Chapter

Prehospital and Emergency Room Airway Management in Traumatic Brain Injury

Dominik A. Jakob, Jean-Cyrille Pitteloud and Demetrios Demetriades

Abstract

Airway management in trauma is critical and may impact patient outcomes. Particularly in traumatic brain injury (TBI), depressed level of consciousness may be associated with compromised protective airway reflexes or apnea, which can increase the risk of aspiration or result in hypoxemia and worsen the secondary brain damage. Therefore, patients with TBI and Glasgow Coma Scale (GCS) ≤ 8 have been traditionally managed by prehospital or emergency room (ER) endotracheal intubation. However, recent evidence challenged this practice and even suggested that routine intubation may be harmful. This chapter will address the indications and optimal method of securing the airway, prehospital and in the ER, in patients with traumatic brain injury.

Keywords: prehospital, emergency room, endotracheal intubation, airway, outcomes, traumatic brain injury

1. Introduction

Traumatic brain injury (TBI) is frequently associated with depressed level of consciousness, compromised protective airway reflexes or apnea, which can increase the risk of aspiration or result in hypoxemia and worsen the secondary brain damage. Therefore, patients with TBI and Glasgow Coma Scale (GCS) ≤ 8 have been traditionally managed by prehospital or emergency room (ER) intubation. This practice is also reflected by the current guidelines: the American College of Surgeons Committee on Trauma Advanced Trauma Life Support (ATLS) recommends intubation for patients with a GCS of 8 or lower for airway protection [1]. Also, the practice management guidelines of the Eastern Association for the Surgery of Trauma give a level 1 recommendation for endotracheal intubation of patients with severe cognitive impairment (GCS ≤ 8) [2].

However, the potential benefit of an intubation in TBI, is also associated with risks: Difficult or failed endotracheal intubation may cause hypoxemia, aspiration, and hypotension and requires admission to the intensive care unit (ICU). In fact, there is no direct evidence supporting routine intubation of all patients with

a GCS ≤ 8. Consequently, recent evidence challenged the practice of a strict GCS threshold for intubation and even suggested that routine endotracheal intubation for GCS ≤ 8 in TBI may be harmful [3].

The primary goal in the prehospital care of the trauma patient is to secure adequate ventilation until transfer to hospital care. To achieve this goal, various techniques for airway establishment and subsequent ventilation can be performed: endotracheal intubation has been considered as the gold standard. However, ventilation may also be achieved by less invasive and time consuming procedures such bag-valve mask (BVM) ventilation with the optional use of oropharyngeal (OPA) or nasopharyngeal (NPA) adjuncts. More advanced techniques include supraglottic airway (SGA) devices. There is a wide range of medications available to facilitate intubation prehospital or in the ER.

To date, there are no evidence-based guidelines for TBI patients regarding standardized airway management in the prehospital setting or in the ER. This explains also why indications and techniques for airway establishment vary in different systems and countries around the world. In the United States of America (USA) prehospital care is usually provided by emergency medical technicians or trained paramedics, whereas prehospital care in most European countries is provided by physicians [4]. Following these differences of American and European Emergency Medical Service (EMS) systems, the US prehospital care strategy follows more "scoop and run approach" with prioritizing rapid patient transport to trauma centers. In Europe the priority lies more on field triage, on scene assessment and initiation of procedures such as intubation "stay and play approach" [5].

This chapter will address the question what airway management strategy best meet the patients need and is associated with most favorable outcomes in TBI. Indications and optimal method of securing the airway prehospital and in the ER will be discussed. In addition, technical aspects including medication for pretreatment, induction, paralysis and sedation for endotracheal Intubation in the presence of TBI will be outlined.

2. Prehospital airway management

Advanced prehospital care has been practiced for several decades in Western countries. In TBI particularly, prehospital airway management is one of the most critical aspects that determine patient outcomes. The importance of the airway management is reflected by the Advanced Trauma Life Support (ATLS) algorithm [1], in which the airway takes priority over any other therapeutic interventions.

General prehospital TBI guidelines [6] are emphasizing avoidance and treatment of hypoxia, prevention and correction of hyperventilation, and avoidance and treatment of hypotension. The implementation of these prehospital guidelines showed that adjusted survival doubled among patients with severe TBI and tripled in the severe, intubated cohort. Furthermore, guideline implementation was significantly associated with survival to hospital admission [7]. These findings support the widespread implementation of the prehospital TBI treatment guidelines. However, specific evidence-based guidelines are needed to establish the optimal airway management in the prehospital setting.

Patients require an advanced airway under two sets of circumstances: failure to maintain a patent airway and the inability to oxygenate and ventilate the patient adequately [8]. While endotracheal intubation in the OR is a very safe and

straightforward procedure with very low complication rate, emergency intubation of an unstable patient in the field is linked to a high rate of complication with up to 25% mortality in some studies. Emergency intubation remains a hazardous maneuver even under the best conditions. And no matter how skilled the prehospital team is, best conditions are seldom encountered in the field. This is why endotracheal intubation should ideally performed by skilled providers in patients who are likely to benefit from this technique. In a prehospital setting the indication to establish an airway is not always that obvious and depends on multiple factors **(Figure 1)** [9].

a. Severity of patients' condition and the presence of hypoxia: Traumatic brain injury (TBI) is frequently associated with depressed level of consciousness, compromised protective airway reflexes or apnea, which can increase the risk of aspiration or result in hypoxemia and worsen the secondary brain damage. During the past 45 years, the quantitative GCS as a simple and practical numeric method for assessing impairment of the level of conscious has become the universal criterion for mental status assessment [10]. Consequently, the GCS is also a frequently used score to decide whether an intubation should be performed or not. According to the ATLS [1] and the practice management guidelines of the Eastern Association for the Surgery of Trauma [2] intubation is recommended for GCS ≤8. However, there is no scientific evidence supporting this practice. The dogma that patients with a GCS ≤ 8 are at higher risk for aspiration or hypoxic injury has now been challenged. A prospective study from Hong Kong, in 2012, showed that of 33 patients with a GCS ≤ 8 36.4% had intact airway reflexes and potentially

Figure 1.
Prehospital airway-management. The indication to establish an airway in a prehospital setting depends on: the severity of patients' condition and the presence of hypoxia; the training and skills of the EMS personnel including the available equipment; and the safety and environment on scene. Figure provided by Clerc EMS Monthey, Switzerland.

capable of maintaining their own airway, whilst many patients with a GCS > 8 have impaired airway reflexes and potentially be at risk for aspiration [11].

The need for immediate establishment of an obstructed or impaired airway or hypoxia is unquestionably associated with better outcomes. However, performing an intubation in a suboptimal environment in the field, especially if performed by paramedics, may be challenging and require multiple attempts and in some cases may result in the loss of airway with catastrophic consequences. A difficult intubation may result in hypoxemia, aspiration, and hypotension, factors that may contribute to worse outcomes. Also, prehospital intubation and hand ventilation is often associated with hyperventilation and hypocapnia, which could worsen brain edema and secondary brain damage. Finally, prolonging the prehospital time and delaying definitive care, may have adverse effects on the patient, especially in the presence imminent herniation due to increased intracranial pressure (ICP) or an ongoing hemorrhage.
In conclusion, it is important to identify those patients who might benefit from prehospital endotracheal intubation and those who can potentially be harmed by the procedure. At this moment there is no class I evidence supporting any specific approach. It might be appropriate to attempt prehospital intubation in a small number of selected patients with imminent airway obstruction or hypoxia not responding to oxygen administration.

b. Training and skills of the EMS personnel and the available equipment: In the United States of America (USA) prehospital care is usually provided by emergency medical technicians for basic life support (BLS) or trained paramedics for advanced life support (ALS), whereas prehospital care in most European countries is provide by physicians. Basic providers are restricted to splinting, bandaging, alignment of displaced limbs, the administration of oxygen including BVM ventilation, chest compression and the use of an automated external defibrillator (AED) in case of cardiac arrest. However, especially in the USA many of BLS providers have obtained an intermediate level (EMT-I); these individuals can obtain a more definitive airway such as using a SGA device or even perform endotracheal intubation. Paramedics are trained and performed endotracheal intubation. However, very often many paramedics, especially in areas with no large trauma volumes may not use this skill very often and may become less competent with the procedure. On the other hand, especially an experienced physician proficient with endotracheal intubation, is more likely to perform an intubation more liberally, often unnecessarily. In the United States, prehospital care strategy follows the principle of "scoop and run" with prioritizing rapid patient transport to trauma centers and minimal interventions on scene. In Europe there is a strong element on field triage and initiation of more advanced therapeutic interventions, such as intubation. This prehospital strategy is also known as "stay and play". A matched cohort study compared patients with isolated severe TBI in Switzerland and the United States [12]. In line with the described differences in prehospital strategies, patients in Switzerland had significantly longer scene times (23 vs. 9 minutes, $p < 0.001$) and prehospital endotracheal intubation was more frequently performed (31% vs. 18.7%, $p = 0.034$). However, no significant differences in outcomes were observed between the two cohorts. The results what prehospital strategy should be prioritized and if an endotracheal intubation should be performed remain controversial, although there is evidence that a

"scoop and run" approach is preferable for penetrating trauma. In these scenarios the number of meaningful interventions that can be made by prehospital providers is limited and rapid transportation to the hospital is the most important aspect, because in-hospital surgery is typically needed for hemorrhage control.

c. Safety and environment on scene: The safety aspect on scene, as well as the transportation mode and the expected time to reach the next hospital are important for considering airway interventions on scene. Especially for longer transports, the time-saving aspect of the scoop and run approach without airway interventions becomes less important and early establishment of an airway may improve patient outcomes.

Considering all factors above, complexity of the decision to perform a prehospital intubation becomes obvious, and it is not surprising that the literature on this topic remains contradictory. A retrospective multicenter study including 13,625 patients with moderate to severe TBI showed that prehospital intubation was independently associated with a decrease in survival [13]. Several other studies implicated out-of-hospital intubation as a factor associated with negative outcomes [14, 15]. In a recently published study prehospital airway management in severe TBI patients did not have a significant impact on mortality or long-term neurological outcomes [16]. Other investigations have also demonstrated no difference or even improved outcomes with field intubation [17, 18].

Besides intubation, different other options for airway management are available in a prehospital setting. The simplest approaches such as the jaw thrust or chin lift maneuver are included in the first aid. Oropharyngeal (OPA) or nasopharyngeal (NPA) adjuncts may be inserted orally or nasally to secure an open airway. More advanced airway techniques include the establishment of an airway using an SGA device and finally the performance of endotracheal intubation. In particular cases, a surgical airway must also be considered. A major challenge in prehospital airway management is to determine the appropriate approach for the individual patient in the present environment and setting. **Table 1** shows various airway management techniques and summarizes advantages and disadvantages in prehospital use.

A recently published systematic review [19] was assessing comparative benefits and harms across three different airway management approaches (BVM, SGA, and endotracheal intubation) for patients with trauma, cardiac arrest, or medical emergencies requiring prehospital ventilatory support or airway protection. Overall, 99 studies involving 630,397 patients from 1990 to September 2020 were considered for analysis. The evaluated outcomes included mortality, neurological function, return of spontaneous circulation (ROSC), and successful advanced airway insertion. Different meta-analyses were stratified first by study design (RCTs or observational studies), and then by emergency type (cardiac arrest, trauma, medical) and population age (adult, pediatric, mixed-age). All meta-analyses outcomes were reported as favoring one of the two compared approaches, or no difference. Sufficient evidence was not available to address all outcomes and all patient characteristics, provider characteristics, and variations in techniques that were specified a priori. For adult trauma patients 1-month post incidence survival was not different when BVM was compared to endotracheal intubation. Other comparisons for adult trauma patients did not show sufficient evidence to favor an airway management strategy over another. Potential harms of airway management for the entire study population were also compared. When comparing BVM vs. SGA and BVM vs. endotracheal intubation, no difference

Airway management techniques	Skills	Training needed	Time needed	Possible complications	Level of sedation/ unconsciousness needed	Equipment needed	Protection against aspiration and airway shutdown	Ventilation possible without face mask
Manual	Trauma jaw thrust, trauma chin lift	+	+	–	+	–	–	–
Simple	Oropharyngeal airway, Nasopharyngeal airway	++	++	+	++	+	–	–
Advanced	Laryngeal mask, laryngeal tube	+++	++	+	++	++	(+)	++
Definitive airway	Endotracheal intubation, surgical airway	++++	++++	++++	++++	++++	++++	+++

Table 1.
Overview of different airway management techniques—advantages and disadvantages in prehospital use.

was found. When comparing SGA to endotracheal intubation, SGA was superior in terms of multiple insertion attempts; endotracheal intubation was superior in terms of inadequate ventilation. No difference was recorded for aspiration, oral/airway trauma and regurgitation. The authors concluded that the currently available evidence does not indicate benefits of more invasive airway approaches based on survival, neurological function, ROSC, or successful airway insertion. However, most included studies were observational. This supports the need for high-quality randomized controlled trials to advance clinical practice and EMS education and policy, and improve patient-centered outcomes.

3. Airway management in the ER

Similar to the prehospital setting the standard indications for an advanced airway establishment in the ER, include low GCS, failure to maintain a patent airway and the inability to oxygenate and ventilate the patient adequately. In the presence of a TBI a diminished level of consciousness with the concern for the loss of airway control is very common and likely the most frequent indication for ER intubation. Therefore, the GCS is most commonly used to decide whether an intubation should be performed or not.

Patients with TBI and a GCS ≤ 8 have been traditionally managed by ER endotracheal intubation. However, this practice is based mainly on expert opinion and long-standing dogma. There is very little evidence to support this policy! Recent work has challenged this practice! A recently published study including patients with isolated severe head injuries suggested that routine endotracheal intubation in the ER for GCS of 7 and 8 may be even harmful [3]. In this study 2727 patients with GCS 7/8 and isolated blunt head trauma were included. Overall, 1866 (68.4%) patients were intubated within 1 hour of admission (immediate intubation), 223 (8.2%) had an intubation >1 hour of admission (delayed intubation), and 638 (23.4%) patients were not intubated at all. After correcting for age, gender, overall comorbidities, tachycardia, GCS, alcohol, illegal drug use, and head injury severity, immediate intubation was independently associated with higher mortality (OR 1.79, CI 95% 1.31–2.44, $p < 0.001$) and more overall complications (OR 2.46, CI 95% 1.62–3.73, $p < 0.001$).

A study [20] evaluating a general trauma population with GCS of 6–8 came to a similar conclusion. An intubation within 1 hour of arrival was associated with an increase in mortality and longer ICU and overall length of stay compared to patients without an intubation. The authors also performed a subgroup analysis of patients with head injury and found similar results to that of the overall trauma population.

These two studies showing worse outcomes associated with immediate intubation and suggest that the existing GCS threshold to mandate intubation in patients with isolated head injuries should be revisited.

Beside the GCS, additional clinical criteria may help to guide the decision to intubate TBI patients in the future. A recently published study showed that head abbreviated injury scale (AIS), tachycardia and younger age were independent clinical factors associated with intubation [3]. These factors could potentially be taken into account to formulate a more selective approach to immediate intubation. In the mentioned study a policy of intubating all isolated blunt head injury patients ≤45 years with head AIS 5 and GCS 7 would have improved intubation management, with 7 immediate instead of delayed intubations and only three potentially unnecessary intubations. If these defined criteria are met (high specificity), an early

intubation should be strongly considered. On the other hand, the defined criteria are not suitable to identify patients who definitely do not require an intubation (low sensitivity). Future research should focus on defining more adequate clinical parameters to identify patients requiring immediate intubation and should avoid fixed GCS threshold.

Muakkassa et al. [21] compared trauma patients who were intubated because of combativeness, and not because of medical necessity. In line with the findings above intubating for combativeness was associated with longer hospital LOS, increased rates of pneumonia, and worse discharge status when compared with matched non-intubated patients. It appears that the risks and adverse events of intubation may outweigh the potential benefits of intubation in specific trauma populations.

Therefore, the following potential risks associated with intubation in TBI patients need to be considered by every health care provider. Laryngoscopy and the endotracheal tube can cause a sympathetic or parasympathetic stimulation. Sympathetic stimulation may increase heart rate, blood pressure [22] and ICP [23], whereas parasympathetic stimulation can trigger bronchospasm or hypotension. Especially the increase in ICP from the sympathetic surge can cause an increase in cerebral blood volume, cerebral edema, and development of worsening hemorrhage or hematoma. Finally, both, sympathetic and parasympathetic stimulations may increase mortality and brain injury.

Ventilation after intubation need to be monitored closely, because both hyper- and hypoventilation can contribute to worse outcomes. Severe hyperventilation (arterial pCO_2 below 25 mm Hg) should be avoided due to the risk of vasoconstriction and cerebral ischemia. In general, a normo-ventilation with an arterial pCO_2 within 35–45 mm Hg should be targeted. However, mild hyperventilation (arterial pCO_2 within 30–34 mm Hg) is commonly used to address high intracranial pressure and may potentially be beneficial [24]. More important to address the elevated ICP in TBI patients is the initiation of hyperosmolar therapy with mannitol or hypertonic saline when additional bleeding is suspected [25].

Technical aspects and medications for endotracheal intubation carries also risks for TBI patients. The following section gives an overview including recommendations for pretreatment, induction, paralysis, and sedation of patients with TBI to prevent secondary brain damage.

4. Technical aspects including medication for pretreatment, induction, paralysis and sedation for endotracheal intubation in the presence of TBI

Endotracheal intubation remains the gold standard for airway management in trauma patients and should be performed via the oral route and a manual in-line stabilization maneuver [26]. Rapid sequence induction (RSI) is widely used for emergency intubation and often considered as the gold standard for trauma patients. This technique uses a fast acting anesthetic in combination with a fast acting relaxant to achieve rapid intubation. Only a few people are aware that this technique was formally described by P. Safar back in 1970 [27]. The primary goal of this technique was to prevent regurgitation during induction of anesthesia in patients with bowel obstruction. Hypoxemia and hypotension were hardly considered at that time, when advanced monitoring and pulse oximetry were still tools of the future. From today's point of view, this technique is not ideally suited to prevent hypoxemia and hypotension. While in standard OR practice, such short events will hardly result in more than

a check on the Q/A sheet, they may have devastating consequences on outcomes in patients with TBI.

In addition, complication rate increases significantly with the number of intubation attempts, with a sharp increase if more than 2 attempts are needed [28]. This suggests that first pass success should be the gold standard in emergency intubation, and return to basic maneuvers or surgical airway should be considered if 2 attempts have failed.

Another important aspect is efficient airway clearance before intubation, which has been shown to significantly increase first pass success [29]. That is why suction of the airway, while having little relevance in the OR can be a game changer in emergency intubation.

Good oxygenation throughout the procedure is paramount in brain injured patients, so meticulous attention should be paid to optimizing precondition. A recent study [30] has shown that when intubation is attempted in a patient with a SpO_2 < 93%, there is almost 100% incidence of severe hypoxemia while incidence goes down to 17% if SpO_2 is 95% or more. While optimizing oxygenation status may take some time, it certainly pays off in terms of patient outcome.

Last but not least a close monitoring during intubation is mandatory. Studies have shown that episodes of hypoxemia during intubation attempts often go unrecognized, both in the field and in the ER. Furthermore, after intubation attention should be taken to avoid hyperventilation as it can cause hypocapnia and thus cerebral vasoconstriction; it also can impair venous return leading to hypotension. As trivial as it might seem, having a team member watching the vital signs is an important factor in the intubation process.

In the following section medication for pretreatment, induction, paralysis and sedation for endotracheal intubation in the presence of TBI are discussed.

There is currently no evidence to support the use of intravenous lidocaine as an intubation pretreatment for RSI in patients with TBI [23]. High-dose fentanyl (at 2–3 mcg/kg) can help to blunt the sympathetic stimulation of intubation and is currently recommended for neuroprotection in patients with increased ICP.

In TBI the induction with etomidate is popular all over the world because of its mild hemodynamic profile. Particularly, in TBI a drop in mean arterial pressure (MAP) and the subsequent decrease in cerebral perfusion pressure (CPP) may have devasting consequences. It's important to be aware that etomidate has no analgesic properties, and neuroexcitation may need to be addressed separately.

Ketamine for induction is a good option, with the additional benefit of analgesic properties. The concern of sympathetic stimulation, leading to an increase in ICP is no longer valid. On the contrary, ketamine may, in fact, be neuroprotective due to an increase in MAP and CPP [31], without an increase in cerebral oxygen consumption or reducing regional glucose metabolism [32]. Ketamine may best be used for induction in the presence of hypotension because of for the described effect of increasing MAP and CPP [33].

For paralysis succinylcholine or rocuronium can be utilized [34]. Succinylcholine, as a depolarizing neuromuscular blocking agent has the advantage of rapid onset and offset properties, which is beneficial in TBI patients regarding early neurological examinations. Rocuronium on the other hand can lead to delays in proper neurological examinations due to prolonged paralysis. A retrospective study of 2016 compared 233 TBI patients requiring intubation in the ER. RSI was either performed with succinylcholine or rocuronium. Overall mortality rate was similar between the two groups. However, for patients with a high head AIS score (4–6), succinylcholine was associated with increased mortality compared with rocuronium (44% vs. 23%, odds

ratio (OR) 4.10, 95% confidence interval (CI) 1.18–14.12; p = 0.026). Prospective studies are need to clarify these findings.

Propofol in TBI patients for post-intubation sedation is widely used and has the advantage of rapid onset of action and short duration of action. However, since it has no analgesic effect, it needs to be combined with medication for pain control. Furthermore, care should be taken in hypotensive patients because it may lower the MAP and subsequently the CPP. For post-intubation continuous sedation, a combination of propofol and fentanyl in the normotensive or hypertensive patient is therefore recommended. Fentanyl is a potent analgesia without appropriate sedation properties. While the hemodynamic properties of fentanyl are relatively stable, a decrease in MAP and HR frequently occur due to the cessation of the sympathetic stimulus triggered by pain. In addition, an increase in ICP has been described in several studies. A minimal appropriate dose for TBI patients is therefore recommended.

In hypotensive patients a combination of midazolam and fentanyl or ketamine alone is a good option. Midazolam as a sedative has the additional benefit of anxiolytic and anticonvulsant properties. Compared to propofol the effect on ICP and CPP are comparable. However, it's important to have in mind that the onset and offset action of midazolam is initially relatively fast but tissue accumulation over time may be associated with delayed awakening. This is particularly disadvantageous in patients with TBI, as rapid clinical assessment after cessation of the drug is wanted.

A relatively new approach for emergency intubation is the delayed sequence induction (DSI) technique described by Weingart and colleagues [35]. In contrast to RSI, the technique of delayed sequence intubation temporally separates administration of the induction agent from the administration of the muscle relaxant to allow adequate pre-intubation preparation. This technique uses ketamine sedation to optimize preoxygenation with CPAP or assisted ventilation before muscle relaxant is given and intubation performed. Recent studies have shown an improved safety profile in emergency intubation using this technique. A ketamine-only breathing intubation, in which ketamine is used without a paralytic is another promising alternative. In this case the patient continues to breathe spontaneously, while ketamine provide hemodynamic benefits compared to standard RSI and is also a valuable agent for post-intubation analgesia and sedation. When RSI is not an optimal airway management strategy, ketamine's unique pharmacology can be harnessed to facilitate alternative approaches that may increase patient safety [36].

5. Conclusion

Airway control is particularly important for patients with TBI because hypoxemia and hypercarbia may cause secondary brain damage.

In a prehospital setting the indication to establish an airway depends on multiple factors such as (a) severity of patients' condition including the presence of hypoxia, (b) the training and skills of the EMS personnel including the available equipment, (c) the safety and environment on scene.

In the presence of a TBI a diminished level of consciousness with the concern for the loss of airway control is very common and likely the most frequent indication for intubation. Traditionally patients with TBI and Glasgow Coma Scale (GCS) ≤ 8 have been managed by prehospital or ER endotracheal intubation. However, recent evidence challenged this practice and even suggested that routine intubation may be harmful. There is evidence that intubation according to a strict GCS threshold is associated with

risks and adverse events that may outweigh the potential benefits of intubation in TBI patients. Future research should focus on defining more adequate clinical parameters to identify patients requiring immediate intubation and should avoid fixed GCS threshold. Furthermore, less invasive airway management strategies such as BVM ventilation or the use of SGA devices may be equally effective and potentially associated with less complications. The cornerstone of prehospital airway management should focus on aggressive prevention and treatment of hypoxemia, hypotension, and, if the patient receiving positive pressure ventilation, prevention of hyperventilation. If an intubation is performed in a TBI patient induction with etomidate or ketamine in the presence of hypotension is recommended. For paralysis succinylcholine or rocuronium can be used. Recommendations for post-intubation continuous sedation medications include a combination of propofol and fentanyl in the normotensive or hypertensive patient. A combination of midazolam and fentanyl or ketamine alone should be considered in the hypotensive patient. Delayed sequence induction (DSI) or a ketamine-only intubation, in which ketamine is used without a paralytic are very promising options for emergency intubation and may become the standard of care in the future. The benefit of these strategies compared to RSI need to be confirmed in large randomized clinical trials.

Acknowledgements

We thank Clerc EMS Monthey, Switzerland for providing **Figure 1**.

Conflict of interest

The authors declare no conflict of interest.

Author details

Dominik A. Jakob[1,2], Jean-Cyrille Pitteloud[3] and Demetrios Demetriades[1*]

1 Division of Trauma and Surgical Critical Care, Department of Surgery, Los Angeles County + University of Southern California Medical Center, University of Southern California, Los Angeles, CA, USA

2 Department of Surgical Emergency Unit, Inselspital University of Bern, Bern, Switzerland

3 Hospital du Jura Bernois, Saint-Imier, Switzerland

*Address all correspondence to: demetrios.demetriades@med.usc.edu

References

[1] Henry SM. American College of Surgeons Committee on Trauma. Student course manual ATLS ® Advanced Trauma Life Support ®. 10th edn. Chicago, IL; 2018

[2] Mayglothling J, Duane TM, Gibbs M, McCunn M, Legome E, Eastman AL, et al. Emergency tracheal intubation immediately following traumatic injury: An Eastern Association for the Surgery of Trauma practice management guideline. Journal of Trauma and Acute Care Surgery. 2012;**73**(5 Suppl. 4):S333-S340. DOI: 10.1097/TA.0b013e31827018a5

[3] Jakob DA, Lewis M, Benjamin ER, Demetriades D. Isolated traumatic brain injury: Routine intubation for Glasgow Coma Scale 7 or 8 may be harmful! Journal of Trauma and Acute Care Surgery. 2021;**90**(5):874-879. DOI: 10.1097/TA.0000000000003123

[4] Oestern HJ, Trentz O, Uranues S. General trauma care and related aspects: Trauma surgery II. New York, NY: Springer; 2013

[5] Choi J, Carlos G, Nassar AK, Knowlton LM, Spain DA. The impact of trauma systems on patient outcomes. Current Problems in Surgery. 2021;**58**(1):100849. DOI: 10.1016/j.cpsurg.2020.100849

[6] Badjatia N, Carney N, Crocco TJ, Fallat ME, Hennes HM, Jagoda AS, et al. Guidelines for prehospital management of traumatic brain injury 2nd edition. Prehospital Emergency Care. 2008;**12**(Suppl. 1):S1-S52. DOI: 10.1080/10903120701732052

[7] Spaite DW, Bobrow BJ, Keim SM, Barnhart B, Chikani V, Gaither JB, et al. Association of statewide implementation of the prehospital traumatic brain injury treatment guidelines with patient survival following traumatic brain injury: The excellence in prehospital injury care (EPIC) study. JAMA Surgery. 2019;**154**(7):e191152. DOI: 10.1001/jamasurg.2019.1152

[8] Broderick ED, Sauerberg N, Reed JJ. EMS Pros And Cons Of Drug-Assisted Intubation. Treasure Island (FL): StatPearls; 2022

[9] Pepe PE, Roppolo LP, Fowler RL. Prehospital endotracheal intubation: Elemental or detrimental? Critical Care. 2015;**19**:121. DOI: 10.1186/s13054-015-0808-x

[10] Teasdale G, Maas A, Lecky F, Manley G, Stocchetti N, Murray G. The Glasgow Coma Scale at 40 years: Standing the test of time. Lancet Neurology. 2014;**13**(8):844-854. DOI: 10.1016/S1474-4422(14)70120-6

[11] Rotheray KR, Cheung PS, Cheung CS, Wai AK, Chan DY, Rainer TH, et al. What is the relationship between the Glasgow coma scale and airway protective reflexes in the Chinese population? Resuscitation. 2012;**83**(1):86-89. DOI: 10.1016/j.resuscitation.2011.07.017

[12] Haltmeier T, Schnuriger B, Benjamin E, Brodmann Maeder M, Kunzler M, Siboni S, et al. Isolated blunt severe traumatic brain injury in Bern, Switzerland, and the United States: A matched cohort study. Journal of Trauma and Acute Care Surgery. 2016;**80**(2):296-301. DOI: 10.1097/TA.0000000000000892

[13] Davis DP, Peay J, Sise MJ, Vilke GM, Kennedy F, Eastman AB, et al. The

impact of prehospital endotracheal intubation on outcome in moderate to severe traumatic brain injury. The Journal of Trauma. 2005;**58**(5):933-939. DOI: 10.1097/01.ta.0000162731.53812.58

[14] Davis DP, Fakhry SM, Wang HE, Bulger EM, Domeier RM, Trask AL, et al. Paramedic rapid sequence intubation for severe traumatic brain injury: Perspectives from an expert panel. Prehospital Emergency Care. 2007;**11**(1):1-8. DOI: 10.1080/10903120601021093

[15] Davis DP, Peay J, Serrano JA, Buono C, Vilke GM, Sise MJ, et al. The impact of aeromedical response to patients with moderate to severe traumatic brain injury. Annals of Emergency Medicine. 2005;**46**(2):115-122. DOI: 10.1016/j.annemergmed.2005.01.024

[16] Gamberini L, Giugni A, Ranieri S, Meconi T, Coniglio C, Gordini G, et al. Early-onset ventilator-associated pneumonia in severe traumatic brain injury: Is there a relationship with prehospital airway management? The Journal of Emergency Medicine. 2019;**56**(6):657-665. DOI: 10.1016/j.jemermed.2019.02.005

[17] Bernard SA, Nguyen V, Cameron P, Masci K, Fitzgerald M, Cooper DJ, et al. Prehospital rapid sequence intubation improves functional outcome for patients with severe traumatic brain injury: A randomized controlled trial. Annals of Surgery. 2010;**252**(6):959-965. DOI: 10.1097/SLA.0b013e3181efc15f

[18] Warner KJ, Cuschieri J, Copass MK, Jurkovich GJ, Bulger EM. The impact of prehospital ventilation on outcome after severe traumatic brain injury. The Journal of Trauma. 2007;**62**(6):1330-1336, discussion 6-8. DOI: 10.1097/TA.0b013e31804a8032

[19] Carney N, Totten AM, Cheney T, Jungbauer R, Neth MR, Weeks C, et al. Prehospital airway management: A systematic review. Prehospital Emergency Care. 2021:1-12. DOI: 10.1080/10903127.2021.1940400

[20] Hatchimonji JS, Dumas RP, Kaufman EJ, Scantling D, Stoecker JB, Holena DN. Questioning dogma: Does a GCS of 8 require intubation? European Journal of Trauma and Emergency Surgery. 2021;**47**(6):2073-2079. DOI: 0.1007/s00068-020-01383-4

[21] Muakkassa FF, Marley RA, Workman MC, Salvator AE. Hospital outcomes and disposition of trauma patients who are intubated because of combativeness. The Journal of Trauma. 2010;**68**(6):1305-1309. DOI: 10.1097/TA.0b013e3181dcd137

[22] Tong JL, Ashworth DR, Smith JE. Cardiovascular responses following laryngoscope assisted, fibreoptic orotracheal intubation. Anaesthesia. 2005;**60**(8):754-758. DOI: 10.1111/j.1365-2044.2005.04238.x

[23] Robinson N, Clancy M. In patients with head injury undergoing rapid sequence intubation, does pretreatment with intravenous lignocaine/lidocaine lead to an improved neurological outcome? A review of the literature. Emergency Medicine Journal. 2001;**18**(6):453-457. DOI: 10.1136/emj.18.6.453

[24] Svedung Wettervik T, Howells T, Hillered L, Nilsson P, Engquist H, Lewen A, et al. Mild hyperventilation in traumatic brain injury-relation to cerebral energy metabolism, pressure autoregulation, and clinical outcome. World Neurosurgery. 2020;**133**:e567-ee75. DOI: 10.1016/j.wneu.2019.09.099

[25] Cook AM, Morgan Jones G, Hawryluk GWJ, Mailloux P, McLaughlin D, Papangelou A, et al. Guidelines for the acute treatment of cerebral edema in neurocritical care patients. Neurocritical Care. 2020;**32**(3):647-666. DOI: 10.1007/s12028-020-00959-7

[26] Langeron O, Birenbaum A, Amour J. Airway management in trauma. Minerva Anestesiologica. 2009;**75**(5):307-311

[27] Stept WJ, Safar P. Rapid induction-intubation for prevention of gastric-content aspiration. Anesthesia and Analgesia. 1970;**49**(4):633-636

[28] Sakles JC, Chiu S, Mosier J, Walker C, Stolz U. The importance of first pass success when performing orotracheal intubation in the emergency department. Academic Emergency Medicine. 2013;**20**(1):71-78. DOI: 10.1111/acem.12055

[29] Root CW, Mitchell OJL, Brown R, Evers CB, Boyle J, Griffin C, et al. Suction assisted laryngoscopy and airway decontamination (SALAD): A technique for improved emergency airway management. Resuscitation Plus. 2020;**1-2**:100005. DOI: 10.1016/j.resplu.2020.100005

[30] Davis DP, Hwang JQ, Dunford JV. Rate of decline in oxygen saturation at various pulse oximetry values with prehospital rapid sequence intubation. Prehospital Emergency Care. 2008;**12**(1):46-51. DOI: 10.1080/10903120701710470

[31] Green SM, Roback MG, Kennedy RM, Krauss B. Clinical practice guideline for emergency department ketamine dissociative sedation: 2011 update. Annals of Emergency Medicine. 2011;**57**(5):449-461. DOI: 10.1016/j.annemergmed.2010.11.030

[32] Hudetz JA, Pagel PS. Neuroprotection by ketamine: A review of the experimental and clinical evidence. Journal of Cardiothoracic and Vascular Anesthesia. 2010;**24**(1):131-142. DOI: 10.1053/j.jvca.2009.05.008

[33] Kramer N, Lebowitz D, Walsh M, Ganti L. Rapid sequence intubation in traumatic brain-injured adults. Cureus. 2018;**10**(4):e2530. DOI: 10.7759/cureus.2530

[34] Tran DT, Newton EK, Mount VA, Lee JS, Wells GA, Perry JJ. Rocuronium versus succinylcholine for rapid sequence induction intubation. Cochrane Database of Systematic Reviews. 2015;**10**:CD002788. DOI: 10.1002/14651858.CD002788.pub3

[35] Weingart SD, Trueger NS, Wong N, Scofi J, Singh N, Rudolph SS. Delayed sequence intubation: A prospective observational study. Annals of Emergency Medicine. 2015;**65**(4):349-355. DOI: 10.1016/j.annemergmed.2014.09.025

[36] Merelman AH, Perlmutter MC, Strayer RJ. Alternatives to rapid sequence intubation: Contemporary airway management with ketamine. The Western Journal of Emergency Medicine. 2019;**20**(3):466-471. DOI: 10.5811/westjem.2019.4.42753