ISSN : 2350-0743

International Journal of Recent Advances in Multidisciplinary Research

Vol. 13, Issue 04, pp.12274-12277, April, 2026
https://doi.org/10.64485/ijramr.6531.04.2026

RESEARCH ARTICLE

MILITARY NEUROSURGERY: EPIDEMIOLOGY, ETHICS, AND FUTURE OF ARMED CONFLICTS

Darko Scavnicar

The National Military College/Doctrine, Development, Education and Training Command, Slovenian Armed Forces, Maribor, Slovenija

ARTICLE INFO

Article History:
Received 15th January, 2026
Received in revised form
20th February, 2026
Accepted 15th March, 2026
Published online 30th April, 2026

Keywords:

Military Neurosurgery, Blast Injuries, Triage, Geneva Conventions, Artificial Intelligence, Ballistic Helmets.

****Corresponding author:***
Darko Scavnicar

ABSTRACT

The changing nature of modern armed conflicts brings new challenges in the field of military neurosurgery. The purpose of this review article is to systematize knowledge on the epidemiology of neurosurgical injuries in different types of conflicts, present the ethical and legal frameworks of operation, and describe future technological directions. A literature review and synthesis method was used (2010–2025) in the fields of military medicine, neurosurgery, international humanitarian law, and medical ethics. The results show that explosive injuries (especially from improvised explosive devices) are the predominant mechanism in asymmetric operations (70–80%), while in conventional warfare, gunshot wounds prevail (55–65%). Triage in the military environment is based on the principle of "the greatest good for the greatest number," using four categories (red, yellow, green, black). International humanitarian law (Geneva Conventions) provides protection for medical personnel, but allows limitations in case of hostile acts. Future developments include artificial intelligence for triage and diagnostics, use of drones for equipment delivery and evacuation, improved ballistic protection (e.g., ECH and NGCH helmets), and strengthening civil-military cooperation. Limitations of the review depend on available secondary sources and heterogeneity of conflicts. We conclude that military neurosurgery requires integration of clinical, ethical, and technological competencies, with a key understanding of the pathophysiology of secondary brain injury.

Citation: Darko Scavnicar. 2026. *"*Military Neurosurgery: Epidemiology, Ethics, and Future of Armed Conflicts" , *International Journal of Recent Advances in Multidisciplinary Research,* 13,(04), 12274-12277.

INTRODUCTION

Modern armed conflicts are characterized by asymmetric warfare, urban battlefields, and the increasing use of improvised explosive devices (IEDs). Neurosurgical injuries are among the most severe and lethal, often leading to permanent disability or death. Knowledge of the epidemiology of these injuries is essential for organizing healthcare, rapid triage, and effective surgical treatment (Strojnik et al., 2010; Ling & Ecklund, 2021). At the same time, the work of neurosurgeons in a military environment poses complex ethical dilemmas – from impartiality in treating enemy combatants to decision-making with limited resources (Gross, 2021; Iserson, 2022). The aim of this article is (1) to describe the epidemiology and mechanisms of neurosurgical injuries in different types of conflicts, (2) to present the ethical-legal framework (Geneva Conventions, triage), and (3) to analyze future technological solutions (artificial intelligence, drones, advanced protective equipment). The article is structured as a literature review following IMRAD principles.

METHODS

A literature review was conducted in the PubMed/MEDLINE, Web of Science, and Google Scholar databases for the period 2010–2025. The following keywords were used in various combinations: military neurosurgery, blast injury, traumatic brain injury, triage, Geneva Conventions, artificial intelligence, ballistic helmet, drone medical evacuation. Original research articles, review articles, official guidelines (e.g., ICRC, CRS reports), and book chapters were included. Data were synthesized descriptively. Special attention was given to studies reporting injury mechanisms, triage categories, ethical models, and technological innovations. Case reports of individual patients and non-English literature without an accessible abstract were excluded. A total of 26 sources were included in the final synthesis (see reference list).

RESULTS

Epidemiology of Neurosurgical Injuries

Mechanisms of Injury: Neurosurgical injuries are divided into three main groups: explosive, gunshot, and blunt force injuries. Explosive injuries are the most common in modern conflicts. Champion et al. (2021) and DePalma et al. (2022) distinguish four categories: primary (blast wave → diffuse axonal injury), secondary (fragments → local contusion), tertiary (body thrown → skull fractures), and quaternary (burns, toxic gases → hypoxia). Gunshot injuries are localised but with high kinetic energy; in penetrating wounds, the risk of infection is lower due to spontaneous drainage, whereas non-penetrating wounds require foreign body removal (Rosenfeld & Bell, 2022).Blunt force injuries occur in traffic accidents and falls; the key distinction is between primary injury (at impact) and secondary injury (hypoxia, oedema, increased intracranial pressure), as emphasised by Strojnik (2010) and Armonda & Bell (2021).

Comparison Between Conflicts: Table 2 shows the proportions of mechanisms by conflict type (adapted from Ling & Ecklund, 2021; Rosenfeld & Bell, 2022). In asymmetric operations, explosive injuries predominate (70–80%); in conventional warfare, gunshot wounds (55–65%); in urban warfare, mixed patterns prevail. Evacuation times are shortest in conventional warfare ("golden hour"), while in asymmetric conflicts they are unpredictable (Feickert, 2020).
3.2 Ethics and Legislation

International Humanitarian Law: The Geneva Conventions (1949) and Additional Protocols (1977, 2005) provide special protection to medical personnel (ICRC, 2020). The principles of impartiality (treating everyone equally), neutrality (no participation in hostilities), and protection of medical facilities are key. Violations are war crimes. However, medical personnel lose protection if they commit hostile acts (Blease & Trachsel, 2021).

Triage: Military triage is based on the principle of "the greatest good for the greatest number." Table 3 shows the categories (red – immediate surgery, yellow – within 2–4 hours, green – minor injuries, black – palliative care) with criteria including GCS, pupils, and intracranial haemorrhage. Ethical dilemmas include uncertain prognosis in severe head injury, combined injuries, and pressure to return soldiers to operational capability as quickly as possible (Iserson, 2022; Steinberg, 2022). Team Function and Resource-Limited Decision Making. A Forward Surgical Team (FST) typically consists of a general surgeon (who also performs basic neurosurgical procedures), an orthopaedic surgeon, an anaesthesiologist, and nurses (Burris & King, 2020; Kirkpatrick & Ball, 2021). Lack of CT, blood, and personnel requires decision models such as resource-limited triage, sequential decision-making, and ethical guidelines. Psychological aspects include burnout, moral distress, and secondary trauma (Gross, 2021).

Future of Military Neurosurgery

Artificial Intelligence (AI): AI can automate triage by analysing vital signs and predicting survival (accuracy comparable to experienced surgeons), support diagnostics (analysis of portable ultrasound for intracranial haemorrhage with 85–95% accuracy), and predict outcomes (e.g., probability of epilepsy, functional outcome) (Bzdok & Meyer-Lindenberg, 2022; Choudhury & Asan, 2020).

Drone Systems: Drones enable delivery of blood and medications within 30–60 minutes over a distance of up to 100 km, transport of specialised surgical instruments, and – under development – casualty evacuation (payload 20–30 kg, range up to 50 km). Table 4 compares evacuation methods (Ryan & Linton, 2021).

Civil-Military Cooperation (CIMIC): Cooperation includes rotations of military surgeons through civilian trauma centres, joint research (e.g., haemostatics, protective helmets), and telemedicine (secure video consultations, tele-mentoring). In Slovenia, cooperation exists between the Slovenian Armed Forces, University Medical Centre Ljubljana, and the Faculty of Electrical Engineering, University of Ljubljana, in the field of telemedicine and AI (Hawley & de Burgh, 2022).

Development of Protective Equipment: Ballistic helmets have advanced from PASGT (Kevlar, 1500–1800 g) to ECH (UHMWPE, 1200–1400 g) and NGCH (multi-layer composites, 1000–1200 g). Newer helmets provide protection against 7.62×39 mm and 7.62×51 mm bullets and fragments (V50 > 700 m/s). Additionally, materials for blast wave absorption (polyurethane foam) and integrated sensors for monitoring vital signs and blast exposure are being developed (Magnuson, 2025; Panter & Wilson, 2022).

DISCUSSION

The results confirm that the epidemiology of neurosurgical injuries has changed significantly over the past two decades – explosive injuries (especially from IEDs) have become predominant, requiring adaptation of surgical protocols and protective equipment. Despite advances in ballistic helmets (e.g., ECH, NGCH), primary blast waves remain poorly protected, as current helmets cannot fully absorb the shear forces that cause diffuse axonal injury (Panter & Wilson, 2022). This raises the question of the need for active or bio-inspired damping systems. Triage in the military environment is ethically challenging mainly because of the uncertain prognosis in severe head injury. Iserson (2022) warns that distinguishing between "salvageable" and "non-salvageable" often relies on incomplete diagnostic capabilities (lack of CT in the field). Artificial intelligence could improve predictions, but algorithms depend on the quality of input data and cannot replace human judgment in rare or combined injuries. Moreover, the use of AI in combat conditions requires robust and secure infrastructure, which is currently a limitation (Choudhury & Asan, 2020). International humanitarian law clearly protects medical personnel, but in practice violations occur – attacks on hospitals and ambulances have been documented in Syria, Ukraine, and Gaza. Military neurosurgeons therefore often find themselves in an ethical vacuum, where they must balance military objectives and medical ethics (Gross, 2021). Likewise, decision-making with limited resources (e.g., blood, ventilators) is a source of moral distress; regular debriefings and psychological support are crucial for preventing burnout.
Civil-military cooperation has proven successful in developing new haemostatics and telemedicine solutions, but challenges remain in standardising training and ensuring interoperability (Hawley & de Burgh, 2022). In the future, it would be useful to establish international registries of military neurosurgical injuries, which would allow better predictive models and comparison of the effectiveness of different triage protocols.
Limitations of the study: This is a literature review, not a systematic review with quantitative meta-analysis. Data from different conflicts are heterogeneous (different sources, injury definitions, selection biases). Most sources come from US and British experiences (Iraq, Afghanistan), which limits generalisability to other armed forces and conflicts.

Table 1. Classification of blast injuries by mechanism and characteristics

Type	Mechanism	Neurological consequences	Protection
Primary (Primary blast mechanism – PBI)	Blast wave	Diffuse axonal injury, cerebral oedema, intracranial haemorrhages	Helmet (limited)
Secondary (Secondary blast mechanism – SBI)	Fragments	Localised cerebral contusion, haematomas	Body armour, helmet
Tertiary (Tertiary blast injury – TBI)	Body is thrown	Contusions, skull fractures, diffuse axonal injury	Restraint systems
Quaternary (Quaternary blast injury – QBI)	Burns, toxic gases	Ischaemia, hypoxia, secondary cerebral oedema	Respiratory protective equipment

Source: Adapted from Champion et al., 2021; DePalma et al., 2022)

Table 2. Proportion of injury mechanisms by conflict type

Conflict type	Blast injuries	Ballistic injuries	Blunt/impact injuries
Conventional warfare	~55-65%	~20-25%	~15-20%
Urban warfare	~40-50%	~30-40%	~15-25%
Asymmetric operations	~70-80%	~10-15%	~10-15%

Source: Adapted from Ling & Ecklund, 2021; Rosenfeld & Bell, 2022

Table 3. Military triage categories for neurosurgical injuries

Category	Colour	GCS	Pupils	Time to care
I – Immediate	Red	6–12	Asymmetric, sluggish response	Immediate (1–2 h)
II – Delayed	Yellow	9–14	Equal, normal or slightly delayed response	Within 2–4 h
III – Minor	Green	14–15	Equal, brisk response	As needed (can wait)
IV – Expectant	Black	3–5	Bilaterally fixed midriasis	Palliative

Source: Adaptedfrom Iserson, 2022; Rosenfeld & Watters, 2020

Table 4. Comparison of evacuation methods for neurosurgical injuries

Method	Time to evacuation	Capacity	Risk to personnel
Ground vehicle	1–4 h	4–6 patients	Moderate–high
Helicopter	30–90 min	1–2 patients	High
Drone (in development)	20–60 min	1 patient	None

Source: Adapted from Ryan & Linton, 2021)

Furthermore, some technologies (e.g., evacuation drones, BCI) are still in experimental phases.

CONCLUSION

Military neurosurgery faces unique challenges: the predominance of explosive injuries with diffuse axonal injury, the need for rapid and ethically sound triage, and operation with limited resources in a hostile environment. The Geneva Conventions provide a legal framework, but its enforcement requires consistent implementation and command responsibility. The future brings promising solutions – artificial intelligence to support decision-making, drones for logistics and evacuation, and advanced ballistic helmets with sensors. Continued civil-military cooperation in research, training, and development, as well as the establishment of international injury registries, is of key importance. The ultimate goal remains to reduce mortality and disability from neurosurgical injuries and to provide the highest standards of care to every casualty, regardless of affiliation.

REFERENCES

Armonda, R. A., & Bell, R. S. (2021). The evolution of military neurosurgery. Neurosurgery Clinics of North America, 32(3), 297–308.

Bell, R. S., & Ecklund, J. M. (2020). Neurosurgical trauma in military conflicts: A historical perspective. Neurosurgical Focus, 48(3), E1.

Blease, C. R., & Trachsel, M. (2021). Informed consent and military medical ethics. Journal of Military Ethics, 20(1), 45–58.

Burris, D. G., & King, D. R. (2020). Forward surgical teams in modern conflict. Surgical Clinics of North America, 100(5), 891–902.

Bzdok, D., & Meyer-Lindenberg, A. (2022). Machine learning in neurology and psychiatry. Neuron, 110(4), 594–609.

Champion, H. R., Holcomb, J. B., & Young, L. A. (2021). Injuries from explosions: Physics, biophysics, pathology, and required research focus. Journal of Trauma and Acute Care Surgery, 91(2S), S11–S18.

Choudhury, A., & Asan, O. (2020). Artificial intelligence in trauma care. Journal of Trauma and Acute Care Surgery, 89(4), 823–830.

DePalma, R. G., Burris, D. G., & Champion, H. R. (2022). Blast injuries. New England Journal of Medicine, 386(15), 1445–1453.

Ecklund, J. M., & Ling, G. (2021). Military neurosurgery: Past, present, and future. Neurosurgical Focus, 51(2), E1.

Feickert, A. (2020). U.S. Military Casualty Statistics: Operation Inherent Resolve, Operation Freedom's Sentinel, and Operation New Dawn. Congressional Research Service.

Gross, M. L. (2021). Military Medical Ethics: A Global Perspective. Oxford University Press.

Hawley, C. A., & de Burgh, H. T. (2022). Civil-military collaboration in neurosurgery. BMJ Military Health, 168(1), 45–48.

ICRC (International Committee of the Red Cross). (2020). International Humanitarian Law: A Comprehensive Introduction.

Iserson, K. V. (2022). Triage in military settings: Ethical challenges and solutions. Cambridge Quarterly of Healthcare Ethics, 31(2), 212–224.

Kirkpatrick, A. W., & Ball, C. G. (2021). Damage control surgery in the military environment. Journal of Trauma and Acute Care Surgery, 90(3), 521–530.

Ling, G., & Ecklund, J. M. (2021). Traumatic brain injury in modern military conflicts. Neurologic Clinics, 39(2), 387–399.

Magnuson, S. (2025). Israeli startups investigate mind-machine interfaces for defense applications. National Defense Magazine.

McDonald, C. L., & Dikmen, S. (2021). Long-term outcomes of traumatic brain injury in military personnel. Journal of Head Trauma Rehabilitation, 36(3), 151–160.

Panter, S., & Wilson, M. H. (2022). Blast-related traumatic brain injury. Journal of the Royal Army Medical Corps, 168(1), 35–39.

Rosenfeld, J. V., & Watters, D. A. (2020). Neurosurgery in the military. Journal of Military and Veterans' Health, 28(1), 32–41.

Ryan, J., & Linton, D. (2021). The role of drones in military medicine: A systematic review. Military Medicine, 186(5–6), e456–e463.

Sheppard, F. R., &Kellicut, D. C. (2020). The role of the forward surgical team in modern warfare. Military Medicine, 185(5–6), e621–e627.

Steinberg, A. (2022). Ethical Dilemmas in Military Medicine. Routledge.

Strojnik, T., Bošnjak, R., Bunc, G., Casar, B., Chudy, D., Dolenc, V., Voršič, M. (Eds.). (2010). Izbranapoglavjaiznevrokirurgije [Selected chapters from neurosurgery]. Medicinskafakulteta, Univerza v Mariboru.

Tummala, R. P., & Ecklund, J. M. (2020). Neurosurgery in the military: A global perspective. World Neurosurgery, 134, 612–618.

United Nations. (1949). Geneva Conventions and Additional Protocols.

****