J Med Sci 2025;45 (6):213-222
DOI: 10.4103/jmedsci.jmedsci_140_25

REVIEW ARTICLE

Spinal Injuries during Military Operations or under Limited Resources: What Must, What Can, and What Should Be Done and When?

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Combat-related spinal injuries have risen from around 1% in the second half of the last century to 5%–8% in the 2000s. With an average disability rate of 60%, spinal disorders are the second-most common cause of disability among retired US veterans. The increase is attributed to changes in war tactics, such as asymmetric warfare in Iraq and Afghanistan, where improvised explosive devices were increasingly used, leading to changes in injury profiles. Moreover, the conflict in Ukraine shows a new high intensity of warfare, in which modern artillery, guided missiles, drones, and cluster bombs are used. These experiences call for a critical analysis of existing guidelines and consensus, which have so far been based on fixed role allocations among the various echelons. It may be necessary to rethink and make more flexible the health care chains currently used in military and austere environments. The purpose of this paper is to provide an overview of the state of the scientific literature and guidelines on the question of which surgical treatments of spinal injuries must, can, or should be performed during military operations or under limited resources. Publicly available guidelines on the timing of surgical treatment of spine injuries in the deployed setting and the medical literature on time of surgery in military and civilian settings published since early 2000 are summarized for this narrative review. This includes the results of a structured literature search using PubMed, Embase, and other sources. According to the existing guidelines of the US Army, it is recommended that surgical procedures that can be postponed without expected adverse effects for the patient should be performed in military hospitals providing a high standard of care. This usually requires the possibility of safe transportation, which can considerably delay surgery. It is also noted that in some cases, early surgery may be beneficial for the patient. These include patients with incomplete spinal cord injuries, open cerebrospinal fluid leaks, and cervical cord injuries, in which an urgent reduction may improve the degree of neurological impairment. The final decision lies with the medical team deployed. Reports on early surgery performed in-country during military operations show inconsistent results, indicating comparable or higher complication and revision rates and slightly better or similar neurological outcomes compared to postponed procedures. Decompression with or without stabilization is the most frequently performed spine surgery in this setting. The evidence from the studies is limited. Civil studies demonstrate that early surgery leads to fewer complications, shorter hospital and intensive care unit stays, and less ventilator support. Patients with incomplete spinal cord injuries, open cerebrospinal fluid leaks, or cervical cord injuries where rapid reduction can improve the degree of neurological impairment, as well as patients who cannot be transported in the foreseeable future, are candidates for early surgery during military operations. The potential benefits of early surgery, such as better neurological recovery and faster rehabilitation, must be weighed on a case-by-case basis by the medical team involved against the higher risk of complications and revision surgery in an austere environment. For patients who require early surgery, the best possible conditions must be created. The conflicts of recent

Received: June 22, 2025; Revised: July 22, 2025;
Accepted: August 13, 2025; Published: October 10, 2025
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How to cite this article: Schulz C, Joubert C, Moro CR, Ciacci JD, Piercey JE. Spinal injuries during military operations or under limited resources: What must, what can, and what should be done and when? J Med Sci 2025;45:213-22.

decades have shown that it is time to rethink the health chain. Instead of fixed role assignments, it depends on the capacities that are currently available in the extreme forward surgical team. These need to be strengthened. Remote technologies such as teleradiology, artificial intelligence, and augmented reality can provide the necessary expertise to nonspecialized surgeons. Sterile and lightweight spinal instruments that can be delivered by drones are needed. Portable, energy-efficient medical devices with minimal electromagnetic footprints may mitigate the risk profiles of existing doctrine.

Key words: Augmented reality, high intensity conflicts, spine surgery in an austere environment, sterile spine implants, strategies for treating combat-related spinal injuries

INTRODUCTION

Today, in developed countries, spinal injuries are usually treated in hospitals with specialized surgical teams and high-tech equipment. However, in the event of military operations, terrorist attacks, or other mass casualty incidents, access to resources that are normally taken for granted is limited. In such situations, well-equipped operating rooms and intensive care units, imaging equipment, and specialized surgical staff may not be sufficiently available. In addition, the supply of anesthetics, blood products, fuel, stable energy, and transportation options, which are also dependent on the current battle situation and the weather, may be severely restricted. Therefore, the consideration and strategic adaptation of medical care in military operations or other situations with limited availability of resources is particularly important.

Combat-related spinal injuries have risen from around 1% in the second half of the last century to 5%–8% in the 2000s.[1-4] With an average disability rate of 60%, spinal disorders are the second-most common cause of disability among retired US veterans.[5] This increase in spinal injuries is attributed to changes in war tactics, such as asymmetric warfare in Iraq and Afghanistan, where improvised explosive devices were increasingly used, leading to changes in injury profiles.[3,4] Explosions are the most common cause of injury, accounting for around 75% of all injuries, and there is an increase in blast and a decrease in bullet injuries. Thus, complex multi-system trauma has become more frequent.[2] Similar developments can be observed for terrorist attacks.[6]

Spinal injuries during military operations in Iraq and Afghanistan

According to a study based on data from the US Joint Theater Trauma Registry on 10,979 evacuated combat casualties, 5.45% sustained injuries to the spinal column or cord.[2] Usually, several sections of the spine were affected multiple times, most frequently the lumbar spine (41%), followed by the thoracic spine (28%), the cervical spine (15%), and the sacrum (11%). The spinal cord was injured in 17% of patients, with neurological deficits of at least one AIS (American Spinal Injury Association Impairment Scale) grade occurring in 84% of cases, requiring surgical intervention in 68%.

Most, but not all, injuries were battle related. Thus, 56% of patients were injured by explosions, 29% by motor vehicle accidents of any kind, and 15% by gunshots. Due to the causes of trauma, concomitant injuries were frequent (78%) and usually affected several organ systems (57%). Spinal fractures were diagnosed in 92% of cases. In total, 30% of patients required surgery. Of these, decompression was performed in 59% and spinal fusion in 73%.[2] Typically, these procedures were carried out in well-equipped military hospitals to which the casualty must be transported. In rare cases, surgeries were performed in battlefield hospitals.

Organization of medical care in military operations

In the military sector, medical care is organized in so-called roles, ranging from role 1 to 4. Different roles mean different care capacities. Role 1 facilities are generally mobile units that provide first aid and basic health care directly in the area of operation. Role 2 facilities provide advanced emergency treatment and resuscitation. Although surgery is not usually foreseen, emergency surgeries must be carried out here in the event of life-threatening injuries with the aim of ensuring the survival of injured patients through simple and quick interventions [Figure 1]. Role 3 facilities are staffed and equipped for complete basic medical care. Diagnostic equipment, specialized medical and surgical resources, as well as facilities for appropriate postoperative care are available [Figure 2]. The goal is to establish the patient's stability for safe transportation to a Role 4 hospital, which can take many hours or even days. Role 4 facilities provide a high standard of care, including specialized surgical and medical treatments, reconstruction, and rehabilitation. They are usually located in the country of origin but can also be established in a theater of operations.[7,8]

The resources available for the surgical treatment of combat injuries increase with distance from the scene of the accident. This means that patients must be transported long distances for complex treatments, which costs time. In military operations, therefore, an acceptable location for surgery is closely linked to the earliest possible time for surgery.

Figure 1: A Role 2 operating room

Figure 2: A Role 3 operating room

High-intensity conflicts

The recent large-scale war in Ukraine shows a new high intensity of warfare, using modern artillery, guided missiles, and cluster bombs. Drones are deployed extensively for observation, target acquisition, and kamikaze attacks. The front lines are moving through densely populated areas, rescue forces and healthcare facilities are repeatedly attacked and destroyed, and many wounded, both civilians and soldiers, cannot be transported from the front to safer facilities for treatment due to the damaged infrastructure.

The number of serious injuries, mainly to the extremities with severe bone defects, has risen significantly, which is attributed to the higher blast energy of modern weapon systems.[9] In a survey, 78% of neurosurgeons interviewed said that combat-related head injuries accounted for most neurosurgical interventions, and 22% reported more spinal cord injuries.[10] Interrupted logistics chains cause major problems for surgeons, as they have only limited resources in terms of equipment, supplies, drugs, sterilization capacities, and stable power supply.[10,11] However, even the use of electrical devices, for example, for monitoring vital functions or for diagnostics, can be dangerous outside of bunkers in combat zones, as the electromagnetic fields generated can easily be identified as a target for attacks. To adapt to the conditions, the NATO system of four-tier medical care is handled flexibly in Ukraine. For example, emergency care in Role 2 facilities is mainly provided in civilian hospitals close to the front and less frequently in mobile military facilities. Roles 3 and 4 care is available in a central combined military medical care center.[9]

These new experiences from the war in Ukraine require a critical analysis of existing guidelines and consensus, and possibly a rethinking of current healthcare supply chains in a military or austere environment.

The purpose of this paper is to provide an overview of the state of the scientific literature and guidelines on the question of which surgical treatments of spinal injuries must, can, or should be performed during military operations or under limited resources.

MATERIALS AND METHODS

Publicly available guidelines on the timing of surgical treatment of spine injuries in the deployed setting and the medical literature on time of surgery in military and civilian settings published since early 2000 are summarized for this narrative review. This includes the results of a structured literature search. This search was conducted using PubMed, Embase and other sources (Google Scholar and reference reviews) on the following keywords: "military AND spine surgery," "combat AND spine surgery," "vertebra fracture AND spine surgery AND military," "vertebra fracture AND spine surgery AND soldier," "afghanistan AND spine surgery," "iraq AND spine surgery." Figure 3 shows the selection process.

RESULTS

Guidelines and consensus papers for a deployed setting

A Chinese expert consensus has issued the following recommendations based on the requirements for the treatment of spinal injuries in combat.[12] First aid is provided at the battle scene. Further emergency treatment takes place after evacuation to the next higher care unit. A detailed examination of the injuries is carried out, including a thorough assessment of the injuries to the spine, spinal cord, and nerves. The focus of treatment here is symptomatic treatment to prevent early complications.

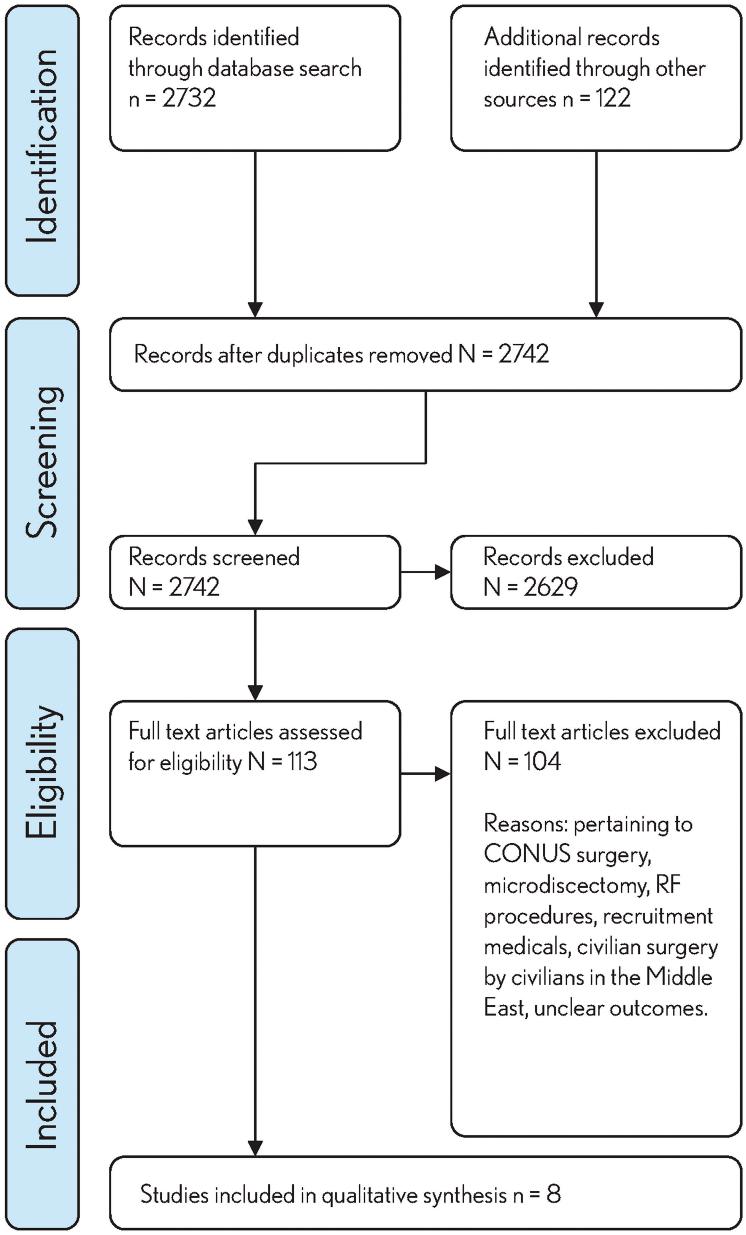

Figure 3: Flow diagram of the selection process for a structured literature search

Spine surgery is not typically performed in battlefield hospitals. However, the consensus paper mentions four indications in which surgery may be considered if specialized staff and equipment are available.

1. Incomplete paralysis with progressive neurological deterioration requiring decompression
2. Penetrating spinal fracture with cerebrospinal fluid leakage or concomitant injury to the thorax or abdomen requiring debridement
3. Incomplete paralysis when evacuation will be delayed by more than 5 days
4. Expected deterioration of neurological deficits during evacuation, which can possibly be avoided by early stabilization surgery.

If the patient is stable and does not require emergency surgery, they will be transported to a specialized military hospital.[12]

The Nato standard AMedP-1.8 lists various sets of skills for surgical modules. Regarding spinal surgery, this includes debridement and spine stabilization as so-called "Damage Control orthopedic Surgery" and "Perform surgery." For neurosurgeons, "Perform spinal surgery" includes laminectomy, spinal instrumentation, spinal fusion, and management of penetrating spinal cord injury as emergency management. However, the applicable skills always depend on the qualifications of the personnel and the applicable standard operating procedures.[13]

A US Army guideline titled "Cervical and Thoracolumbar Spine Injury Evaluation, Transport and Surgery in the Deployed Setting" provides comprehensive information on the best clinical management of patients with spinal or spinal cord injuries.[14] Determining the best time and location for surgery of spinal injuries that have occurred in the combat zone is described as challenging. An initial or progressive spinal cord injury is usually due to fracture displacement, compression by bone fragments or hematomas, spinal cord edema, or infarction. Early surgical interventions with wide decompression have the potential for neurological recovery, especially in incomplete injuries due to nonpenetrating injury mechanisms. However, the challenges of surgery in an austere environment, particularly the increased risk of infection, must be carefully weighed against these potential benefits.

The general recommendation is that surgical procedures that can be postponed without expected adverse effects for the patient should be performed in a Role 4 military hospital. However, it is also noted that in some cases, early surgery may be beneficial for the patient. These include the following indications

1. Incomplete spinal cord injuries
2. Open cerebrospinal fluid leaks
3. Expected longer delay in transportation
4. Cervical cord injuries in which an urgent reduction may improve the degree of neurological impairment.

Consequently, in cases of incomplete spinal cord injury, spinal decompression should be performed as soon as it is safe to do so, and the necessary resources are available. In these cases, it should be considered whether a staged surgery with early noninstrumental decompression and later stabilization with implants is an option. However, if stabilization is performed directly in theater, implants and instruments that are sterile and compatible with those used in the higher level of care must be available. Due to the complexity of injuries, the current combat, weather, and supply conditions, as well as the expertise of the operating team and technical medical equipment, the decision on surgical treatment of spinal injuries in the theater always lies with the surgical team deployed.[14]

Structured literature search

A structured literature review revealed eight peer-reviewed publications on in-country spine surgery in a military context in the Middle East between 2001 and 2020 [Table 1].

In total, 396 spine surgeries were reported, most of which were done in Role 3 medical treatment facilities in Afghanistan. The patients suffered from combat-related and noncombat-related spinal disorders, including ISAF (International Security Assistance Force) troops, other armed forces, and, to a large extent, civilians. Decompression and spinal fusion were the most frequently performed spinal procedures. Since the members of the ISAF troops are transferred to specialized medical care as soon as the situation permits and all others to regional facilities, only a few authors can report on medium to long-term results. Therefore, several papers focus more on the role of deployed neurosurgeons as well as a detailed description of the mechanisms of injury and the initial surgical treatment required than on conclusions about the ideal timing of surgery.[15,17,20,21]

Formby *et al*. described 13 patients who underwent primary spine surgery at a Role 3 or 4 facility and secondary surgery in the United States, representing 6.8% of all surgically treated spine injuries at that hospital. Secondary surgeries were additional anterior or posterior fusion (n = 6), revision of posterior fusion (n = 5), and irrigation and debridement (n = 2). Five years after injury, two patients showed a neurological improvement of at least two motor levels. Although the authors found minimal neurological improvement in all patients with spinal cord injury, possibly indicating minimal benefit from early surgery, the available data do not allow a recommendation for or against early surgery. Formby *et al*. referred to the military guidelines against in-country surgery for most indications and conclude that early stabilization should be considered temporary rather than definitive treatment.[18]

Steele reports on the operative experiences of a single neurosurgeon in a Role 3 hospital in Afghanistan, where spinal injuries were the most frequent reason for neurosurgical intervention. Based on 23 spinal instrumentations with a 30-day follow-up period, he concluded that spinal instrumentation performed in the country can result in morbidity comparable to that in the United States.[19] In their comparison of immediate postoperative outcomes after spine surgery, Schoenfeld *et al*. found significantly higher complication rates in Role 3 versus Role 4 facilities, leading to an increased risk of revision surgery. The proportion of patients with neurological improvement was higher with early surgery, but not significantly different. The authors refer to the guideline stating that early surgery in Role 3 facilities should only be performed in selected cases after a thorough risk-benefit assessment. They suggest that in cases of progressive neurological deterioration, immediate decompression should be performed in-theater, followed by subsequent stabilization surgery later in a Role 4 hospital.[1]

Table 1: Results of a structured literature review on in-country spine surgery in a military context between 2001 and 2020

Author	Role	Study design	FU	*n*	With combat injury	Surgery performed	Neurological improvement	Postoperative complications	Revision
Joubert *et al*.[15]	3	RCS	-	42	23	Osteosynthesis (37), spinal canal recalibration (85), discectomy (103)	NR	NR	5 (11.9%)
Ragel *et al*.[16]	3	RCS	-	52	19	Stabilization (31) others (21)	NR	1 (1.9%: Increased paraparesis in tuberculous spondylitis (civilian))	NR
Eisenburg *et al*.[17]	3	RCS	-	13	12	NR	NR	NR	NR
Formby *et al*.[18]	3,4	RCS	5.5 years	13	13	Laminectomy (3), duroplasty (5), fusion (10)	≥2 motor levels: 2 (15.4%); AIS unchanged	Instability/progressive kyphosis (6), inadequate decompression (4), infection (1), persistent drainage (1), epidural haematoma (1)	13 (6.8% of all surgical combat spine trauma)
Steele[19]	3	RCS	30 days	23	NR	Fusion with laminectomy and autograft	NR	Incl. 1 screw misplacement	2 instrumentations (8.7%)
Schulz *et al*.[20]	3	RCS	-	188	34	19.8% emergency, 17.3% delayed urgency, 62.9% elective surgery	NR	NR	NR
Schoenfeld *et al*.[1]	3 vs. 4	RCCS	-	50 (30 vs. 20)	50 (30 vs. 20)	Decompression (9), decompression and fusion (34), fusion (7)	Role 3: 3 (10%) Role 4: 1 (5%)	Role 3: 12 (40%) Role 4: 4 (20%)	Role 3: 5 (16.7%: retained drain (1), malalignment (2), incomplete decompression (2) Role 4: 0 (0%)
Ravindra *et al*.[21]	3	RCS	-	15	10	Corpectomy and fusion (5), instrumented fusion (10) (off-label use)	1 (6.7%)	0 (0%)	NR

FU=Follow up; AIS=American Spinal Injury Association Impairment Scale; RCS=Retrospective case series; RCCS=Retrospective case-control series; NR=Not reported

Early versus late fixation of spinal injuries

Numerous publications in recent years have dealt with the best timing of surgical treatment of unstable spinal injuries in the civilian population, including register-based evaluations of large cohorts and systematic reviews and meta-analysis. Table 2 provides an overview and summarizes recommendations and conclusions.

DISCUSSION

Spinal operations were not only carried out for the allied troops during the operations in Afghanistan and Iraq but also to a considerable extent for the civilian population for humanitarian reasons, as there was no adequate medical aid in these regions.[15-17,19-21] Schulz *et al*. pointed out that only 20.7% of spinal surgery was performed strictly according to military order. [20] Furthermore, the war in Ukraine demonstrates the need for emergency medical care for troops and civilians in densely populated frontline areas, requiring a more flexible organization of the medical care chain and a closer integration of civilian and military facilities.[28]

However, the current guidelines do not consider this changing operational situation but focus on the treatment of injured troops organized in hierarchical roles of medical care, including highly specialized and well-equipped hospitals in home countries. Although it is recommended herein that any surgery that can be safely postponed until the patient arrives at a Role 4 hospital should be delayed, it is also explicitly stated that some patients may benefit from early surgery. These include patients with incomplete spinal cord injuries, open cerebrospinal fluid leaks or cervical cord injuries, where rapid reduction can improve the degree of impairment, as well as patients who cannot be transported in the foreseeable future. Particularly in an austere environment, it must always be considered on an individual basis whether a patient with a spinal injury is better treated locally in the short term or transferred to a more distant but better-equipped hospital.

Table 2: Timing of surgical treatment of unstable spinal injuries

Author	Study design	Diagnosis	*n*	Recommendation and conclusion
Guttman *et al*.[22]	Retrospective multicenter study (TQIP)	Traumatic spinal fractures without SCI, AIS ≥ 3	19,310	≤24 h early fixation can reduce the rate of major complications by 25%–30%
Ndlovu *et al*.[23]	Systematic review and meta-analysis	Unstable thoracolumbar spine fractures	3874	<72 h early fixation is safe and leads to shorter hospital and ICU stays and fewer respiratory complications; the benefit is more pronounced in thoracic fractures with neurological symptoms
Bliemel *et al*.[24]	Prospective multicenter registry analysis (DGU)	Thoracic or lumbar spine injuries by blunt trauma, AIS ≥3	2303	<72 h patients may benefit from early surgery by shorter hospital stay and fewer complications
Klimo *et al*.[25]	PubMed review	Acute management of penetrating spinal injury	1435	Highly controversial topic, with some evidence suggesting that decompressive laminectomy does not improve neurological function; US military neurosurgeons consider decompression within 24–48 h for patients with incomplete neurological injury and spinal canal compromise, in addition to stabilization for an unstable spine
Qadir *et al*.[26]	Retrospective study	Nonpenetrating traumatic SCI at the thoracolumbar junction	317	<72 h more patients benefit from a neurological recovery of ≥2 degrees if surgery is performed within 24 h; time of surgery does not influence neurological recovery in complete SCI
Chipman *et al*.[27]	Retrospective registry analysis (Trauma Registry at NMMC)	Thoracolumbar spine injuries, ISS ≥1 5	146 (69 <72 h vs. 77 >72 h)	<72 h early surgery is associated with fewer complications, shorter hospital and ICU stays, and less ventilator support; it does not affect the neurological status

TQIP=American College of Surgeons Trauma Quality Improvement Program; SCI=Spinal cord injury; AIS=Abbreviated Injury Scale; ICU=Intensive care unit; DGU=Deutsche Gesellschaft für Unfallchirurgie (German Trauma Society); NMMC=North Memorial Medical Center (US); ISS=Injury severity score

Numerous parameters play a central role in this decision, including the current offensive situation, the type of injury, the availability of basic resources such as energy and fuel, as well as medical and sterile surgical equipment, the experience of the surgical team on site, and the possibilities for postoperative treatment and safe, rapid transportation. The decision for or against early forward surgery must, therefore, be made on a case-by-case basis by the medical team deployed, as stated in the guideline.

In terms of risk–benefit assessment, reports from the military environment show inconsistent results for early surgery, indicating comparable or higher complication and revision rates and slightly better or similar neurological outcomes.[1,18,19] Schoenfeld *et al*. recommend performing only necessary decompressions in the field and subsequent stabilization in a better-equipped facility,[1] while Formby *et al*. recommended that stabilizations done in-theater should be considered only temporarily.[18] However, these statements are based on studies with only limited evidence, very small case numbers, and a high risk of selection bias regarding the decision for or against early surgery. In contrast, studies from the civilian field with significantly higher case numbers show that early surgery, usually no more than 72 h after the injury occurred, leads to fewer complications, shorter hospital and intensive care unit stays, and less ventilator support.[23,24,26,27] Some authors advocate surgery as soon as possible, preferably within 24 h, as this can significantly reduce the number of major complications and increase the degree of neurological recovery.[22,26] However, civilian results are not fully transferable to operations in combat or under limited resources. On the one hand, surgeons must cope with the challenges of an austere environment, such as enemy attacks, power cuts, limited imaging technology (X-ray, computed tomography [CT], MRI), nonspecialized surgical team, less specific instrumentation, and limited sterilization and storage capacities. On the other hand, combat or terror-related spinal injuries tend to be more severe and involve multiple, often unrelated spinal levels compared to civilian spine trauma.[29] Nevertheless, the target should be to achieve the potential benefits of early surgical treatment even under limited resources.

Based on the lessons learned from the asymmetric conflicts in Iran and Afghanistan and the high-intensity conflict in Ukraine, where modern weapons systems, including drone strikes, are regularly deployed, it is time to rethink the health chain. Instead of fixed role assignments, it depends on the capacities that are currently available in the extreme forward surgical team. These need to be targeted, strengthened, and supported. For spinal surgery in particular, the aim must be to create the best possible conditions for a successful outcome for those injured soldiers and civilians who need surgery as soon as possible, for those who could benefit from the earliest possible surgery, and for those who cannot be evacuated for any reason.

Early surgery requires a safe environment to perform the procedure, adequate diagnostics including X-ray and CT, sufficient power supply, expertise of the surgical team, sterile instrumentation, and the ability to control possible complications and provide basic postoperative care. The surgery can be carried out in a military care facility located near the front, but also in a mobile, armored operating room or a civilian hospital. Sufficient protection against enemy attacks is important, for example, through shielded bunkers. One reason for this is the electromagnetic field caused by all electronic devices in use, which can be detected and targeted by drones within 10 min. Technologies such as teleradiology,[30] learning health systems,[31] artificial intelligence (AI),[32-34] and remote consultations have the potential to support the front team in diagnosis and decision making. Remote mentoring with the help of robots or augmented reality (AR), as in the RAPACE (Augmented Reality for Expert Surgical Assistance) project for armed forces forward surgery, could also provide surgeons who are not experts with the necessary skills during surgery.[35]

The sterilization and storage of complex sets for spinal instrumentation pose a problem in combat operations and mass casualty situations. Sterile reprocessing requires a lot of energy and time. With a high volume of injured patients, the re-sterilization of instruments represents a significant bottleneck and can limit the number of surgeries. Sterile, consistently streamlined and lightweight disposable instruments such as the Neo Pedicle Screw System™ (Neo Medical S.A., Villette, Switzerland), which cover the entire spectrum of spinal surgery, including minimally invasive procedures and are therefore also suitable for any subsequent surgery, represent a solution. Surgical instruments should be small and light enough to be delivered by drones to always guarantee the supply chain. In general, the closer to the front line, the more robust, portable, energy-efficient and easy-to-use medical devices should be, while minimizing their electromagnetic footprint.

The limitations of this review lie in its narrative design and the limited scientific evidence of published studies on the best timing of spinal surgery during military operations. The latter is due to the specific setting of combat operations, where prospective randomized controlled studies cannot be conducted. Furthermore, the number of cases in the conflicts in Iraq and Afghanistan was fortunately relatively low for the allied troops. However, a simple, standardized reporting system for spinal combat injuries, which also contains information on at least the medium-term results, is desirable for the future.

CONCLUSION

Patients with incomplete spinal cord injuries, open cerebrospinal fluid leaks or cervical cord injuries, where rapid reduction can improve the degree of impairment, as well as patients who cannot be transported in the foreseeable future are candidates for early surgery during military operations. The potential benefits of early surgery, such as better neurological recovery and faster rehabilitation, must be weighed on a case-by-case basis by the medical team involved against the higher risk of complications and revision surgery in an austere environment. Decompression with or without stabilization is the most frequently performed spine procedure in this setting. The conflicts of recent decades have shown that the extreme forward surgical teams need to be strengthened. Remote technologies such as teleradiology, AI, and AR can provide necessary expertise to nonspecialized surgeons. Sterile and lightweight spinal instruments that can be delivered by drones are needed. Portable, energy-efficient medical devices with minimal electromagnetic footprints may mitigate the risk profiles of existing doctrine.

Acknowledgments

We would like to thank the attendees of the 2nd International Military Spine Expert Symposium, SENSE Military Spine Group, military spine surgeons from around the world, whose expertise and experience form the scientific foundation of this paper.

Dr. Jean-Marc Delmas – France, Dr. Arnaud Dagain – France, Dr. Bogdan Ene – France, Dr. Rafael Garcia-Canas – Spain, Dr. Francisco Javier Martin-Ramos – Spain, Dr. Julio Quintero-Quesada – Spain, Prof. Uwe Max-Mauer – Germany, Dr. Ilia Levikov -Germany, Prof. Dueng-Yuan Hueng – Taiwan, Prof. Yi-Lin Yu – Taiwan, Dr. Juan Cristobal Illanes – Chile, Dr. Gonzalo Suarez – Chile, Dr. Vincenzo Piccinni, Italy, Prof. Vladimir Prandjev – Bulgaria, Dr. Jorge Mario – Portugal.

We thank Dipl. Ing. Nele Borm, Kiel, Germany, for the support with the literature search and writing assistance.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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