



Airway Management in the Critically Ill Patient

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Abstract

Purpose of Review This paper will evaluate the recent literature and best practices in airway management in critically ill patients. **Recent Findings** Cardiac arrest remains a common complication of intubation in these high-risk patients. Patients with desaturation or peri-intubation hypotension are at high risk of cardiac arrest, and each of these complications have been reported in up to half of all intubations in critically ill patient populations.

Summary There have been significant advances in preoxygenation and devices available for performing laryngoscopy and rescue oxygenation. However, the risk of cardiovascular collapse remains concerningly high with few studies to guide therapeutic maneuvers to reduce this risk.

Keywords Intubation · Critically ill · Preoxygenation · Cardiovascular collapse · Desaturation · Hemodynamics

Introduction

Airway management has always been central to critical care. It is noted, for instance, in ancient Egyptian hieroglyphs, Hippocratic writings, a tale of Alexander the Great opening the trachea of an asphyxiating soldier, and reports of George Washington's death from a peritonsillar abscess. Accessing what Leonardo da Vinci referred to as the *arteria aspera* has been a source of danger, marvel, and intense study for as long as physicians have cared for the ill. Almost seven decades ago during a polio epidemic, modern critical care emerged when the Danish anesthesiologist Bjørn Ibsen saved lives by performing tracheostomies on polio patients with respiratory failure. Today, a new global pandemic is again forcing critical care medicine to struggle with whom to intubate with acute respiratory failure and how to best perform a procedure that carries a 2–4% cardiac arrest rate [1]. Intubation practices for treating acute critically ill patients outside of the operating

room (OR) are largely based on OR techniques. For example, rapid sequence induction and intubation, developed to prevent aspiration, was adopted to facilitate laryngoscopy and intubation success in the emergency department (ED) and then in the intensive care unit (ICU)—now singularly referred to as rapid sequence intubation (RSI). Preoxygenation to avoid the need for mask ventilation as well as to prevent aspiration evolved to avoid desaturation, the most common and dangerous complication outside of the OR, despite critically ill patients being mostly unfasted and at a high risk of aspiration. In addition, supraglottic airway devices designed to facilitate operative cases without requiring an endotracheal tube have become invaluable reoxygenation tools in critically ill patients with missed attempts and desaturation. Yet, despite adoption and evolution of OR practices to the ED and ICU, the first guidelines specific for critically ill patients were not published until 2018 [2], and recognition of deranged physiology that increases the risk of complications despite the presence or absence of procedural difficulty with laryngoscopy—i.e., the physiologically difficult airway—is only recently becoming more clear [3]. It is starting to be recognized that focusing on airway strategies that take into account physiology and attempt to reduce the risk of rapid desaturation or cardiovascular collapse plays an important role in these patients. Focusing on the most expedient laryngoscopy possible and attempting to rescue the decompensation after the intubation increases the risk in this high-risk population. In this paper, we will review advances in airway management in the critically ill patient, focusing on physiologic optimization, preparation,

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and devices used to prevent and manage the difficult airway. A summary of our recommendations can be found in Table 1.

Search Strategy

We conducted a Medline search using PubMed with the following search terms, from 2000–present: intubation [tiab] [MeSH Terms], AND (sequentially): ((critically ill [tiab]) OR (critical illness [MeSH Terms]) OR (emergency [tiab]) OR (emergency services [MeSH Terms]) OR (preoxygenation [tiab]) OR (mask ventilation [tiab]) OR (rapid sequence intubation [tiab]) OR (awake intubation [tiab]) OR (hypotension [tiab]) OR (shock [tiab]) OR (shock [MeSH Terms]) OR (respiratory insufficiency [MeSH Terms]) OR (respiratory failure [tiab]) OR (sepsis [tiab]) OR (cricoid pressure [tiab]) OR (bougie [tiab]) OR (tracheal introducer [tiab]) OR (direct laryngoscopy [tiab]) OR (video laryngoscopy [tiab]) OR (endoscope [tiab]) OR (supraglottic airway [tiab]) OR (laryngeal mask airway [tiab]) OR (extraglottic airway [tiab]) OR (cricothyrotomy [tiab]) OR (front of neck access [tiab]) OR (critically ill [tiab]) AND ((intubation[MeSH Terms])) AND (“2000/01/01”[Date - Create] : “3000”[Date - Create])).

Studies on neonates or pediatric patients ≤ 18 years and non-English language reports were excluded. Abstracts were reviewed for relevance, and references from each selected article were reviewed for pertinent articles. A (non-exhaustive) list of important articles as determined by the authors for establishing or verifying important concepts or changing practice are detailed in Table 2.

Preoxygenation

Preoxygenation was introduced at a time when the biggest risk from intubation was aspiration during induction for high-risk surgeries, such as bowel obstructions or cesarean sections [1, 4–6]. The idea was to have patients breathe 100% oxygen prior to induction to avoid gastric insufflation with mask ventilation. This practice developed prior to the invention of pulse oximetry, and it has been assimilated into airway management in all clinical settings. The intent has evolved to avoid desaturation more so than passive regurgitation and aspiration with mask ventilation [1•]. In critically ill patients, desaturation is a very common and serious threat to patient safety [1•], which carries a fourfold increase in the adjusted

Table 1 Authors’ recommendations for airway management in critically ill patients

Topic	Recommendation	Comments
Positioning	<ol style="list-style-type: none"> 1. Ramped plus “sniffing” (lower cervical spine is flexed, the upper cervical spine is extended, and the ear is leveled with the sternal notch) positions for all patients 2. Gastric decompression when faced with a high risk of aspiration 	<ol style="list-style-type: none"> 1. If supine position planned, recommend preoxygenating in upright position to optimize oxygen delivery. 2. Gastric ultrasound can help stratify risk.
Preoxygenation	<ol style="list-style-type: none"> 1. Flush flow* rate oxygen should be the default preoxygenation method. 2. In patients with higher risk of desaturation, preoxygenation should be performed with HFNO or NIPPV. 3. For those most severely hypoxemic, where RSI is still planned, preoxygenation should be performed with NIPPV. 4. For those most severe where an awake intubation is planned, HFNO during the procedure should be used. 5. Consider mask ventilation between induction and laryngoscopy when feasible. 6. Apneic oxygenation should be used when feasible. 	<ol style="list-style-type: none"> 1. In patients with acute hypoxemic respiratory failure, a PaO2 to FiO2 ratio (or SpO2 to FiO2 equivalent) can be helpful to stratify preoxygenation. 2. PaO2 to FiO2 ratio > 200 on NRB at flush rate = proceed with RSI 3. PaO2 to FiO2 ratio < 100–200 on NRB at flush rate = escalate to NIPPV or HFNO 4. PaO2 to FiO2 ratio < 100 on NIPPV or HFNO = consider awake intubation
Hemodynamics	<ol style="list-style-type: none"> 1. Hemodynamics should be assessed prior to intubation. 2. Optimization should be informed by the underlying physiology on assessment. 	<ol style="list-style-type: none"> 1. We recommend fluid resuscitation where appropriate. 2. We recommend norepinephrine infusion as the default vasopressor or choice. 3. We recommend an RV-guided resuscitation when necessary. 4. Some patients are too unstable for RSI and need a staged awake intubation and gradual transition to positive pressure ventilation.
Laryngoscopy	<ol style="list-style-type: none"> 1. We recommend VL as the default laryngoscope when available. 2. Consider routine use of a bougie when using traditional Macintosh geometry laryngoscopy (either DL or VL). 3. A second-generation supraglottic airway device should be used when available if rescue oxygenation cannot be accomplished with bag-valve-mask ventilation. 	<ol style="list-style-type: none"> 1. There are many advantages and very little downside to routine use of VL. In addition, there are many cost-effective options for VL that are widely available.

RSI, rapid sequence intubation; NIPPV, noninvasive positive pressure ventilation; HFNO, high-flow nasal oxygen; NRB, nonrebreathing mask; DL, direct laryngoscopy; VL, video laryngoscopy

*Flush flow rate oxygen refers to using a standard nonrebreathing reservoir mask and opening the valve from the wall regulator all the way, which generally provides between 50 and 80 l of oxygen depending on the hospital’s oxygen system pressurization

odds of cardiac arrest compared to patients without desaturation [7]. The strategy for preoxygenation of a patient with severe pneumonia or acute respiratory distress syndrome (ARDS) should be different from a patient who requires intubation but does not present with significant respiratory pathology. Preoxygenation can be very challenging, especially when patients require intubation for acute hypoxemic respiratory failure after failing noninvasive strategies, such as noninvasive positive pressure ventilation (NIPPV) or high flow nasal oxygen (HFNO) [8, 9]. Patients that fail NIPPV and require intubation have, at best, modest increases in the partial pressure of arterial oxygen (PaO₂) when preoxygenated with the traditional practice of breathing 100% oxygen for 4 min [10]. Furthermore, extending the preoxygenation time has only been marginally effective at further increasing the PaO₂, and the PaO₂ of many patients worsened [11].

We have learned a great deal about preoxygenation over the last decade. Safe apnea provided by preoxygenation is improved with maximal denitrogenation, an adequate functional residual capacity (FRC), and minimizing shunting [12, 13]. Essentially, you need three things to achieve safe apnea: (1) a reservoir to draw upon during apnea (i.e., the FRC), (2) maximum oxygen in that reservoir (i.e., denitrogenation), and (3) availability of that reservoir to resaturate hemoglobin (i.e., minimal shunt). In patients without airspace disease, traditional preoxygenation usually accomplishes the first goal, while FRC and shunt are not usually concerns. However, the more severe a patient's airspace disease and hypoxemia are (e.g., ARDS), the more each of those three requirements become distinct challenges of their own that need to be addressed.

Denitrogenation of the FRC is impaired by diluting the oxygen source with ambient room air [14, 15]. The higher the patient's work of breathing and the greater the peak inspiratory flow rate, the more room air is entrained and the effective fraction of inspired oxygen (FiO₂) lowers—reducing the ability to denitrogenate the FRC. This can be evaluated by assessing the fraction of expired oxygen (FeO₂) by measuring the end-tidal oxygen (ETO₂). Once the leak is introduced in or around the oxygen source and is contaminated by ambient room air, the FeO₂ drops by about half [10, 15–17]. The same is true of bag-valve-masks that do not have a one-way exhalation valve [14]. Despite a seal, room air is entrained and the FeO₂ drops. Overcoming this leak by adding a nasal cannula is only mildly effective [15], yet if high enough flows are used (15 lpm), a goal ETO₂ can be reached more rapidly than BVM alone [18]. However, overcoming room air entrainment by increasing the flow rate to “flush rate,” where the wall regulator valve is completely open, can effectively restore adequate denitrogenation and ETO₂ that approaches those achieved with a tight seal [19].

Removing the source of oxygen prior to the patient being fully apneic after induction leads to a rapid renitrogenation

with any spontaneous breaths that occurred before the onset of apnea [20]. Continuous insufflation of oxygen in the nasopharynx during apnea can attenuate this renitrogenation and prolong safe apnea time; however, clinical data are mixed [21–28] and this is less likely to be effective in the presence of a large shunt fraction [12, 29]. Preoxygenation in the upright position has a potential to increase the FRC by recruiting the lung bases [30], as well as preoxygenation with NIPPV [31–33, 34••] and, potentially, mask ventilation in the latent period [35].

In patients with hypoxemic respiratory failure (e.g., ARDS), the large shunt fraction is extremely problematic to safe apnea [12]. Not only is the FRC smaller, but also the shunt renders that deoxygenated reservoir is less forgiving of inadequacies (e.g., removing oxygen and room air entrainment) and relinquishes the reservoir only partially available to resaturate hemoglobin [12]. Thus, in these patients, more aggressive preoxygenation modalities are necessary for there to be any chance of safe apnea during RSI.

While these more aggressive forms of preoxygenation come from HFNO and NIPPV, the literature can be challenging to interpret regarding which one to use and when. Preoxygenation with NIPPV in hypoxemic patients has shown benefits with fewer patients desaturating compared to bag-valve-mask preoxygenation [36]. HFNO has the potential benefit of remaining in place for apneic oxygenation—particularly useful for the difficult airway—yet the required trial to definitively answer this question would be unethical in critically ill patients. Vourc'h et al. reported that the rate of difficult intubation was (statistically) similar, although clinically significant, with 1.6% difficult intubations in the HFNO group and 7.1% in the facemask group [37]. Most studies evaluate success rates rather than apnea duration, and despite significant heterogeneity, studies have generally shown HFNO to be at least as good as facemask preoxygenation [21, 22, 26, 32, 34••, 38–41]. For preventing desaturation, there is also substantial heterogeneity in the patient population selected and the severity of hypoxemia between studies. In general, HFNO prevents desaturation, prolongs safe apnea time, and limits the depth of desaturation compared to facemask preoxygenation, but not NIPPV [21, 24, 26, 34••, 37–43]. Miguel-Montanes et al. reported an incidence of 14% in a nonbreather group, 2% in the HFNO group, with HFNO being an independent predictor of preventing desaturation < 80% (aOR 0.14 0.01;0.90) in a multivariable regression model [42]. In the patients with the most severe hypoxemia undergoing RSI, HFNO may not be as useful [37], where NIPPV appears to provide the best preoxygenation [24, 32, 34••]. However, HFNO can remain in place for apneic oxygenation and may provide some benefit. In a recent study, the incidence of desaturation was higher for HFNO (23%), compared to 2.5% for NIPPV; however, none of the HFNO patients desaturated to < 70% compared to 13% of the NIPPV patients [38].

Table 2 Important studies over the last 10 years

Year	Author(s)	Journal	Importance
2010	Jaber S. et al.	<i>Intensive Care Med</i> 2010; 36: 248–255	This study found that implementation of a bundle aimed at improving safety reduced complications by more than 10%.
2011	Aziz M. et al.	<i>Anesthesiology</i> 2011; 114: 34–41	This observational study showed that GlideScope use resulted in a very high first-attempt success as both the primary device (98%) and after failed direct laryngoscopy (96%).
2011	Marsch S. et al.	<i>Crit Care</i> 2011; 15: R199	This study compared rocuronium and succinylcholine in the ICU and showed no difference in desaturation incidence, depth or duration, intubating conditions, or success rates.
2012	Heffner A. et al.	<i>J Crit Care</i> 2012; 27: 417.e419–413	This observational study established post-intubation hypotension as an independent predictor of mortality, longer ICU stay, and longer hospital stay.
2012	Heffner A. et al.	<i>J Crit Care</i> 2012; 27: 587–593	This observational study established shock index as a significant predictor of post-intubation hypotension.
2012	Wilcox S. et al.	<i>Crit Care Med</i> 2012; 40: 1808–1813	This observational study established RSI in ICU as associated with reduced complications and improved success and intubating conditions.
2013	De Jong A. et al.	<i>Am J Respir Crit Care Med</i> 2013; 187: 832–839	This study developed and validated the MACOCHA score to predict difficult airways in the ICU population.
2013	McPhee L. et al.	<i>Crit Care Med</i> 2013; 41: 774–783	This study established that etomidate for RSI in ICU patients with sepsis, severe sepsis, or septic shock has no association with mortality or vasopressor requirement.
2013	Sakles J. et al.	<i>Acad Emerg Med</i> 2013; 20: 71–78	This study established first-attempt success as the indicator of safety in emergency airway management, as the second attempt was associated with a 40% increase in adverse events.
2014	De Jong A. et al.	<i>Intensive Care Med</i> 2014; 40: 629–639	This meta-analysis showed VL was associated with increased odds of first-attempt success, fewer difficult intubations, and reduced complications compared to DL.
2015	Mosier J. et al.	<i>Ann Am Thorac Soc</i> 2015; 12: 734–741	This study confirmed RSI in ICU patients is associated with improved odds of first-attempt success and reduced complications.
2016	Hypes C. et al.	<i>Ann Am Thorac Soc</i> 2016; 13: 382–390	This study confirmed VL was associated with increased odds of first-attempt success in ICU patients.
2017	Driver B. et al.	<i>Ann Emerg Med</i> 2017; 69: 1–6	This study established “flush rate” oxygen as an optimal method for denitrogenation.
2017	Hypes C. et al.	<i>Intern Emerg Med</i> 2017; 12: 1235–1243	This study confirmed that first-attempt success is the measure of safety in ICU patients, with a 40% increase in complications on the second attempt, and extended the knowledge that physiological abnormalities increase the risk of complications despite first-attempt success.
2017	Lascarrou J. et al.	<i>Jama</i> 2017; 317: 483–493	This RCT showed no difference in outcomes between VL and DL in the ICU.
2018	Higgs A. et al.	<i>Br J Anaesth</i> 2018; 120: 323–352	This guideline is the first evidence-based guideline for airway management in critically ill patients.
2018	Taboada M. et al.	<i>Anesthesiology</i> 2018; 129: 321–328	This study established that patients intubated in the ICU within a month of an elective OR intubation by the same group of anesthesiologists had worse views, more complications, and fewer first-attempt successes.
2019	Frat J. et al.	<i>Lancet Respir Med</i> 2019; 7: 303–312	This study established HFNO and NIPPV as equivalent for preoxygenation in patients with acute hypoxemic respiratory failure, except for those with the most severe shunt (PF < 200), where NIPPV provided the best preoxygenation.
2019	Casey J. et al.	<i>N Engl J Med</i> 2019; 380: 811–821	This study established mask ventilation between induction and laryngoscopy reduced desaturation rates without increased aspiration rates in ICU patients at low risk of aspiration.
2019	Janz D. et al.	<i>Lancet Respir Med</i> 2019; 7: 1039–1047	This trial showed that starting a fluid bolus in undifferentiated ICU patients did not reduce the rate of cardiovascular collapse.
2020	April M. et al.	<i>Acad Emerg Med</i> 2020; 27: 1106–1115. 2020/06/28	This study showed that ketamine was associated with more post-intubation hypotension in undifferentiated normotensive ED patients.
2020	Brown M. et al.	<i>Acad Emerg Med</i> 2020; 27: 100–108	This study showed that VL was associated with increased odds of first-attempt success compared to various configurations of “augmented” direct laryngoscopy.
2020	Khan A. et al.	<i>Anaesthesia</i> 2020; 75: 634–641	This trial showed no difference in hypotension rates despite goal-directed fluid resuscitation prior to induction.
2020	Mohr N. et al.	<i>Acad Emerg Med</i> 2020; 27: 1140–1149	This study showed ketamine was associated with more post-intubation hypotension than etomidate in ED patients with sepsis.

Although NIPPV provides better preoxygenation for severe hypoxemia in patients where RSI is performed, still nearly 25% of patients desaturated [24, 34••]. Some patients are so severely hypoxemic that safe apnea is not possible despite optimal preoxygenation. RSI in these patients is a race to the bottom of the cliff (that is, cardiac arrest) between one's laryngoscopy skill and the patient's rapid desaturation. While the operator's laryngoscopy skill may be second-to-none, this is still very dangerous for the patient, especially if any difficulty is encountered that delays the onset of mechanical ventilation. These patients are likely more safely intubated awake and spontaneously breathing [12•]. This not only alleviates the requirement of safe apnea for RSI, but also leverages the regional physiology that occurs in spontaneously breathing patients with ARDS—the very physiology that must be eliminated after intubation to avoid patient self-inflicted lung injury.

We stratify our preoxygenation strategy based on the severity of the patient's hypoxemia, the risk of desaturation, and factor in the potential anatomic difficulty that may delay a rapid intubation (see Table 1).

Hemodynamics

From the battlefield to the ICU, compromised hemodynamics in critically ill patients undergoing airway management is a common and consequential phenomenon. Peri-intubation hemodynamic compromise is associated with longer inpatient stays, increased duration of mechanical ventilation, increased need for renal replacement therapy, and decreased likelihood of survival [44–48]. Therefore, resuscitation is a vital part of airway management in this population, but data regarding peri-intubation resuscitation are limited. This includes the lack of a standard definition, delineation of timing pre- or post-intubation, and vital sign thresholds.

Cardiovascular collapse and shock after intubation are not newly recognized phenomena. We have always sought to reduce this risk, thus the seemingly unending debate over etomidate as an induction agent in sepsis. Common practice is to resuscitate prior to intubation. A recent large national survey showed that most physicians are likely to use crystalloid resuscitation prior to emergency airway management, especially in patients requiring intubation for trauma or pneumonia [49]. Respondents are more likely to use vasopressors in patients with heart failure [49].

Even though we are mindful of peri-intubation hypotension rates (reported in 30–46% of patients), predicting an individual patient's risk of cardiovascular collapse during intubation

remains challenging. An elevated shock index is a specific but insensitive marker of post-intubation hypotension [45–47, 50–53]. Recent regression analyses and two recent prediction scores have been developed, which all find that in general, older age, hypotension or shock prior to intubation, intubation for respiratory failure, and higher APACHE score are all strong predictors of post-intubation cardiovascular collapse [52, 54–56].

If predicting cardiovascular collapse is challenging, preventing it is even more elusive. Resuscitation was included in an intubation bundle that successfully decreased complications in an ICU setting [57]. Unfortunately, replicating that finding in recent trials has been less successful. In a randomized controlled trial of normotensive patients, which excluded patients in whom fluids were indicated per clinical assessment and one-third of patients were already on vasopressors, *initiation* of a 500-ml crystalloid bolus did not decrease the chances of hemodynamic collapse compared to not initiating a bolus [58]. Longer ICU lengths-of-stay, longer duration of mechanical ventilation, and decreased survival were seen in patients in whom cardiovascular collapse occurred regardless of the group to which they were randomized [58]. Fluid *optimization* prior to induction in an operating room setting did not show a difference in outcomes, and one-third of the patients were on vasopressors within 15 min of induction regardless of goal-directed optimization [59]. Interestingly, a pre-intubation blood product-based resuscitation reduced the incidence of hypotension, cardiac arrest, and mortality in injured combat troops, [48] indicating that in the right patients, fluid resuscitation is useful to improve outcomes.

Induction medication choice also serves as a point of intervention to reduce cardiovascular collapse and is often a source of heated debates. Propofol and midazolam at RSI doses are potent venodilators. Etomidate evolved as the solution to that venodilation as it is considered “hemodynamically neutral,” but itself has long been debated over fear of adrenal suppression [60, 61]. Ketamine emerged as an alternative agent for patients with sepsis for its desirable indirect sympathomimetic effect [62–64], and in some forums, it is considered a buffer against all hemodynamic problems. However, there is no good evidence that etomidate-related transient adrenal insufficiency worsens outcomes, and recent evidence shows that hypotension from etomidate may be mediated through a reduced arterial elastance rather than adrenal suppression [65]. Furthermore ketamine is also a direct myocardial depressant that has been associated with cardiac arrest during RSI, and very recent observational studies showed ketamine to be associated with worse hypotension rates than etomidate, especially when propensity-matched [66, 67•].

Just as with preoxygenation where the approach requires personalization based on the underlying physiology, so too is the case with a patient's hemodynamics. Regardless of the lack of definitive data, clear definitions, and lackluster data on interventions, the physiological rationale for resuscitation prior to intubation in the critically ill is logical and prudent. Reduced effective circulating volume, vasoplegia, and sympatholytic medications all become exaggerated during the transition to positive pressure ventilation, causing further loss in preload [3, 68–70]. However, indiscriminate fluid boluses or relying on side effects of induction medications will not reduce danger from cardiovascular collapse in isolation.

In reality, the peri-intubation cardiopulmonary interactions are likely much more complex than simply volume depletion, vasodilating induction drugs, and positive pressure-mediated reduction in preload. In supine, spontaneously breathing patients, diaphragm displacement is predominantly dorsal, leading to an increase in FRC and improved ventilation to perfusion matching in the dependent lung zones [71–74]. In patients with ARDS, this is exaggerated through transpulmonary force amplification mediated by regional stress risers. Eliminating spontaneous breathing with any induction agent leads to a loss in that dependent diaphragm displacement, loss of FRC, dependent atelectasis, worsened ventilation to perfusion mismatch, increased pulmonary vascular resistance, and a reduced cardiac output. Mask or mechanical ventilation in these patients results in predominantly ventral diaphragm displacement, which fails to restore the physiological benefits of spontaneous breathing. Any disturbance in any variable within this complex interaction can be the trigger for cardiovascular collapse rather than just transient hypotension.

For example, ARDS patients have reduced FRC and increased pulmonary vascular resistance. Patients with decompensated right ventricular failure do not have reserve for increases in pulmonary vascular resistance. Patients with left ventricular failure, restrictive physiology, or constrictive pericarditis may not have tolerance for the reductions in venous return from volume depletion or contractility from ketamine. Patients with vasoplegia may not have reserve for reduced arterial elastance from etomidate, and those with septic cardiomyopathy may not tolerate myocardial depression from ketamine. Hemodynamic management is complex, and requires more personalized nuance than indiscriminate fluid administration, rescue vasopressors, or a single induction choice.

When feasible, we recommend assessing for evidence of volume responsiveness and volume tolerance, as well as ventricular function to understand the hemodynamic challenges to patient safety with intubation. Ultrasonography allows for rapid assessment of each of these aspects of hemodynamics [75] and allows for a more in-depth evaluation of potential threats. For example, ultrasound permits a more nuanced assessment of volume tolerance, diastolic function, and atrial pressures for patients with left ventricular disease; contractile reserve,

systolic function, and volume status in patients with right ventricular disease; and response to fluid challenges in patients with vasoplegia. We recommend volume expansion in *responders* and using vasopressors in *nonresponders*, preferably as an infusion and especially in patients at risk of cardiovascular collapse based on pre-intubation assessment or shock index ≥ 0.8 . Peripheral venous lines can safely be used to infuse vasopressors [76], with norepinephrine as the preferred agent. Vasopressors given as an IV bolus (i.e., “Push Dose”) vasopressors have been safely and effectively used in this scenario [77, 78], but rescue push dose vasopressors should be reserved for transient unexpected decreases in otherwise hemodynamically stable patients. Push dose phenylephrine should be used cautiously due to concern about increased blood pressure but a reduction in cardiac output [78, 79]. Pharmacologic agents used for preparation, sedation, and induction play an important role and should be personalized. Patients with right ventricular (RV) failure should have an RV-guided resuscitation to avoid the dangerous spiral of decreased RV systolic function, RV pressure/volume overload, decreased left ventricular filling, decreased cardiac output, and hypotension [3, 80]. This includes pulmonary vasodilators to reduce RV afterload; norepinephrine to increase mean arterial pressure, coronary perfusion pressure, and in some cases RV contractility; and diuretics if RV volume overload is present. In general, pre-intubation resuscitation can reduce having to rely on beneficial, or react to undesirable, side effects of the induction agents to prevent complications. Our standard practice is pre-intubation resuscitation and use of full-dose etomidate and rocuronium when RSI is planned. Just as in preoxygenation, though, some patients are so fragile that an awake approach should be considered. We recommend that patients with complex, refractory disease, where more than one untoward effect of induction and transition to positive pressure is a risk should be considered for an awake intubation where feasible. An example would be a patient with decompensated right ventricular failure, where the combined effects of the loss of spontaneous breathing and positive pressure ventilation on pulmonary vascular resistance, and hypotension from induction medications may precipitate cardiac arrest. See Table 1 for further recommendations.

Preparation

Time sensitivity during emergency airway management often does not allow for adequate pre-procedural assessment and preparation. Regardless, some assessment of anatomic and physiologic factors that may make airway management difficult for the operator and dangerous for the patient must be carried out. A systematic approach with succeeding plans and a checklist is highly recommended. Conducting a pre-intubation assessment; creating and communicating an intubation strategy that includes backup plans; acquiring the

necessary equipment and help; and positioning, preoxygenation, and hemodynamic resuscitation can all occur concurrently [2], and can be abbreviated when required such as with a crash airway where cardiac arrest is imminent. The LEMON mnemonic can be used to assess difficulties with laryngoscopy [81], but ignores physiological abnormalities. The MACHOCA score was developed and validated in the ICU population and accounts for physiological abnormalities (hypoxemia), but has not been validated for video laryngoscopy (VL) [82]. In addition to difficulty with laryngoscopy, potential difficulty with mask ventilation, supraglottic airway placement, and cricothyrotomy should also be assessed to inform the airway management strategy [83–87].

Just as positioning is important for preoxygenation, positioning is important for the laryngoscopic view of the airway and tube placement. The sniffing position with neck flexion and head extension has long been considered the standard, but ramped position with “bed-up-head-elevated” (BUHE) positions have also shown advantages [88–90]. Despite lack of clear data on cricoid pressure as a measure to prevent aspiration [91–93], including data that it worsens laryngoscopic view [93–95], it remains part of airway management guidelines [2]. In patients at high risk of aspiration, bedside gastric ultrasonography can identify patients that may benefit from cricoid pressure or, even better, gastric decompression prior to laryngoscopy [96, 97].

Based on anatomic and physiological assessment as well as optimization opportunity, a plan may be developed in terms of approach, device selection, and pharmacologic options, along with consideration of why the initial attempt may not be successful. A successive “plan B,” therefore, must include maneuvers or techniques that may overcome the point of failure of the initial plan and preparation to perform that plan. Checklists allow for patient optimization, promote a disciplined and systematic approach with a shared mental model for airway management, and they can ensure that appropriate personnel, equipment, and medications are prepared prior to intubation. Finally, operator training and experience is a contributing factor of success but does not replace planning and preparation. Out-of-OR airway management, when compared to routine management in the OR, increases difficulty and complications, despite being performed by the same operators [98]. As such, robust curricula and quality improvement programs should be considered to improve overall intubation safety in EDs and ICUs [99, 100].

Devices

The smoldering debate over direct laryngoscopy versus VL continues in critically ill patients as the data remain conflicted. One complication to interpreting the data is the definition of VL. While putting a camera on the end of a laryngoscope blade makes a video laryngoscope, the geometry of the blade

affects performance and thus traditional Macintosh geometry blades should not be compared to hyperangulated blades. The former is designed for routine use with the benefit of reducing unanticipated difficult intubations, while the latter is designed for patients with predicted difficult intubations. However, on the balance of data, VL provides benefits over direct laryngoscopy with little downside. We routinely use VL (traditional geometry for routine airways and hyperangulated for predicted difficult airways) and train our fellows extensively on VL. As the senior author stated in a recent paper, VL has been shown in the literature to improve the grade of view (which directly correlates with desaturation risk [101••]), reduce difficult intubations (which are difficult to predict), reduce airway trauma, aid faster skill acquisition in both experienced operators and novices, and improve successful intubations in patients with difficult airways [1•], even compared to “optimized” direct laryngoscopy [102].

One recent clinical trial performed in a single ED showed that the routine use of a bougie can further increase first-attempt success when using either direct laryngoscopy or traditional geometry VL [103]. While a multicenter study is ongoing (NCT03928925) to replicate the results of this trial, the major lesson learned is that a systematic training program and routine use of traditional geometry VL with a bougie can achieve a 96% first-attempt success rate in patients with any difficult airway characteristic, 98% in all patients [103]. When difficulty is encountered and mask ventilation cannot accomplish reoxygenation, supraglottic airways have been shown to restore oxygenation most of the time [104], and provide a conduit for tracheal intubation when combined with a flexible endoscope—which are now widely available, disposable, and cost-effective.

Intubation in COVID-19

Intubation in patients with COVID-19 initially presented a challenge not generally considered in the airway management plan—risk of infection to healthcare workers. There was fear over bioaerosol production leading to transmission of infectious particles that increase the risk of infecting the healthcare team. This fear prompted several recommendations, including (1) avoiding high-flow nasal oxygen or noninvasive ventilation, (2) performing all intubations by RSI, (3) avoiding mask ventilation, (4) using video laryngoscopy to increase distance between the patient and operator, and (5) using a barrier device like a plexiglass intubation box. These recommendations were prudent given the information available at the time, and given the widespread lack of protective equipment for staff; however, over the last year, we have gained significant knowledge to inform our practice. There is now evidence that high-flow nasal cannulas and noninvasive ventilation have no increased aerosol production compared to standard nasal

cannula or facemask oxygen [105, 106]. While a benefit of both RSI and video laryngoscopy is a reduction in aerosol production and increased distance from the operator to the patient, respectively, the major reason both should be used routinely is for the improvement in first-attempt success that we already knew prior to COVID-19. Not mask ventilating patients and not performing awake intubations in indicated patients are potentially harmful recommendations given what we know now, and in the presence of adequate personal protective equipment. We also now know that intubation boxes do not reduce aerosol exposure and are potentially harmful for patients when the operator is faced with any difficulty [107–109]. One remaining challenge for teams to address, however, is communication between members of the intubation team, where face shields, masks, and hoods severely diminish the ability to verbally and nonverbally communicate. Teams should prepare and rehearse for crisis situations during intubation given these limitations.

Conclusion

Airway management in critically ill patients has advanced over the last decade, with important knowledge gained on the risk of cardiac arrest imposed by physiological disturbances. Despite significant technological advances that reduce the incidence of and optimize the management of difficult airways, more research is needed to better determine how to predict and prevent cardiac arrest and severe hypoxemia in critically ill patients.

Declarations

Conflict of Interest Bhupinder Natt declares that he has no conflict of interest. Jarrod Mosier serves on an advisory board for Verathon Medical, and has received non-financial support (equipment) as a result.

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