Brain and Spine 4 (2024) 104146

Contents lists available at ScienceDirect

Brain and Spine

journal homepage: www.journals.elsevier.com/brain-and-spine

The acute phase management of traumatic spinal cord injury (tSCI) with polytrauma: A narrative review

Edoardo Picetti [a], Nicolò Marchesini [b], Walter L. Biffl [c], Susan E. Biffl [d], Fausto Catena [e], Raul Coimbra [f], Michael G. Fehlings [g,h], Wilco C. Peul [i], Chiara Robba [j,k], Michele Salvagno [l], Fabio S. Taccone [l], Andreas K. Demetriades [i,m,*]

[a] Department of Anesthesia and Intensive Care, Parma University Hospital, Parma, Italy
[b] Department of Neuroscience, Biomedicine and Movement, Section of Neurosurgery, University of Verona, Verona, Italy
[c] Trauma and Acute Care Surgery, Scripps Memorial Hospital La Jolla, La Jolla, CA, USA
[d] Department of Orthopedics, Physical Medicine and Rehabilitation, Rady Children's Hospital, University of California San Diego, San Diego, CA, USA
[e] General and Emergency Surgery Department, Bufalini Hospital, Cesena, Italy
[f] Riverside University Health System Medical Center, Comparative Effectiveness and Clinical Outcomes Research Center - CECORC, Moreno Valley, CA, USA
[g] Division of Neurosurgery, Krembil Neuroscience Centre, Toronto Western Hospital, University Health Network, Toronto, Ontario, Canada
[h] Division of Neurosurgery and Spine Program, Department of Surgery, University of Toronto, Ontario, Canada
[i] Department of Neurosurgery, University Neurosurgical Center Holland, UMC | HMC | HAGA, Leiden, The Hague, the Netherlands
[j] IRCCS Ospedale Policlinico San Martino, Genoa, Italy
[k] Department of Surgical Science and Integrated Diagnostic, University of Genova, Genoa, Italy
[l] Department of Intensive Care, Hôpital Universitaire de Bruxelles (HUB), Brussels, Belgium
[m] Department of Neurosurgery, Royal Infirmary, Edinburgh, UK

ARTICLE INFO

Handling Editor: Prof F Kandziora

Keywords:
Traumatic spinal cord injury
Polytrauma
Multidisciplinary approach
Emergency surgery
Spinal trauma
Damage control surgery

ABSTRACT

Introduction: Traumatic spinal cord injury (tSCI) is frequently observed in polytrauma patients.
Research question: What is the optimal strategy to manage tSCI in the setting of polytrauma?
Material and methods: This narrative review focuses on: 1) extraspinal damage control surgery and resuscitation, 2) the perioperative protection of the injured spine during emergency surgery, 3) imaging and timing of spinal surgery in polytrauma, 4) early interventions for skin, bowel and bladder, and 5) the multidisciplinary approach to tSCI polytrauma patients.
Results: Damage control resuscitation (DCR) and damage control surgery (DCS), aim to prevent/correct post-traumatic physiological derangements to minimize bleeding until definitive hemostasis is achieved. Spinal protection during emergency surgery is of paramount importance to reduce secondary insults to the injured spine. Imaging, especially magnetic resonance imaging (MRI), is useful for decision-making regarding surgical management of the injured spine. Early decompressive surgery (within 24 h from trauma) is associated with better neurological outcomes. Early consultation with a physical medicine and rehabilitation physician is beneficial to optimize recovery. A close collaboration between different medical specialties involved in the early management of tSCI patients with polytrauma is advisable to improve outcome.
Discussion and conclusion: This narrative review aims to collate basic knowledge regarding acute phase management of tSCI patients in the context of polytrauma. More evidence and data form well-powered studies are necessary in this setting.

1. Introduction

Traumatic spinal cord injury (tSCI) is an increasing global health problem associated with lifelong disability and costly long-term medical care affecting both young and elderly patients (GBD Spinal Cord Injuries Collaborators, 2023; Ahuja et al., 2017). The most frequent causes are falls and road traffic accidents (GBD Spinal Cord Injuries Collaborators, 2023; Ahuja et al., 2017). Multisystem trauma is also frequently

* Corresponding author. Department of Neurosurgery, University Neurosurgical Center Holland, UMC | HMC | HAGA, Leiden, The Hague, the Netherlands.
E-mail address: andreas.demetriades@gmail.com (A.K. Demetriades).

https://doi.org/10.1016/j.bas.2024.104146
Received 8 September 2024; Received in revised form 3 November 2024; Accepted 19 November 2024
Available online 28 November 2024

associated with SCI, especially in the case of motor vehicle collisions (Yue et al., 2017). Among polytrauma patients, exsanguination is the leading cause of preventable death and the most common cause of early mortality (Callcut et al., 2019). Traumatic brain injury (TBI) and tSCI present some similarities; in particular, secondary injuries, the severity of which is closely linked to the patient's outcome, can be further exacerbated by dangerous secondary insults, such as hypoxia and hypotension, frequently observed in unstable polytrauma patients (Yue et al., 2017; Hachem et al., 2017; Mavrovounis et al., 2023)

Extraspinal injuries are associated with an increase in intrahospital mortality in polytrauma patients with cervical SCI (Alvarez Reyes et al., 2022; Marchesini et al., 2023; Pandrich and Demetriades, 2020). Rates of concomitant tSCI and TBI range from 10% to 30% (Pandrich and Demetriades, 2020). The coexistence of these two conditions makes tSCI diagnosis and treatment challenging (Tachino et al., 2024). Recent data suggest as concomitant head injury delays surgical management for patients with tSCI, especially in case of severe TBI (Azad et al., 2024). Unfortunately, limited data is available regarding this challenging topic. Therefore, this narrative review focuses on the main principles of tSCI management in the context of polytrauma in high-income countries and without severe TBI, as the management of severe TBI in the setting of polytrauma has been addressed in previous literature (Picetti et al., 2019, 2021). Similarly, several articles are already available on issues related to the management of tSCI in low- and middle-income countries (Marchesini et al., 2022a, 2022b; Demetriades et al., 2022).

2. Methods

2.1. Search strategy

This narrative review is based on a literature search in MEDLINE, PubMed, and Google Scholar where available evidence was sought from clinical trials, meta-analyses, randomised controlled trials and systematic reviews. The search was restricted to literature published in English up to and including May 2024.

Relevant studies were identified by screening of the titles and abstracts. Duplicates were eliminated. Full text screening articles was then performed to determine inclusion in the review. At any stage, discrepancies between two consistent reviewers were resolved based on the consensus of a third reviewer.

The key studies discussed in this narrative review are those that, in the opinion of the authors, will impact on current clinical practice and future guidelines; the main articles utilized for this review are reported in Table S1 as supplementary material.

2.2. Data extraction

We aimed at summarizing recent advances in the contemporary management of tSCI in polytrauma. The included studies have been organised into clinically relevant themes focusing on.

i) Extraspinal damage control surgery and resuscitation for bleeding control,
ii) The perioperative protection of the injured spine during emergency surgery (both spinal and extraspinal),
iii) Imaging investigations and the timing of spinal surgery in the setting of polytrauma,
iv) Early interventions for skin, bowel and bladder, and
v) The multidisciplinary approach to tSCI polytrauma patients.

3. Extraspinal damage control surgery and resuscitation for bleeding control

Hemorrhage is the leading cause of preventable death among trauma patients (Callcut et al., 2019; LaGrone et al., 2023). Damage control resuscitation (DCR) consists in a series of strategies, which in combination with damage control surgery (DCS), aims to prevent/correct post-traumatic physiological derangements to minimize ongoing bleeding until definitive hemostasis is achieved (LaGrone et al., 2023; Lammers and Holcomb, 2023). DCR mainly focuses on: 1) early use of whole blood or balanced blood product transfusions (i.e., red blood cell, plasma, platelets) and minimizing the utilization of crystalloid solutions, 2) hypotensive resuscitation, and 3) correction of metabolic derangements (LaGrone et al., 2023; Lammers and Holcomb, 2023). The main goal of DCR is to avoid the lethal triad of hypothermia, acidosis and coagulopathy (LaGrone et al., 2023; Lammers and Holcomb, 2023).

DCS usually includes different stages: 1) an abbreviated surgery (such as laparotomy, thoracotomy, or a procedure in the pelvis or extremity) focusing on rapid contamination/bleeding control, 2) resuscitation and restoration of altered physiology in the intensive care unit (ICU), and 3) eventual return to the operating room, after improvement or restoration of physiological parameters, for definitive resection or repair/reconstruction of injured organs and wound closure (Chung and Scalea, 2023; Risinger and Smith, 2023).

In recent years, several endovascular approaches and techniques [e.g., angioembolization, resuscitative endovascular balloon occlusion of the aorta (REBOA), etc.] have gained popularity in the management of unstable bleeding trauma patients (Hörer et al., 2021). Some of these procedures may stop bleeding alone, avoiding surgical explorations or in combination with DCS ("hybrid approach") (Hörer et al., 2021). Key aspects of DCR are reported in Fig. 1 (LaGrone et al., 2023; Lammers and Holcomb, 2023; Rossaint et al., 2023).

4. The perioperative protection of the injured spine during emergency surgery

tSCI polytrauma patients may need emergency surgery (spinal or extraspinal) during the acute phase. Scarce data regarding optimal patient management is available in this setting. In this regard, a multidisciplinary consensus conference, endorsed by the World Society of Emergency Surgery (WSES) and the European Association of Neurosurgical Societies (EANS), was recently published (Picetti et al., 2024). The consensus recommendations related to spinal protection during emergency surgery in the acute phase (within 24 h after trauma) are summarized in Fig. 2.

Firstly, the protection and maintenance of spine alignment, to minimize secondary insults to the injured spine, are mandatory in tSCI polytrauma patients needing extraspinal interventions for life-threatening conditions (Picetti et al., 2024).

Arterial hypotension and hypoxia are dangerous secondary insults for the injured spinal cord (Ryken et al., 2013a; Saadoun and Papadopoulos, 2021). These events are frequently observed both after cervical isolated tSCI and in polytrauma (Yue et al., 2017; Ryken et al., 2013a). The Congress of Neurological Surgeons (CNS) guidelines for managing tSCI patients recommend maintaining a mean arterial pressure (MAP) between 85 and 90 mmHg for the first week following acute cervical SCI (Level III Evidence) (Ryken et al., 2013a). Recent AO Spine/Praxis clinical practice guidelines for the management of acute SCI suggest: 1) the augmentation of MAP to at least 75–80 mmHg but not higher than 90–95 mmHg in order to optimize spinal cord perfusion in acute traumatic SCI (Quality of Evidence: very low; Strength of Recommendation: weak), and 2) the augmentation of MAP for a duration of 3–7 days in order to optimize spinal cord perfusion in acute SCI (Quality of Evidence: very low; Strength of Recommendation: weak) (Kwon et al., 2024). Considering the use of permissive hypotension during DCR, it's challenging to achieve this target in acutely bleeding polytrauma patients (LaGrone et al., 2023; Lammers and Holcomb, 2023). In this scenario, the potential benefit of hypotensive resuscitation (i.e., better bleeding control) should be balanced with the risks associated with spinal cord hypoperfusion and unfavorable long-term neurological outcomes. Some publications emphasize the avoidance of hypotension,

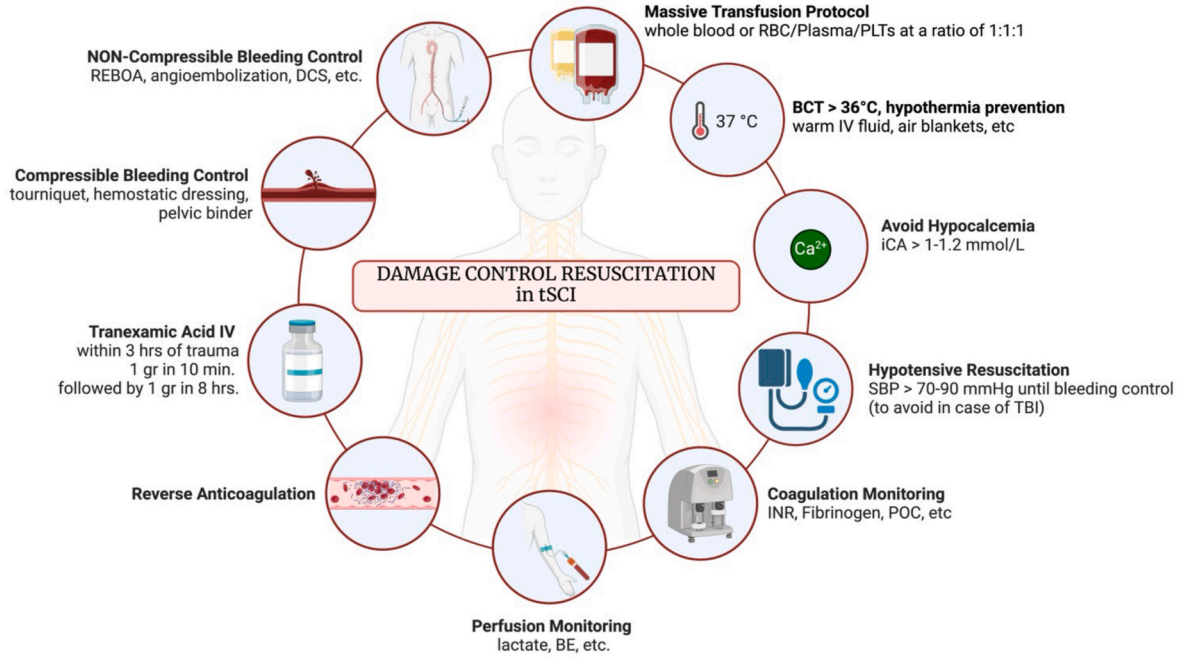

Fig. 1. Key Aspects of Damage Control Resuscitation in Traumatic Spinal Cord Injury. This figure illustrates the key components of Damage Control Resuscitation as applied to traumatic spinal cord injury. CT - Body Core Temperature; BE - Base Excess; DCS - Damage Control Surgery; INR - International Normalized Ratio; iCA - Ionized Calcium; IV – Intravenous; POC - Point of Care; PLTs – Platelets; RBC - Red Blood Cell; REBOA - Resuscitative Endovascular Balloon Occlusion of the Aorta; tSCI - Traumatic Spinal Cord Injury; TXA - Tranexamic Acid.

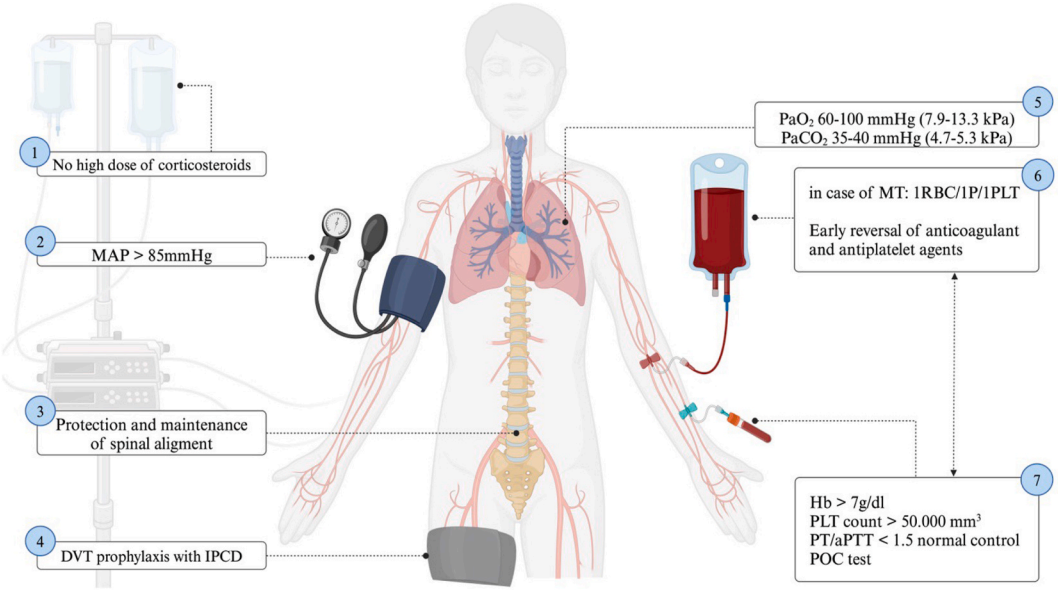

Fig. 2. Consensus Recommendations for Spinal Protection During Emergency Surgery in the Acute Phase. This figure summarizes the consensus recommendations, issued jointly by the World Society of Emergency Surgery (WSES) and the European Association of Neurosurgical Societies (EANS), for maintaining spinal integrity during emergency surgical procedures within the first 24 h following trauma. Hb - Hemoglobin; IPCD - Intermittent Pneumatic Compression Device; MAP - Mean Arterial Pressure; MT - Massive Transfusion; $PaCO_2$ - Partial Pressure of Carbon Dioxide; PaO_2 - Partial Pressure of Oxygen; PLT - Platelet; POC - Point of Care; PT/aPTT - Prothrombin Time/Activated Partial Thromboplastin Time; RBC - Red Blood Cell; P - Plasma.

and an assessment of the risks of prolonged MAP augmentation, including the use of vasopressors, the need for invasive monitoring, prolonged immobilization, and the use of critical care resources. Whether to do it, and for how long, should probably be individualized (American College of Surgeons (ACS) - Trauma Quality Program (TQP), 2022; Menacho and Floyd, 2021). The WSES/EANS consensus recommends maintaining MAP >85 mmHg during interventions for life-threatening hemorrhage or emergency spinal surgery, tolerating lower values transiently to achieve hemostasis in case of difficult intraoperative bleeding control (Picetti et al., 2024). Monitoring intraspinal pressure (ISP), by surgically implanting an intradural extramedullary probe at the injury site, may be a way to individualize the arterial blood pressure target, considering the spinal cord perfusion pressure (SCPP = MAP-ISP), but it is invasive and not commonly available (Saadoun and Papadopoulos, 2021). Recent data suggest that an increase in SCPP is associated with improved neurological outcomes

(Squair et al., 2017; Visagan et al., 2022, 2023; Hogg et al., 2021a, 2021b). However, more evidence is necessary to integrate this type of monitoring into daily clinical practice.

Data on optimal hemoglobin (Hb) values and respiratory targets are lacking in tSCI patients. In this regard, during interventions for life-threatening hemorrhage or emergent spinal surgery, the WSES/EANS consensus recommends: 1) red blood cells (RBCs) transfusion in case of Hb < 7 g/dl (a higher Hb threshold is allowed in patients with limited cardiovascular reserve for pre-existing heart disease, etc.), 2) an arterial partial pressure of oxygen (PaO_2) of 60–100 mmHg (7.9–13.3 kPa), and 3) an arterial partial pressure of carbon dioxide ($PaCO_2$) of 35–40 mmHg (4.7–5.3 kPa) (Picetti et al., 2024). These suggestions are influenced by recommendations for patients with polytrauma and TBI (Picetti et al., 2019; Rossaint et al., 2023; Robba et al., 2020)

No specific guidelines regarding coagulation management in tSCI patients have been published until now. In bleeding polytrauma patients, it is suggested to maintain the prothrombin time (PT) and the activated partial thromboplastin time (aPTT) < 1.5 times the normal control and a platelet (PLT) count >50,000/mm^3 [20]. Moreover, a PLT count >100,000/mm^3 was recommended in case of ongoing bleeding, TBI and neurosurgery (Rossaint et al., 2023; Hess et al., 2021). Coagulation point-of-care (POC) tests are increasingly used in bleeding trauma patients (Rossaint et al., 2023). They offer the advantage of being rapid and precise in the assessment of hemostasis and providing useful information about specific coagulation deficiencies, such as in patients taking novel oral anticoagulants (NOACs) and in cases of PLTs dysfunction associated with trauma and/or drugs (Rossaint et al., 2023). Regarding the reversal of anticoagulant/antiplatelets agents, several guidelines are available; however, conflicting indications regarding antiplatelet drugs are reported (LaGrone et al., 2023; Frontera et al., 2016; Kietaibl et al., 2023; Iaccarino et al., 2024). The WSES/EANS consensus recommends: 1) a PLT count >50.000/mm^3 in case of interventions for life-threatening hemorrhage, with higher values (75.000–100.000/mm^3) in case of spinal surgery (decompression/stabilization), 2) a PT/aPTT value < 1.5 normal control during interventions for life-threatening hemorrhage or emergency spinal surgery, 3) the utilization of POC tests [e.g., thromboelastography (TEG), rotational thromboelastometry (ROTEM), etc.] to assess/optimize the coagulation function during interventions for life-threatening hemorrhage or emergency spinal surgery and 4) the early reversal of anticoagulant/antiplatelet agents in interventions for life-threatening hemorrhage or emergency spinal surgery (Picetti et al., 2024).

Bleeding trauma patients frequently require massive transfusion (LaGrone et al., 2023; Rossaint et al., 2023). To prevent coagulopathy, a transfusion strategy involving plasma, PLTs, and RBCs in a 1:1:1 ratio or the utilization of whole blood has been recommended (LaGrone et al., 2023; Rossaint et al., 2023). No specific data regarding trauma coagulopathy and tSCI progression are available. In this regard, the WSES/EANS consensus recommends starting a transfusion protocol of RBCs/plasma/PLTs at a ratio of 1:1:1, with subsequent modifications according to laboratory values (Picetti et al., 2024). Tranexamic acid (TXA) is an antifibrinolytic agent frequently utilized in bleeding trauma patients; its use (within 3 h of injury) results in the reduction of mortality and need for blood transfusion without significant deleterious/adverse effects (LaGrone et al., 2023; Rossaint et al., 2023; CRASH-2 trial collaborators, 2010). Studies regarding the utilization of TXA in tSCI are lacking and should be implemented. The use of plasma resuscitation could be a promising therapy in the setting of TBI with brain contusions as shown by animal and human studies (Jin et al., 2012; Halaweish et al., 2015; Chang et al., 2017; Gruen et al., 2020). Awaiting future studies confirming their benefits in TBI, tSCI could be another setting where the effect of plasma resuscitation can be investigated.

tSCI patients are at increased risk of developing venous thromboembolism (VTE); early initiation of mechanical thromboprophylaxis with intermittent pneumatic compression devices is recommended in immobile trauma patients with elevated bleeding risk (Rossaint et al., 2023; Yorkgitis et al., 2022). The WSES/EANS consensus recommends DVT prophylaxis with intermittent pneumatic compression devices (if available and feasible) as soon as possible after tSCI and polytrauma (Picetti et al., 2024). Also, as suggested by recent guidelines, pharmacologic DVT prophylaxis should be considered within 48 h of injury or spine surgery (Yorkgitis et al., 2022).

The utilization of corticosteroids after tSCI remains highly debated (Ahuja et al., 2017; Picetti et al., 2022; Bracken et al., 1985, 1990, 1997). The CNS guidelines do not recommend their use (Hurlbert et al., 2013). The AO spine guidelines suggest: (1) not offering a 24-h infusion of high-dose Methylprednisolone Sodium Succinate (MPSS) to adult patients who present after 8 h with acute SCI (Quality of Evidence: moderate; Strength of Recommendation: weak), (2) a 24-h infusion of high-dose MPSS to adult patients within 8 h of acute SCI as a treatment option (Quality of Evidence: moderate; Strength of Recommendation: weak), and (3) not offering a 48-h infusion of high-dose MPSS to adult patients with acute SCI (Quality of Evidence: no included studies; Strength of Recommendation: weak) (Fehlings et al., 2017a). In this regard, the WSES/EANS consensus recommends against routine high-dose corticosteroid therapy (Picetti et al., 2024) as was utilized in the National Acute Spinal Cord Injury Studies (NASCIS) I-III studies (Bracken et al., 1985, 1990, 1997). The use of corticosteroids at lower doses or in selected patients (i.e., young patients with high cervical SCI who can tolerate an infectious or other steroid-related complications) is a matter of debate and warrants further studies.

5. Imaging investigations and the timing of spinal surgery in the setting of polytrauma

Whole-body computed tomography (CT) scan is a key diagnostic tool in the management of polytrauma patients (Huber-Wagner et al., 2018; Wirth et al., 2020) and is considered the initial imaging modality in tSCI (Daffner and Hackney, 2007; Ryken et al., 2013b). In particular, spine reconstruction and reformatting from a whole-body CT scan can be obtained rapidly, allowing useful time-saving in a potentially challenging polytrauma setting (Shabani et al., 2021). Spinal CT provides important information regarding bone pathology (e.g., fractures, dislocations, and misalignment), disc herniations, and hematomas (epidural/subdural) (Daffner and Hackney, 2007; Ryken et al., 2013b; Shabani et al., 2021). Magnetic resonance imaging (MRI) allows a careful evaluation of the spinal cord/neural elements and surrounding soft tissues (Shabani et al., 2021). For this reason, MRI is considered the imaging modality of choice for tSCI, especially for decision-making regarding surgical management of the injured spine and spinal cord (Shabani et al., 2021; Fehlings et al., 2017b). In this regard, AO spine guidelines recommend MRI: 1) prior to surgical intervention, when feasible, to facilitate improved clinical decision-making (Quality of Evidence: very low; Strength of Recommendation: weak), and 2) in the acute period following SCI, before or after surgical intervention, to improve prediction of neurologic outcome (Quality of Evidence: low; Strength of Recommendation: weak) (Fehlings et al., 2017b). However, its execution time is longer than CT scanning, making it challenging in unstable polytrauma patients with cardiorespiratory compromise. The precise indications and the ideal timing of MRI in tSCI patients have not clearly defined are not clearly defined. Considering adult tSCI polytrauma patients, the WSES/EANS consensus recommends performing spine MRI after cardiorespiratory stabilization and spinal specialist consultation to determine the severity of spinal cord damage and aid in surgical decision-making (Picetti et al., 2024).

Early decompressive surgery (within 24 h from trauma) is associated with better neurological outcomes, highlighting the “time is spine” concept (Badhiwala et al., 2021; Hsieh et al., 2021; Quddusi et al., 2023). An “ultra-early” approach (within 12 h or less from trauma) has also been proposed, especially in the case of an incomplete spinal cord lesion (Quddusi et al., 2023; Sánchez et al., 2020). Recent AO

Spine/Praxis guidelines recommend that early surgery be offered as an option for adult patients with acute SCI regardless of level (Quality of Evidence: moderate; Strength of Recommendation: strong) (Fehlings et al., 2024). These guidelines are unable to make recommendations regarding ultra-early surgery (i.e., ≤4, 8 or 12 h after injury) because of the small sample sizes, variable definitions of what constituted "ultra--early" and the inconsistency of the evidence (Fehlings et al., 2024). Data on the optimal timing of spinal surgery in polytrauma patients are lacking. More studies are still necessary in this field, as this remains a very complex scenario requiring a personalized approach according to clinical needs (i.e., intracranial and cardiorespiratory stabilization). In this regard, the WSES/EANS consensus recommends, in all salvageable tSCI polytrauma patients with surgical spinal lesions, considering urgent intervention (decompression/spine stabilization) after controlling life-threatening conditions, preferably within 24 h from the initial injury (Picetti et al., 2024). It is likely that, in the absence of neural compression, surgical intervention could be slightly delayed. However, this aspect also requires further specific studies. Rapid spinal stabilization in a critically ill trauma patient could be useful when there is a need for prone ventilation or special positioning for extraspinal surgical procedures. The utilization of Minimally Invasive Spine Surgery (MISS), as a part of spinal damage control strategy, could be very useful in tSCI polytrauma patients (Camacho et al., 2019). MISS, eventually followed by a more definitive treatment, is associated with favorable outcomes (e.g. lower length of hospital stay and ventilator-dependent days, etc.) (Stahel et al., 2013). This approach, characterized by a reduced physiologic derangement, need to be validated in future multicenter prospective studies.

6. Early interventions for skin, bowel and bladder

The patient with SCI and polytrauma may have high priorities such as shock, respiratory failure, or severe TBI. However, the transition to rehabilitative care and long-term outcomes can be impacted by poor protection of the skin and inadequate management of neurogenic bowel and bladder (Donhauser et al., 2020; Qi et al., 2018; Panicker, 2020).

Pressure ulcers notably under medical devices and splints, and in areas of bony prominences, especially in insensate areas, are a significant source of morbidity (Consortium for Spinal Cord Medicine Clinical Practice Guidelines, 2001; Consortium for Spinal Cord Medicine, 2008; Kruger et al., 2013). A specialized bed, which promotes even pressure distribution and allows airflow, will help avoid damaging pressure on the skin. Pressure ulcers can occur in as little as 1 h and can result in delays to mobility, rehabilitation for days, weeks or months and may necessitate additional procedures including, in extreme cases, amputation. Padding bony prominences, avoiding shear injuries during transfers and repositioning is critical. Avoiding elevating the head of the bed for prolonged periods of time in favor of reverse Trendelenburg can avoid undue pressure on the sacrum. Frequent turning and repositioning to allow reperfusion, and frequently checking the skin for any pressure areas including under medical devices, is critical. Early mobilization is essential and should be implemented in collaboration with physical therapy and bedside nurses in consultation with a physical medicine and rehabilitation physician. Transferring patients safely to a chair with a pressure relieving cushion, use of protective footwear, and weight shifts to allow reperfusion every 15 min are necessary. Prompt action must be taken if any areas concerning for pressure injury are noted. Being mindful of skin protection in bed, during any imaging and procedures and when up out of bed can prevent significant morbidity.

The neurogenic bladder should be drained with an indwelling Foley catheter for the critical care phase (Panicker, 2020; Consortium for Spinal Cord Medicine, 2008). In relation to the necessary neuro-urological assistance to the paraplegic patient, and in order to prevent damage to the urethra, the guidelines of the Association of the Scientific Medical Societies in Germany (AWMF) suggest that the initially inserted transurethral catheter be exchanged for a suprapubic catheter as quickly as possible (Association of the Scientific Medical Societies in Germany, 2021).

Fluid shifts are common, particularly in the multisystem injured patient. In patients with an injury to T6 or higher, an overdistended bladder can lead to autonomic dysreflexia. Leave indwelling catheter in place until the patient is hemodynamically stable, no longer needing strict attention to fluid status, and able to be educated by a rehabilitation physician/nurse team on alternate methods of neurogenic bladder management.

Initial ileus is expected and will likely require a bowel cleanout, possibly using an enema and promotility agents (Qi et al., 2018; Consortium for Spinal Cord Medicine, 2008). Once enteral nutrition is given, a bowel program should be implemented to promote regular, planned, and predictable evacuation of stool. A daily rectal suppository is given after a meal at a consistent time that doesn't interfere with other activities. Suppository insertion is followed by gentle digital rectal dilation with a lubricated gloved finger for 20–30 s, repeated until the evacuation is complete, preferably upright over a commode. This establishes a pattern for functional continence and avoidance of significant constipation, which can affect feeding tolerance, discomfort and, if injury is T6 or higher, can cause autonomic dysreflexia.

Early consultation with a physical medicine and rehabilitation physician is beneficial to establish care, support the critical care team and provide information to the patient and family on short and long-term rehabilitation plans with a focus on functional independence and empowerment (Consortium for Spinal Cord Medicine, 2008).

7. The multidisciplinary approach to the tSCI polytrauma patient

As described above, managing actively bleeding polytrauma patients with a spinal cord lesion is a very challenging scenario. The treatment pathway in the acute phase must prioritize actions to prevent patient death. Similarly, it is crucial to preserve the injured spine to limit disabilities and to enhance neurological recovery. In such a situation, doctors from various specialties collaborate (Fig. 3). Within this multidisciplinary context, it is paramount harmony, clear lines of communication and mutual respect to allow working together to improve patient outcomes. Basically, a comprehensive understanding of the clinical issue to be addressed should be shared by all parties involved. In this regard, the WSES/EANS consensus recommends close collaboration between different medical specialties (e.g., critical care medicine, acute care surgery, neurosurgery, neurology, emergency medicine, orthopedics, etc.) involved in the early management of tSCI patients with polytrauma (Picetti et al., 2024). The role of each specialty is strictly linked to the other, akin the concept of the "chain of survival" in cardiac arrest (Cummins et al., 1991). The final outcome is probably linked to the participation of every specialty.

8. Conclusions

This narrative review aims to collate basic knowledge regarding the acute phase management of tSCI patients in the context of polytrauma. The importance of a multidisciplinary approach to this challenging scenario is highlighted. The concept of rapid bleeding control should integrate into *"the time is spine"* approach. More evidence and data form well-powered studies are necessary in this setting. In the meantime, we hope that the concepts elucidated in this article may be useful for improving not only mortality but also neurological disability in this field.

Ethical approval

Since this was a narrative review, no ethical approval was required.

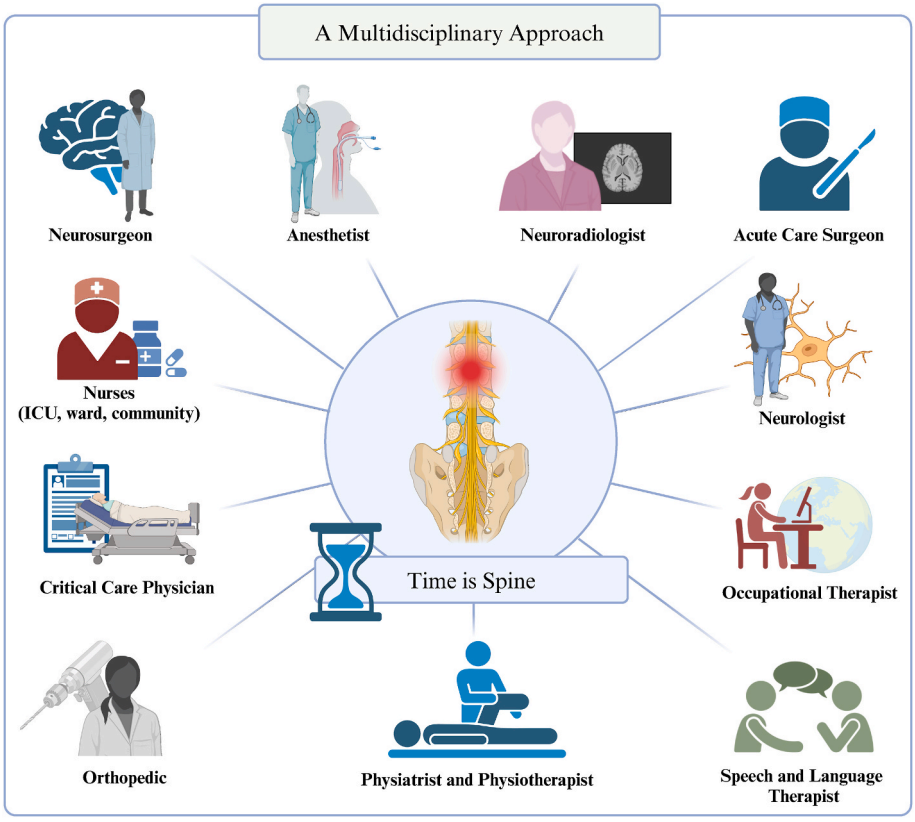

Fig. 3. Multidisciplinary Collaboration in the Management of tSCI Patients. This figure demonstrates the "time is spine" concept, highlighting how each specialty's interconnected role is crucial in the comprehensive treatment pathway for the acute management of polytrauma patients with spinal cord injuries. A multidisciplinary approach aims to optimize patient outcomes. ICU - Intensive Care Unit.

Funding

None.

Declaration of competing interests

The authors declare no competing interests.

Acknowledgements

The images have been created with BioRender.com.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2024.104146.

References

Ahuja, C.S., Wilson, J.R., Nori, S., Kotter, M.R.N., Druschel, C., Curt, A., et al., 2017. Traumatic spinal cord injury. Nat Rev Dis Primers 3, 17018.

Alvarez Reyes, A., Hurlbert, R.J., Dumont, T.M., Ramey, W.L., 2022. The Number of organ System injuries is a predictor of intrahospital mortality in complete cervical spinal cord injury. World Neurosurg 158, e788–e792.

American College of Surgeons (ACS), Trauma Quality Program (TQP), 2022. Spine Injury Best Practice Guidelines.

Association of the Scientific Medical Societies in Germany (AWMF), 2021. Neuro-urologische Versorgung querschnittgelähmter Patientem. https://register.awmf.org/assets/guidelines/179-001l_S2k_Neuro-urologische-Versorgung-querschnittgelaehmter-Patienten_2021-11.pdf.

Azad, T.D., Raj, D., Ran, K.R., Vattipally, V.N., Warman, A., Raad, M., et al., 2024. Concomitant traumatic brain injury delays surgery in patients with traumatic spinal cord injury. Neurosurgery. https://doi.org/10.1227/neu.0000000000002816. Jan 10. Epub ahead of print. PMID: 38197654.

Badhiwala, J.H., Wilson, J.R., Witiw, C.D., Harrop, J.S., Vaccaro, A.R., Aarabi, B., et al., 2021. The influence of timing of surgical decompression for acute spinal cord injury: a pooled analysis of individual patient data. Lancet Neurol. 20 (2), 117–126.

Bracken, M.B., Shepard, M.J., Hellenbrand, K.G., Collins, W.F., Leo, L.S., Freeman, D.F., et al., 1985. Methylprednisolone and neurological function 1 year after spinal cord injury. Results of the national acute spinal cord injury study. J. Neurosurg. 63 (5), 704–713.

Bracken, M.B., Shepard, M.J., Collins, W.F., Holford, T.R., Young, W., Baskin, D.S., et al., 1990. A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury. Results of the Second National Acute Spinal Cord Injury Study. N. Engl. J. Med. 322 (20), 1405–1411.

Bracken, M.B., Shepard, M.J., Holford, T.R., Leo-Summers, L., Aldrich, E.F., Fazl, M., et al., 1997. Administration of methylprednisolone for 24 or 48 hours or tirilazad mesylate for 48 hours in the treatment of acute spinal cord injury. Results of the third national acute spinal cord injury randomized controlled trial. National acute spinal cord injury study. JAMA 277 (20), 1597–1604.

Callcut, R.A., Kornblith, L.Z., Conroy, A.S., Robles, A.J., Meizoso, J.P., Namias, N., et al., 2019. The why and how our trauma patients die: A prospective Multicenter Western Trauma Association study. J. Trauma Acute Care Surg. 86 (5), 864–870.

Camacho, J.E., Usmani, M.F., Strickland, A.R., Banagan, K.E., Ludwig, S.C., 2019. The use of minimally invasive surgery in spine trauma: a review of concepts. J Spine Surg 5 (Suppl. 1), S91–S100.

CRASH-2 trial collaborators, 2010. Effects of tranexamic acid on death, vascular occlusive events, and blood transfusion in trauma patients with significant haemorrhage (CRASH-2): a randomised, placebo-controlled trial. Lancet 376 (9734), 23–32.

Chang, R., Folkerson, L.E., Sloan, D., Tomasek, J.S., Kitagawa, R.S., Choi, H.A., et al., 2017. Early plasma transfusion is associated with improved survival after isolated traumatic brain injury in patients with multifocal intracranial hemorrhage. Surgery 161 (2), 538–545.

Chung, C.Y., Scalea, T.M., 2023. Damage control surgery: old concepts and new indications. Curr. Opin. Crit. Care 29 (6), 666–673.

Consortium for Spinal Cord Medicine Clinical Practice Guidelines, 2001. Pressure ulcer prevention and treatment following spinal cord injury: a clinical practice guideline for health-care professionals. J Spinal Cord Med. 24 (Suppl. 1), S40–S101.

Consortium for Spinal Cord Medicine, 2008. Early acute management in adults with spinal cord injury: a clinical practice guideline for health-care professionals. J Spinal Cord Med. 31 (4), 403–479.

Cummins, R.O., Ornato, J.P., Thies, W.H., Pepe, P.E., 1991. Improving survival from sudden cardiac arrest: the "chain of survival" concept. A statement for health professionals from the advanced cardiac life support Subcommittee and the

emergency cardiac care Committee, American heart association. Circulation 83 (5), 1832–1847.
Daffner, R.H., Hackney, D.B., 2007. ACR Appropriateness Criteria on suspected spine trauma. J. Am. Coll. Radiol. 4 (11), 762–775.
Demetriades, A.K., Marchesini, N., Alves, O.L., Rubiano, A.M., Sala, F., 2022. A survey on the early management of spinal trauma in low and middle-income countries: from the scene of injury to the diagnostic phase (part II). Brain Spine 2, 101185.
Donhauser, M., Grassner, L., Klein, B., Voth, M., Mach, O., Vogel, M., et al., 2020. Severe pressure ulcers requiring surgery impair the functional outcome after acute spinal cord injury. Spinal Cord 58 (1), 70–77.
Fehlings, M.G., Wilson, J.R., Tetreault, L.A., Aarabi, B., Anderson, P., Arnold, P.M., et al., 2017a. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the use of methylprednisolone sodium succinate. Global Spine J. 7 (3 Suppl. l), 203S–211S.
Fehlings, M.G., Martin, A.R., Tetreault, L.A., Aarabi, B., Anderson, P., Arnold, P.M., et al., 2017b. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the role of baseline magnetic resonance imaging in clinical decision making and outcome prediction. Global Spine J. 7 (3 Suppl. l), 221S–230S.
Fehlings, M.G., Tetreault, L.A., Hachem, L., Evaniew, N., Ganau, M., McKenna, S.L., et al., 2024. An update of a clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the role and timing of decompressive surgery. Global Spine J. 14 (3-suppl), 174S–186S.
Frontera, J.A., Lewin, JJ 3rd, Rabinstein, A.A., Aisiku, I.P., Alexandrov, A.W., Cook, A. M., et al., 2016. Guideline for reversal of Antithrombotics in intracranial hemorrhage: a statement for healthcare professionals from the Neurocritical care Society and Society of critical care medicine. Neurocrit Care 24 (1), 6–46.
GBD Spinal Cord Injuries Collaborators, 2023. Global, regional, and national burden of spinal cord injury, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Neurol. 22 (11), 1026–1047.
Gruen, D.S., Guyette, F.X., Brown, J.B., Okonkwo, D.O., Puccio, A.M., Campwala, I.K., et al., 2020. Association of Prehospital plasma with survival in patients with traumatic brain injury: a secondary analysis of the PAMPer Cluster randomized clinical trial. JAMA Netw. Open 3 (10), e2016869.
Hachem, L.D., Ahuja, C.S., Fehlings, M.G., 2017. Assessment and management of acute spinal cord injury: from point of injury to rehabilitation. J Spinal Cord Med. 40 (6), 665–675.
Halaweish, I., Bambakidis, T., He, W., Linzel, D., Chang, Z., Srinivasan, A., et al., 2015. Early resuscitation with fresh frozen plasma for traumatic brain injury combined with hemorrhagic shock improves neurologic recovery. J. Am. Coll. Surg. 220 (5), 809–819.
Hess, A.S., Ramamoorthy, J., Hess, J.R., 2021. Perioperative platelet transfusions. Anesthesiology 134 (3), 471–479.
Hogg, F.R.A., Kearney, S., Solomon, E., Gallagher, M.J., Zoumprouli, A., Papadopoulos, M.C., et al., 2021a. Acute, severe traumatic spinal cord injury: improving urinary bladder function by optimizing spinal cord perfusion. J. Neurosurg. Spine 36 (1), 145–152.
Hogg, F.R.A., Kearney, S., Gallagher, M.J., Zoumprouli, A., Papadopoulos, M.C., Saadoun, S., 2021b. Spinal cord perfusion pressure correlates with anal sphincter function in a cohort of patients with acute, severe traumatic spinal cord injuries. Neurocrit Care 35 (3), 794–805.
Hörer, T.M., Pirouzram, A., Khan, M., Brenner, M., Cotton, B., Duchesne, J., et al., 2021. Endovascular resuscitation and trauma management (EVTM)-Practical aspects and Implementation. Shock 56 (1S), 37–41.
Hsieh, Y.L., Tay, J., Hsu, S.H., Chen, W.T., Fang, Y.D., Liew, C.Q., et al., 2021. Early versus late surgical decompression for traumatic spinal cord injury on neurological recovery: a systematic review and meta-analysis. J. Neurotrauma 38 (21), 2927–2936.
Huber-Wagner, S., Kanz, K.G., Hanschen, M., van Griensven, M., Biberthaler, P., Lefering, R., 2018. Whole-body computed tomography in severely injured patients. Curr. Opin. Crit. Care 24 (1), 55–61.
Hurlbert, R.J., Hadley, M.N., Walters, B.C., Aarabi, B., Dhall, S.S., Gelb, D.E., et al., 2013. Pharmacological therapy for acute spinal cord injury. Neurosurgery 72 (Suppl. 2), 93–105.
Iaccarino, C., Carretta, A., Demetriades, A.K., Di Minno, G., Giussani, C., Marcucci, R., et al., 2024. Management of Antithrombotic drugs in patients with isolated traumatic brain injury: an Intersociety consensus Document. Neurocrit Care 40 (1), 314–327.
Jin, G., DeMoya, M.A., Duggan, M., Knightly, T., Mejaddam, A.Y., Hwabejire, J., et al., 2012. Traumatic brain injury and hemorrhagic shock: evaluation of different resuscitation strategies in a large animal model of combined insults. Shock 38 (1), 49–56.
Kietaibl, S., Ahmed, A., Afshari, A., Albaladejo, P., Aldecoa, C., Barauskas, G., et al., 2023. Management of severe peri-operative bleeding: guidelines from the European Society of Anaesthesiology and intensive care: Second update 2022. Eur. J. Anaesthesiol. 40 (4), 226–304.
Kruger, E.A., Pires, M., Ngann, Y., Sterling, M., Rubayi, S., 2013. Comprehensive management of pressure ulcers in spinal cord injury: current concepts and future trends. J Spinal Cord Med. 36 (6), 572–585.
Kwon, B.K., Tetreault, L.A., Martin, A.R., Arnold, P.M., Marco, R.A.W., Newcombe, V.F. J., et al., 2024. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on hemodynamic management. Global Spine J. 14 (3-suppl), 187S–211S.
Lammers, D.T., Holcomb, J.B., 2023. Damage control resuscitation in adult trauma patients: what you need to know. J. Trauma Acute Care Surg. 95 (4), 464–471.
LaGrone, L., Stein, D., Cribari, C., Kaups, K., Harris, C., Miller, A.N., et al., 2023. American association for the surgery of trauma (AAST)/American College of Surgeons Committee on trauma (ACS-COT): clinical protocol for damage control resuscitation for the adult trauma patient. J. Trauma Acute Care Surg. 96 (3), 510–520.
Marchesini, N., Demetriades, A.K., Alves, O.L., Sala, F., Rubiano, A.M., 2022a. Exploring perspectives and adherence to guidelines for adult spinal trauma in low and middle-income healthcare economies: a survey on barriers and possible solutions (part I). Brain Spine 2, 100932.
Marchesini, N., Rubiano, A.M., Sala, F., Demetriades, A.K., Alves, O.L., 2022b. Secondary damage management of acute traumatic spinal cord injury in low and middle-income countries: a survey on a global scale (Part III). Brain Spine 2, 101694.
Marchesini, N., Demetriades, A.K., Peul, W.C., Tommasi, N., Zanatta, P., Pinna, G., et al., 2023. Concomitant trauma of brain and upper cervical spine: lessons in injury patterns and outcomes. Eur. J. Trauma Emerg. Surg. Epub ahead of print.
Mavrovounis, G., Makris, M., Demetriades, A.K., 2023. Traumatic spinal cord and spinal column injuries: a bibliometric analysis of the 200 most cited articles. J Craniovertebr Junction Spine 14 (4), 346–364.
Menacho, S.T., Floyd, C., 2021. Current practices and goals for mean arterial pressure and spinal cord perfusion pressure in acute traumatic spinal cord injury: Defining the gaps in knowledge. J Spinal Cord Med 44 (3), 350–356.
Pandrich, M.J., Demetriades, A.K., 2020. Prevalence of concomitant traumatic cranio-spinal injury: a systematic review and meta-analysis. Neurosurg. Rev. 43 (1), 69–77.
Panicker, J.N., 2020. Neurogenic bladder: Epidemiology, diagnosis, and management. Semin. Neurol. 40 (5), 569–579.
Picetti, E., Rossi, S., Abu-Zidan, F.M., Ansaloni, L., Armonda, R., Baiocchi, G.L., et al., 2019. WSES consensus conference guidelines: monitoring and management of severe adult traumatic brain injury patients with polytrauma in the first 24 hours. World J. Emerg. Surg. 14, 53.
Picetti, E., Rosenstein, I., Balogh, Z.J., Catena, F., Taccone, F.S., Fornaciari, A., et al., 2021. Perioperative management of polytrauma patients with severe traumatic brain injury Undergoing emergency Extracranial surgery: a narrative review. J. Clin. Med. 11 (1), 18.
Picetti, E., Iaccarino, C., Coimbra, R., Abu-Zidan, F., Tebala, G.D., Balogh, Z.J., et al., 2022. The acute phase management of spinal cord injury affecting polytrauma patients: the ASAP study. World J. Emerg. Surg. 17 (1), 20, 2022.
Picetti, E., Demetriades, A.K., Catena, F., Aarabi, B., Abu-Zidan, F.M., Alves, O.L., et al., 2024. Early management of adult traumatic spinal cord injury in patients with polytrauma: a consensus and clinical recommendations jointly developed by the World Society of Emergency Surgery (WSES) & the European Association of Neurosurgical Societies (EANS). World J. Emerg. Surg. 19 (1), 4.
Qi, Z., Middleton, J.W., Malcolm, A., 2018. Bowel dysfunction in spinal cord injury. Curr. Gastroenterol. Rep. 20 (10), 47.
Quddusi, A., Pedro, K.M., Alvi, M.A., Hejrati, N., Fehlings, M.G., 2023. Early surgical intervention for acute spinal cord injury: time is spine. Acta Neurochir. 165 (9), 2665–2674.
Risinger, W.B., Smith, J.W., 2023. Damage control surgery in emergency general surgery: what you need to know. J. Trauma Acute Care Surg. 95 (5), 770–779.
Robba, C., Poole, D., McNett, M., Asehnoune, K., Bösel, J., Bruder, N., et al., 2020. Mechanical ventilation in patients with acute brain injury: recommendations of the European Society of Intensive Care Medicine consensus. Intensive Care Med. 46 (12), 2397–2410.
Rossaint, R., Afshari, A., Bouillon, B., Cerny, V., Cimpoesu, D., Curry, N., et al., 2023. The European guideline on management of major bleeding and coagulopathy following trauma: sixth edition. Crit. Care 27 (1), 80.
Ryken, T.C., Hurlbert, R.J., Hadley, M.N., Aarabi, B., Dhall, S.S., Gelb, D.E., et al., 2013a. The acute cardiopulmonary management of patients with cervical spinal cord injuries. Neurosurgery 72 (Suppl. 2), 84–92.
Ryken, T.C., Hadley, M.N., Walters, B.C., Aarabi, B., Dhall, S.S., Gelb, D.E., et al., 2013b. Radiographic assessment. Neurosurgery 72 (Suppl. 2), 54–72.
Saadoun, S., Papadopoulos, M.C., 2021. Acute, severe traumatic spinal cord injury: monitoring from the injury site and expansion duraplasty. Neurosurg Clin N Am 32 (3), 365–376.
Sánchez, J.A.S., Sharif, S., Costa, F., Rangel, J.A.I.R., Anania, C.D., Zileli, M., 2020. Early management of spinal cord injury: WFNS spine Committee recommendations. Neurospine 17 (4), 759–784.
Shabani, S., Meyer, B.P., Budde, M.D., Wang, M.C., 2021. Diagnostic imaging in spinal cord injury. Neurosurg Clin N Am 32 (3), 323–331.
Squair, J.W., Bélanger, L.M., Tsang, A., Ritchie, L., Mac-Thiong, J.M., Parent, S., et al., 2017. Spinal cord perfusion pressure predicts neurologic recovery in acute spinal cord injury. Neurology 89 (16), 1660–1667.
Stahel, P.F., VanderHeiden, T., Flierl, M.A., Matava, B., Gerhardt, D., Bolles, G., et al., 2013. The impact of a standardized "spine damage-control" protocol for unstable thoracic and lumbar spine fractures in severely injured patients: a prospective cohort study. J. Trauma Acute Care Surg. 74 (2), 590–596.
Tachino, J., Demetriades, A.K., Peul, W., Nakao, S., Katayama, Y., Tanaka, K., et al., 2024. Effects of concomitant traumatic spinal cord and brain injury on in-hospital mortality: a Retrospective analysis of a Nationwide trauma Registry in Japan. J. Neurotrauma. https://doi.org/10.1089/neu.2024.0168, 2024 Jul 3. Epub ahead of print. PMID: 38877809.
Visagan, R., Hogg, F.R.A., Gallagher, M.J., Kearney, S., Zoumprouli, A., Papadopoulos, M.C., et al., 2022. Saadoun S. Monitoring spinal cord tissue oxygen in patients with acute, severe traumatic spinal cord injuries. Crit. Care Med. 50 (5), e477–e486.

Visagan, R., Boseta, E., Zoumprouli, A., Papadopoulos, M.C., Saadoun, S., 2023. Spinal cord perfusion pressure correlates with breathing function in patients with acute, cervical traumatic spinal cord injuries: an observational study. Crit. Care 27 (1), 362.
Wirth, S., Hebebrand, J., Basilico, R., Berger, F.H., Blanco, A., Calli, C., et al., 2020. European Society of Emergency Radiology: guideline on radiological polytrauma imaging and service (short version). Insights Imaging 11 (1), 135.
Yorkgitis, B.K., Berndtson, A.E., Cross, A., Kennedy, R., Kochuba, M.P., Tignanelli, C., et al., 2022. American association for the surgery of trauma/American College of Surgeons-Committee on trauma clinical protocol for inpatient venous thromboembolism prophylaxis after trauma. J. Trauma Acute Care Surg. 92 (3), 597–604.
Yue, J.K., Winkler, E.A., Rick, J.W., Deng, H., Partow, C.P., Upadhyayula, P.S., et al., 2017. Update on critical care for acute spinal cord injury in the setting of polytrauma. Neurosurg. Focus 43 (5), E19.