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## 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)

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RESEARCH

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# 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)

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## Abstract

**Background** The early management of polytrauma patients with traumatic spinal cord injury (tSCI) is a major challenge. Sparse data is available to provide optimal care in this scenario and worldwide variability in clinical practice

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has been documented in recent studies.

**Methods** A multidisciplinary consensus panel of physicians selected for their established clinical and scientific expertise in the acute management of tSCI polytrauma patients with different specializations was established. The World Society of Emergency Surgery (WSES) and the European Association of Neurosurgical Societies (EANS) endorsed the consensus, and a modified Delphi approach was adopted.

**Results** A total of 17 statements were proposed and discussed. A consensus was reached generating 17 recommendations (16 strong and 1 weak).

**Conclusions** This consensus provides practical recommendations to support a clinician's decision making in the management of tSCI polytrauma patients.

**Keywords** Traumatic spinal cord injury, Polytrauma, Management

## Background

Traumatic spinal cord injury (tSCI) is a devastating condition associated with high mortality and morbidity [1, 2]. Falls from height and road traffic collisions are the most frequent causes of tSCI [1, 2]. In the latter scenario, an association of multisystem trauma was observed in about 80% of accidents [3]. In tSCI, as in traumatic brain injury (TBI), both primary and secondary injuries can occur; the latter, in particular, can be further exacerbated by dangerous secondary insults (such as hypoxia and hypotension) frequently observed in unstable polytrauma patients [3, 4]. Increased organ system injuries are associated with greater intrahospital mortality in polytrauma patients with cervical SCI [5, 6]. Unfortunately, few data are available regarding the acute phase management of tSCI patients with multisystem trauma. A recent survey showed a great worldwide variability in clinical practices in this setting [7]. Moreover, as in TBI, early therapeutic choices can deeply impact the outcome and prognosis of tSCI patients.

Considering the above, the specific aim of this consensus is to provide recommendations on the early management (within 24 h from trauma) of adult tSCI patients with polytrauma.

## Methods

An international multidisciplinary consensus panel was composed, including neurosurgeons ( $n=44$ ), anesthesiologists/intensivists/neurointensivists ( $n=23$ ), acute care surgeons ( $n=14$ ), orthopedists ( $n=3$ ), neuroradiologists ( $n=2$ ), emergency physicians ( $n=2$ ) and neurologists ( $n=1$ ) having expertise in tSCI polytrauma care (Additional file 1: Appendix 1). The methodology used was similar to previously published consensus conferences [8, 9]. Briefly, following a non-systematic review of the literature, the steering committee (EP, CR and FC) generated a list of questions to be assessed by

the panel. Two subsequent online questionnaires were administered between May and September 2023. The list of statements (17) was formulated and distributed to the panelists to allow modifications or additional statements. The analysis of voting results was performed by a non-voting experienced methodologist (CR). Statements were classified as strong recommendation, weak recommendation and no recommendation when  $>85\%$ ,  $75-85\%$  and  $<75\%$  of votes were in favor, respectively. This consensus is for tSCI polytrauma patients without severe TBI. Regarding the early management of severe TBI in polytrauma patients, we refer to the 2019 World Society of Emergency Surgery (WSES) consensus conference [8]. The current consensus was endorsed jointly by the WSES and the European Association of Neurosurgical Societies (EANS).

## Results

The consensus provided 17 recommendations (Table 1): 16 were strong recommendations, while 1 was a weak recommendation. The consensus algorithm is reported in Fig. 1. The consensus recommendations are listed below with the percentage of agreement.

### Recommendation 1

We recommend that all salvageable tSCI polytrauma patients with life-threatening conditions need immediate life support interventions (e.g., intubation, mechanical ventilation, hemodynamic support, extraspinal surgery/interventional radiology for bleeding control, etc.) (agreement: 98.9%, *strong* recommendation).

### Recommendation 2

We recommend that tSCI polytrauma patients needing extracranial interventions (e.g., surgery, interventional radiology, etc.) for life-threatening conditions require careful positioning (protection and maintenance of spine alignment) to avoid secondary insults to the injured spine (agreement: 100%, *strong* recommendation).

**Table 1** List of consensus recommendations

| N  | Recommendation  | Level                 |
|----|---|-----------------------|
| 1  | We recommend that all salvageable tSCI polytrauma patients with life-threatening conditions need immediate life support interventions (e.g., intubation, mechanical ventilation, hemodynamic support, extraspinal surgery/interventional radiology for bleeding control, etc.)  | Strong recommendation |
| 2  | We recommend that tSCI polytrauma patients needing extracranial interventions (e.g., surgery, interventional radiology, etc.) for life-threatening conditions require careful positioning (protection and maintenance of spine alignment) to avoid secondary insults to the injured spine   | Strong recommendation |
| 3  | We recommend that tSCI polytrauma patients, without life-threatening conditions or after cardiorespiratory stabilization, need urgent neurological evaluation and imaging (i.e., spine reconstruction from a whole-body CT scan)  | Strong recommendation |
| 4  | We recommend, in tSCI polytrauma patients (without life-threatening conditions or after cardiorespiratory stabilization), to perform spine MRI after spinal specialist consultation to determine the severity of spinal cord damage and aid in surgical decision making   | Strong recommendation |
| 5  | We recommend, in all salvageable tSCI polytrauma patients with surgical spinal lesions, after control of life-threatening conditions, to consider an urgent intervention (decompression/spine stabilization), possibly within 24 h from trauma  | Strong recommendation |
| 6  | We recommend the maintenance of a MAP > 85 mmHg during interventions for life-threatening hemorrhage or emergency spinal surgery. In case of difficult intraoperative bleeding control, lower values could be tolerated for the shortest possible time  | Strong recommendation |
| 7  | We recommend that the Hb level, during interventions for life-threatening hemorrhage or emergency spinal surgery, be adjusted according to a patient's tolerance to anemia. An Hb < 7 g/dl should promptly trigger RBCTs. A higher threshold for RBCTs could be used in patients "at risk" (e.g., elderly and/or with limited cardiovascular reserve because of pre-existing heart disease, etc.) | Strong recommendation |
| 8  | We recommend the maintenance of a PaO <sub>2</sub> between 60 and 100 mmHg (7.9–13.3 kPa) during interventions for life-threatening hemorrhage or emergency spinal surgery  | Strong recommendation |
| 9  | We recommend the maintenance of a PaCO <sub>2</sub> between 35 and 40 mmHg (4.7–5.3 kPa) during interventions for life-threatening hemorrhage or emergency spinal surgery   | Strong recommendation |
| 10 | In case of interventions for life-threatening hemorrhage, we recommend the maintenance of a PLT count > 50.000/mm <sup>3</sup> . In the case of spinal surgery (decompression/stabilization), a higher value (75.000–100.000/mm <sup>3</sup> ) would be advisable   | Strong recommendation |
| 11 | We recommend the maintenance of a PT/aPTT value < 1.5 normal control during interventions for life-threatening hemorrhage or emergency spinal surgery   | Strong recommendation |
| 12 | We recommend, if available, the utilization of POC tests (e.g., TEG, ROTEM, etc.) to assess and optimize the coagulation function during interventions for life-threatening hemorrhage or emergency spinal surgery  | Weak recommendation   |
| 13 | We recommend the early reversal of anticoagulant/antiplatelet agents in all salvageable tSCI polytrauma patients needing interventions for life-threatening hemorrhage or emergency spinal surgery  | Strong recommendation |
| 14 | In adult patients with tSCI and polytrauma, we recommend the transfusion of RBCs/Plasma/PLTs at a ratio of 1/1/1 during massive transfusion protocol initiation. Afterward, this ratio can be modified according to laboratory values   | Strong recommendation |
| 15 | We recommend against high-dose corticosteroid therapy (e.g., NASCIS I-III) in tSCI patients and polytrauma  | Strong recommendation |
| 16 | We recommend DVT prophylaxis with intermittent pneumatic compression devices (if available and feasible) as soon as possible after tSCI and polytrauma  | Strong recommendation |
| 17 | We recommend a strict collaboration between the 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  | Strong recommendation |

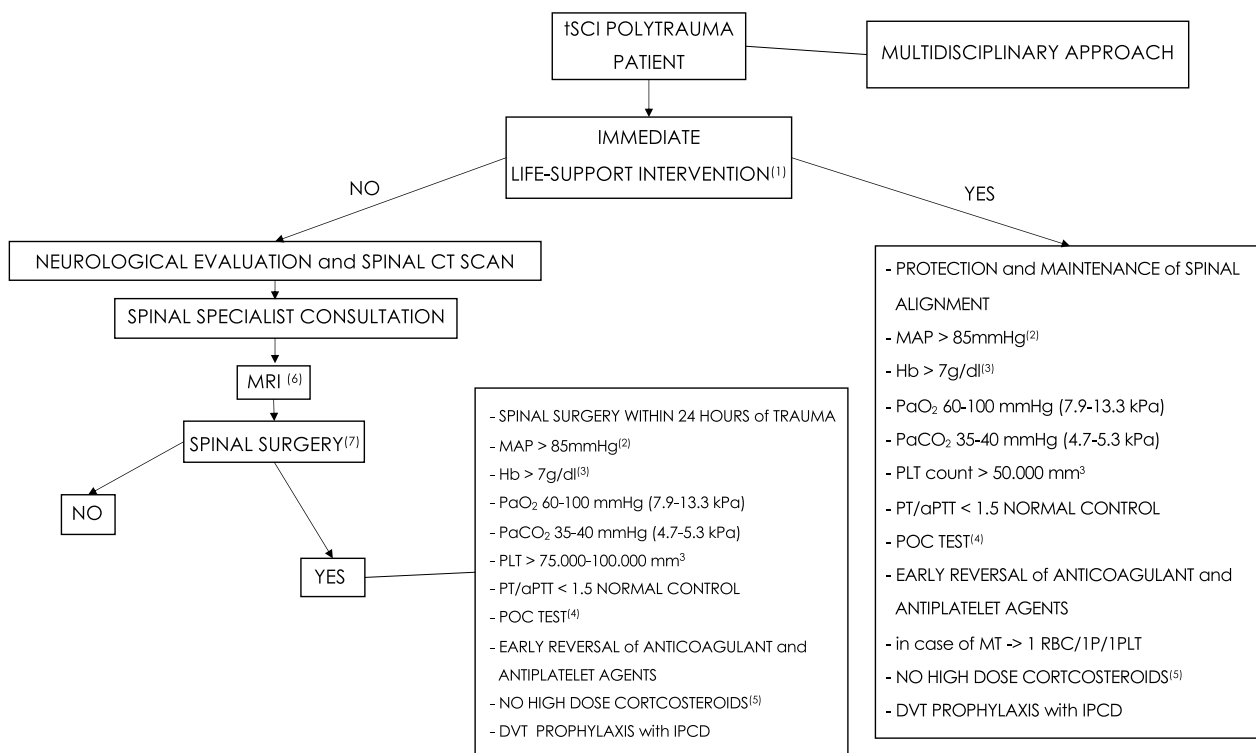
tSCI Traumatic spinal cord injury, CT Computed tomography, MRI Magnetic resonance imaging, MAP Mean arterial pressure, Hb Hemoglobin, RBC Red blood cell, RBCT RBC transfusion, PLT Platelet, PT Prothrombin time, aPTT Activated partial thromboplastin time, POC Point-of-care, TEG Thromboelastography, ROTEM Rotational thromboelastometry, PaCO<sub>2</sub> Arterial partial pressure of carbon dioxide, PaO<sub>2</sub> Arterial partial pressure of oxygen, NASCIS National Acute Spinal Cord Injury Study

### Recommendation 3

We recommend that tSCI polytrauma patients, without life-threatening conditions or after cardiorespiratory stabilization, need urgent neurological evaluation and imaging [i.e., spine reconstruction from a whole-body computed tomography (CT) scan] (agreement: 95.5%, *strong* recommendation).

### Recommendation 4

We recommend, in tSCI polytrauma patients (without life-threatening conditions or after cardiorespiratory stabilization), to perform spine magnetic resonance imaging (MRI) after spinal specialist consultation to determine the severity of spinal cord damage and aid in surgical decision making (agreement: 95.5%, *strong* recommendation).



**Fig. 1** Consensus flowchart. (1) intubation, mechanical ventilation, hemodynamic support, extraspinal surgery/interventional radiology for bleeding control, etc. (2) In case of difficult intraoperative bleeding control, lower values could be tolerated for the shortest possible time. (3) higher values in patients "at risk" (e.g., elderly and/or with limited cardiovascular reserve because of pre-existing heart disease, etc.). (4) if available (e.g., TEG, ROTEM, etc.). (5) as utilized in NABISC I-III studies. (6) in order to determine the severity of spinal cord damage and aid in surgical decision making. (7) decompression and/or stabilization. tSCI=Traumatic spinal cord injury, CT=Computed tomography, MRI=Magnetic resonance imaging, MAP=Mean arterial pressure, Hb=Hemoglobin, PaO<sub>2</sub>=Arterial partial pressure of oxygen, PaCO<sub>2</sub>=Arterial partial pressure of carbon dioxide, PLT=Platelet, PT=Prothrombin time, aPTT=Activated partial thromboplastin time, POC=Point-of-care, P=Plasma, RBC=Red blood cell, MT=Massive transfusion, DVT=Deep vein thrombosis, IPCD=Intermittent pneumatic compression device

**Recommendation 5**

We recommend, in all salvageable tSCI polytrauma patients with surgical spinal lesions, after control of life-threatening conditions, to consider an urgent intervention (decompression/spine stabilization), possibly within 24 h from trauma (agreement: 92%, strong recommendation).

**Recommendation 6**

We recommend the maintenance of a mean arterial pressure (MAP)>85 mmHg during interventions for life-threatening hemorrhage or emergency spinal surgery. In case of difficult intraoperative bleeding control, lower values could be tolerated for the shortest possible time (agreement: 88.6%, strong recommendation).

**Recommendation 7**

We recommend that the hemoglobin (Hb) level, during interventions for life-threatening hemorrhage or emergency spinal surgery, be adjusted according to patient's tolerance to anemia. An Hb<7 g/dl should promptly

trigger red blood cell transfusions (RBCTs). A higher threshold for RBCTs could be used in patients "at risk" (e.g., elderly and/or with limited cardiovascular reserve because of pre-existing heart disease, etc.) (agreement: 92%, strong recommendation).

**Recommendation 8**

We recommend the maintenance of an arterial partial pressure of oxygen (PaO<sub>2</sub>) between 60 and 100 mmHg (7.9–13.3 kPa) during interventions for life-threatening hemorrhage or emergency spinal surgery (agreement: 93.2%, strong recommendation).

**Recommendation 9**

We recommend the maintenance of an arterial partial pressure of carbon dioxide (PaCO<sub>2</sub>) between 35 and 40 mmHg (4.7–5.3 kPa) during interventions for life-threatening hemorrhage or emergency spinal surgery (agreement: 93.2%, strong recommendation).

**Recommendation 10**

In case of interventions for life-threatening hemorrhage, we recommend the maintenance of a platelet (PLT) count  $>50.000/\text{mm}^3$ . In the case of spinal surgery (decompression/stabilization), a higher value ( $75.000\text{--}100.000/\text{mm}^3$ ) would be advisable (agreement: 93.2%, *strong* recommendation).

**Recommendation 11**

We recommend the maintenance of a prothrombin time (PT)/activated partial thromboplastin time (aPTT) value  $<1.5$  normal control during interventions for life-threatening hemorrhage or emergency spinal surgery (agreement: 92%, *strong* recommendation).

**Recommendation 12**

We recommend, if available, the utilization of point-of-care (POC) tests [e.g., thromboelastography (TEG), rotational thromboelastometry (ROTEM), etc.] to assess and optimize the coagulation function during interventions for life-threatening hemorrhage or emergency spinal surgery (agreement: 84.1%, *weak* recommendation).

**Recommendation 13**

We recommend the early reversal of anticoagulant/antiplatelet agents in all salvageable tSCI polytrauma patients needing interventions for life-threatening hemorrhage or emergency spinal surgery (agreement: 92%, *strong* recommendation).

**Recommendation 14**

In adult patients with tSCI and polytrauma, we recommend the transfusion of RBCs/Plasma/PLTs at a ratio of 1/1/1 during massive transfusion protocol initiation. Afterward, this ratio can be modified according to laboratory values (agreement: 94.3%, *strong* recommendation).

**Recommendation 15**

We recommend against high-dose corticosteroid therapy (i.e., National Acute Spinal Cord Injury Study (NASCIS) I-III [10–12]) in tSCI patients and polytrauma (agreement: 89.8%, *strong* recommendation).

**Recommendation 16**

We recommend deep vein thrombosis (DVT) prophylaxis with intermittent pneumatic compression devices (if available and feasible) as soon as possible after tSCI and polytrauma (agreement: 94.3%, *strong* recommendation).

**Recommendation 17**

We recommend a strict collaboration between the 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 (agreement: 98.9%, *strong* recommendation).

**Discussion****Cardiorespiratory management and bleeding control in tSCI polytrauma patients**

Life-threatening hemorrhage is a major preventable cause of early death after trauma [13]. Bleeding control with circulating blood volume restoration is a priority in polytrauma care and the main goal of damage control strategies [14, 15]. Arterial hypotension and hypoxia are frequently observed after isolated tSCI, especially when the injury occurs at high spinal cord levels [1]. These secondary insults, associated with an unfavorable neurological outcome, may occur further in severe polytrauma patients [1, 3]. The most recent guidelines by the Congress of Neurological Surgeons (CNS) for managing tSCI patients recommend maintaining MAP between 85 and 90 mmHg for the first 7 days following an acute cervical SCI (Level III) [16]. These values are difficult to obtain in the acute phase management of bleeding polytrauma patients, also considering the worldwide increase in the utilization of permissive hypotension in the setting of damage control resuscitation [14]. Considering the above, we recommend the maintenance of a MAP  $>85$  mmHg during interventions for life-threatening hemorrhage or emergency spinal surgery. However, in case of difficult intraoperative bleeding control, we suggest tolerating lower values for the time strictly necessary to achieve bleeding control. Some panelists suggested individualizing an arterial pressure target, considering the spinal cord perfusion pressure (SCPP) [17]. To obtain this, it is necessary to monitor the intraspinal pressure (ISP) by surgically implanting an intradural extramedullary probe at the injury site [17]. Increased SCPP is associated with decreased spinal cord ischemia and favorable neurological outcomes [18–22]. At present, more data are necessary to spread this promising type of monitoring into daily clinical practice. Data about optimal Hb values in tSCI are lacking [16, 23]. We recommend RBCTs in case of  $\text{Hb} < 7$  g/dl according to current guidelines [8, 24] and the tolerance to anemia; in this regard, a higher Hb threshold could be used in patients "at risk" (e.g., elderly and/or with limited cardiovascular reserve because of pre-existing heart disease, etc.). As for Hb values, data regarding optimal  $\text{PaO}_2$  and  $\text{PaCO}_2$  targets in this setting

are lacking. Our recommendations are probably influenced by what is suggested in patients with acute brain damage [25].

### Imaging and spinal surgery timing

Whole-body CT scan can be considered a crucial standard diagnostic tool in the acute management of severely injured patients [26, 27]. CT scan is also recommended as the initial imaging modality evaluation of tSCI [28, 29]. Spine reconstruction from a whole-body CT scan can be quickly obtained, limiting the waste of time in the potentially challenging polytrauma setting [30]. Precisely, for the cervical spine, the appropriate standard is a thin slice helical CT scan from the base of the skull to at least the first thoracic vertebra (T1) with both sagittal and coronal reconstructions [30]. This examination should be undertaken as standard practice with the first CT brain scan in all head-injured patients with an altered level of consciousness [30]. The remaining thoracic and lumbar spine may be adequately imaged by sagittal and coronal reformatting of helical CT scans of the chest, abdomen and pelvis as part of a modern CT trauma series [30]. CT provides important information regarding bone pathology (e.g., fractures), disk herniations and epidural/subdural hematomas [28–30]. MRI, allowing a precise evaluation of the spinal cord and related soft tissues, is considered the imaging modality of choice for the evaluation of tSCI patients and for the decision of final neurosurgical/spinal treatment [30, 31]. Recent guidelines suggest MRI examination: (a) before surgical intervention, when feasible, to facilitate improved clinical decision making (Quality of Evidence: Very Low, Strength of Recommendation: Weak) and (b) in the acute period following SCI, before or after surgical intervention, to improve prediction of neurological outcome (Quality of Evidence: Low Strength of Recommendation: Weak) [31]. MRI requires more time from execution with respect to CT scan and can be challenging in cardiorespiratory unstable polytrauma patients. Precise MRI indications and timing in tSCI patients are not clearly defined, and in this regard, more studies are necessary. In the meantime, we recommend performing spine MRI after cardiorespiratory stabilization and spinal specialist consultation to determine the severity of spinal cord damage and aid in surgical decision making. Early decompressive surgery (performed within 24 h from trauma) seems to be associated with better neurological outcomes, highlighting the concept of “time is spine” [32–34]. A more rapid approach (within 12 h or less—“ultra-early”) was also proposed, especially in the case of incomplete spinal lesion [34]. Recent guidelines suggest early surgery (<24 h after injury) as a treatment option for adult acute SCI patients, regardless of level (Quality of Evidence: Low. Strength of

Recommendation: Weak) [35]. Some panelists suggest a wider timing in case of spinal fracture needing surgical stabilization in the absence of neural compression. The optimal timing of spinal surgery in tSCI polytrauma patients must be established and probably individualized according to clinical needs and after intracranial, hemodynamic and respiratory stabilization.

### Coagulation management

In bleeding polytrauma patients, an attempt is generally made to maintain PT/aPTT < 1.5 times the normal control and the PLT count > 50,000/mm<sup>3</sup> [31]. A PLT count > 100,000/mm<sup>3</sup> was recommended for patients with ongoing bleeding and/or TBI and in the case of neurosurgery [24, 36]. POC tests (i.e., TEG, ROTEM, etc.) are increasingly used to evaluate coagulation function in bleeding trauma patients [24]. These tests are useful for a rapid and precise assessment of hemostasis and to provide critical information about specific coagulation deficiencies, especially in patients taking novel oral anticoagulants (NOACs) and in the evaluation of PLTs dysfunction induced by trauma and/or drugs [24]. Several published guidelines about the reversal of anticoagulant/antiplatelets in different settings are available; these, especially regarding antiplatelet drug reversal, provide conflicting indications [24, 37–39]. To our knowledge, no specific guidelines about coagulation management in tSCI patients have been published until now. More studies are needed to provide robust recommendations in this setting. Meanwhile, we recommend the early reversal of anticoagulant/antiplatelet agents in tSCI polytrauma patients needing interventions for life-threatening hemorrhage or emergency spinal surgery. Massive transfusion is frequently utilized in bleeding trauma patients [14, 40]. The pragmatic randomized optimal platelet and plasma ratios (PROPPR) study, involving 680 trauma patients with major bleeding, was performed to determine the safety and the effectiveness of a transfusion strategy involving plasma, PLTs and RBCs in a 1:1:1 ratio compared with a 1:1:2 ratio. None of the studied strategies resulted in significant differences in mortality. However, patients in the 1:1:1 group achieved hemostasis with fewer deaths due to exsanguination within the first 24 hours [41]. Some of our panelists suggest, as an alternative to this strategy, the utilization of whole blood transfusion as indicated in a recently published clinical protocol for damage control resuscitation by the American Association for the Surgery of Trauma (AAST) and the American College of Surgeons Committee on Trauma (ACS-COT) [14]. No data are available regarding trauma coagulopathy and the progression of tSCI. Therefore, we recommend initiating a transfusion protocol of RBCs/plasma/PLTs at a ratio of 1:1:1. This ratio



may be modified afterward according to laboratory values. Patients with SCI are at increased risk of developing venous thromboembolism after trauma [42]. Early initiation of mechanical thromboprophylaxis with intermittent pneumatic compression was recommended in immobile trauma patients with elevated bleeding risk [24, 43]. In this regard, we recommend DVT prophylaxis with intermittent pneumatic compression devices (if available and feasible) as soon as possible after tSCI and polytrauma. The initiation of pharmacologic DVT prophylaxis should be considered within 48 h of injury or spine surgery, as suggested by recent published guidelines [43].

### Corticosteroid therapy

The utilization of corticosteroid therapy with methylprednisolone sodium succinate (MPSS) after tSCI is a highly debated and controversial topic [2, 7, 10–12]. Specifically, CNS guidelines do not recommend its use [44], whereas AO spine guidelines suggest: (1) “not offering a 24-h infusion of high-dose MPSS to adult patients who present after 8 h with acute SCI”; (2) “a 24-h infusion of high-dose MPSS to adult patients within 8 h of acute SCI as a treatment option” and (3) “not offering a 48-h infusion of high-dose MPSS to adult patients with acute SCI” [45]. We strongly recommend against routine high-dose corticosteroid therapy as proposed in NASCIS I-III studies [10–12]. Some panelists are in favor of the use of corticosteroids at lower doses or in certain patients who may have a favorable risk/benefit ratio. This topic requires further studies, especially in a challenging scenario such as tSCI in polytrauma.

### Notes on the use of the current consensus

This consensus aims to support clinicians’ decision making in the early management of tSCI patients with polytrauma in the first 24 h after injury. The included statements are created to assist a physician’s clinical judgment, which is necessary to provide appropriate (personalized) therapy. Considering the lack of high-quality studies in this setting, we adopted a modified Delphi approach involving experts from different countries worldwide; this approach is less rigorous than evidence-based guidelines. However, our methodology can provide useful and practical recommendations for this challenging clinical scenario. The guidelines promulgated in this work do not represent a standard of practice and have no legal implications. They are suggested plans of care based on the best available evidence and the consensus of experts, but they do not exclude other approaches as being within the standard of practice. Ultimately, responsibility for treatment results rests with those directly engaged therein and not with the consensus group. Moreover, as recommended, we think that a strict collaboration between different medical specialties (i.e., a

multidisciplinary approach) is of paramount importance for improving the outcome of these patients. This aspect is of great importance not only in the first 24 h after trauma but also in the long-term care (i.e., high-quality neurorehabilitation).

### Conclusion

In the future, more studies should be encouraged to improve clinical outcomes for polytrauma patients with tSCI. This international multidisciplinary consensus conference was created to provide practical recommendations to deliver the best early possible care for tSCI polytrauma patients in the first 24 h after injury.

### Abbreviations

|                   |   |
|-------------------|---|
| SCI               | Spinal cord injury                                      |
| tSCI              | Traumatic spinal cord injury                            |
| WSES              | World Society of Emergency Surgery                      |
| EANS              | European Association of Neurosurgical Societies         |
| TBI               | Traumatic brain injury                                  |
| CT                | Computed tomography                                     |
| MRI               | Magnetic resonance imaging                              |
| MAP               | Mean arterial pressure                                  |
| Hb                | Hemoglobin  |
| RBCT              | Red blood cell transfusion                              |
| PaO <sub>2</sub>  | Arterial partial pressure of oxygen.                    |
| PaCO <sub>2</sub> | Arterial partial pressure of carbon dioxide.            |
| PLT               | Platelet  |
| PT                | Prothrombin time  |
| aPTT              | Activated partial thromboplastin time.                  |
| POC               | Point-of-care   |
| TEG               | Thromboelastography                                     |
| ROTEM             | Rotational thromboelastometry                           |
| NASCIS            | National acute spinal cord injury study                 |
| DVT               | Deep vein thrombosis                                    |
| CNS               | Congress of neurological surgeons                       |
| SCPP              | Spinal cord perfusion pressure                          |
| ISP               | Intraspinal pressure                                    |
| T1                | First thoracic vertebra.                                |
| NOAC              | Novel oral anticoagulant                                |
| PROPPR            | Pragmatic randomized optimal platelet and plasma ratios |
| AAST              | American Association for the Surgery of Trauma          |
| ACS-COT           | American College of Surgeons Committee on Trauma        |
| DVT               | Deep vein thrombosis                                    |
| MPSS              | Methylprednisolone sodium succinate                     |

### Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13017-023-00525-4>.

**Additional file 1: Appendix 1.**

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### Author contributions

EP, AKD, CR and FC have designed the study. CR has performed acquisition of data. CR has done the analysis and interpretation of data. EP, AKD, CR and FC have drafted the article. All authors have revised it critically for important intellectual content. All authors have given final approval of the version to be submitted.

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**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations****Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

AWK serves as the PI of the COOL trial, which previously was partially supported by the 3M/Acelity Corporation until August 2022. AWK is also a member of the Canadian Forces Medical Services and has consulted for the 3M/Acelity Corporation, Zoll Medical, Innovative Trauma Care and CSL Behring. AWK is the Director of the TeleMentored Ultrasound Supported Medical Interventions (TMUSMI) Research group and serves in the Canadian Forces Medical Services. IH receives funding from the Finnish Medical Foundation, the Päivikki and Sakari Sohlberg Foundation, the Paulo Foundation and the Finnish Cultural Foundation. PJH is supported by the UK NIHR-Senior Investigator Award, Cambridge BRC, Brain Injury Medtech Co-operative, Global Health Research Group on Acquired Brain and Spine Injury and the Royal College of Surgeons of England.

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