PERIODICUM BIOLOGORUM
VOL. 127, No 1–2, 101–106, 2025
DOI: 10.18054/pb.v127i1-2.36112

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Review article

Extubation of patients with cervical spine injury

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Keywords: cervical vertebrae; spinal cord injuries; airway extubation

Abbreviations

ASIA	– American Spinal Injury Association
CSI	– cervical spine injury
DAS	– Difficult Airway Society
ED	– emergency eepartment
FiO_2	– fraction of inspired oxygen
ICU	– intensive care unit
MV	– mechanical mentilation
NAP	– National Audit Project
NEISS	– National Electronic Injury Surveillance System
p_aO_2	– partial pressure of oxygen in the arteries
p_aCO_2	– partial pressure of carbon dioxide in the arteries
RSBI	– Rapid Shallow Breathing Index
SCI	– Spinal Cord Injury

Received April 17, 2025
Revised July 6, 2025
Accepted July 7, 2025

Abstract

Background and purpose: *Extubation in patients with cervical spine injury (CSI) is a high-stakes clinical intervention, requiring a nuanced understanding of spinal pathophysiology, respiratory mechanics, and risk mitigation strategies. This review synthesizes the current evidence on the demographics, injury mechanisms, and extubation risks associated with CSI, highlighting the complexities that arise from associated spinal cord injuries, diaphragmatic dysfunction, and airway instability.*

Results: *Epidemiological data reveal a bimodal age distribution and an increasing incidence of CSI due to falls, especially among the elderly. The anatomical vulnerability of the cervical spine and the two-phase pathophysiology of spinal cord injury—primary mechanical insult and secondary inflammatory cascades—complicate respiratory management and timing of extubation. Patients with CSI often face unique extubation challenges, including impaired airway reflexes, agitation, and upper airway edema. Existing guidelines, such as those from the Difficult Airway Society, underscore the need for high-risk extubation protocols, emphasizing preparedness, appropriate sedation, and airway reflex control strategies like remifentanil infusion or delayed extubation in select cases. Several predictors of extubation failure in patients with CSI have been investigated, such as prolonged surgery, vertebral level involvement and blood loss.*

For ventilator-dependent tetraplegic patients, individualized weaning strategies based on neurological and diaphragmatic function are crucial. The use of adjuncts like cough-assist devices post-extubation is essential for airway secretion clearance.

Conclusion: *Safe extubation in CSI patients demands a multidisciplinary, protocol-driven approach tailored to individual pathophysiological and surgical risk profiles.*

INTRODUCTION

Extubation of patients with cervical spine injury presents a complex challenge requiring extensive knowledge in both mechanical ventilation and the specific pathophysiologic features of cervical spine injuries (CSI), both with and without spinal cord involvement.

The aim of this literature review is to present the available evidence regarding the timing, risks and interventions to maximize the safety of extubation in this sensitive and specific patient population.

MATERIALS AND METHODS

A literature search was conducted using the MEDLINE (PubMed), Scopus, Google Scholar and Web of Science databases. The following search terms and combinations thereof were used: "cervical vertebrae"; "spinal cord injuries"; "airway extubation".

Research papers were included in this narrative review if they presented original research pertaining to the topic. Relevant professional society guidelines were included and cited in sections regarding practice recommendations. Textbook chapters and review articles were cited in sections describing injury mechanisms and anatomical relationships. Among the screened papers, 37 were included and cited in this narrative review on the basis of the above-mentioned criteria and relevance to the topic.

Demographics of cervical spine injury

To properly discuss the management of extubation in patients with CSI, it is important to be acquainted with the basic demographics of this severe clinical condition. A study by Futch et al., analyzing data from the National Electronic Injury Surveillance System (NEISS) database on 11,822 patients with CSI during a 20-year period (2002 to 2022) demonstrated several significant trends that may be of interest to the reader *(1)*. Firstly, patients suffering from CSI were mostly middle aged to elderly, with the mean patient age being 62.4 years. The male to female ratio was close to 1:1 with 52.4% of patients being male. There was a significant gap in patient age when grouping patients by gender, with male patients being significantly younger. The authors divided the injuries by anatomical location, grouping all injuries affecting the C1 to C3 vertebrae into "upper" and those affecting the C4 to C7 vertebrae into "lower" CSI - about half of the patients had upper CSI, 42% had lower CSI, while the rest had a combination of both upper and lower CSI. Patients with upper CSI were significantly older, more likely to be female and more often required transfer to a higher acuity or specialty care center, while being significantly less likely to be discharged from the Emergency Department (ED).

In general, the available epidemiological evidence displays two important and significant peaks in the incidence of CSI - male patients in the second and third decades of life and female patients older than 65 years of age *(2)*.

Regarding the cause of injury, while earlier records implicated motor vehicle collisions and sports injuries as the two major causative mechanisms, recent literature attributes a large majority of observed and treated CSIs (46% to 83%, depending on the source) to falls *(1,3)*. The proposed reason behind this change is the significant increase in the proportion of the elderly in the global population, especially in the Western world. The increased incidence of falls in the elderly is attributed to diminishing bone quality and the presence of multiple medical comorbidities such as poor vision, loss of proprioception, diabetes, syncope, and medication side effects *(1)*.

Pathophysiology of cervical spine injuries

Anatomical and biomechanical studies have repeatedly demonstrated an inherent bony instability of the cervical spine, accompanied by an overreliance on ligamentous structures for stability. The combination of these factors makes the cervical spine prone to injury following a traumatic event *(4)*. The primary external forces that can be applied to the cervical spine are flexion, extension, compression, shear, and rotation. When applied in tandem, these forces can be magnified to a degree causing significant injury *(5)*. According to the main causative force of the injury, CSIs are typically divided into flexion, extension, axial compression and distraction injuries *(6)*. All of the mentioned injury types can lead to spinal cord injury (SCI) with varying incidences, depending on the degree of injury and the magnitude of the causative force applied to the cervical spine. If an SCI occurs following cervical spine trauma, it most usually develops through two distinctive stages. The primary injury is a result of the mechanical forces applied to the spinal cord at the time of a traumatic event and is caused by displaced bone fragments, disc materials, or ligaments bruising and tearing into the spinal cord tissue *(7)*. Four main characteristic mechanisms of primary injury have been identified: impact plus persistent compression, impact alone with transient compression, distraction and laceration/transection *(8)*. The most common form of primary injury is impact plus persistent compression, typically occurring due to bone fragments compressing the spinal cord or through fracture-dislocation injuries *(9)*.

The mechanism and extent of the primary injury play a major role in both the severity and prognosis of long-term outcomes of an SCI *(10)*. Secondary injury is defined as a result of a series of cellular, molecular and biochemical phenomena that continue to damage spinal cord tissue and impede neurological recovery following SCI *(11)*. The mechanisms of secondary injury include vascular damage, ionic imbalance, neurotransmitter accumulation (excitotoxicity), free radical formation, calcium influx, lipid peroxidation, inflammation, edema, necrotic cell death (acute phase), apoptosis, demyelination of surviving axons, Wallerian degeneration, axonal dieback, matrix remodeling, evolution of a glial scar around the injury site (subacute phase), formation of a cystic cavity, progressive axonal die-back, and maturation of the glial scar (chronic phase)*(12,13)*. The secondary injury usually begins minutes to hours following the primary injury and continues for weeks or months *(11)*. Neurological outcomes of an SCI are generally determined at 72 hours after injury using the American Spinal Injury Association (ASIA) scoring system *(14)*. Patients afflicted with an SCI often experience a certain degree of spontaneous recovery of sensory and motor functions. It has been observed that most of the recovery occurs during the first 90 days following the primary injury and plateaus by the 9th month post-injury. Long-term outcomes are dependent on the level of the SCI, the mechanism and severity of the primary injury and the progression of the secondary injury *(15).* Patients afflicted with an SCI often experience a certain degree of spontaneous recovery of sensory and motor functions. It has been observed that most of the recovery occurs during the first 90 days following the primary injury and plateaus by the 9th month post-injury. Long-term outcomes are dependent on the level of the SCI, the mechanism and severity of the primary injury and the progression of the secondary injury. Due to the high anatomical level of injury, cervical SCI may present with tetraplegia (partial or total loss of sensory or motor function in all four limbs). Tetraplegia itself can be either incomplete or complete, with the incomplete variant associated with better functional outcomes and recovery at multiple levels below the lesion within 12 months from the injury. Patients with complete tetraplegia often (66-90%) regain function at one level below the injury *(16).*

Specific to cervical SCI is diaphragmatic dysfunction, which presents because of a loss of innervation from the phrenic nerve *(17).* Following the onset of diaphragmatic dysfunction, several changes in respiratory physiology, including increased airway secretions, changes in lung and chest wall mechanics, and reduced abdominal muscle activity may impair ventilation and complicate the weaning and extubation processes *(18).* There is also a significant decrease in the patient's ability to clear airway secretions due to a weakened cough *(19).* Although there is a paucity of data on the rates of functional recovery of the diaphragm following cervical SCI in human patients, data on rats with unilateral cervical SCI demonstrates a spontaneous recovery rate of around 40% by 2 weeks post injury *(20).*

Risks of extubation

While safe endotracheal intubation is a matter of both intense debate and research interest in patients with cervical spine injuries, reflected by the recent publication of the multi-society Guidelines for airway management in patients with suspected or confirmed cervical spine injury, spearheaded by the Difficult Airway Society (DAS) *(21),* there is not much data on best evidence practices for safe extubation in this patient population. One possible explanation is the fact that most of the patients whose data and outcomes are available in the literature are acute trauma patients, in whom the cervical spine is usually either "cleared" by preoperative computed tomography or confirmed as injured (in which case they most often undergo spinal fixation, following which the risk of cervical spine injury on extubation is significantly reduced). Still, even in patients without CSI, extubation presents an important area of clinical management, with a potentially high risk of periprocedural adverse events. This risk is well established in the available literature, with Cook et al noting in their National Audit Project 4 (NAP4) report that 28% of all of the observed serious adverse events related to airway management occurred during the extubation and recovery phases of anesthesia *(22).* Recognition of extubation as a potentially high-risk procedure is also reflected by the publication of the Difficult Airway Society Guidelines for the management of tracheal extubation in 2012 (23).

All of the general principles outlined in the DAS guidelines and NAP4 recommendations regarding preparedness, equipment, human factors, proper planning and risk factor optimization, apply to the management of patients with cervical spine injury. It is important to note that, due to either cervical spine fixation postoperatively, or cervical spine immobilization with a collar, all patients with CSI are categorized into the "restricted airway access" group according to the DAS guidelines and therefore have to be managed using the DAS "high risk extubation" algorithm *(23).*

There are several important patient-related factors to be mindful of when planning a safe extubation of the patient with cervical spine injury. In order to achieve and maintain adequate cervical spine immobilization during extubation, it is necessary to be mindful of the possible patient-related complication that may complicate the process. These are, in no particular order: airway complications following extubation (laryngospasm, upper airway collapse), patient agitation (due to pain, hypoxia, hypercapnia etc.) and activation of protective airway reflexes caused by the presence of the endotracheal tube and emergence from anesthesia. The incidence of agitation on emergence is estimated between 3 and 6% in adult patients and therefore presents a significant risk factor with the potential to severely compromise the safety of the extubation process *(24).* Risk factors for agitation include musculoskeletal or abdominal surgery, preoperative use of benzodiazepines, long duration of surgery, high postoperative pain scores and patient age <40 and >64 years *(25).*

In patients requiring prolonged mechanical ventilation in the Intensive Care Unit (ICU), diaphragmatic dysfunction caused by positive pressure ventilation may present an obstacle to the achievement of spontaneous ventilation by the patient. In a study evaluating diaphragmatic function before, during and after prolonged positive pressure mechanical ventilation (MV) using ultrasound in patients with CSI, Statsenko et al. found that ultrasonographic indicators of diaphragmatic function (diaphragmatic excursion and thickness) declined compared to baseline following the initiation of mechanical ventilation *(26).* The indicators remained on a trajectory of steady decline over the first 3 days on MV, returning to baseline by the 5th day and exceeding initial values by the 10th day. This dynamic is important in order to properly time the transition to spontaneous ventilation with minimal complications, which is a crucial prerequisite to successful extubation.

Maximizing extubation safety

Having discussed the most common complicating factors for safe extubation, more attention can be paid to the technical management of each. Management of agitation on emergence should be focused on prevention where possible (avoiding preoperative benzodiazepines, providing adequate pain control) and providing prompt sedation in the case of unexpected emergence agitation. Sedation of unexpected emergence agitation can be achieved using intravenous fast-acting benzodiazepines (e.g. midazolam) or haloperidol, taking into account their potential for reducing the patient's respiratory drive.

In the ICU, a safer, more adequately tailored sedation prior to extubation can be achieved using propofol or dexmedetomidine infusions. A study by Reade et al randomized 74 ICU patients in whom extubation was considered inappropriate because of the severity of agitation and delirium to receive either standard care or standard care plus a dexmedetomidine infusion (up to 1.5 μg/kg/h). Patients who received dexmedetomidine had a significantly lower time to extubation (21 vs 43 hours) (27).

Another risk factor is the resurgence of the patient's airway protection reflexes following a sedation hold or emergence from general anesthesia. There are several different strategies to suppress these reflexes, with the DAS extubation guideline suggesting one of the two: remifentanil infusion and/or use of a laryngeal mask exchange technique *(23).* Remifentanil has been shown to significantly reduce the activation of airway reflexes on extubation if infused in the periextubation period, minimizing straining, coughing and agitation *(28).* While the laryngeal mask exchange technique provides a smoother, less irritating emergence for the patient, it does not provide adequate protection against aspiration and is therefore not viable in emergency procedures (which most of the trauma cases, including CSI, are).

Regarding the risk of upper airway collapse or laryngeal edema, there are conflicting opinions and sparse evidence regarding the optimal timing for extubation following cervical spine surgery. Sagi et al. analyzed data on 311 patients who had undergone anterior cervical spine surgery. In their cohort, 6.1% of patients had an airway complication post-extubation and 1.9% required reintubation, with the average time of symptom onset being 36 hours postoperatively. An exceedingly large majority of the complications were attributable to pharyngeal edema. Patients in whom more than three vertebral bodies were exposed during surgery or had undergone exposures involving C2, C3 or C4 vertebrae had a significantly higher risk of developing airway complications. Patients who had undergone surgeries lasting longer than 5 hours or had lost more than 300 mL of blood intraoperatively were also at a significantly higher risk for airway complications *(29).* Kim et al conducted a similar analysis on 400 patients undergoing anterior cervical spine surgery. In their cohort, 2.75% of patients developed a postoperative airway complication. Intraoperative blood loss greater than 300 mL and operative time longer than 5 hours significantly correlated with a higher risk of developing an airway complication, as did higher patient age and the presence of diabetes mellitus *(30).* Suk et al analyzed serial X-rays (preoperatively, immediately postoperatively and for five consecutive postoperative days) of 87 patients who had undergone anterior cervical spine surgery. They noted prevertebral soft tissue swelling postoperatively, which peaked on the second and third postoperative day, with a gradual decrease after the fourth. In their cohort, only 1,1% of patients required reintubation due to prevertebral soft tissue swelling *(31).* Following the cited research, it may be prudent to decide on waiting for 36 hours in select patient groups burdened with one of the high-risk features listed before attempting tracheal extubation, especially if they underwent anterior approach cervical spine surgery. Another possible way of risk-stratification was described by De Bast et al., who attempted to use the endotracheal tube cuff leak test in order to stratify patients according to risk of laryngeal edema. In their cohort of 76 patients intubated for more than 12 hours, 11% required reintubation for laryngeal edema. Those who required reintubation had significantly lower cuff leak % values. Following the institution of the cut-off at 15.5% gas leak, 3% of patients in the high leak group and 24% of patients in the low leak group required reintubation. Their method was found to have a negative predictive value of 96.1% *(32).*

One final safety consideration pertains to patients on mechanical ventilation who are tetraplegic and/or have confirmed diaphragmatic dysfunction. While there is no true consensus nor a "one size fits all" approach on the exact thresholds for weaning patients from mechanical ventilation, there are approximate reasonable values often used in clinical practice for the general population (for example, but not limited to – partial pressure of oxygen in the arteries (p_aO_2) > 80mmHg with fraction of inspired oxygen (FiO_2) 0.4; partial pressure of carbon dioxide in the arteries (p_aCO_2) <45mmHg, Rapid Shallow Breathing Index <105 beats/min/L, minute ventilation <10L/min and vital capacity >10mL/kg) *(33).* On the other hand, there are no studies or clear clinical guidelines for weaning patients with cervical SCI off mechanical ventilation. Observational data indicates that success rates of weaning in tetraplegic patients are highly dependent on the level of the injury, with 15% success for C1 injuries, 28% for C2, 60% for C3 and 85% for C4 and below *(34).* There are different methods of evaluating readiness for weaning in this patient population, with both spirometry and electromyography shown as potential predictors *(35).* Still, the decision to wean is highly individualized and depends on a slew of different factors, among which are the level of the cervical SCI and the degree of the diaphragmatic dysfunction (which can be reliably and serially evaluated using ultrasound) *(36).* Following successful weaning and extubation, in patients with residual diaphragmatic dysfunction, additional measures have to be taken in order to compensate for the weakened cough and impaired Valsalva maneuvers, most often in the form of providing the patient with a "cough assist" device to enable adequate secretion clearance during periods of upper respiratory tract infections *(37)*.

CONCLUSION

Extubation of patients with cervical spine injury is a high-risk, complex intervention requiring the integration of professional society guideline-directed care, careful consideration of patient-related risk and complexity factors and optimization of sedation and ventilation, along with the knowledge and awareness of potential early and late post-extubation complications.

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