

REVIEW

Intubation in the ICU: we could improve our practice

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Introduction

Airway management is a commonly performed procedure in the intensive care unit (ICU). Hypoxemia and cardiovascular collapse represent the initial and most serious life-threatening complications associated with difficult airway access, both in emergency intubation in the critically ill [1]–[4] and in planned intubations (e. g., scheduled surgery or invasive procedures) [5]. To prevent and limit the incidence of life-threatening complications following intubation, several pre-oxygenation techniques and intubation algorithms have been entertained.

The objectives of the present chapter are to:

- 1) describe new tools (e. g., the MACOCHA Score) to better identify patients at high-risk of difficult intubation and related complications;
- 2) describe new strategies for improving pre-oxygenation before intubation (e. g., continuous positive airway pressure [CPAP] or non-invasive ventilation [NIV]);
- 3) propose an intubation bundle (the Montpellier-ICU intubation algorithm) to limit complications related to the intubation procedure;
- 4) report recent data on the role of videolaryngoscopes in the ICU; and, finally,
- 5) propose an algorithm for secure airway management in the ICU (The Montpellier-airway ICU algorithm).

Which patients are ‘at risk’ of complications during intubation?

All ICU patients could be considered at risk of complications during intubation. The main indication for intubation in the ICU is acute respiratory failure [1]–[4]. In these cases, the risk of hypoxemia and cardiovascular collapse during the intubation process (often crucial) is particularly elevated (15 to 50 %) [3]. Respiratory muscle

weakness (‘ventilatory insufficiency’) and gas exchange impairment (‘respiratory insufficiency’) are often present. It is thus worth anticipating that life-threatening complications may occur during intubation [6]. Obesity and pregnancy are the two main situations where functional residual capacity (FRC) is decreased and where the risk of atelectasis is increased leading to hypoxemia [6]. Other ‘at risk’ patients include those who cannot safely tolerate a mild degree of hypoxemia (epilepsy, cerebrovascular disease, coronary artery disease, sickle cell disease, etc. ...). Finally, patients considered to be ‘difficult to intubate’, in particular require adequate pre-oxygenation [7].

How to identify risk factors for difficult intubation in the ICU?

Although several predictive risk factors and scores for difficult intubation have been identified in anesthesia practice, until recently no (*a priori*) clinical score had been developed for ICU patients. However, a recent study assessed risk factors for difficult intubation in the ICU [3] and developed a predictive score of difficult intubation, the MACOCHA score, which was then externally validated. The main predictors of difficult intubation were related to the patient (Mallampati score III or IV, obstructive sleep apnea syndrome, reduced mobility of cervical spine, limited mouth opening), the pathology (coma, severe hypoxia) and the operator (non-anesthesiologist) (Table 1). By optimizing the discrimination threshold, the discriminative ability of the score is high. In order to reject difficult intubation with certainty, a cut-off of 3 or greater seems appropriate, providing an optimal negative predictive value (97 % and 98 % in the original and validation cohorts, respectively) and sensitivity (76 % and 73 % in the original and validation cohorts, respectively). The MACOCHA score enables patients at risk of difficult intubation to be identified and further studies are needed to determine whether calculating this score before each intubation could help

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Table 1 MACOCHA score calculation worksheet

	Points
Factors related to patient	
Mallampati score III or IV	5
Obstructive sleep apnea syndrome	2
Reduced mobility of cervical spine	1
Limited mouth opening < 3 cm	1
Factors related to pathology	
Coma	1
Severe hypoxemia (< 80 %)	1
Factor related to operator	
Non-anesthesiologist	1
Total	12

Coded from 0 to 12, 0 = easy, 12 = very difficult

reduce the incidence of difficult intubations and related complications.

Of note, the Intubation Difficulty Scale (IDS) is a quantitative scale of intubation difficulty, which can be useful for objectively comparing the complexity of endotracheal intubation, but *a posteriori* and *a priori* [21].

How to improve pre-oxygenation before intubation?

Spontaneous ventilation

Several maneuvers in spontaneous ventilation (e. g., 3–8 vital capacities vs 3 minutes tidal volume breathing) exist to improve pre-oxygenation before intubation and seem to be almost equally effective [8]. Some technical details, however, can make a significant difference. First, the clinician needs to make sure that the facemask properly fits the patient's facial morphology. Second, fresh gas flow needs to be set at a high range to homogenize ventilation through the lungs and to decrease the impact of leaks [9], [10]. Third, leaks should be avoided and diagnosed either by a flaccid reservoir bag or by the absence of a normal capnograph waveform, because leaks impair the efficacy of pre-oxygenation.

End-tidal oxygen concentration (EtO₂ in %) is available as a surrogate for oxygen alveolar pressure (PAO₂) which reflects, in part, the oxygen reserve in the lungs; the target commonly adopted is 90 % [11]. This target is reached more quickly when pure oxygen is administered. Although the clinician must be aware of the potential complication of de-nitrogenation-induced atelectasis, the benefit of reaching an end-inspiratory oxygen fraction of 90 % before attempting intubation outweighs the risk of developing atelectatic-related hypoxia in 'at risk' patients.

In critically ill patients, the advantage of a prolonged period of pre-oxygenation has not been clearly demonstrated. Most such patients present with acute respiratory failure with a certain amount of shunt, a reduced FRC, and do not respond to administration of oxygen as well as

patients scheduled for surgery [12]. Mort et al. demonstrated a moderate increase in arterial oxygen pressure (PaO₂) after 4 min of oxygen therapy before intubation (from 62 to 88 mmHg before and after oxygen therapy) [12]; despite pre-oxygenation, half of the 34 patients included in the study experienced severe hypoxia during intubation.

Position

Patient position is an important factor and limits the decrease in FRC. Studies have reported that pre-oxygenation in the semi-sitting position or in the 25° head-up position can achieve higher PaO₂. It may also prolong the time to hypoxemia in obese patients scheduled for surgery [13], [14]. To our knowledge, thus far only one study, performed in non-obese patients scheduled for surgery, has reported a beneficial impact of semi-sitting (20° head up) during pre-oxygenation in terms of time to desaturation [15]. This position seems not to be beneficial in pregnant patients, probably because of the gravid uterus constraining the diaphragm in its upper position and because of the detrimental effect of the sitting position on vena caval back flow [16]. In the critically ill, there are so far no pre-oxygenation studies evaluating the semi-sitting versus the supine positions.

Non-invasive ventilation with positive pressure

Positive end-expiratory pressure (PEEP) with high-flow oxygen has been evaluated as a pre-oxygenation method in the morbidly obese. The aim of positive pressure used as a pre-oxygenation method is to increase the proportion of aerated lung, thereby limiting the decrease in FRC. This limitation in FRC decrease will result in an increase in lung oxygen stores, and may also help keep the closing capacity below the FRC. The closing capacity is the volume of air at which airways begin to close during expiration. The volume of air between the closing capacity and the residual volume is called the closing volume.

The first study was performed in the early 2000s and found that applying 7 cmH₂O of CPAP for 3 minutes did not prolong time to desaturation in morbidly obese women [17]. Important limitations of this study were the absence of ventilation between the onset of apnea and intubation, and the relative brevity of the pre-oxygenation (only 3 minutes). Later studies, however, showed a benefit of applying CPAP with oxygen during pre-oxygenation in morbidly obese patients [18], [19]. Compared to O₂ alone, CPAP of 10 cmH₂O + O₂ for 5 min increased the time to desaturate and reduced the amount of atelectasis following intubation [18], [19]. Immediately after intubation, the amount of atelectasis measured by computed tomography (CT) was 10 % in the oxygen group compared to only 2 % in the 10 cmH₂O PEEP group [18].

In a landmark study of morbidly obese patients, our group showed that NIV using a pressure support ventilation (PSV) level of 8 cmH₂O and PEEP of 6 cmH₂O for 5 minutes was safe, feasible, and efficient [20]. We reported that 95 % of patients could reach the end-expiratory oxygen fraction target of 90 % with NIV compared to 50 % in the oxygen group [20]. The impact of the combination of both semi-sitting position and NIV in obese and non-obese surgical patients needs to be evaluated.

Pre-oxygenation with NIV in pregnant patients has never been formally evaluated, as it may be harmful because of the risk of aspiration in this patient population.

NIV as a pre-oxygenation maneuver has also been evaluated in critically ill patients; our group reported its benefits compared to administration of oxygen alone [21]. Indeed, in a randomized controlled trial including hypoxemic patients, the incidence of severe hypoxemia (SpO₂ < 80 %) within 30 min after intubation was 7 % in the NIV group (PSV 5–15 cmH₂O, PEEP 5–10 cmH₂O, FiO₂ = 100 %), compared to 42 % in the oxygen group. To perform NIV for 3 to 5 min in critically ill patients, the facial mask available in every ICU room is adequate. The patient should be in the semi-sitting position, FiO₂ set at 100 %, inspiratory pressure set to observe a tidal volume of 6 to 10 ml/kg and respiratory rate of 10 to 25 cycles/min. The duration of the procedure usually corresponds with the time needed to prepare the drugs and equipment for intubation. NIV was included in a bundle and was associated with a decrease in life-threatening hypoxemia following intubation in a multicenter study [1], [2] (Table 2).

Recruitment maneuver

As discussed earlier, the rationale of use NIV during pre-oxygenation is to recruit lung tissue available for gas exchange: 'Open the lung' with the PSV and 'keep the lung open' with PEEP, which limits alveolar de-recruitment. Conversely, the combination of de-nitrogenation (with 100 % O₂) and the apneic period associated with the intubation procedure can dramatically decrease the aerated lung volume ratio, thereby causing atelectasis. In obese patients pre-oxygenated without positive pressure, the proportion of atelectasis following intubation can represent 10 % of the total lung volume [18]. One option to limit alveolar de-recruitment after intubation is to ventilate the patient using a bag-valve balloon. However, it is not possible to measure the pressure delivered when patients are ventilated using this method.

A recruitment maneuver (RM) consists of a transient increase in inspiratory pressure. Several maneuvers exist, but the one best described in this situation consists of applying a CPAP of 40 cmH₂O for 30 to 40 s [22]–[24]. In

Table 2 The Montpellier-ICU intubation algorithm, adapted from [2]

PRE-INTUBATION
1. Presence of two operators
2. Fluid loading (isotonic saline 500 ml or starch 250 ml) in absence of cardiogenic edema
3. Preparation of long-term sedation
4. Pre-oxygenate for 3 min with NIV in case of acute respiratory failure (FiO ₂ 100 %, pressure support ventilation level between 5 and 15 cmH ₂ O to obtain an expiratory tidal volume between 6 and 8 ml/kg and PEEP of 5 cmH ₂ O)
PER-INTUBATION
5. Rapid sequence induction: <ul style="list-style-type: none">– Etomidate 0.2–0.3 mg/kg or ketamine 1.5–3 mg/kg– Succinylcholine 1–1.5 mg/kg (in absence of allergy, hyperkalemia, severe acidosis, acute or chronic neuromuscular disease, burn patient for more than 48 h and medullar trauma)– Rocuronium: 0.6 mg/kg IVD in case of contraindication to succinylcholine or prolonged stay in the ICU or risk factor for neuromyopathy
6. Sellick maneuver

POST-INTUBATION

7. Immediate confirmation of tube placement by capnography
8. Norepinephrine if diastolic blood pressure remains < 35 mmHg
9. Initiate long-term sedation
10. Initial 'protective ventilation': tidal volume 6–8 ml/kg, PEEP < 5 cmH ₂ O and respiratory rate between 10 and 20 cycles/min, FiO ₂ 100 % for a plateau pressure < 30 cmH ₂ O
11. Recruitment maneuver: CPAP 40 cmH ₂ O during 40 s, FiO ₂ 100 % (if no cardiovascular collapse)
12. Maintain intubation cuff pressure from 25–30 cmH ₂ O

NIV: non-invasive ventilation; CPAP: continuous positive airway pressure; FiO₂: inspired fraction of oxygen

the ICU, a randomized controlled trial was conducted by our group in 40 critically ill patients requiring intubation for acute hypoxemic respiratory failure [22]. Compared to no RM, an RM performed immediately after intubation was associated with a higher PaO₂ (under 100 % FiO₂) 5 min (93 ± 36 vs 236 ± 117 mmHg) and 30 min (110 ± 39 and 180 ± 79 mmHg) after intubation.

In the operating room, an initial study assessed the impact of applying several PEEP (0, 5, 10 cmH₂O) values following intubation in obese and non-obese patients scheduled for surgery [24]. At each step, end-expiratory lung volume, static elastance, gas exchange and dead space were measured. In both obese and non-obese patients, PEEP of 10 cmH₂O compared with zero end-expiratory pressure (ZEEP) improved end-expiratory lung volume and elastance without effects on oxygenation. We then randomized 66 morbidly obese patients (body mass index 46 ± 6 kg/m²) scheduled for surgery into 3 groups: Conventional pre-oxygenation, pre-oxygenation with NIV and pre-oxygenation with NIV + post-intubation RM [23]. The study demonstrated that the

combination of pre-oxygenation with NIV + post-intubation RM helped maintain lung volumes and oxygenation during anesthesia induction more so than pre-oxygenation with either pure oxygen alone or with NIV. One of the main take home messages of this study was that to improve PaO₂ 5 min after intubation, an RM added to NIV could be performed. Both oxygenation (PaO₂, 234 ± 73 mmHg vs 128 ± 54 mmHg) and capnia (PaCO₂ 42 ± 3 vs 40 ± 3 mmHg) were improved in the RM + NIV group compared to NIV alone.

Bundle to limit complications related to intubation (the Montpellier-ICU intubation algorithm)

Pre-oxygenation and RMs are only two of the procedures that can improve airway safety. Managing the airway of 'at risk' patients presents some unique challenges for the anesthesiologist/intensivist. The combination of a limited physiologic reserve in these patients and the potential for difficult mask ventilation and intubation mandates careful planning with a good working knowledge of alternative tools and strategies, should conventional attempts at securing the airway fail. Pre-oxygenation techniques can be combined to limit the risk of hypoxia during intubation attempts. To limit the incidence of severe complications occurring after this potentially hazardous procedure, we believe that the whole process (pre-, per- and post-intubation) should be guided by protocols geared toward patient safety. We designed a multicenter study and described how implementation of such a bundle protocol could improve the safety of airway management in the ICU [1], [2]. This bundle, the Montpellier-ICU intubation algorithm, is summarized in Table 2.

Briefly, pre-intubation period interventions consisted of fluid loading if there was no cardiogenic edema, pre-oxygenation with NIV in the case of acute respiratory failure, preparation of sedation by the nursing team and the presence of two operators. NIV applied during the 3-min pre-oxygenation phase was performed with an ICU ventilator (most often those which served to provide invasive mechanical ventilation) and a standard face mask. The PSV level was set between 5 and 15 cmH₂O, adjusted to obtain an expired tidal volume of 6 to 8 ml/kg of ideal body weight. The FiO₂ was set at 100 % and we used a PEEP level of 5 cm H₂O.

During the intubation period, rapid sequence induction (RSI) was recommended using short-acting, well tolerated hypnotics (etomidate or ketamine), and a rapid onset muscle relaxant (succinylcholine), with application of cricoid pressure (Sellick maneuver). The Sellick maneuver was performed to prevent gastric contents from leaking into the pharynx, by external obstruction of the esophagus, and associated inhalation of substances into the lungs, as well as vomiting into an unprotected airway.

Just after the intubation (post-intubation period), we recommended verifying the tube's position by capnography (a technique which allows the endotracheal position of the tube to be confirmed and verifies the absence of esophageal placement), initiation of long-term sedation as soon as possible (to avoid agitation) and use of 'protective' mechanical ventilation settings, as defined by the ARDS network. At any time, vasopressors were mandatory in the event of severe hemodynamic collapse.

Intubation devices: role of videolaryngoscopes in the ICU

Videolaryngoscopes are indirect rigid fiberoptic laryngoscopes with a video camera mounted at the end of an angled blade. The blade is inserted into the mouth in the midline and guided down the back of the tongue until the glottis is visualized. The tip of the endotracheal tube can then be visualized on the video screen and is positioned to enter the glottic inlet. New videolaryngoscope devices are suggested to improve airway management both in anesthesia care and in critically ill patients [25]. In recent years, the role of videolaryngoscopes has been debated, particularly in the ICU where there has been a lack of scientific evidence and generally intubation conditions are more difficult than in the operating room [26]. Recently, however, videolaryngoscopes, such as C-Mac [27], [28] or Glide-scope [29], [30], have demonstrated their effectiveness in the ICU setting. Moreover, a recent study [31] assessed a new mixed videolaryngoscope that can be used as a direct or indirect view laryngoscope. This before-after prospective study showed that the systematic use of a mixed videolaryngoscope for intubation in a quality improvement process using an airway management algorithm significantly reduced the incidence of difficult laryngoscopy and/or difficult intubation. In multivariate analysis, standard laryngoscope use was an independent risk factor for difficult laryngoscopy and/or difficult intubation, as were Mallampati score III or IV and non-expert operator status. Moreover, in the subgroup of patients with difficult intubation predicted by the MACOCHA score [3], incidence of difficult intubation was much higher in the standard laryngoscope group (47 %) than in the mixed videolaryngoscope group (0 %).

In summary, videolaryngoscopes seem to be effective at reducing difficult intubation in ICU patients, but a large multicenter study is needed to assess whether complications of intubation are decreased using videolaryngoscopes.

Airway management algorithm

As previously recommended in the operating room [32], an airway management algorithm is advised in the ICU (Figure 1). First, the difficulty of intubation is evaluated

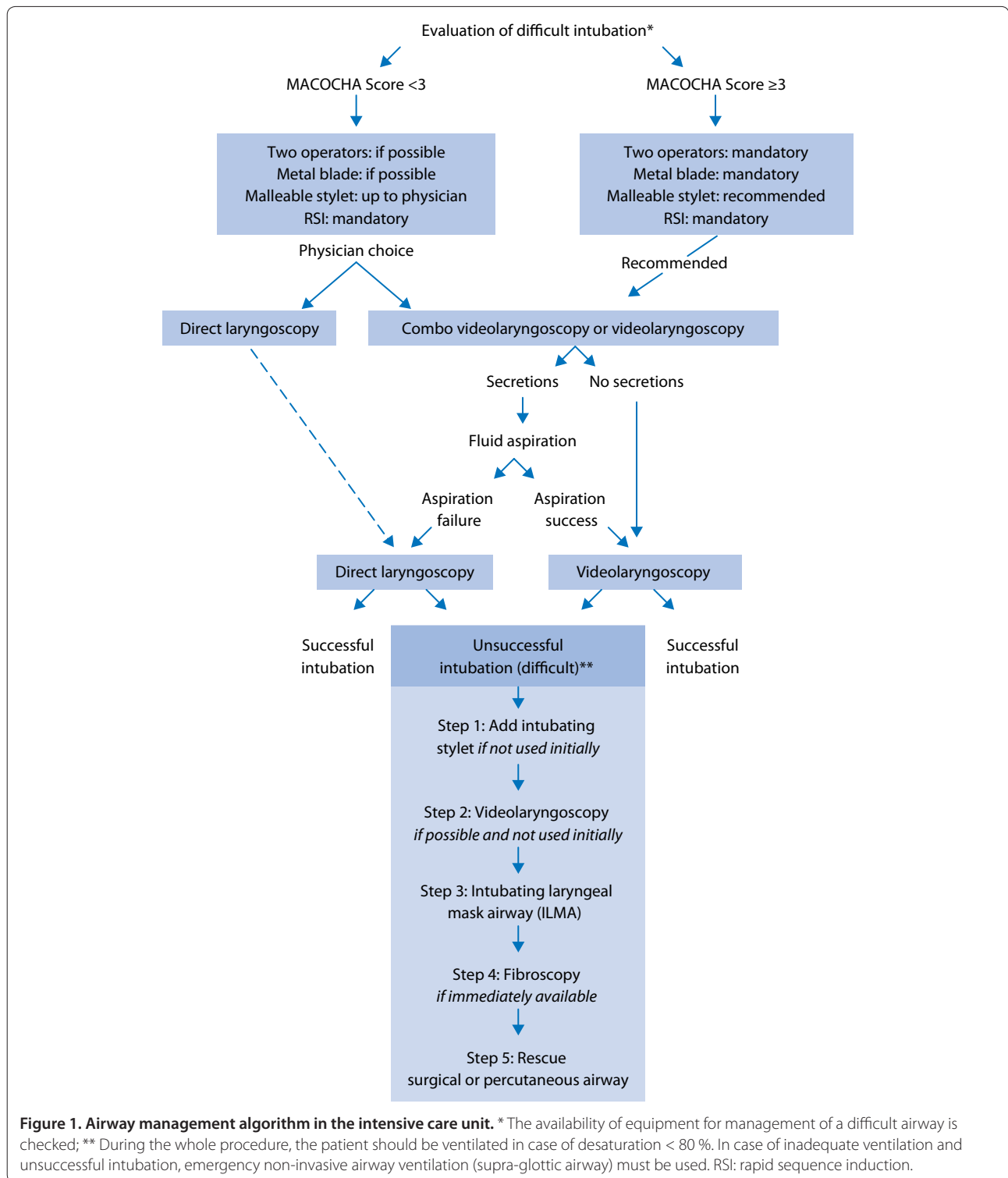


Figure 1. Airway management algorithm in the intensive care unit. * The availability of equipment for management of a difficult airway is checked; ** During the whole procedure, the patient should be ventilated in case of desaturation <math>< 80\%</math>. In case of inadequate ventilation and unsuccessful intubation, emergency non-invasive airway ventilation (supra-glottic airway) must be used. RSI: rapid sequence induction.

using the MACOCHA score. The availability of equipment for management of a difficult airway is checked. During the procedure, the patient should be ventilated in case of desaturation to <math>< 80\%</math>. In case of inadequate ventilation and unsuccessful intubation, emergency

non-invasive airway ventilation (supraglottic airway) must be used. If a difficult intubation is predicted (MACOCHA score ≥ 3), the presence of two operators, use of a metal blade, and use of a malleable stylet are recommended. The videolaryngoscopy or combo

videolaryngoscopy are also recommended in case of predicted difficult intubation. In other cases, choice of the device is at the discretion of the physician. In cases of abundant secretions even after aspiration, direct laryngoscopy is preferred rather than videolaryngoscopy. Finally, in cases of intubation failure, an intubating stylet (malleable stylet or long flexible angulated stylet) should be added first, followed successively by the use of videolaryngoscopy if not initially used, an intubation laryngeal mask airway, fiberoptic and finally the use of rescue percutaneous or surgical airway.

Studies are needed to assess whether applying this protocol in the ICU enables reduction of difficult intubation and complications. In each ICU, this airway management algorithm could be adapted according to local ICU practice.

Conclusions

Pre-oxygenation is a standard of care before intubation in the operating room and in the ICU. The aim of pre-oxygenation is to increase the lungs' stores of oxygen. In the critically ill patient, the combination of pure oxygen, NIV, de-nitrogenation and post-intubation recruitment maneuvers outweighs the potential risk of post-intubation atelectasis. Moreover, potential risk factors for difficult intubation should be assessed in ICU patients, in order to identify patients at risk of difficult intubation using a simple score applicable at the bedside. An intubation bundle should then be applied in order to reduce complications of intubation. Finally, an airway management algorithm is strongly advised in the ICU, as in the operating room. In this setting, new intubation devices, such as videolaryngoscopes, should be used after an appropriate training program.

List of abbreviations used

CPAP: continuous positive airway pressure; EtO₂: end-tidal oxygen concentration; FRC: functional residual capacity; ICU: intensive care unit; IDS: Intubation Difficulty Scale; NIV: non-invasive ventilation; PAO₂: oxygen alveolar pressure; PEEP: positive end-expiratory pressure; PSV: pressure support ventilation; RSI: rapid sequence induction.

Competing interests

The authors declare that they have no competing interests.

Declarations

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