 injuries per patient (interquartile range [IQR] 1.0–2.22; Table 2).

Most series were drawn from recent conflicts. Fifteen of the nineteen reports explicitly sampled casualties from Iraq and Afghanistan and together contributed 30,959 patients; one smaller series (50 patients) reported Afghanistan alone, and three studies (400 patients) did not specify the area of operations (Figure 2).

Demographics and spinal cord involvement. Fifteen cohorts reported age data. The patient-weighted mean age at injury was 25.4 years (uw-mean 28.0 years), and the median of study-level means was 26.6 years (range 25.3–39.1 years; Table 2). Sex distribution, where reported (12 cohorts), was overwhelmingly male, with a pooled, patient-weighted mean proportion of 96.6% male casualties (Table 2).

Thirteen cohorts reported the proportion of patients with traumatic spinal cord injury. Across these, the pooled patient-weighted mean proportion with spinal cord injury was 27.6%, while the median study-level proportion was 41.5% (IQR 17.4–76.0%; range 0–100%; Table 2). Most of the included cohorts did not report ASIA impairment scores or other standardized neurological grades, so we could not break these figures down by completeness of injury or compare all outcomes by severity.

Mechanisms and types of injury. Mechanism of injury was reported in 15 of 19 cohorts (Figure 5). In the pooled, patient-weighted analysis, explosions or blasts accounted for 79.1% of combat spine injuries, gunshot wounds for 14.3%, motor vehicle crashes for 19.9%, and falls for 6.2%. At the study level, the corresponding medians of reported proportions were 65.0% for explosions (range 23.1–100.0%), 15.1% for gunshot wounds (range 9.4–44.1%), 11.9% for motor vehicle crashes (range 5.0–34.4%), and 5.8% for falls (range 5.0–7.4%; Figure 5). Because mechanisms were not coded as mutually exclusive in all registries, these percentages can sum to more than 100%.

Traumatic spinal cord injury was reported in 27.6% of the pooled patient population, with a median study-level prevalence of 41.5%. Twelve cohorts reported broad injury type (Figure 5). Blunt trauma accounted for a pooled, patient-weighted mean of 68.1% of cases and penetrating trauma for 30.7%. The median study-level proportions were 81.2% for blunt trauma (range 33.1–100.0%) and 23.8% for penetrating trauma (range 9.4–97.9%; Figure 5). Several primary studies classified blast injuries variably as blunt, penetrating, or in separate categories, which is reflected in the observed ranges.

Anatomical distribution. Segment level involvement was variably reported, with 5–6 cohorts (n = 699–767 patients) providing patient level data and up to 13 cohorts (n ≈ 32,000 spine injuries) reporting injury level distributions (Figure 3). At the patient level, the uw-mean prevalence of involvement at each spinal region was 39.3% for cervical, 21.2% for thoracic, 65.5% for lumbar, and 41.0% for sacral segments; percentages exceed 100% because many patients had multilevel injuries. At the injury level the mean prevalence across cohorts was 30.2% for cervical, 28.2% for thoracic, 39.9% for lumbar, and 14.0% for sacral injuries.

Operative care and timing. Eight cohorts reported the proportion of patients undergoing operative management. Across these series, 40.7% of spine injured patients were treated surgically in the pooled, patient weighted analysis. At the study level, the uw mean operative rate was 58.4%, with a median of 65.6% (range 5.9–100.0%). Where the level of care was specified (two cohorts), 12 spine operations were performed at deployed Role 3 hospitals in the area of combat before strategic evacuation and 47 were performed after arrival at Role 4 hospitals in the rear support area, so about one in five recorded spine procedures (20.3%) took place forward in the combat zone (Table 2).

Surgical timing was reported for 351 patients across three cohorts. In this group, the median time to initial surgery reported was 1.7 days and the uw-mean was 2.9 days. Timing for definitive reconstruction was tracked in two smaller cohorts totaling 33 patients; in this subset, the median time to fixation was 15.5 days and the mean was 16.5 days (Figure 4).

Concomitant injuries. Five cohorts comprising 1,587 patients reported head injuries in 58.9% of cases (Figure 5). Extremity fractures affected 54.1% of the 734 patients tracked across five studies. Six cohorts (n=812) reported abdominal injuries in 28.7% of cases, while three cohorts (n=649) identified chest trauma in 26.7%.

Complications, reoperation, and mortality. Outcomes were synthesized based on the available patient pools for each metric (Figure 5, Table 2). Nine cohorts comprising 1,738 patients reported mortality; the average rate across the total patient population was 7.4%, whereas the median rate reported among individual studies was 3.1% (range 0–100.0%). Complication profiles were available for a similar group of 1,687 patients (nine studies), yielding a population average of 14.8% (median study value 16.7%; range 0–69.2%). Reoperation data was tracked in seven cohorts totaling 483 patients; in this subset, the reoperation rate was 17.6% across the population (median study value 14.0%; range 7.7–100.0%).

Specific complications were reported less consistently (Figure 5). Five cohorts comprising 997 patients tracked wound infections; the average rate across this population was 5.9%, compared to a median study-level rate of 9.0% (range 3.1–20.0%). Venous thromboembolism was monitored in a subset of 740 patients (five studies), yielding a population average of 3.6% (median study value 2.5%; range 0–53.8%). Pneumonia was reported in three cohorts totaling 677 patients; the average rate was 3.0% across the population (median study value 0%; range 0–3.4%).

Table 2. Summary Statistics of the Top-Cited Papers in Combat Spinal Trauma

PMC Citations	First Author	Year	Title	Journal	Study Type
24	*Schoenfeld AJ (1)*	*2013*	*Spinal injuries in United States military personnel deployed to Iraq and Afghanistan: an epidemiological investigation involving 7877 combat casualties from 2005 to 2009.*	*Spine*	*Retrospective Cohort*
12	*Ragel BT (5)*	*2009*	*Fractures of the thoracolumbar spine sustained by soldiers in vehicles attacked by improvised explosive devices.*	*Spine*	*Retrospective Cohort*
9	*Blair JA (3)*	*2012*	*Military penetrating spine injuries compared with blunt.*	*The Spine Journal*	*Retrospective Cohort*
8	*Lehman RA Jr (4)*	*2012*	*Low lumbar burst fractures: a unique fracture mechanism sustained in our current overseas conflicts.*	*The Spine Journal*	*Retrospective Cohort*

8	*Formby PM (13)*	*2016*	*Operative management of complex lumbosacral dissociations in combat injuries.*	*The Spine Journal*	*Retrospective Cohort*
8	*Lawless MH (14)*	*2018*	*Surgical management of penetrating spinal cord injury primarily due to shrapnel and its effect on neurological outcome: a literature review and meta-analysis.*	*Journal of Neurosurgery: Spine*	*Systematic Review/ Meta-analysis*
6	*Patzkowski JC (15)*	*2012*	*Multiple associated injuries are common with spine fractures during war.*	*The Spine Journal*	*Retrospective Cohort*
6	*Mok JM (16)*	*2013*	*Effect of vacuum spine board immobilization on incidence of pressure ulcers during evacuation of military casualties from theater.*	*The Spine Journal*	*Retrospective Cohort*
5	*Freedman BA (17)*	*2014*	*The combat burst fracture study--results of a cohort analysis of the most prevalent combat specific mechanism of major thoracolumbar spinal injury.*	*Archives of Orthopaedic and Trauma Surgery*	*Case-Control*
4	*Eardley WG (18)*	*2012*	*Spinal fractures in current military deployments.*	*Journal of the Royal Army Medical Corps*	*Retrospective Cohort*
3	*Spurrier E (19)*	*2016*	*Identifying Spinal Injury Patterns in Underbody Blast to Develop Mechanistic Hypotheses.*	*Spine*	*Retrospective Cohort*
3	*Stewart SK (20)*	*2019*	*Fatal head and neck injuries in military underbody blast casualties.*	*Journal of the Royal Army Medical Corps*	*Retrospective Cohort*
2	*Possley DR (21)*	*2012*	*Complications associated with military spine injuries.*	*The Spine Journal*	*Retrospective Cohort*
2	*Formby PM (22)*	*2015*	*Reoperation after in-theater combat spine surgery.*	*The Spine Journal*	*Retrospective Cohort*
2	*Breeze J (23)*	*2012*	*Outcomes from penetrating ballistic cervical injury.*	*Journal of the Royal Army Medical Corps*	*Case Series*
1	*Sommer F (24)*	*2023*	*Spinal injuries after ejection seat evacuation in fighter aircraft of the German Armed Forces between 1975 and 2021.*	*Journal of Neurosurgery: Spine*	*Retrospective Cohort*
1	*Cuthbertson JL (25)*	*2020*	*Spinal Immobilization in Disasters: A Systematic Review.*	*Prehospital and Disaster Medicine*	*Systematic Review/ Meta-analysis*
1	*Wagner SC (26)*	*2015*	*Operative treatment of new onset radiculopathy secondary to combat injury.*	*Military Medicine*	*Retrospective Cohort*
0	*MacGregor AJ (27)*	*2023*	*Research Letter: Prevalence of Spine Injuries Among US Military Personnel With Combat-Related Concussion (27).*	*Journal of Head Trauma Rehabilitation*	*Retrospective Cohort*

Caption: **The 19 most-cited primary clinical studies on combat-related spinal trauma (2000–2025) ranked by citation frequency.** The top 30 most-cited articles identified by the search strategy were screened in full text; 19 met the inclusion criteria for data extraction. Citation counts reflect PubMed-to-PubMed citations, serving as a proxy for clinical influence within the peer-reviewed biomedical literature. *Abbreviations: PMC, PubMed Central.*

Table 2. Summary Statistics of the Top-Cited Papers in Combat Spinal Trauma

Clinical Variable	*Studies (k)*	*Total Patients (N)*	*Total Events (n)*	*Pooled Prevalence*
		COHORT OVERVIEW		
Total Included Cohort	*19*	*31,409*	-	-
Total Spinal Injuries	*19*	*31,409*	*36,100*	-
		DEMOGRAPHICS		
Age (Mean Years)	*15*	*30,660*	-	*25.40%*
Male Sex	*12*	*30,272*	*29,249*	*96.60%*
		INJURY CHARACTERISTICS		
Traumatic Spinal Cord Injury	*13*	*2,688*	*741*	*27.60%*
		MANAGEMENT		
Surgical Intervention	*8*	*1,679*	*683*	*40.70%*
Operations in Combat Zone	*2*	*59*	*12*	*20,30%*
		OUTCOMES		
Overall Complication Rate	*9*	*1,687*	*250*	*14.80%*
Reoperation Rate	*7*	*483*	*85*	*17.60%*
Mortality	*9*	*1,738*	*129*	*7.40%*

Caption: Aggregate data summary of combat-related spinal trauma. This table details the pooled prevalence of key demographic, injury, and management variables. For each variable, the data reflects only the subset of studies (k) that explicitly reported that outcome. Columns show the total number of patients evaluated for that specific variable (N), the total count of observed events or cases (n), and the resulting pooled percentage. *Abbreviations: k, number of studies; N, total patient denominator; n, total number of events.*

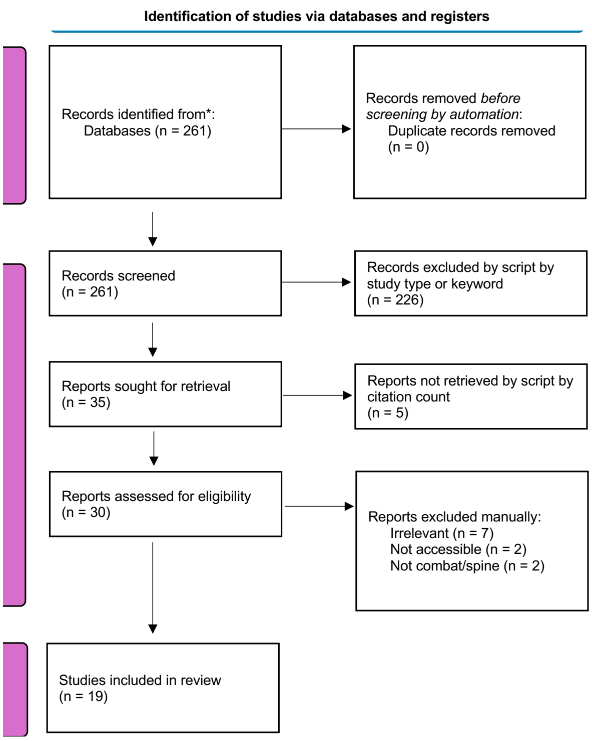

Figure 1. PRISMA 2020 flow diagram

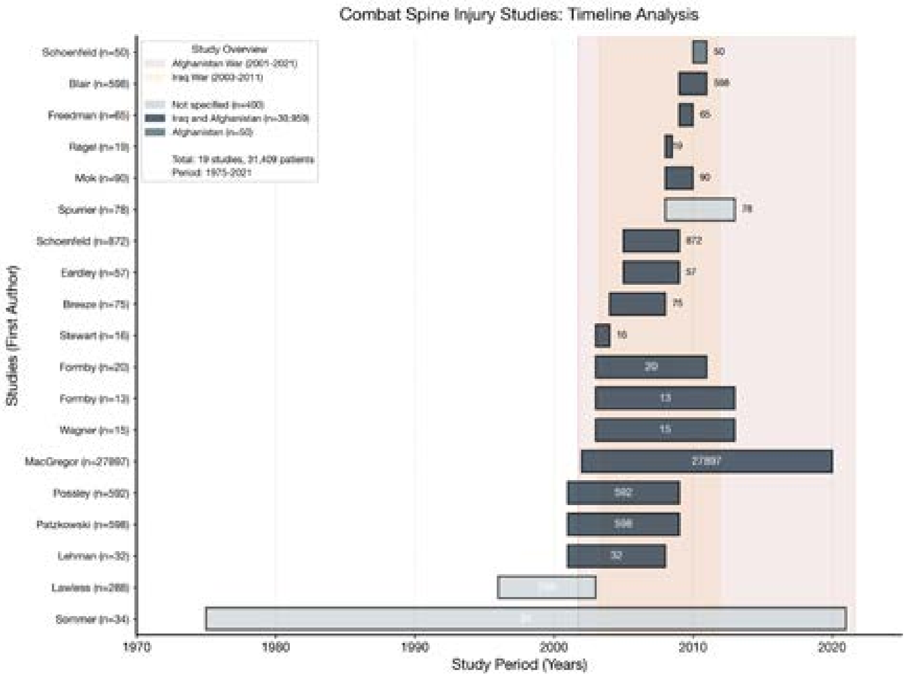

Figure 2. Temporal distribution of included studies.

A timeline visualization of the 19 studies included in the analysis representing a total cohort of 31,409 patients over a 46-year period (1975–2021). The horizontal bars indicate the data collection period for each publication, color-coded by war theater. The majority of studies (n=15) correspond to the Iraq and Afghanistan conflicts. Abbreviations: n, number.

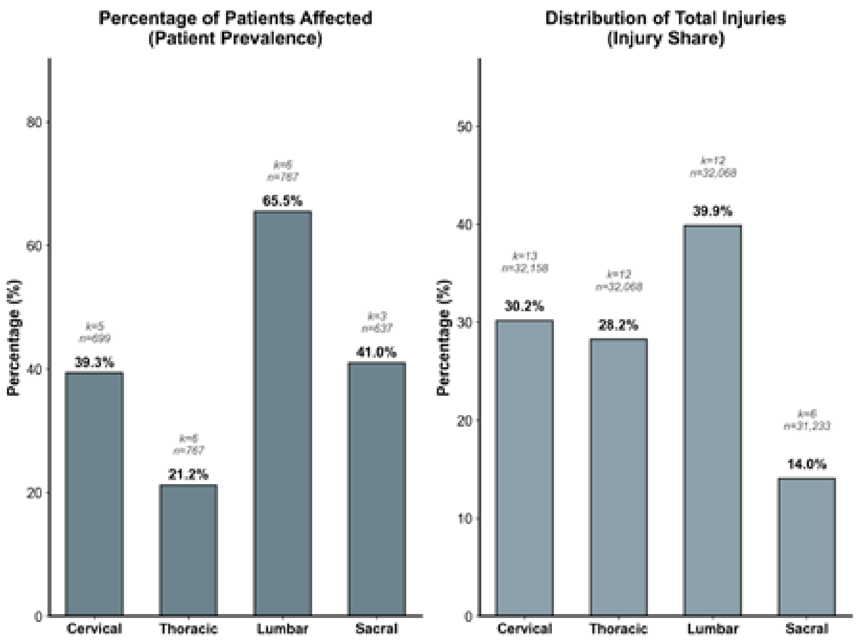

Figure 3. Anatomical distribution of spinal injuries.

The data is presented in two ways to distinguish between patient involvement and total injury burden. (Left) Percentage of Patients Affected: Shows the proportion of patients who sustained an injury at each specific level. Because individual patients often have injuries at multiple levels (e.g., a patient with both cervical and lumbar fractures), these percentages sum to more than 100%. (Right) Distribution of Total Injuries: Shows the breakdown of all spinal injuries combined. This treats the injuries as the unit of analysis, showing what percentage of the total injury pool occurred at each level (summing to 100%). Lumbar segments show the highest prevalence in both analyses (65.5% of patients; 39.9% of total injuries). Labels above bars indicate the number of studies (k) and contributing sample size (n).

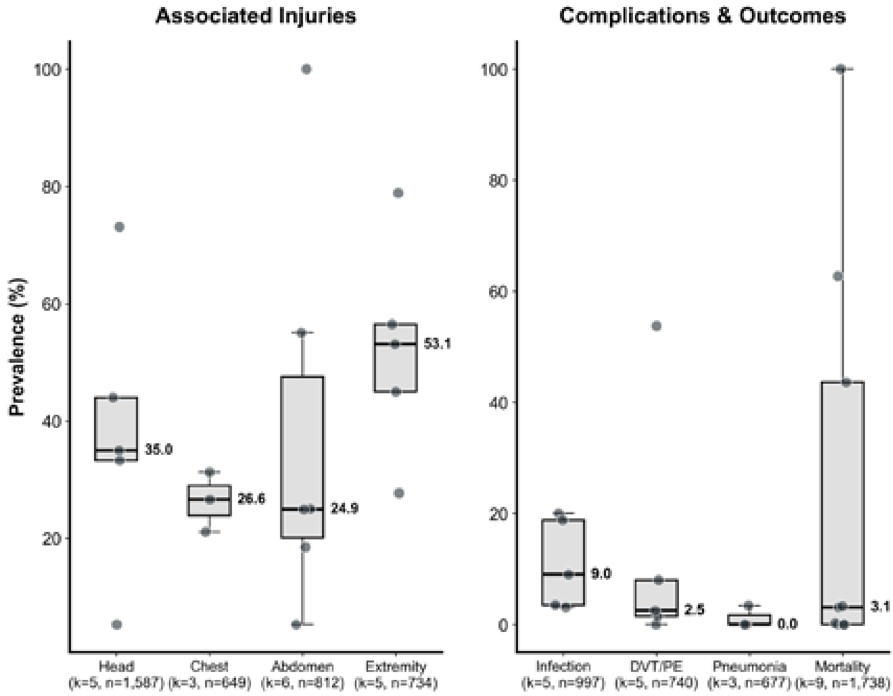

Figure 4. Surgical timing intervals.

Box plots display the distribution of reported mean times to surgery. Initial surgery (typically decompression) occurred at a median of 1.7 days (k=3 studies). Definitive stabilization occurred at a median of 15.5 days (k=2 studies). The black line indicates the median; dots represent individual study means. Abbreviations: n, number of studies.

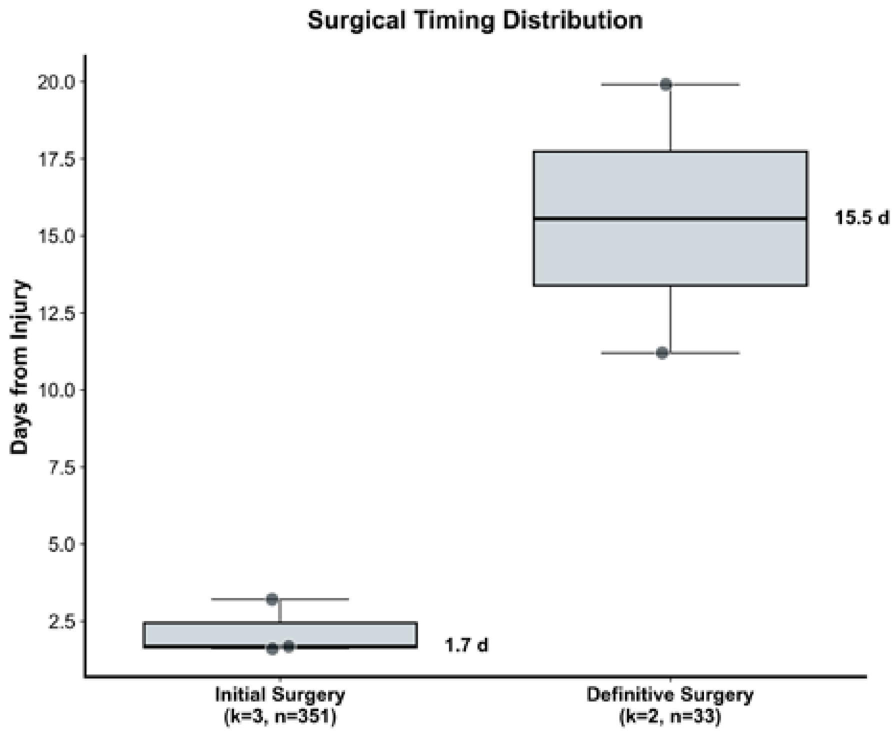

Figure 5. Associated injury burdens and clinical complications.

(Left) Non-Spinal Injuries: Extremity fractures were most common (median 53.1%), followed by head trauma (35.0%).(Right) Complications: Infection was the most frequent issue (median 9.0%). Mortality was 3.1% (median of 9 studies). Note: The text cites a higher mortality (7.4%) because it averages all patients (total burden), whereas this figure shows the typical rate reported by a single study. Abbreviations: DVT, deep vein thrombosis; PE, pulmonary embolism

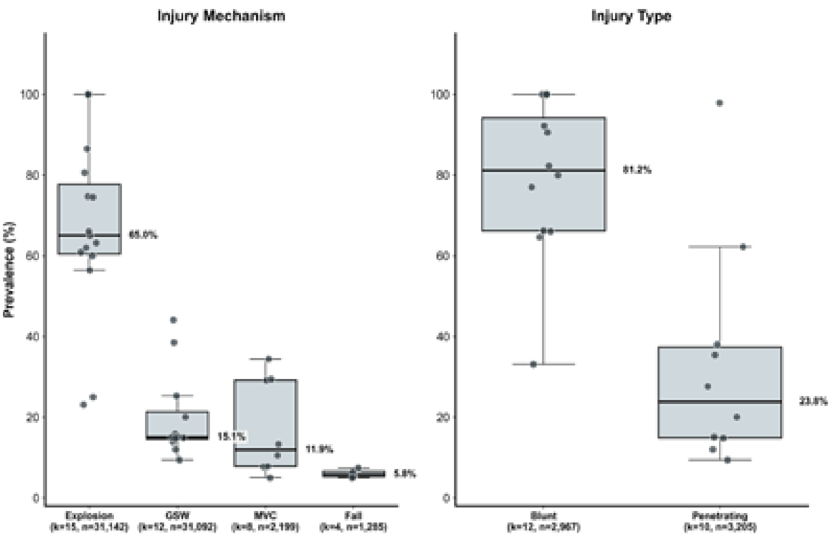

Figure 6. Trauma mechanisms and injuryclassification.

Injury mechanisms and types. (Left) Mechanism: Explosions were the primary cause of injury (median 65.0%), followed by gunshot wounds (15.1%) and motor vehicle collisions (11.9%). (Right) Injury Type: Blunt trauma (median 81.2%) was significantly more common than penetrating trauma (23.8%). Note: Data represents the median of reporting studies (k). Abbreviations: GSW, gunshot wound; MVC, motor vehicle collision.

Discussion

The epidemiology synthesized here confirms that modern combat spinal trauma is a distinct clinical entity, diverging sharply from civilian patterns in mechanism, anatomy, and patient demographic. While civilian tSCI is increasingly a geriatric syndrome defined by cervical tSCI after low energy falls and decreasing numbers in high velocity motor vehicle accidents [28, 29], the combat cohort is young (mean ~25–28 years), predominantly male, and overwhelmingly shaped by explosive mechanisms (median 65%). This specific injury pattern – burst fractures in the lower spine following underbody blasts – requires the deployed surgeon to anticipate complex reconstruction needs that differ from the cervico-thoracic decompression workload seen in civilian trauma centers. Most series did not provide ASIA grades or consistent descriptions of open versus closed spinal wounds, so we cannot determine whether patients with complete spinal cord injuries or open spinal wounds were triaged or evacuated differently from those with incomplete deficits.

A central tension exists between the biological imperative for decompression and the logistical imperative for evacuation. The civilian standard has solidified around the "24-hour rule"; decompression within this window is associated with superior neurological recovery and is now recommended by global guidelines [6, 8, 30].

However, our synthesis shows that the battlefield reality does not meet this 24-hour target: the median time to the first spine operation is 1.7 days (about 41 hours). This delay is mostly a structural feature of the Role 1–4 system rather than a failure of individual teams. Operating at a deployed Role 3 hospital close to the zone of active operations means accepting a deliberate «tactical hold" on evacuation to carry out surgery, whereas deferring the case to a Role 4 hospital outside the theatre of operations allows rapid movement out of the combat zone but inevitably adds time before decompression. In the cohorts that reported level of care, only about one in five spine operations was performed at these forward Role 3 facilities; the remainder were done after strategic evacuation. This pattern suggests that deployed surgeons use forward capability selectively reserving it for patients who seem most likely to benefit (for example, those with incomplete spinal cord injuries at risk of deterioration) and moving patients with complete (AIS A) cord injuries or mechanically stable fractures quickly to rear based care [31].

Primary clinical cohorts suggest that forward surgical capability is utilized selectively to achieve decompression within the 24-hour window for patients with significant neurological deficits, and even in those, is not always achievable. In the only direct comparison of theater-level versus rear-echelon management, patients treated in Afghanistan presented with a markedly higher prevalence of incomplete spinal cord injury (42% ASIA D) compared to those evacuated to Germany (13% ASIA D); consequently, the in-theater cohort underwent surgery at a mean of 0.8 days, with 90% treated within 48 hours (Schoenfeld 2014 Evaluation of Immediate Postoperative Complications) [32]. By contrast, patients stabilized for evacuation to Landstuhl Regional Medical Center waited a mean of 3.0 days for definitive fixation (Schoenfeld 2014 Evaluation of Immediate Postoperative Complications) [32]. This aggressive forward timeline for neurologically injured casualties is corroborated by analyses of patients requiring reoperation, where a cohort predominantly affected by SCI (12 of 13 patients) underwent index stabilization at a mean of 1.6 days, with nearly a quarter treated on the day of injury [22]. Even among complex lumbosacral dissociations where reconstruction was typically delayed (mean 19.9 days), immediate intervention (day 0) was reserved specifically for cases of progressive neurological deterioration [13]. However, historical variance is significant; a meta-analysis of penetrating injuries noted mean surgical intervals ranging from as rapid as 2.4 hours to as delayed as 6.3 days depending on the specific conflict and logistical constraints [14].

The complication profile emerging from this review highlights the specific risks of the combat environment. The median wound infection rate (~9%) is notably higher than the 1–5% seen in elective or closed civilian trauma [33, 34]. This is a direct consequence of high-energy explosive mechanisms, which drive debris into the spinal column, compounded by the necessity of staged debridement and prolonged open wound management during evacuation.

Conversely, the low reported rates of pneumonia (0–3.4%) and VTE (median 2.5%) likely reflect the fragmented observation windows of the evacuation chain rather than true clinical success. In civilian cohorts, respiratory failure is a leading cause of early morbidity [35]. In deployed military cohorts, casualties are usually younger and have fewer comorbidities, and many of the most severely injured either die before reaching facilities with ventilatory and imaging capability or are evacuated out of theater early; pneumonias that develop during prolonged transport or at Role 4 hospitals are therefore unlikely to be captured by the mostly short in theater follow up reported in registries. Similarly, VTE is probably under diagnosed because imaging and screening are inconsistent along the evacuation chain, and the low baseline risk profile of this young population may further reduce the number of clinically apparent events.

The data implies that while the goals of military and civilian care are aligned, the pathways are distinct. The military system achieves acceptable outcomes not by adhering strictly to the 24-hour rule, but by utilizing rapid aeromedical evacuation to reach definitive care as close to that window as logistics allow. To optimize this system, future efforts should focus on high-yield areas. First, every hour saved in pre-operative logistics – imaging, transfers, handoffs, and operating room access – is critical; standardized checklists and time stamped workflows at each echelon can expose avoidable delays and support continuous process improvement. At the same time, meticulous mechanical spinal stabilization is required to prevent a «second hit" to the cord during prolonged, multi leg evacuation. Contemporary guidance emphasizes early immobilization with an appropriately sized cervical collar and rigid or vacuum spine board, careful in line handling during extrication and transfers, and early conversion from hard surfaces to padded or vacuum mattresses once definitive imaging and initial resuscitation are complete, balancing the need for motion restriction against the risks of pressure injury in protracted transport [16, 25, 36]. Further, when surgery is unavoidably delayed, hemodynamic management becomes the principal neuroprotective bridge. Current recommendations support maintaining a mean arterial pressure of roughly 75–80 mmHg for the first 3–7 days after injury, a target that is achievable across intensive care and critical care transport platforms and should be protocolized throughout the evacuation chain [37, 38]. Pharmacologic strategies remain more controversial. High-dose methylprednisolone is still the only agent with phase III randomized trial evidence for neuroprotection when initiated within 8 hours of injury (30 mg/kg IV bolus over 15 minutes followed by 5.4 mg/kg/h for 23 hours), with modest motor score improvements reported in selected patient subgroups of the landmark National Acute Spinal Cord Injury Studies (NASCIS) randomized trials [39]. However, the American College of Surgeons Best Practices Guidelines for Spine Injury and the

Cochrane review highlight increased rates of infection, gastrointestinal bleeding, hyperglycemia and even mortality, such that methylprednisolone is not recommended as routine care but, at most, as an individualized option in carefully selected patients [36, 38, 39]. Other candidate neuroprotective agents – including riluzole, granulocyte colony stimulating factor, minocycline, progesterone plus vitamin D, and GM1 ganglioside/Sygen [40-44] – have shown encouraging signals in preclinical and early phase clinical studies, and riluzole and granulocyte colony stimulating factor may improve neurological outcomes, but current evidence remains inconclusive and insufficient to justify routine use in the first 24–72 hours after tSCI, particularly in austere or resource limited settings [38]. In summary, optimizing tSCI care in deployed environments will depend on systematically reducing avoidable delays to decompression, enforcing best practice mechanical and hemodynamic neuroprotection during prolonged evacuation, and rigorously standardizing data. Future registries should adopt uniform definitions of «early" surgery (for example, ≤24 vs >24 hours), align these thresholds with contemporary evidence syntheses, and capture 30 day outcomes – especially venous thromboembolism and infection – that span theater boundaries, thereby enabling meaningful benchmarking and iterative improvement of the military spine trauma system [30, 36, 38].

Strengths and limitations. This study's primary strength lies in its influence-weighted methodology, which captures the specific body of evidence that has most heavily shaped current military doctrine by prioritizing high-impact studies over a broad keyword sweep. Furthermore, our strictly descriptive synthesis respects the structural heterogeneity of the data, avoiding the false precision of meta-analysis to allow the diverse denominators and follow-up windows of combat registries to stand on their own.

The main weaknesses come from the underlying studies. Only a minority report operative timing clearly enough to separate damage control surgery in deployed Role 2/3 facilities from definitive surgery at Role 4 hospitals, so the exact impact of surgical «holds» on delay is hard to quantify. Neurological detail is limited: ASIA grades, completeness of injury and standardized mortality time points are rarely given, and mechanism categories often overlap (for example, blast injuries counted as both blunt and penetrating trauma). Several cohorts draw on overlapping trauma registries from the same conflicts and time periods; we had no way to identify individual patients across publications, so some may be counted more than once. Our figures should therefore be read as descriptive summaries of the influence weighted literature rather than as de duplicated registry data. This is also, why we report both calculated pooled means, as well as median values.

Prehospital and early in theater external stabilization is another critical but poorly captured element of care. Contemporary military protocols, including the American College of Surgeons Best Practices Guidelines: Spine Injury, emphasize rigid cervical collars, vacuum mattresses or spine boards, careful log roll techniques, and avoidance of unnecessary transfers to minimize secondary displacement of unstable spinal injuries during prolonged evacuation; a recent systematic review of spinal immobilization in disasters reached similar conclusions.

There is also important selection bias. Most included series describe US and UK forces in Iraq and Afghanistan, where coalition air superiority and the «golden hour" mandate – strictly enforcing casualty transport to surgical capability within 60 minutes – leveraged dense rotary wing coverage to produce historically low case fatality rates [45]. Planning documents for future large scale or near peer conflicts warn that such rapid, at will evacuation cannot be assumed; adversaries are expected to contest airspace and target medical evacuation assets [46-48]. Early reports from Ukraine already describe much longer and more variable evacuation times – often 8–12 hours or more to reach medical facilities, sometimes ≥6 hours just to reach basic stabilization – and deliberate delays due to drone surveillance and artillery threat [49-51]. Our timing data should therefore be viewed as a best case benchmark from well resourced forces with air superiority. In less permissive environments, longer delays will make disciplined neuroprotective medical care – even in the absence of definitive surgery – central to tSCI management. Role 2 and 3 facilities should therefore be equipped to monitor MAP continuously and deliver vasoactive support along the evacuation chain. Pharmacologically, high dose methylprednisolone remains controversial despite historical trial data, and other candidate neuroprotective agents such as riluzole, granulocyte colony stimulating factor, minocycline, progesterone plus vitamin D, and GM 1 ganglioside are still investigational and not standard of care in the first 24–72 hours after injury.

Finally, because selection was driven by cumulative citation counts, our sample inherently favors established literature, potentially underrepresenting high-quality but recent studies from the mature phases of the conflicts that have not yet accrued sufficient bibliometric weight.

Conclusion. In the most cited modern series, combat spinal trauma emerges as a young, blast driven, thoracolumbar heavy injury pattern: about one in four casualties sustain traumatic spinal cord injury, nearly 80% of injuries are blast related, and lumbar segments are involved in roughly two thirds of patients. Despite this high risk profile, only about 40% undergo spine surgery, with typical time to first definitive operation on the order of 2–3 days after injury and only a minority of procedures performed at forward Role 3 facilities, even when tSCI and/or neurological deficit are present. This stands in contrast to civilian guidelines, which now recommend decompression within 24 hours whenever feasible. Yet these timelines were achieved in a best case logistic environment – air superiority, robust aeromedical capacity, and short, protected evacuation routes – and are unlikely to be replicated in future large scale or contested conflicts. Our focus should therefore be clear: while we continue to pursue earlier decompression when it can be done safely, the core of combat spine doctrine must be deliberate, system wide neuroprotection during prolonged evacuation – reliable immobilization and careful handling, hemodynamic optimization, and disciplined avoidance of secondary insults – so that neurological potential is preserved as far as possible when guideline concordant early surgery cannot be guaranteed.

Author Contributions Data collection: S.F. Schaible, P. Störrle. **Manuscript drafting:** S.F. Schaible, M.C. Deml. **Editing and review:** All authors.

Ethical Standards not applicable in a review.

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