## PCCL session topic and date:

**Under Pressure - Things That Go Lump in the Head**

**February 16, 2024.**

## Learning objectives:

- **Review the signs and symptoms of increased intracranial pressure (ICP).**
- **Spotlight challenges in identification and management in community emergency departments that see both pediatric and adult patients.**
- **Discuss non-pharmacologic strategies and pharmacologic management of increased ICP.**
- **Highlight special considerations around intubation, ventilation and hemodynamic support of a child with increased ICP.**

**Case:**
8-year-old female with 2 days of fever, headache and vomiting. She awoke the morning of presentation with pins and needles to left side and falling to her left side but stabilized herself with her right side. EHS brought her to the Emergency Department. Glasgow Coma Scale (GCS) was 10-13. She had elevated White Blood Count (WBCs) and CT head which demonstrated multiple bilateral intracranial masses in subcortical distribution. Given her findings and relative bradycardia with irritability, there are concerns of Cushing's triad. Pediatric Intensive Care Unit (PICU) and Neurosurgery were consulted and supported the treatment with 3% saline, cefotaxime, metronidazole and vancomycin.

**Learnings:**
Not all children with decreased Level Of Consciousness (LOC) need to be intubated, but those with decreased LOC and inability to protect their airway (lack of cough, gag, inability to manage secretion) OR with poor respiratory drive need intubation. Consideration of trajectory, especially with regard to transport, is needed.

**Clinical signs of increased ICP dependent on duration:**
Acute increased ICP - decreased LOC, coma (acute bleed).
Chronic increased ICP - (brain tumor or hydrocephalus) may have longer standing issues (headache – worse in AM or with Valsalva, nausea/vomiting, diplopia). Older children can complain of these symptoms, but younger children usually present only with irritability and non-specific findings. Papilledema may not be seen in an acute presentation, but always good to look (if possible).

**Intubation with increased ICP:**

1) Preparation
    a. Ensure fluid resuscitated – consider fluid bolus if poor perfusion, and have fluid available during intubation if falling blood pressure (BP)
    b. Document GCS prior to intubation to support neurosurgery and tertiary care team
2) Intubation:
    a. Drugs – goal of adequate sedation with paralysis while maintaining hemodynamics. Suggestion from BCCH and VGH PICU -> ketamine and rocuronium. No contra-indication to ketamine with increased ICP, and ketamine will not contribute to increased ICP
    b. Ensure Bag Mask Ventilation as sedation/paralytic effects seen to keep normal $CO_2$
3) Post:
    a. Keep Head of Bed (HOB) 30 degrees and head midline.
    b. Endotracheal Tube taped to face and limit circumferential tapes/ties which may impair Central Nervous System venous drainage.
    c. Sedation and analgesia: need to start soon after intubation – midazolam and morphine infusion are typically used in PICU.
    d. Target normal $CO_2$ (35-40 mmHg) via blood gas and end tidal $CO_2$ monitor.
    e. Normal oxygen saturation (greater than 95%).
    f. Minimize Peak Inspiratory Pressure/Positive End Expiratory Pressure to avoid impairment of cerebral venous drainage
    g. Avoid hypotension, consider volume or inotropes (norepinephrine or epinephrine) to support blood pressure if required.
    h. Serial monitoring of pupils and vital signs as clinical neurological exam will be 'lost' once intubated and sedated.

When treating ICP pharmacologically – both 3% saline and mannitol are acceptable agents - first line is whatever is most easily accessible. In severe cases, multiple doses or alternating between the two agents may be required. Patients requiring greater than 1 dose should have the airway secured as part of their management to ensure $CO_2$ and airway control.

**Resources:**

The physiologically difficult airway: an emerging concept. Myatra et al, *Curr Opin Anaesthesiol* 2022 Apr 1;35(2):115-121.

INTUBATION IN PEDIATRIC TRAUMA GUIDELINES (for possible increased ICP)

Intubation in pediatric patients' guideline BCCH

# The physiologically difficult airway: an emerging concept

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**Purpose of review**
The physiologically difficult airway is one in which physiologic alterations in the patient increase the risk for cardiorespiratory and other complications during tracheal intubation and transition to positive pressure ventilation. This review will summarize the recent literature around the emerging concept of the physiologically difficult airway, describe its relevance and various patient types in which this entity is observed.

**Recent findings**
Physiologic derangements during airway management occur due acute illness, pre-existing disease, effects of anesthetic agents, and positive pressure ventilation. These derangements are especially recognized in critically ill patients, but can also occur in otherwise healthy patients including obese, pregnant and pediatric patients who have certain physiological alterations. Critically ill patients may have a physiologically difficult airway due to the presence of acute respiratory failure, hypoxemia, hypotension, severe metabolic acidosis, right ventricular failure, intracranial hypertension, and risk of aspiration of gastric contents during tracheal intubation.

**Summary**
Understanding the physiological alterations and the risks involved in patients with a physiologically difficult airway is necessary to optimize the physiology and adopt strategies to avoid complications during tracheal intubation. Further research will help us better understand the optimal strategies to improve outcomes in these patients.

**Keywords**
airway in the obese, airway management in ICU, airway management in the critically ill, difficult airway, obstetric airway, pediatric airway

## INTRODUCTION

The 'difficult airway' has been defined by the 2022 American Society of Anesthesiologists (ASA) guidelines on management of the difficult airway as the clinical situation in which anticipated or unanticipated difficulty or failure is experienced by a physician trained in anesthesia care, including but not limited to one or more of the following: facemask ventilation, laryngoscopy, ventilation using a supraglottic airway, tracheal intubation, extubation, or invasive airway [1▪]. The focus of airway evaluation and management has traditionally been on anatomical factors that may make mask ventilation, laryngoscopy, or tracheal intubation difficult [2]. Modern strategies, including devices, such as videolaryngoscopes and flexible bronchoscopes, improved perintubation oxygenation techniques, and availability of guidelines [1▪,3,4], have overcome several of the challenges posed by the anatomically difficult airway.

Even in patients whose airways are not 'anatomically difficult', physiologic derangements due to acute illness, pre-existing disease, the effects of anesthetic agents and positive pressure ventilation can result in severe cardiopulmonary complications during tracheal intubation after induction of general anesthesia with rapidly acting intravenous agents, neuromuscular blockade and apnea. This risk is especially recognized in critically ill patients, but can also

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## KEY POINTS

- The physiologically difficult airway is characterized by physiologic alterations that place the patient at an increased risk for cardiovascular collapse and other complications during tracheal intubation and transition to positive pressure ventilation.
- Physiologic derangements occur due to acute illness, pre-existing disease, effects of anesthetic agents, and positive pressure ventilation.
- These derangements are especially recognized in critically ill patients, but can also occur in otherwise healthy patients with physiological alterations, including obese, pregnant, and pediatric patients.
- It is important to understand the physiological alterations and the risks involved to optimize the physiology and adopt strategies to avoid complications during tracheal intubation in patients with a physiologically difficult airway.



occur in otherwise healthy patients with physiological alterations that may increase the risk of complications during tracheal intubation. These include obese, pregnant, and pediatric patients. It is therefore important to understand the concept of the physiologically difficult airway as one in which physiologic alterations place the patient at an increased risk for cardiovascular collapse and death during tracheal intubation and transition to positive pressure ventilation [5]. Figure 1 depicts differences in the time to desaturation in different types of patients, after the administration of a neuromuscular blocking agent.

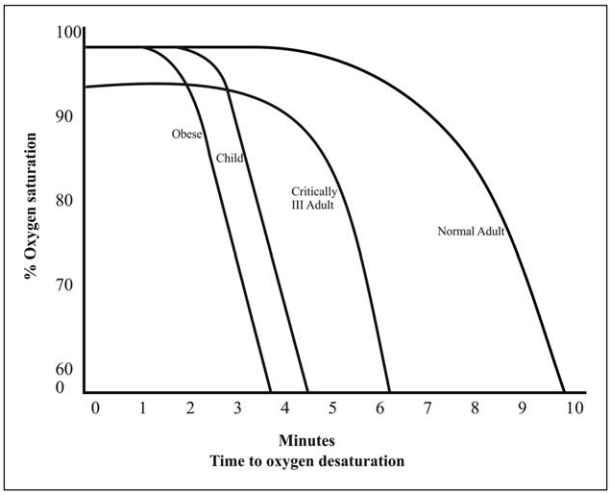


**FIGURE 1.** Graph showing differences in the time to critical oxygen desaturation in a normal healthy adult, a critically ill adult, a child, and an obese patient after administration of neuromuscular blockade.

In the National Audit Project Four (NAP4) report, complications that resulted in death or brain injury occurred in 61% of airway management episodes in the intensive care unit (ICU) compared to 14% of airway management episodes during anesthetic care [6]. The International Observational Study to Understand the Impact and Best Practices of Airway Management in Critically Ill Patients (INTUBE) involving 2964 critically ill patients undergoing tracheal intubation from 29 countries, found at least one major adverse peri-intubation event in 45.2% of patients. The predominant complication was cardiovascular instability, (42.6% of patients), followed by severe hypoxemia (9.3%) and cardiac arrest (3.1%). Risk factors for major adverse events included lower systolic arterial pressure, administration of a fluid bolus before intubation, higher heart rate, and cardiovascular instability as a reason for tracheal intubation. First-pass intubation success was associated with a reduced likelihood of peri-intubation complications [7▪▪]. A multicenter study in which the incidence of cardiac arrest during intubation in the ICU was 2.7%, identified preintubation hypotension, preintubation hypoxemia, obesity, nonperformance of preoxygenation, and age more than 75 years as predictors for cardiac arrest [8▪▪]. During failed tracheal intubation, significantly more obstetric patients had SpO2 < 90% compared to nonobstetric patients (70 vs. 2%), and the lowest SpO2 observed was 40% and 84% in obstetric and nonobstetric patient, respectively [9]. Kinsella *et al.* reviewed the literature on obstetric failed tracheal intubation and found 1 death per 90 failed intubations for cesarean section. Maternal deaths occurred due to aspiration or hypoxemia after airway obstruction or esophageal intubation [10,11].

These studies suggest that physiological derangements are associated with increased postintubation complications. It is therefore essential to evaluate patients for a physiologically difficult airway and to have strategies to prevent cardiovascular decompensation and other complications arising from a physiologically difficult airway. These strategies include improving preoxygenation and peri-intubation oxygenation, improving first-attempt intubation success rate, and preventing hemodynamic decompensation during and after intubation [3,12,13▪,14▪,15▪▪,16]. Further, patients with both an anatomically and physiologically difficult airway are at grave risk and alternative strategies including awake intubation may be required [17]. This review will focus on the recent literature regarding the emerging concept of physiologically difficult airway, its relevance and various patient types in which this entity is observed.

## TYPES OF PHYSIOLOGICALLY DIFFCULT AIRWAY

The presence of a physiologically difficult airway increases the risk of complications during tracheal intubation [18]. This risk is especially recognized in critically ill patients, but can also occur in otherwise healthy patients with physiological alterations, including obese, pregnant, and pediatric patients [19▪].

### Critically ill patients

Critically ill patients may have a physiologically difficult airway due to the presence of acute respiratory failure, hypoxemia, hypotension, severe metabolic acidosis, right ventricular failure, intracranial hypertension, and risk of aspiration of gastric contents during tracheal intubation.

### Hypoxemia

Patients with pre-existing hypoxemia are at increased risk of complications, such as desaturation, hypoxic brain injury, cardiac dysrhythmias, and cardiac arrest during tracheal intubation [18]. The common causes of acute hypoxemic respiratory failure include pneumonia, acute respiratory distress syndrome, pulmonary edema, and asthma. The mechanism of hypoxemia is due to a shunt and ventilation-perfusion (V/Q) mismatch. In normal healthy mechanically ventilated patients under anesthesia, there may be a V/Q mismatch; however, this mismatch can be easily overcome by recruiting the lungs and increasing the fraction of inspired oxygen ($FIO_2$). In critically ill patients, there is a significant shunt where alveoli in the affected area are unable to participate in gas exchange. In these cases, increasing the $FIO_2$ alone would not help, as the oxygen delivered is not able to reach the capillaries. Hence, these patients are at an increased risk of rapid desaturation during tracheal intubation. In such patients, the use of measures to prolong the safe apnea time (time until significant desaturation after inducing apnea) and optimize peri-intubation oxygenation using various strategies is paramount [20▪▪].

### Hypotension

The most predominant complication in critically ill patients during tracheal intubation is cardiovascular instability [7▪▪]. Peri-intubation hypotension is associated with adverse events, such as bradycardia, cardiovascular collapse, and death. Common causes of hypotension among critically ill patients are hypovolemia, capillary leak, decreased peripheral vascular resistance, and positive pressure ventilation following tracheal intubation. Pre-existing hypotension and shock index, *i.e.,* heart rate/systolic blood pressure more than 0.8 both increase the risk of post-intubation hypotension and cardiac arrest [21]. Not all patients will be in shock due to reflex compensatory mechanisms. Therefore, an elevated shock index represents an early sign of shock despite otherwise normal vitals.

In a spontaneously breathing person, negative intra-thoracic pressure helps improve the venous return. When the pressure in the right atrium increases due to positive pressure ventilation, this increase in pressure decreases the venous return thereby decreasing the cardiac output. While normal healthy patients can easily compensate for this reduction in cardiac output, critically ill patients, who may already be hypotensive and have exhausted their compensatory mechanisms, may worsen. The high incidence of cardiovascular instability following tracheal intubation in the critically ill makes it imperative to prevent hypotension with the early use of fluids or vasopressors, and identify and treat the hypotension early, if it occurs.

### Right ventricular failure

The right ventricle, a highly compliant, low-pressure chamber is often a neglected entity. Its unique structure allows it to accommodate greater volume, *i.e.,* preload. However, it does not tolerate increases in afterload as readily as the left ventricle. Conditions that increase right ventricle afterload are chronic pulmonary hypertension secondary to lung or left heart disease, pulmonary embolism, and left ventricular failure. The right ventricle responds to this increase in afterload by increasing its contractility, preload, and eventually undergoing hypertrophy. Patients with pulmonary hypertension thus need evaluation for right ventricular dysfunction and right ventricle failure (RVF). Consequences of RVF include right ventricular dilatation, tricuspid insufficiency, decreased right coronary artery perfusion, hypotension, and cardiovascular collapse. In patients with RVF, mechanical ventilation has deleterious effects. Positive pressure ventilation can lead to an increase in airway pressure which in turn gets transmitted to pulmonary vasculature, resulting in increase in afterload in addition to reduction in preload. This results in a high risk of cardiovascular collapse in patients with RVF who transition to positive pressure ventilation. Other conditions that increase the pulmonary pressures and subsequently worsen RVF are hypoxemia and hypercarbia, which can occur during a brief duration of apnea during airway management [22].

Echocardiography can be used to evaluate the right ventricular function. In patients with right ventricle dysfunction, judicious fluid loading may

be beneficial. However in patients with RVF, this may be deleterious as it may worsen left ventricular filling and stroke volume. Vasopressors can be used prior to intubation with the goal of increasing the mean arterial pressure without increasing pulmonary artery pressures. Hypoxemia and hypercarbia should be avoided during the peri-intubation period along with maintenance of a low mean airway pressure.



### Metabolic acidosis

Critically ill patients may have associated metabolic acidosis. Common causes are diabetic ketoacidosis, lactic acidosis, and salicylate poisoning. The presence of organic acids increases in proportion to the non-organic ions when there is metabolic acidosis. This acidosis leads to a compensatory increase in alveolar ventilation to maintain acid base balance. Patients with severe metabolic acidosis are at increased risk of complications during intubation as brief periods of apnea can cause a sharp rise in $CO_2$ that can derange acid-base balance. Following tracheal intubation, the increased ventilation requirements may not be met with the limitations due to lung protective strategies used which can lead to a drop in arterial pH and precipitate cardiac arrest. A trial of noninvasive ventilation may be given to reduce work of breathing during which correction of the underlying acidosis may be undertaken. Ventilator modes should be chosen that allow the patient to maintain their respiratory compensation. However, these with high minute ventilation are at risk of developing relative hypoventilation, flow starvation, patient-ventilator asynchrony, and worsened acidosis [5].

### Neurological injury

In brain injured patients such as those with traumatic brain injury, it is important to maintain cerebral perfusion pressure and avoid secondary injuries due to hypoxemia and hypercapnia. These patients often need tracheal intubation for airway protection against aspiration, due to an altered sensorium or to facilitate surgery. Induction of anesthesia can lead to hypotension which may compromise cerebral perfusion pressure. Laryngoscopy can lead to sympathetic stimulation which may increase the intracranial pressure. Hypoxemia or hypercarbia during tracheal intubation can further worsen neurological injury [23].

During tracheal intubation in these patients, induction agents with the least hemodynamic effects, such as etomidate and ketamine, should be used. Ketamine may be safely used as it does not increase the intracranial pressure, as was previously believed. Pharmacological agents to reduce the sympathetic surge during tracheal intubation may be used. The time from laryngoscopy to tracheal intubation should be minimized and hypoxemia and hypercarbia should be avoided [24].

## Obese patients

Difficult intubation and related complications are twice as common in obese patients in the ICU. The odds ratio of severe complications related to intubation occurred 20 times more often in the ICU [25]. Obese patients are at higher risk for anatomical factors associated with increased difficulty in tracheal intubation [25,26]. In addition, these patients have a physiologically difficult airway due to the higher resting metabolic demand, higher oxygen consumption, and a higher cardiac output. This hypermetabolic state is also an independent risk factor for heart failure due to changes in the heart resulting from volume and pressure overload and the vascular stiffness. The resulting left ventricular hypertrophy and decrease in left ventricular compliance may cause left ventricular failure. Delayed gastric emptying in obese patients also increases the risk of aspiration [27].

Obese patients have a diminished total lung capacity and vital capacity. This, along with the decreased chest wall compliance and increased intra-abdominal pressure, significantly reduces the functional residual capacity (FRC) and the closing capacity to the extent that many a times the closing capacity is higher than the FRC thereby closing the smaller airways even during normal tidal volume breathing. Oxygen desaturation often occurs early after induction, secondary to the FRC and atelectasis worsened by the supine position [26]. Obese patients may have obstructive sleep apnea causing intermittent and repeated upper airway collapse, leading to partial or total airway occlusion for short periods during sleep. This condition results in an irregular breathing pattern, episodic sleep-associated oxygen desaturation, and hypercarbia, along with cardiovascular dysfunction and excessive daytime sleepiness. Frequent episodes of hypoxemia and hypercarbia may also lead to an increase in pulmonary arterial pressures with subsequent right ventricular dysfunction.

These factors result in an increased risk of hypoxemia in obese ''patients'' due to the short safe apnea time, making tracheal intubation challenging and increasing the risk of complications compared to other patients [27]. During tracheal intubation, preoxygenation using the ramped position is widely recommended. The use of videolaryngoscopy and apneic oxygenation has been recommended during tracheal intubation in this high-risk group. After tracheal intubation, application of positive end expiratory pressure is recommended [26].

## Pediatric patients

The pediatric airway differs from the adult both anatomically (larger occiput, larger or more pronounced epiglottis and/or tongue, anterior larynx, and a tendency for airway obstruction from flexion of the cervical spine) and physiologically. The most dreaded complication during tracheal intubation in a child is hypoxemia. The average oxygen consumption is double that in the adult. When combined with a lower FRC and a higher closing capacity, this elevated oxygen consumption makes children vulnerable to rapid desaturation and hypoxemia during tracheal intubation [28]. The muscle tone is further reduced following anesthesia and sedation and can lead to collapse of the small airways [29,30]. A higher carbon dioxide ($CO_2$) production also results in a need for greater respiratory rate to achieve adequate $CO_2$ clearance [31]. Furthermore, gastric distension may occur because of prolonged bag-mask ventilation. The major physiological differences in children are most pronounced before the age of two years. These factors make children vulnerable to rapid desaturation during tracheal intubation. Peri-intubation oxygenation and other strategies to avoid complications are vital in this vulnerable group [32].

## Pregnant patients

Pregnancy increases the risk of hypoxemia, aspiration, cardiopulmonary arrest, and mortality following attempted intubation. The obstetric airway is usually handled only when a need arises to give general anesthesia during an obstetric emergency related to the fetus or mother, such as an emergency cesarean delivery or critical illness of the mother. The incidence of failed intubation in obstetrics was 1 in 224 patients in a study from the UK [9]. The reason is due to both anatomical changes and physiological alterations in the parturient.

Hormonal changes and fluid retention in late pregnancy led to a variety of physiological changes that include an increase in oxygen consumption, upward displacement of the diaphragm, reduced FRC, and increased minute ventilation which further increases during active labour. Anemia related to pregnancy may contribute to decreased oxygen reserves. These factors reduce the safe apnea time while securing the airway and increase the risk of hypoxemia. In addition, the decrease in the tone of the lower esophageal sphincter due to delayed gastric emptying and the action of progesterone makes them vulnerable for gastric reflux and pulmonary aspiration [33].

A potential for cardiovascular instability also arises in pregnant patients in the event of massive bleeding from ante-partum or postpartum hemorrhage. Pre-eclampsia is a specific complication of pregnancy that further increases the physiological difficulty of airway management. Pre-eclampsia may cause narrowing of the upper airway or enlargement of the tongue, and/or increase the risk of airway bleeding following multiple attempts at laryngoscopy, secondary to coagulopathy of thrombocytopenia [33,34].

Intubation in the pregnant patient is more often performed out of hours or in an emergent situation. As a result, human factors play a significant role in the potential for error and a failed intubation [35]. Recent guidelines have been proposed for airway management of the pregnant patient. They include a need for a thorough airway assessment, limiting intubation attempts, early insertion of a supraglottic airway after failed intubation, and regular discussion and teaching of airway management in this patient group [36,37].

## At risk for aspiration

The NAP4 study estimated fatal aspiration to occur in 1 in 350,000 episodes of anesthesia, making it the most significant cause of airway-related mortality and responsible for 50% of anesthetic deaths [6]. Patient factors increasing the risk of peri-intubation aspiration include a full stomach, delayed gastric emptying (pregnant patients, trauma patients and gastroparesis of critical illness, diabetes), incompetent lower esophageal sphincter, esophageal diseases, and intestinal obstruction. Surgical factors include gastrointestinal surgery, lithotomy, or head down position and laparoscopy [38]. These patients are at an increased risk for regurgitation and pulmonary aspiration during induction and tracheal intubation. Pulmonary aspiration can lead to hypoxemia, pneumonitis, pneumonia, acute respiratory distress syndrome, and even cardiovascular collapse and death. Recommendations to reduce aspiration have included reducing gastric pressure and pH, having an experienced airway operator for all cases, rapid sequence intubation, and extubation awake and/or in the lateral position [3,4].

# CONCLUSION

Patients with physiologic derangements due to acute illness, pre-existing disease, and the effects of anesthetic agents and positive pressure ventilation can have severe complications during tracheal intubation, even without having an anatomically difficult airway. This risk is especially recognized in critically ill ''patients,'' but can also occur in otherwise healthy patients with physiological alterations

which include obese, pregnant, and pediatric patients. The physiologic alterations in these patients put them at an increased risk for hypoxemia or cardiovascular collapse during tracheal intubation. A thorough understanding of the physiological alterations and the risks involved is essential to adopt strategies to avoid complications during tracheal intubation in patients with a physiologically difficult airway.


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## Conflicts of interest

*There are no conflicts of interest.*

## REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- ■ of special interest
- ■■ of outstanding interest


1. ■ Apfelbaum JL, Hagberg CA, Connis RT, *et al.* 2022 American Society of Anesthesiologists Practice Guidelines for Management of the Difficult Airway. Anesthesiology 2022; 136:31–81.

The most recently published ASA practice guidelines for the management of the difficult airway developed by an international task force of anesthesiologists representing several anesthesiology, airway, and other medical organizations. It provides new algorithms and infographics for adult and pediatric difficult airway management.

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This prospective observational study that included 2964 patients from 197 sites across 29 countries showed that among an international sample of critically ill patients undergoing tracheal intubation, major cardiopulmonary events occurred frequently. At least one major clinical event occurred after intubation in 45.2% of patients, including cardiovascular instability in 42.6%, severe hypoxemia in 9.3%, and cardiac arrest in 3.1%.

8. ■■ De Jong A, Rolle A, Molinari N, *et al.* Cardiac arrest and mortality related to intubation procedure in critically ill adult patients: a multicenter cohort study. Crit Care Med 2018; 46:532–539.

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Emergency airway management outside the operating room (OR) requires expertise at handling not only the anatomically difficult airway but also the physiologically and situationally difficult airway. This review discusses the various challenges associated with airway management outside the OR, provides guidance on appropriate preparation and highlights the role of a coordinated multidisciplinary approach to out-of-OR airway management.

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This review highlights that tracheal intubation is a high-risk procedure in the critically ill associated with increased morbidity and mortality, due to the presence of a physiologically difficult airway. An evidence-based approach to improve first pass success in tracheal intubation while maintaining patient safety in the critically ill is provided.

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Consensus recommendations by a multidisciplinary working group of 12 airway specialists from Society for Airway Management, for the management of the physiologically difficult airway, to provide practical guidance for tracheal intubation in the critically ill.

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This review highlights the high risk of complications associated with tracheal intubation in patients with a physiologically difficult airway. This includes those who are critically ill and those who are not. Strategies to prevent complications associated with a physiologically difficult airway including measures to improve the chance of first-pass intubation success are included in this review.

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