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REVIEW ARTICLE

Tracheal intubation in the critically ill patient

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Tracheal intubation is among the most commonly performed and high-risk procedures in critical care. Indeed, 45% of patients undergoing intubation experience at least one major peri-intubation adverse event, with cardiovascular instability being the most common event reported in 43%, followed by severe hypoxemia in 9% and cardiac arrest in 3% of cases. These peri-intubation adverse events may expose patients to a higher risk of 28-day mortality, and they are more frequently observed with an increasing number of attempts to secure the airway. The higher risk of peri-intubation complications in critically ill patients, compared with the anaesthesia setting, is the consequence of their deranged physiology (e.g. underlying respiratory failure, shock and/or acidosis) and, in this regard, airway management in critical care has been defined as "physiologically difficult". In recent years, several randomised studies have investigated the most effective preoxygenation strategies, and evidence for the use of positive pressure ventilation in moderate-to-severe hypoxemic patients is established. On the other hand, evidence on interventions to mitigate haemodynamic collapse after intubation has been elusive. Airway management in COVID-19 patients is even more challenging because of the additional risk of infection for healthcare workers, which has influenced clinical choices in this patient group. The aim of this review is to provide an update of the evidence for intubation in critically ill patients with a focus on understanding peri-intubation risks and evaluating interventions to prevent or mitigate adverse events.

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KEY POINTS

- Tracheal intubation in critically ill patients may be associated with a high incidence of major peri-procedure adverse events.
- Haemodynamic collapse is the most commonly observed peri-intubation event and future strategies to mitigate this event should be investigated.
- Optimisation of physiology and strategies to increase first pass success of intubation should be sought to mitigate risks in critically ill patients.

Introduction

Tracheal intubation is among the most commonly performed procedures in critically ill patients. Different variables increase the risk of peri-intubation major adverse events in the critical care setting. Underlying pathophysiology (e.g. underlying hypoxia, hypoperfusion and acidosis) plays a major role in increasing a patient's risk of haemodynamic collapse, severe hypoxia and cardiac arrest once exposed to positive pressure ventilation, induction agents and the apnoea period of each laryngoscopy attempt.[1]

The term 'physiologically difficult airway' has been introduced to describe the features of airway management in critically ill patients, whose disordered physiology poses specific challenges in addition to the anatomical difficulty, which may be encountered in the anaesthesia setting.[1] Additional considerations are operator variables with differing levels of expertise and training. Finally, even the location of the procedure, with varying levels of human and equipment resources available, may also play a role.[2]

Until now, data on peri-intubation adverse events were available from local or national level observational studies.[2–4]

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The National Audit Project 4 collected data on airway management in both the anaesthesia and critical care setting during 1 year of observation in UK hospitals. The report, published 10 years ago, increased the awareness of the high burden of morbidity and mortality that airway complications may have in critically ill patients. Indeed, 61% of airway complications in the ICU led to death or brain damage. Of relevance, almost 50% of patients admitted to the ICU had a BMI greater than 30 kg m^{-2} and this was associated with a higher risk of airway-related complications, especially displacement of an existing tracheostomy tube. Moreover, when an airway-related adverse event occurred in an obese patient, this was more frequently associated with death or permanent brain damage than in a nonobese patient.[2] An analysis of these adverse events captured critical flaws during airway management, such as unavailability of experts out-of-hours, poor identification of high-risk patients and either lack of or misinterpretation of capnography.[2] Recently, additional data has become available from a large prospective international study, the INTUBE study.[5] This study collected data on 2964 adult critically ill patients undergoing in-hospital intubation across 197 sites worldwide. It reported an incidence of 45.2% of major peri-intubation adverse events, with cardiovascular instability observed in 42.6% of patients, which represented the leading adverse event, followed by severe hypoxemia in 9.3% and cardiac arrest in 3.1% of patients.[5] The risk of major peri-intubation adverse events increased with failure of the first attempt at tracheal intubation and they were associated with a significantly higher risk of both ICU mortality with an adjusted odds ratio (OR) of 1.52 [95% confidence interval (CI) 1.26 to 1.83], *P* less than 0.001, and a 28-day mortality-adjusted OR of 1.44 (95% CI, 1.19 to 1.74), *P* less than 0.001. An additional value of INTUBE study is the detailed collection of information on the current practice of airway management and gauging how best evidence interventions are implemented in real life around the world.[5]

The aim of this review is to provide an update on the evidence regarding intubation in critically ill patients with a focus on understanding peri-intubation risks and evaluating interventions aimed at preventing or mitigating adverse events. In particular, we will describe the evidence on cognitive tools to enhance safety of airway management, the essential monitoring to apply, peri-intubation oxygenation and haemodynamic optimisation strategies, and methods to maximise first attempt intubation success. Finally, we will also describe specific issues related to airway management in coronavirus disease 2019 (COVID-19) critically ill patients.

Cognitive tools to enhance airway management safety

Cognitive tools, such as checklists and protocols, can improve performance and aid the systematic preparation for airway management in the critically ill.[6]

Cognitive overload, which impairs decision-making and performance, is a distinct problem during airway crises.[6,7] Human factor deficits, such as lack of patient preparation, equipment checks or protocol deviation occur in up to half of critical incidents in intensive care.[2,6,8]

During airway management, dysfunctional team dynamics – characterised by poor communication, inadequate leadership and lack of a shared mental model–contribute to many human factor issues occurring during airway management.[9,10] Use of cognitive tools, effective teamwork and effective communication during airway crises can mitigate human factor-related issues, such as failing to call for help, loss of situational awareness, crisis resource management or barriers to the use of emergency 'front of neck access'.[9] Help from other team members can provide an 'airway manager' with additional processing capacity for the necessary integration of basic information.[9,11,12] In situ multidisciplinary training improves team dynamics and communication.[9,13] During airway crises, progress through a protocol or algorithm may not reflect the urgency required. Moreover, errors of fixation and impaired decision-making may play a major role for patient's outcome.[6] The simple graphic Vortex approach to airway crisis management is designed to be easily recalled and utilised practically by clinicians during a difficult airway management process.[6]

This visual model is a cognitive aid based on the principle that there are three nonsurgical techniques for patient's oxygenation: use of a facemask, of a supraglottic airway and of an endotracheal tube. In case of failure with each of these three techniques, despite the best efforts of the most experienced clinician, timely transition to the central zone of the vortex is required, indicating the need for emergency front of neck access.[14]

A checklist is a cognitive aid consisting of a list of tasks to undertake and equipment to be at hand during complex and stressful situations. It is usually a written list of items organised in checkboxes.

Checklists may allow for patient optimisation, promote a disciplined approach to airway management, and establish that appropriate personnel, equipment and medications are prepared for tracheal intubation.[15] In a trial of adults undergoing tracheal intubation, patients were randomised to the use of a written, verbally performed pre-intubation checklist or 'usual care' but this simple 10-step preprocedure checklist did not increase the lowest oxygen saturation or lowest SBP from induction to 2 min after tracheal intubation of critically ill adults.[16] However, if the checklist had included interventions aiming at physiological optimisation (e.g. noninvasive positive pressure ventilation during the preoxygenation phase, fluid bolus and/or early administration of vasopressors), and this checklist also utilised for the most urgent tracheal intubations, which were excluded in this study, then perhaps it may have influenced the outcomes

studied. A large multicentre study, involving expert and nonexpert centres, with a more complete checklist, may possibly clarify the evidence surrounding use of preintubation checklists.[17]

A protocol is the operative description of a bundle of evidence-based (and locally feasible) interventions aimed at standardising practice and thus avoiding unacceptable variability. Protocol implementation may be particularly useful in stressful situations/environments. In a pre- versus post- intervention study performed in three French ICUs, a protocol bundle of 10 items was implemented and its effect on intubation-related complications compared with the baseline period. Among the items Included in the protocol were a requirement for two operators, administration of a fluid bolus, preoxygenation with noninvasive ventilation in the presence of respiratory failure, rapid sequence induction with etomidate or ketamine as agents of choice, and starting of vasopressors when postintubation hypotension occurred.[18]

The implementation of this protocol was associated with a significant reduction of major overall complications from 34 to 21%, with a 50% reduction in cases of either severe hypoxemia or cardiovascular collapse 25 to 10% and 27 to 15% respectively.[18]

Despite the evidence for such cognitive tools, it appears there are gaps in implementation.

The INTUBE study found that a standard protocol for airway management was used in only 51% of patients whereas in 34% a protocol was not available. In 15% of cases, despite the availability of a protocol, it was not implemented during the procedure.[5]

Monitoring during airway management

Guidelines for monitoring during tracheal intubation recommend peripheral oxygen saturation, waveform capnography, blood pressure, heart rate, ECG and, wherever available, end-tidal oxygen concentration as standard.[6] Given the high incidence of cardiovascular instability, whenever feasible, invasive monitoring of arterial pressure may be considered in order to follow its rapid fluctuations during the procedure.

Waveform capnography is the gold standard for confirming correct endotracheal tube placement. It has a high sensitivity and specificity. It is important to remember that even in the context of resuscitation during cardiac arrest, waveform capnography remains the most reliable method for confirming correct endotracheal tube placement, as highlighted in the 2021 European Resuscitation Guidelines for cardiopulmonary resuscitation.[19]

In the NAP4 cohort of critical care patients, lack of or misinterpretation of capnography contributed to 74% of the reported airway-related deaths or persistent neurological injury.

This finding had a major resonance in UK and campaigns, such as the No Trace = Wrong Place by the Royal College of Anaesthetists (RCoA) and the Difficult Airway Society (DAS) were launched to increase the awareness of the importance of capnography in confirming tracheal intubation in all clinical settings.[20]

Ten years on from the NAP4 publication, the INTUBE study reports that around the globe, we are far from this goal. Indeed, waveform capnography was used as method to confirm tracheal intubation in only 25.6% of patients. Of concern was the observation that in 68.9% of patients with oesophageal intubation, capnography was not applied.[5]

Peri-intubation oxygenation strategies

Desaturation during airway management in critical care carries a fourfold increase in the adjusted odds of cardiac arrest compared with patients without desaturation.[4]

Safe apnoea time (i.e. the apnoeic period of laryngoscopy without desaturation to the critical level of 90%) is improved by maximal denitrogenation, an adequate functional residual capacity (FRC) and minimised shunting.[21] Depending on severity of a patient's airspace disease and hypoxaemia, these three requirements become distinct challenges requiring consideration. In attempts to prolong the safe apnoea period, various preoxygenation strategies have been investigated.[22]

Patient position at the moment of preoxygenation may play an important role. Indeed, the 'ramped' position (i.e. head of the bed elevated to 25°) during elective tracheal intubation in the operating room increases FRC thereby postponing desaturation compared with the sniffing position, especially in the obese population.[23] In addition, the ramped position may achieve better laryngeal exposure and reduce the duration of the procedure.[24] A multicentre study randomised critically ill patients to either the ramped position or the sniffing position. The study did not identify any difference in median lowest oxygen saturation between induction and 2 min after intubation. However, they observed poorer intubating conditions and decreased first pass success rates with the ramped position compared with sniffing position.[25] The specific setting of critical illness and operator's experience may explain the discrepancy with previous findings from the anaesthesia setting.[23,24]

In a landmark article published 15 years ago by Baillard and colleagues, hypoxaemic patients ($P_aO_2 < 100$ mmHg receiving 10 l min^{-1} via a nonrebreathing mask) were randomised to either bag-valve mask (BVM) support or noninvasive ventilation (NIV). Patients receiving NIV had a higher SpO_2 at the end of preoxygenation and during the whole procedure, with a significantly higher number of patients in the BVM group experiencing severe desaturation.[26]

More recently, patients with a P_aO_2/FiO_2 300 mmHg or less were randomised to either NIV or high-flow nasal cannula (HFNC).[27] The incidence of the primary outcome of severe hypoxaemia did not differ between the two groups considering the overall population. However, in the subgroup of patients with a P_aO_2/FiO_2 200 mmHg or less, severe hypoxaemia occurred less frequently in the NIV group compared with the HFNC group.[27]

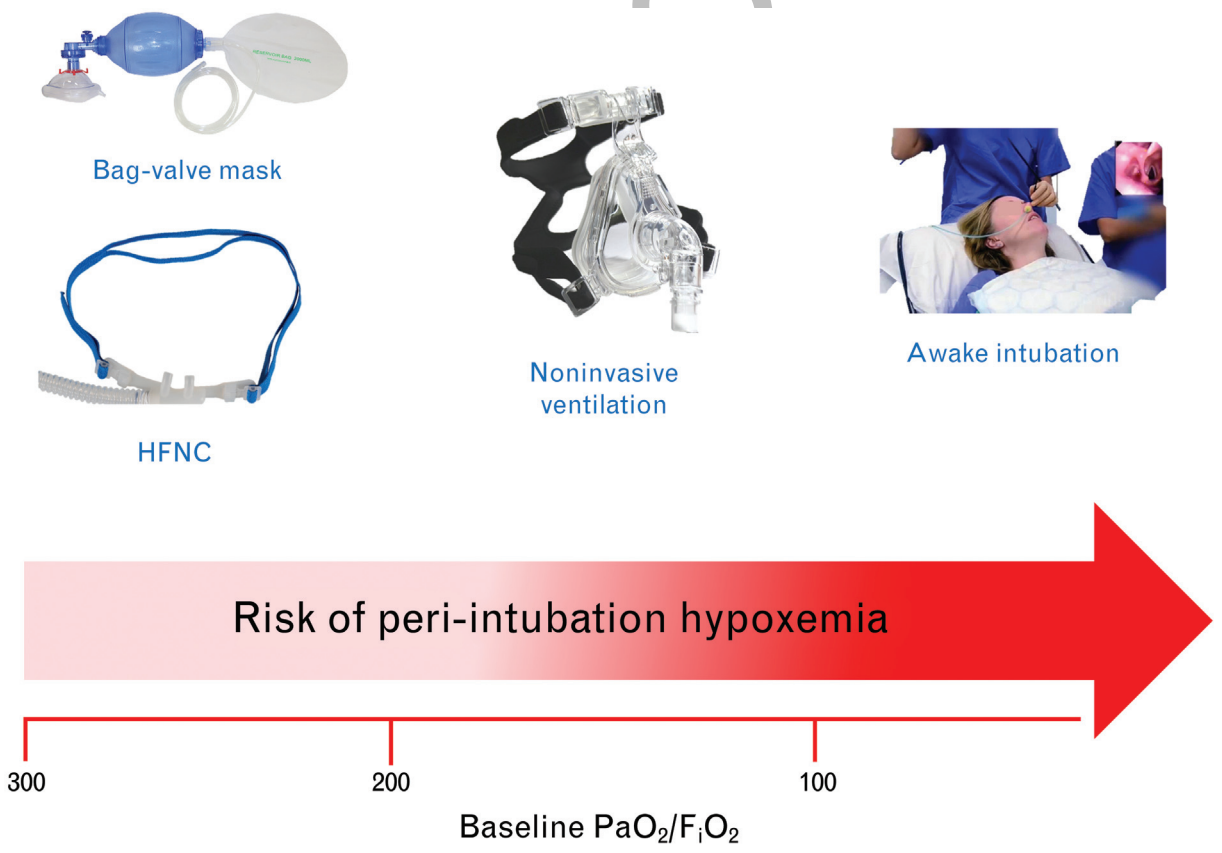
In the 'proof of concept' OPTINIV trial, the benefits of NIV in hypoxic patients were combined with the delivery of apnoeic oxygenation by the use of HFNC, with a lower degree of desaturation in the combination strategy group: median [IQR] saturation was 100 [95 to 100]% compared with the control group of patients receiving NIV alone, 96 [92 to 99]%.[28] In order to elucidate the generalisability of this strategy, a larger study should confirm its efficacy and safety. Moreover, clinicians should consider the potential for impaired rescue ventilation using a facemask because of the presence of HFNC.

Finally, HFNC was compared with BVM in the PRO-TRACH study by Guitton and colleagues. In this study, enrolling nonseverely hypoxemic patients ($P_aO_2/FiO_2 > 200$ mmHg), the lowest SpO_2 did not differ between the two groups.[29]

The INTUBE study found severe hypoxemia to be the second most common major adverse peri-intubation event, observed in 9.3% of tracheal intubations in the critically ill.[5] In this cohort of patients with a median P_aO_2/FiO_2 of 165 mmHg, the most adopted preoxygenation method was BVM (62% of patients) whereas NIV was applied in only 11.6% of patients.[5]

In summary, the current evidence on pre-oxygenation supports the use of either BVM or HFNC in the general ICU population with mild hypoxaemia (Fig. 1).[29] With increasing level of baseline hypoxaemia (from moderate to severe), the evidence supports the use of NIV[26,27] (increased lung volumes and FRC, reduced shunt fraction), which, in more severe cases, may be combined with HFNC.[28] For patients with refractory hypoxaemia at high risk of cardiac arrest, guidelines suggest the option of awake tracheal intubation, which has the theoretical benefits of maintenance of spontaneous ventilation and

Fig. 1 Evidence on peri-intubation oxygenation strategies according to the level of baseline hypoxemia



Patients with mild hypoxemia may receive either bag-valve mask or HFNC, whereas patients with moderate-to-severe hypoxemia should receive NIV as most effective respiratory support before intubation. In selected cases with severe hypoxemia and high risk of cardiac arrest following intubation, awake intubation may be considered. HFNC, high flow nasal cannula; noninvasive ventilation.

avoidance of induction agents. However, this procedure is not without risks and should be performed by a highly skilled operator.[6]

Peri-intubation haemodynamic optimisation

Tracheal intubation is frequently associated with cardiovascular collapse.[5] However, predicting an individual patient's risk of cardiovascular collapse, and intervening therapeutically to mitigate such risks remains elusive. An increased shock index (>0.8) is a specific, albeit insensitive, marker of postintubation hypotension.[30–32] Five independent risk factors for peri-intubation cardiac arrest have been identified, including preintubation arterial hypotension (SBP <90 mmHg), preintubation hypoxaemia, absence of preoxygenation, BMI greater than 25 kg m^{-2}, and age greater than 75 years.[4] Furthermore, two prediction scores, along with regression analyses find that older age, preintubation hypotension or shock, tracheal intubation for respiratory failure and higher APACHE scores are strong predictors of postintubation cardiovascular collapse.[33–36]

Risk reduction through haemodynamic optimisation is complex and requires an individualised approach.[15] The effects of a reduced effective circulating volume, vasoplegia and sympatholytic medications all become more pronounced during the transition to positive pressure ventilation, causing further reduction in preload.[37]

Implementation of the Montpellier bundle for tracheal intubation, which includes a crystalloid bolus of 500 ml and norepinephrine started early after tracheal intubation in the event of persisting low diastolic pressure, was associated with a significant reduction of cardiovascular collapse compared with the baseline period.[18]

However, the only randomised study investigating the administration of a 500 ml bolus of crystalloids, the PREPARE trial, was interrupted for futility after randomisation of 337 patients. Indeed, no difference was reported in the incidence of cardiovascular collapse between patients receiving a fluid bolus compared with patients not receiving it.[38]

Medications used for preparation, sedation and induction should be dictated by individualised haemodynamic considerations as peri-intubation cardiopulmonary interactions are complex.[15] ARDS patients have reduced FRC and increased pulmonary vascular resistance. Patients with decompensated right ventricular (RV) failure cannot tolerate further increases in pulmonary vascular resistance and should have an RV-guided resuscitation (e.g. echocardiography performed before and after tracheal intubation and inhaled nitric oxide ready to use). Patients with left ventricular failure, restrictive physiology, septic cardiomyopathy or constrictive pericarditis may not tolerate either a reduction in venous return from volume depletion, or drug-induced reduction in contractility or vasoplegia (e.g. by propofol or midazolam).[15]

The INTUBE study found that peri-intubation cardiovascular instability is the most common peri-intubation event, observed in 42.6% of patients, and it was associated with a reduced likelihood of 28-day survival. In this study, 3.1% of patients had a cardiac arrest following tracheal intubation, of which 47.3% died, with the main reported reason for arrest being hypovolaemia or haemodynamic instability.[5] Notably, in the INTUBE study cohort, 41.5% of patients received propofol as the induction agent whereas etomidate and ketamine were used in only 17.8 and 14.2% of patients, respectively.[5]

Patients with complex, refractory disease (e.g. decompensated RV failure) should be considered for an awake intubation wherever feasible to minimise the risk of cardiac arrest on induction and transition to positive pressure ventilation.[15] Positive pressure ventilation with large tidal volumes, high respiratory rate and high PEEP may worsen hypotension and should be avoided, especially in case of intravascular volume depletion.[6]

The timing of tracheal intubation in critically ill patients is complex, and balancing the risks of delaying tracheal intubation against the potential benefits of a more stable induction following resuscitation requires expertise.[6] Further studies to guide therapeutic interventions are needed to discern how best to optimise haemodynamics in critically ill patients.

Direct laryngoscopy vs. videolaryngoscopy

The merits of direct laryngoscopy vs. videolaryngoscopy for airway management in critically ill patients have been a matter of debate over the last few years.[1]

Current studies on the subject are difficult to interpret with certainty, given some limitations in design, how providers' expertise/experience were defined, the specific techniques used in the delivery of the intervention (i.e. use of stylet or not), and the heterogeneity in the type of devices utilised (i.e. hyperangulated blades vs. Macintosh-style videolaryngoscopy).[39]

A recent systematic review and meta-analysis of tracheal intubation outside the operating room reported higher first attempt success and lower oesophageal intubation rates with videolaryngoscopy vs. direct laryngoscopy in ICU patients.[40] However, the use of videolaryngoscopy was associated with more life-threatening complications including systemic hypotension. Two meta-analyses of randomised trials reported that the use of video- laryngoscopy did neither increased first-attempt intubation success rate in ICU nor improved outcomes compared with direct laryngoscopy.[41,42] Similarly, some studies included in these meta-analyses have shown a higher incidence of severe life-threatening complications with videolaryngoscopy use. A potential explanation for these findings is that persistence with tracheal intubation attempts when there is a clear laryngeal view using videolaryngoscopy but difficulties in endotracheal tube

delivery may then lead to prolonged apnoea time and other complications. Indeed, full glottic visualisation with videolaryngoscopy does not necessarily translate to easy intubation, as normally occurs with direct laryngoscopy. These considerations highlight the importance of appropriate training in the use of each specific device and related troubleshooting techniques. It appears that with adequate expertise, the above noted limitations could be overcome.[43] Indeed, the consistent improvement in glottic visualisation as compared with direct laryngoscopy and the reduction in incidence of oesophageal intubation observed with videolaryngoscopy in several circumstances in different studies led many experts to consider videolaryngoscopy an important tool for difficult airway management in ICU, especially in experienced hands.[15] On the basis of such considerations, recent guidelines have recommended the use of videolaryngoscopy as the first-line device, wherever available.[9]

Additional potential advantages of videolaryngoscopy over direct laryngoscopy are, firstly, the ability of the operator to avoid close proximity to a patient's face and respiratory tract (desirable when transmissible respiratory conditions are present or suspected) and, secondly, the capability to share the videolaryngoscopy view with other team members, enabling a shared approach and anticipation of next steps in the event of failure. Potential disadvantages of videolaryngoscopy, on the other hand, include costs and the need of specific training.

Videolaryngoscopy should be considered the method of choice for patients with suspected cervical spine injury. Cervical spine injury is present in between 2 and 5% of major trauma patients.[44,45] Limiting cervical movement is critical in these circumstances. Rapid sequence induction should be performed with manual in-line stabilisation with removal of at least the anterior part of the cervical collar.[6] The laryngeal view may be worsened by this manoeuvre and videolaryngoscopy, by providing a better laryngeal exposure with minimal cervical movement, should be adopted electively by skilled operators.[6]

In the INTUBE study cohort, videolaryngoscopy was used electively in 17% of critically ill patients and in 60% of cases where at least one anatomical predictor of difficulty was present.[5]

Future trials will define better the role of videolaryngoscopy in ICU, especially with respect to appropriate use of airway adjuncts, optimal patient position and the ideal glottic view required for a successful videolaryngoscopy-assisted intubation. Also, considering that heterogeneity across important clinical variables was common in meta-analyses comparing videolaryngoscopy to direct laryngoscopy, future videolaryngoscopy research should differentiate blade type, clinical context and patient-related primary outcomes, such as severe complications, rather than first pass intubation success rate alone.[39,46]

Adjuncts to facilitate tracheal intubation

Given the importance in achieving first pass success in order to reduce adverse events, different adjuncts to facilitate tracheal intubation have been investigated to overcome anatomical difficulties.[1,47,48]

In a randomised study performed in a single US Emergency Department, critically ill patients undergoing tracheal intubation with a Macintosh blade (direct laryngoscopy or videolaryngoscopy) were randomised to the use of either bougie or stylet. All the patients included had at least one anatomical predictor of difficult airway management. First attempt success was higher in the bougie group (96%) compared with the stylet group (82%), absolute difference 14% (95% CI, 8 to 20%), with no difference in the duration of procedure or peri-intubation hypoxaemia.[47] The main limitation of this trial was its single-centre design with operators experienced in bougie use. Hence, the generalisability of these findings need confirmation.

Recently, a large multicentre study conducted in 32 ICUs in France randomised critically ill adults undergoing tracheal intubation to either stylet use or no stylet. A higher first attempt intubation success rate with direct laryngoscopy was reported for the stylet group, without an increase in complications, and a similar rate of traumatic injuries between the two groups.[48] As the authors suggest, considering the study findings, the low cost, widespread availability and ease of use, the risk–benefit assessment is largely in favour of using a stylet whenever performing a tracheal intubation in critically ill patients.

Failed tracheal intubation

In the INTUBE Study cohort, first pass intubation success was achieved in 79.8% of patients, second pass success was achieved in 15.6% and 4.5% required more than two attempts. Failed first pass intubation was independently associated with a significantly higher risk of overall major peri-intubation complications. Of note, reintubation in the ICU of the same patients who underwent uneventful tracheal intubation in the operating room may be associated with a higher risk of technical difficulties and complications.[49]

Although most guidelines recommend a maximum of three laryngoscopy attempts before an unacceptable risk of developing difficult ventilation and physiology deterioration would ensue,[6] it should be taken in consideration that a significantly higher risk of major peri-intubation events is present from the second attempt.[5]

Following failure of tracheal intubation, guidelines recommend starting a phase of airway rescue where oxygenation is the goal to be achieved either by attempts of supraglottic airway (SGA) insertion interspersed with attempted facemask ventilation. A maximum of three attempts at each oxygenation strategies is recommended, with at least one performed by the most experienced

Table 1 Equipment that should be available at the bedside during airway management in ICU

Equipment for an airway management trolley of an adult ICU
Oxygenation
Facemask of various sizes
Oropharyngeal airways
Nasopharyngeal airways
Second-generation supraglottic airway of various sizes (e.g. no 3, 4, 5).
Intubation
Laryngoscope with Macintosh blade no 3 and 4
Videolaryngoscope (two blade sizes for Macintosh type, hyperangulated blade if available)
Tracheal tubes of different sizes (including specific tubes for intubating supraglottic airway)
Bougies of different sizes (adult and pediatric)
Airway exchange catheter
Flexible intubating fibrescope (with light source)
Berman/Ovassapian airways
Mucosal nebuliser/spray devices
Lubricant
Lidocaine (4 and 10%)
Front of neck access
Cricothyroidotomy cannulas of various sizes[a]
Scalpel (blade no 10 and 20)
Tracheal dilator or tracheal hook
Bougie
Cuffed tracheal tubes no 5, 6, 7

[a] According to the local protocol and training, a complete, preprepared, cricothyroidotomy set may be present.

available clinician.[6] A second-generation SGA is preferable as a rescue oxygenation strategy, given its higher oropharyngeal sealing pressure and presence of an oesophageal drain tube, allowing ventilation and maintenance of PEEP with some protection from gastric aspiration.[6,50] Table 1 describes the recommended equipment, which should be available at bedside during airway management in ICU.

Clinician skills/experience in airway management

Although expertise in airway management remains difficult to quantify with precision, and optimal learning curves with each device vary, the role of experience in airway management remains important.[2]

The presence of a second skilled operator supervising junior doctors from the start of the procedure has been associated with a lower risk of major tracheal intubation-related adverse events and this has been included in intubation bundles and guidelines.[3,18,51]

Recently, the INTUBE study observed that being an attending physician or consultant versus being in training was significantly associated with a reduced likelihood of first-pass intubation failure.[5] A similar association was noted with having anaesthesia as the primary specialty, a finding that was previously observed in the MACOCHA study.[5,52] The MACOCHA score has been developed to predict difficult tracheal intubations in ICU. Its calculation includes Mallampati score III and IV, obstructive sleep apnea syndrome, reduced mobility of the cervical spine, limited mouth opening less than 3 cm, coma, severe hypoxaemia and non-anaesthesiologist operators.[52] The impact of different levels of training and base specialty may vary across different educational programs and healthcare systems. Considering the negative effect of repeated intubation attempts and the high rates of complications associated with intubating critically ill patients, it would appear prudent that an experienced clinician always be at the bedside in such circumstances, wherever available. Future studies will help inform optimal approaches and training.

Peri-intubation adverse events

Tracheal intubation is associated with a high risk of adverse events as the consequence of the unique features of critical illness and the intubation setting. Cardiovascular collapse, severe hypoxaemia and cardiac arrest have been identified as the most common complications, with increased ICU and 28-day mortality.

However, other relevant complications may be the consequence of induction and airway instrumentation. Aspiration of gastric contents was reported in 3.9% of critically ill patients in the INTUBE study cohort and a similar incidence has been reported in a previously published report in critically ill patients.[3]

Evidence supporting cricoid pressure to mitigate the aspiration risk is controversial. The shortcomings of this manoeuvre are the interference with laryngeal exposure and the need of a specific training to properly perform it. In the largest randomised study investigating cricoid pressure in 3472 patients undergoing rapid sequence induction prior to surgery, the authors failed to demonstrate the noninferiority of a sham procedure compared with cricoid pressure, given the unexpectedly low incidence of pulmonary aspiration in the population recruited.[53] Further studies should elucidate the efficacy of cricoid pressure in the critical care setting and its influence on time to intubation and first pass success rates.

Airway injuries have been reported in 0.7% of patients and, among these, laryngeal laceration accounted for 33% of injuries, followed by tracheal laceration (24%) and bronchial laceration (5%).[5] A postintubation pneumothorax was observed in 0.7% of patients and a pneumomediastinum in 0.3%.[5] Although not particularly common, these complications may be associated with an increased morbidity, mortality and prolonged ICU stay.

Specific issues relating to coronavirus disease 2019

With over 180 million confirmed COVID-19 cases worldwide and up to 13% of hospitalised patients requiring invasive mechanical ventilation at some point of the disease stage,[54] critical care physicians have been facing the hardest challenge of their professional activity. In

addition to the previously described features of physiologically difficult airways (i.e. tracheal intubation of a severely hypoxic patient), airway management in COVID-19 patients poses a high risk of infection for the personnel involved in the procedure.[55] Additional challenges are posed by the personal protective equipment (PPE) that healthcare workers need to wear during airway management as this has been associated with reduced comfort, poor communication because of ears being covered by the protective clothing and vision impaired by fogged up goggles. These factors may play a relevant role for communication and team working. The recommended PPE for all healthcare workers present during intubation is represented by a N95 respirator, gloves, a fluid resistant gown and goggles or face shield.[56]

The evidence regarding airway management in COVID-19 indicates use of experts for most interventions of the peri-intubation bundle.[57–59] Preoxygenation methods and videolaryngoscopy were the most recurrent topics for the recommendations issued. Positive pressure ventilation and high-flow respiratory support methods were considered a high risk for operators, and most experts suggested their avoidance. Virus dispersion during different respiratory support methods was recently reappraised by a simulation study.[60] This study simulated a negative pressure ICU room with a mannequin exhaling nebulised bacteriophages from the lower respiratory tract during the following respiratory support methods: invasive mechanical ventilation, helmet ventilation with a PEEP valve (and a high efficiency particulate HEPA filter), bilevel positive airway pressure ventilation, nonrebreathing facemask, HFNC (set at 40 l min^{-1} O_2) and nasal prongs at 4 l min^{-1} O_2. Air samplers were placed around the simulator's head at a distance consistent with the operator's and assistants' positions during tracheal intubation. Although invasive ventilation was the modality associated with the lowest virus dispersion, helmet ventilation also resulted in a very low dispersion, which was not significantly different from invasive mechanical ventilation. HFNC and nasal prongs with standard oxygen were the methods associated with the highest virus dispersion. This finding contrasts with the recommendations issued to date, given the much higher dispersion with standard nasal prongs despite the lower O_2 flow, compared with nonrebreather mask or bilevel ventilation. We may argue that O_2 flow is not the major determinant for the risk of viral dispersion but also interfaces may play a relevant role.

In a consensus from the ICU Lombardy Network on the management of COVID-19 patients, helmet CPAP was suggested as the most preferable preoxygenation method for two main reasons.[61] Firstly, helmet CPAP is among the most used respiratory support methods for COVID-19 patients with respiratory failure worldwide and it can be left in place for preoxygenation. Secondly, as also confirmed by the previously described simulation study, by providing a barrier between the patient's head and the environment (adding a HEPA filter at the helmet exhalation port), it may be considered the best balance between effective preoxygenation and operators' safety.

Early after the pandemic surge, experts considered videolaryngoscopy to be the safest method given the indirect visualisation of laryngeal structures and the greater distance between patient's airways and operator allowed by this technique. This is particularly true with videolaryngoscopy with a separated screen (i.e. not integrated to the blade). From the report of the INTUBATE Covid, 75.2% of tracheal intubations in COVID-19 patients were performed with videolaryngoscopy. However, videolaryngoscopy was not significantly associated with a higher chance of first pass success in this study.[62]

A wider adoption of videolaryngoscopy for tracheal intubation of COVID-19 patients will presumably increase the expertise of operators with this technique.

Future directions

Tracheal intubation is associated with a high incidence of adverse events possibly influencing morbidity and mortality of critically ill patients. Achieving first pass success without desaturation and haemodynamic collapse is the desired goal of airway management in critical care and it may be considered as the outcome for future trials.[5]

Videolaryngoscopy may be of high value for overcoming anatomical difficulties but studies so far have yielded conflicting results in the critical care setting, suggesting the need for larger prospective clinical trials.[46] The operator's proficiency in videolaryngoscopy has a major role on success rates and previous trials may have underestimated the importance of this aspect. The COVID-19 pandemic may have contributed to the wider adoption of videolaryngoscopy in ICUs and to the possibility of operators progressing along the learning curve given the high number of procedures required in a short time interval. Future trials should then take account of operators' experience.

Many randomised trials have investigated strategies to maximise peri-intubation oxygenation and the evidence on NIV in patients with moderate-to-severe hypoxaemia is established. Interventions for peri-intubation haemodynamic opimisation, such as early administration of vasopressors, have been rarely investigated to date. Further trials should investigate alternative strategies to mitigate peri-intubation haemodynamic instability and its potential impact on morbidity and mortality.

Conclusion

Tracheal intubation is associated with a high incidence of major adverse events in critically ill patients. Peri-intubation haemodynamic optimisation should have a high priority in the bundle of interventions. Future research should elucidate, which strategies should be

implemented to achieve first attempt tracheal intubation without haemodynamic collapse or desaturation.

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