REVIEW ARTICLE

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Management of the Difficult Airway

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Management of the difficult airway is one of the most relevant issues for practicing emergency physicians, intensivists, and anesthesiologists, since airway loss in an unconscious patient can lead to brain damage or even death. Despite revolutionary innovations in airway management, such as the laryngeal mask airway and video laryngoscopy, and despite major efforts in monitoring, education, and training, it is still unclear whether safety in airway management has improved during the past decade.

The Fourth National Audit Project (NAP4) of the Royal College of Anaesthetists and the Difficult Airway Society in the United Kingdom showed that 1 of 22,000 cases of tracheal intubation was associated with severe adverse airway management events in the operating room, such as death, brain damage, need for an emergency surgical airway, or unplanned intensive care unit (ICU) admission.[1] However, the number of cases may have been underreported, and the true incidence of severe events might actually have been 4 times as high (1 of 5500 cases).[1,2] Thus, vigilance in airway management remains essential.

A subsequent analysis estimated that the incidence of adverse events associated with airway management in the emergency department was higher by a factor of 35 than the incidence of adverse events associated with airway management in patients under anesthesia, and the incidence of adverse events in the ICU was higher by a factor of 55.[3,4] Recent results of the new U.S. closed-claims analysis with regard to difficult tracheal intubation have yielded worrisome figures as well.[5] Although claims related to difficult tracheal intubation in perioperative locations (operating or recovery rooms) were similarly distributed between two time periods — 1993 to 1999 and 2000 to 2012 — the incidence of brain damage or death at induction of anesthesia was higher by a factor of 5.5 in the latter period. In healthy patients who undergo anesthesia for elective procedures, complications associated with airway management are still the leading cause of death or permanent brain damage.[6]

Considering that more than 320 million surgical procedures annually would be needed to address the burden of disease for a population of around 7 billion (data from 2010),[7] and further considering that 20 to 40% of the more than 5 million patients who are admitted annually to ICUs in the United States require mechanical ventilation, it is evident that even small changes in the practice of airway management are highly relevant to outcomes (https://www.sccm.org/Communications/Critical-Care-Statistics).[8]

This review provides an overview of the definition, incidence, and prediction of a difficult airway; management of unanticipated and anticipated difficult airways; management of tracheal extubation of a difficult airway in the operating room, the ICU, and the emergency department; and human factors in airway management.

DEFINITION, INCIDENCE, AND PREDICTION OF A DIFFICULT AIRWAY

DEFINITION

The term "difficult airway" covers a spectrum ranging from problems in ventilating a patient's lung with a face mask or supraglottic airway to problems in intubating (and strictly speaking, also extubating) a patient's trachea. A standard definition of the difficult airway cannot be identified in the available literature.[9] A recent guideline update defines the difficult airway as an airway for which an experienced practitioner anticipates or encounters difficulty with face-mask ventilation, tracheal intubation, or supraglottic airway use or recognizes the need for an emergency surgical airway.[10] The following scale is useful for classifying the difficulty of face-mask ventilation: grade 1 — ventilation by mask can be performed without any problems; grade 2 — ventilation by mask is possible with an oral airway or another adjuvant; grade 3 — mask ventilation is difficult, defined as inadequate, unstable, or requiring two providers; grade 4 — mask ventilation is impossible.[11] This information, whether it has been determined with or without administration of a muscle relaxant to the patient, is useful.[12] Ideally, ventilation should be confirmed by observation of a rise in the chest, by a capnographic tracing, and by an increase in oxygen saturation.[13]

Difficult tracheal intubation must be distinguished from difficult laryngoscopy, especially since the introduction of video laryngoscopy into airway management.[14] A poorly visualized larynx may not be indicative of difficult tracheal intubation, especially if an adjunct such as a styleted tube is used. A poorly visualized larynx on direct laryngoscopy (classified as grade 3 or 4 on the Cormack–Lehane grading scale, on which grades range from 1 to 4, with higher grades indicating poorer visibility) might be more successfully visualized by using a different device, such as a flexible bronchoscope or a video laryngoscope, and this in turn may allow for easy tracheal intubation. But in some instances (e.g., the use of video laryngoscopy with a hyperangulated blade), tracheal intubation may still be challenging.[14,15] With direct laryngoscopy, there is a straight pathway from teeth to larynx, generally allowing for straightforward tube delivery, whereas with hyperangulated-blade video laryngoscopes, tube delivery must occur around a curve, which may make it more challenging.[14,15] Therefore, with video laryngoscopy, it makes sense to describe the view of the glottis (full, partial, or none) and the ease of tracheal intubation (easy, difficult, or unachievable) and to note the device used to facilitate tracheal intubation.[16]

INCIDENCE

The difficult airway is a rare phenomenon. The incidence of difficult face-mask ventilation ranges from 1.4 to 5.0%, and the incidence of impossible ventilation from 0.07 to 0.16%.[17,18] The incidence of difficult tracheal intubation ranges from 5 to 8%, and failed tracheal intubation from 0.05 to 0.35%.[15] The success rate for tracheal intubation with video laryngoscopes is between 97.1 and 99.6% overall and between 95.8 and 100% when a difficult airway is predicted.[19,20] The incidence of failed tracheal intubation in obstetrics ranges from 0.15 to 0.6%.[21] Maternal mortality from failed tracheal intubation is approximately 4 times as high as mortality from failed tracheal intubation in the general population, according to the NAP4 report.[22,23]

PREDICTION

To maximize patient safety, it is reasonable to try to predict a difficult airway and to adjust management of it accordingly. We must determine whether airway management is planned after induction of general anesthesia, whether tracheal intubation is warranted while the patient is awake, or whether additional help is needed from the beginning. We also try to predict whether fallback techniques such as face-mask ventilation or a surgical airway will succeed or fail.

If airway difficulty is predicted but does not occur (a false positive result), there are almost no consequences. The positive predictive value, which is the probability that a positive test result, such as the thyromental distance, is correct (difficulty predicted and actually encountered), will always be low as long as the prevalence of the phenomenon — a difficult airway — is low.[24] On the other hand, if an easy airway is predicted but a difficult airway is encountered (a false negative result, which is rare), there may be consequences. The negative predictive value, which is the probability that a negative test result is

correct (no difficulty predicted and none encountered), is usually very high.[25]

A Cochrane systematic review of data from 844,206 study participants concluded that none of the current bedside screening tests, alone or in any combination, were well suited to detecting an unanticipated difficult airway, because they missed a large number of people with difficult airways.[26] The upper-lip bite test performed best, even though it was not widely used, with a sensitivity of approximately 60% for the detection of difficulty in tracheal intubation.[27]

A complete airway assessment includes, besides bedside screening tests, consideration of anatomical and physiological features, as well as contextual issues that may affect the approach to airway management (Tables 1 and 2). Irrespective of the importance we attribute to screening tests in predicting difficulty, and regardless of whether a preoperative airway assessment predicts no difficulty or fails to predict difficulty,[25,29] performing an airway examination is a strategy that requires a clinician to use cognitive skills in deducing how to approach unanticipated difficulty.[28] However, airway examination is only one aspect of difficult airway management. The other aspects are technical skills and human factors.

PREDICTORS OF DIFFICULTY

Predictors of difficulty with airway management can be categorized as anatomical, physiological, or contextual. Anatomical predictors can be further divided into predictors of difficult direct or video laryngoscopy, difficult face-mask ventilation, difficult supraglottic airway insertion or use, and difficult front-of-neck airway access (Table 1).[28]

Obesity is a significant predictor of airway difficulty because of a combination of anatomical and physiological factors.[1] Obese patients are twice as likely to have a severe airway complication as those who are not obese, and patients with a body-mass index (the weight in kilograms divided by the square of the height in meters) that is higher than 40 (i.e., those who are morbidly obese) are 4 times as likely to have a severe complication.[1] In the recent anesthesia closed-claims analysis, obesity was a factor in 68% of claims involving difficult tracheal intubation.[5]

The anatomical changes that accompany obesity, such as a neck circumference of more than 40 cm, are associated with difficult mask ventilation, difficult laryngoscopy, and difficult tracheal intubation.[30,31] Obesity or a thick neck also predicts difficult identification of the landmarks for cricothyrotomy.[32,33] Physiological threats such as reduced functional residual capacity and, particularly, the resulting decrease in the manageable duration of apnea must be considered as well.[34]

MANAGEMENT OF DIFFICULT AIRWAYS

Most airway management practitioners and most national professional societies recommend distinguishing between management of the unanticipated difficult airway and management of the anticipated difficult airway.[35,36] These recommendations are based on the best available published evidence. When high-quality evidence is lacking, recommendations are based on group consensus statements.[37] There are inherent difficulties in conducting adequately powered, randomized, controlled studies for special airway scenarios, as well as problems justifying such studies from an ethical point of view.[38] However, the information available from database analysis and cohort studies is just as useful as data from randomized, controlled trials.[4] In a cohort study involving 188,064 patients, there were 3391 difficult tracheal intubations and 857 cases of difficult mask ventilation, confirming that difficult tracheal intubation and difficult mask ventilation are rare events. Of the 3391 difficult tracheal intubations, 3154 (93%) were unanticipated.[39] Likewise, difficult mask ventilation was unanticipated in 808 of 857 cases (94%). The clinician should be prepared with a good approach to difficulty going into every case and should attain and maintain competence in required techniques.[9,40,41]

UNANTICIPATED DIFFICULTY

If airway assessment predicts no difficulty, or in some circumstances even if difficulty is predicted, management will most often occur after the induction of general anesthesia. This is common practice, regardless of whether the situation has been judged to be easy or difficult.

Difficult or Failed Face-Mask Ventilation

Difficult airway management is frequently and inappropriately focused on tracheal intubation only. Face-mask ventilation is usually the first

Table 1. Anatomical and Physiological Predictors of Difficulty with Airway Management.*

Type of Predictor	Specific Predictor
Anatomical	
Predictors of difficult direct laryngoscopy	Limited mouth opening Blood or emesis in the oropharynx Narrow dental arch Limited mandibular protrusion Short thyromental distance Poor submandibular compliance Modified Mallampati class III or IV† Limited head and upper neck extension Increased neck circumference Obesity Adverse dentition Difficult face-mask ventilation Operator inexperience with direct laryngoscopy
Predictors of difficult video laryngoscopy	Limited mouth opening Blood or emesis in the oropharynx Limited mandibular protrusion Short thyromental distance History of neck irradiation or neck surgery, neck disease, limited neck mobility, thick neck Obesity Known Cormack–Lehane grade 3 or 4 during direct laryngoscopy‡ Operator inexperience with video laryngoscopy
Predictors of difficult face-mask ventilation	Beard or other factor affecting mask seal Male sex Lack of teeth Age >50 yr Limited mandibular protrusion Modified Mallampati class III or IV† BMI >26 History of snoring or obstructive sleep apnea History of neck irradiation Difficult intubation
Predictors of difficult SGA insertion or use	Limited mouth opening Obstructing or distorting lesion in the upper airway Fixed neck-flexion deformity Applied cricoid pressure BMI >29
Predictors of difficult front-of-neck airway access	Female sex Age <8 yr Thick neck Obesity Displaced trachea Overlying disorder (e.g., irradiation damage or other tissue induration) Fixed neck-flexion deformity
Physiological	Full stomach Rapid oxygen desaturation and the onset of apnea due to reduced functional residual capacity or increased oxygen consumption (e.g., obese, septic, or pregnant patients) Large minute ventilation (e.g., compensatory for metabolic acidosis) Hemodynamic instability: shock states, including hypovolemia and right ventricular failure

* The information in the table is adapted from Law and Heidegger.[28] BMI denotes body-mass index (the weight in kilograms divided by the square of the height in meters), and SGA supraglottic airway.
† The modified Mallampati classification is used to evaluate the visibility of oropharyngeal structures. Class III denotes visibility only of the soft palate and the base of the uvula, and class IV denotes no visibility of the soft palate.
‡ The Cormack–Lehane grading scale ranges from grades 1 to 4, with grade 1 indicating full view of the glottis and grade 4 indicating no view of the epiglottis.

Table 2. Contextual Issues that May Affect the Approach to Airway Management.*

Issue	Explanation
Experience and skills of primary clinician or team	When difficulty is predicted, the clinician must be sufficiently experienced in the planned technique to achieve acceptable success rates.
Availability of skilled help	Rendering a patient apneic when the potential for technical difficulty in securing the airway has been identified can be stressful for both the patient and the care team. Having a colleague stand by during the process or even knowing that a colleague is nearby and could be called on, should serious difficulty be encountered, can alleviate such stress. When difficulty is predicted, the absence of readily available help may affect the decision about how to proceed by elevating the advisability of tracheal intubation while the patient is awake.
Availability of appropriate equipment	When difficulty is predicted, the necessary equipment to expeditiously manage the airway after induction of general anesthesia or in the awake state (flexible bronchoscope) should be available.
Behavior of the patient	Although tracheal intubation while the patient is awake may have been identified as the safest approach after assessment of anatomical predictors of technical difficulty, this may be precluded by a patient who does not respond appropriately to instructions.
High urgency	A high-urgency situation during resuscitation may preclude tracheal intubation while the patient is awake because of the need to rapidly move on to other resuscitation priorities.

* The information in the table is adapted from Law and Heidegger.[28]

step in airway management in an unconscious patient and is an integral part of difficult airway management. It is a commonly used rescue maneuver between unsuccessful attempts at tracheal intubation or supraglottic airway insertion.

Effective face-mask ventilation can be confirmed by observation of a rise in the chest, a capnographic tracing, and an increase in oxygen saturation. Appropriate aids are an oropharyngeal or nasopharyngeal airway and modified, two-handed face-mask ventilation with an exaggerated jaw lift.[42] A video demonstrating modified, two-handed face-mask ventilation can be viewed at NEJM.org. For effective face-mask ventilation, it is crucial to open the airway, usually by performing jaw-thrust and chin-lift maneuvers, and to keep the airway open. It is generally accepted that mask ventilation improves after the establishment of neuromuscular blockade, as noted in guidelines regarding airway management.[10,40,43,44]

A video showing a technique for performing face-mask ventilation is available at NEJM.org

Difficult or Failed Ventilation with a Supraglottic Airway Device

Supraglottic airway devices such as the laryngeal mask airway are an integral part of routine airway management and are recommended by almost all airway guidelines.[35,36,38] Difficult or failed ventilation with a supraglottic airway and subsequent, inadequate oxygenation may be due to light anesthesia, incorrect positioning, or anatomical factors. If none of these factors is responsible and ventilation and oxygenation still fail, tracheal intubation or face-mask ventilation should be attempted. In addition to its use in primary airway management, a supraglottic airway is an established rescue device when tracheal intubation has failed (Fig. 1).[9,10,40] Further information on supraglottic airway devices can be found elsewhere.[45,46]

Difficult or Failed Laryngoscopy or Tracheal Intubation

Difficulty in visualizing the larynx can sometimes be overcome by means of simple measures, such as improving the anesthesia level and inducing relaxation in case of inability to open the mouth or changing the position of the head and neck if the view of the glottis is impaired.[47,48]

If difficult or even failed laryngoscopy occurs but oxygenation through a face mask or supraglottic airway ventilation is possible, there is time to consider different options (Fig. 1). If tracheal intubation is necessary, up to two further optimized attempts at tracheal intubation are valid before an alternative strategy is considered. There is a strong association between multiple tracheal intubation attempts and adverse outcomes, such as hypoxemia, airway trauma, or cardiac arrest.[5,10,49-56] A study that involved 1828 orotracheal intubations in an emergency department showed that

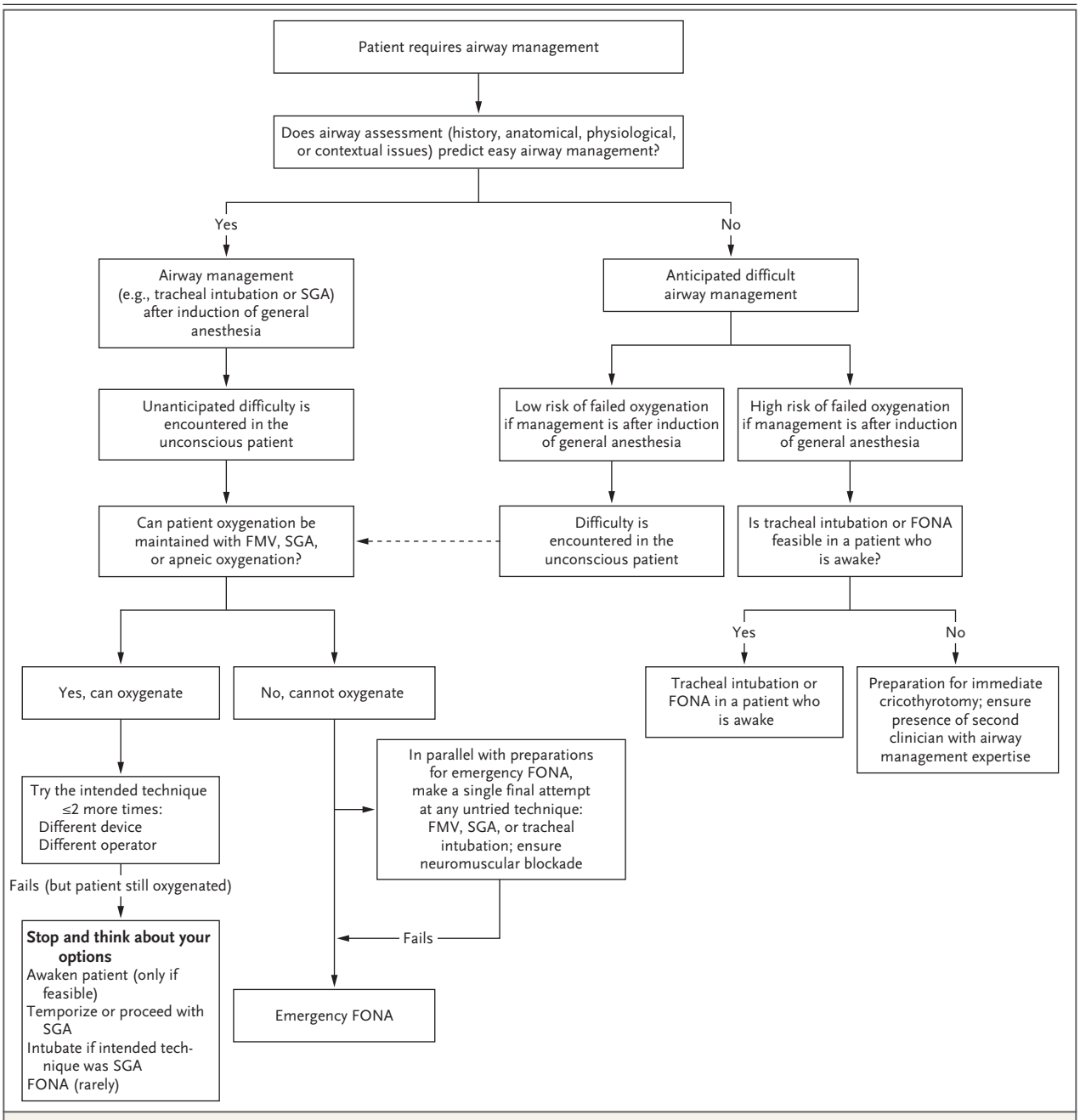

Figure 1. Airway Management Algorithm.

Practitioners performing airway management should call for help when they have difficulty with maintenance of patient oxygenation. Front-of-neck airway (FONA) access while the patient is awake or sufficiently conscious and breathing spontaneously is rarely practiced but is not unusual in situations such as those involving a high risk of failed oxygenation if airway management is performed after induction of general anesthesia or a high risk that tracheal intubation in a patient who is awake might fail (e.g., in a patient with a massive tumor in the supraglottic region). Adapted from Law and Heidegger.[28] FMV denotes face-mask ventilation, and SGA supraglottic airway.

even in cases requiring two attempts, the incidence of one or more adverse events, such as desaturation or esophageal intubation, was 47%, as compared with 14% in cases with one attempt.[57]

A major contribution to a bad outcome in the management of a difficult airway is perseveration, defined as the repeated application of any airway management technique or tool in three or more attempts without deviation or change.[5] Besides changing the operator, which should

always be considered, changing to video laryngoscopy is a valid alternative for a second or third attempt[58] and may be considered the technique of first choice for tracheal intubation, as recommended by the recently updated guidelines of the Canadian Airway Focus Group.[10] The first-attempt or overall success rate for tracheal intubation facilitated by video laryngoscopy is rarely lower and is often higher than the rate for tracheal intubation facilitated by direct laryngoscopy.[10,59-61] However, video laryngoscopy is not a panacea,[62] and the data are still conflicting.

In a multicenter study involving 720 patients with simulated limited mouth opening and restricted neck movement,[63] the primary outcome for each of the six video laryngoscopes used was that the lower limit of the 95% confidence interval for the rate of a successful first attempt within 180 seconds was 90% or higher. However, when this model is used for trauma patients, the amount of time taken is a concern. With 60 seconds as a more reasonable cutoff time, the first-attempt success rate was less than 70%. A Cochrane review comparing video laryngoscopy with direct laryngoscopy in the operating room, ICU, and emergency department concluded that video laryngoscopy may reduce the number of failed tracheal intubations, particularly among patients with a difficult airway, but that there was insufficient evidence that the use of a video laryngoscope reduces the number of tracheal intubation attempts or the incidence of hypoxia or respiratory complications. In addition, mostly because of a lack of standardization of outcome measures, there was no evidence that the use of a video laryngoscope affects the time required for tracheal intubation.[64]

A systematic review and two meta-analyses of studies conducted in ICUs suggest that video laryngoscopy does not perform better than traditional direct laryngoscopy across a wide range of conditions, even if video laryngoscopy can offer better visualization of the glottis.[65-67] However, published data on video laryngoscopy in critically ill patients are generally of poor quality.[68] The Difficult Airway Society of the United Kingdom states that a video laryngoscope should be available and considered as an option for all intubations of critically ill patients, provided that the physician is appropriately trained in the use of this device.[68]

When ventilation and oxygenation are possible but tracheal intubation with direct or video laryngoscopy has failed after a maximum of three attempts, it is time to stop and think about the options. These are awakening the patient (usually not an option in the emergency department or ICU), temporizing or proceeding with a supraglottic airway, intubating if the intended technique was insertion of a supraglottic airway, making a further attempt at tracheal intubation (e.g., with the use of a flexible bronchoscope),[69] or on rare occasions, using front-of-neck airway access (Fig. 1).[28]

"Cannot Intubate, Cannot Oxygenate" Situation

If oxygenation is impaired and oxygen saturation is declining, an emergency situation must be declared, with immediate preparation for front-of-neck airway access. In parallel, a final attempt at any untried technique is recommended (Fig. 1), and neuromuscular blockade should be established (or reestablished).[43,44]

If a "cannot intubate, cannot oxygenate" situation persists, establishment of front-of-neck airway access must be attempted immediately. Most airway societies recommend a scalpel–bougie–tube approach for cricothyrotomy, but a cannula-based technique can be considered by physicians who are experienced in its use.[70]

ANTICIPATED DIFFICULTY

When no technical difficulty is predicted, airway management generally occurs after the induction of general anesthesia.[28] This affords optimized conditions for technical management mainly because of the administration of medications, including neuromuscular blocking agents. The use of general anesthesia with neuromuscular blockade for airway management is more comfortable for the patient and the clinician than management while the patient is awake and is most often safe. Since the patient is unconscious and often apneic, however, airway patency and gas exchange must be addressed while the airway is being secured.

Even when laryngoscopy or tracheal intubation is predicted to be difficult but airway management during general anesthesia is considered to be safe, the induction of general anesthesia can be attempted as long as a strategy for addressing difficulty or failure is available (Fig. 1).[14,71] The

goal should be to achieve first-pass success, since rescue techniques are much more likely to fail.[72] However, when tracheal intubation is predicted to be very difficult or fallback techniques are predicted to be difficult, or both, an extra margin of safety might be afforded by performing tracheal intubation while the patient is awake.[73]

Tracheal Intubation while the Patient Is Awake

Tracheal intubation while the patient is awake or sufficiently conscious and breathing spontaneously involves securing the airway and applying topical airway anesthesia, with or without the use of sedation.[73,74] However, a patient's responsiveness to stimuli, airway reflexes, and ability to maintain spontaneous ventilation may be impaired by deep sedation.[75,76] The device typically used to perform tracheal intubation while the patient is awake is a flexible bronchoscope, although in selected cases, a video laryngoscope can be used. Tracheal intubation while the patient is awake might be indicated, especially when there is a high risk of failed oxygenation after the induction of general anesthesia (e.g., in patients with morbid obesity or tumors in the oropharyngeal region).[10,69] Airway management techniques for patients who are awake have been underused in cases of a difficult airway that is clearly recognizable.[1,5]

Airway Management in Obese Patients

On the basis of the increased incidence of bad outcomes of airway management in obese patients,[1] airway societies have begun declaring such patients to be at elevated risk, and management of the anticipated difficult airway should be undertaken accordingly.[73] Basically, the same principles of airway management in patients with an anticipated difficult airway (described above) can be used for airway management in obese patients. However, since obesity is a significant predictor of airway difficulty and of increased risk related to apnea, as noted above,[1,34] special considerations must be addressed to maximize safety, such as tracheal intubation while the patient is awake or general anesthesia with attention to the details of implementation (e.g., apneic oxygenation) and arrangement for the presence of a second clinician.[73,77,78] Because obese patients are at particularly high risk for airway obstruction,[79-81] there is still controversy regarding the benefit of apneic oxygenation.[79,82,83]

TRACHEAL EXTUBATION OF THE DIFFICULT AIRWAY

As compared with tracheal intubation, relatively little has been published about tracheal extubation, which is a tricky part of airway management.[84] Since planned tracheal extubation is always an elective procedure, there should be time for careful preparation.

The Difficult Airway Society of the United Kingdom has published guidelines for the management of tracheal extubation.[85] Even though they were developed for the perioperative period, the basic principles can readily be applied in the ICU as well.[68,86] The guidelines define the main goals of safe extubation as ensuring uninterrupted oxygen delivery and having a backup plan for tracheal reintubation, should tracheal extubation fail. The crucial consideration is whether the patient will be at risk after tracheal extubation (Fig. 2). Patients may be at risk either because they cannot withstand tracheal extubation or because of the potential difficulty of tracheal reintubation. Risk factors for unsuccessful tracheal extubation are functional airway obstruction such as muscle weakness or impaired cognitive status, anatomical airway obstruction such as airway edema or secretion overload, and cardiopulmonary issues such as fluid overload or compromised functional residual capacity. Risk factors for difficult reintubation include known difficult tracheal intubation or upper airway surgery. A detailed list of all factors that put patients at risk after tracheal extubation can be found elsewhere.[73,85,87]

The key questions are whether it is safe to remove the tube, to postpone extubation, or to perform a tracheotomy (Fig. 2). Different advanced techniques are available, and recommendations vary among professional societies.[73,85,87] However, none of the techniques cover all clinical scenarios, and none of the techniques are without risk. The use of an airway exchange catheter for extubation in an at-risk patient in whom reintubation might be difficult is recommended, but the practitioner must be experienced in this technique.[73,85,87] The patient's trachea can be immediately reintubated through this placeholder in the case of a failed extubation. In this case, reintubation can be improved by using a video laryngoscope.[88] A catheter of the appropriate size is

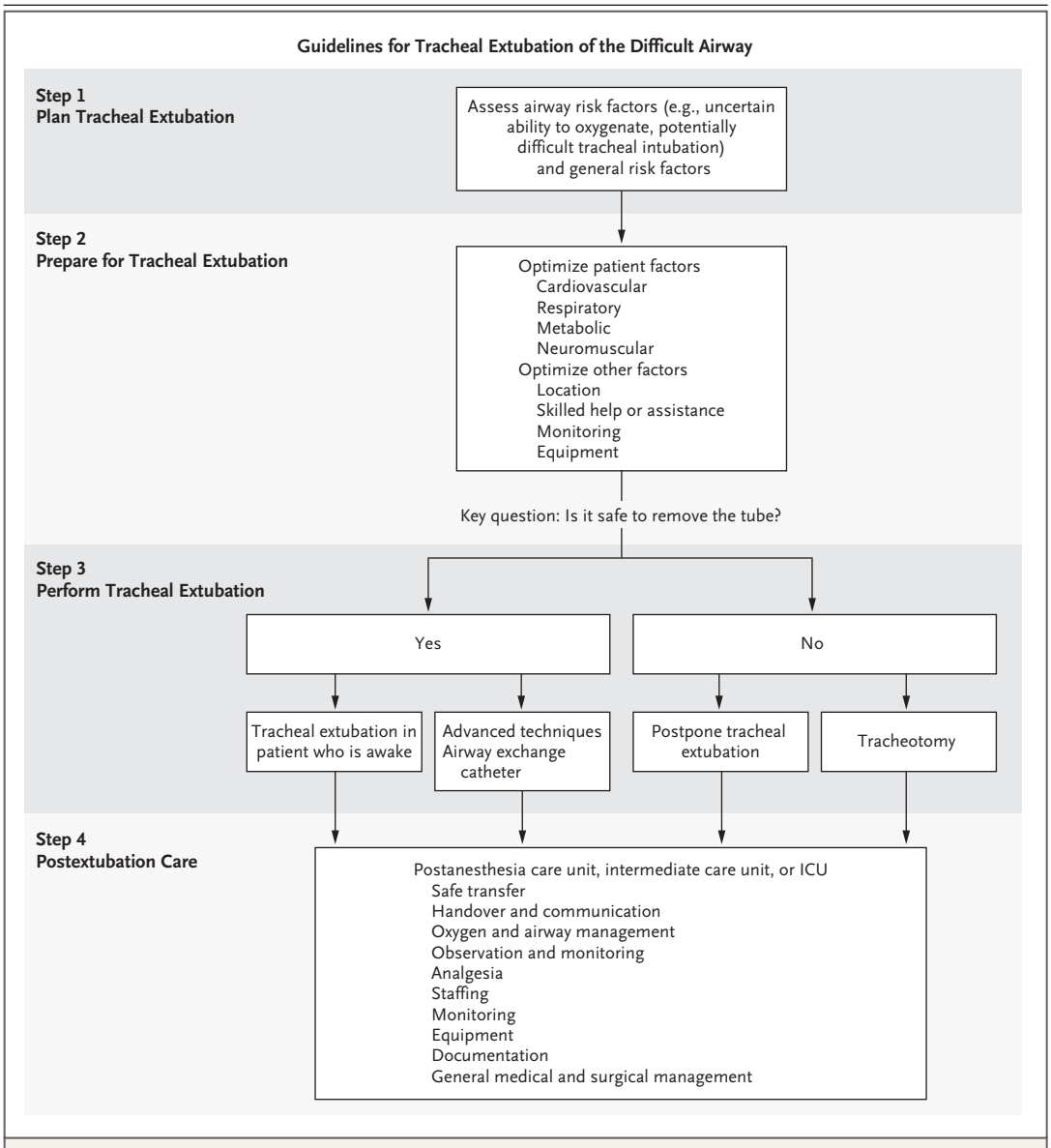

Figure 2. Guidelines for Tracheal Extubation of the Difficult Airway.

Tracheal extubation of the difficult airway is associated with the following airway risk factors: preexisting airway difficulties (e.g., obesity and risk of aspiration), perioperative airway deterioration (e.g., edema resulting from surgery), restricted airway access (e.g., cervical spine fixation and mandibular wiring), and general risk factors (e.g., impaired respiratory function and cardiovascular instability). Adapted from Popat et al.[85] ICU denotes intensive care unit.

placed and secured above the carina before the tube is removed. These catheters are usually not problematic and can be left in situ until tracheal reintubation is unlikely to be needed. However, since severe barotrauma and subsequent death have been reported after continuous application of oxygen through an airway exchange catheter,[89] routine oxygen insufflation through this device is discouraged.[73] Instead, supplemental oxygen should be administered by means of a face mask or high-flow nasal cannulae.[90]

HUMAN FACTORS AND ERGONOMICS IN AIRWAY MANAGEMENT

The study of human factors is the discipline that applies theoretical principles, data, and methods to design in order to optimize human well-being

and overall system performance, including patient safety.[91] In the NAP4 study, human factors contributed to 40% of serious airway complications and were major factors in 25% of these cases.[1] A follow-up analysis showed that these proportions were grossly underestimated.[92] Poor situational awareness (e.g., failure to anticipate a problem), job factors (e.g., task difficulty), and personal factors (e.g., tiredness) had the greatest influence.[92,93]

Failure of judgment and a delay in attempting a surgical airway in an emergency "cannot intubate, cannot oxygenate" situation were common human factors in the U.S. closed-claims analysis.[5] An analysis of closed civil cases involving anesthesiologists, reported by the Canadian Medical Protective Association, showed that 46 of the 406 cases (11%) were related to problems with airway management.[94] The outcomes were severe, with death or permanent brain damage occurring in two thirds of the 46 cases. Inadequate preoperative airway evaluation was the most common judgment failure (accounting for 59% of the cases).

Human factors, including adequate assessment and planning, decision making, situational awareness, avoidance of perseveration, communication, and teamwork, play an essential role in airway management safety.[93,95,96] A detailed description can be found elsewhere.[71,97-99]

CONCLUSIONS

Management of the difficult airway is an important issue, since even small changes in the performance of airway management are highly relevant to the outcome. Airway management is a process that requires thorough preparation, which includes careful airway assessment, planning, and appropriate decision making. Management of the airway involves the use of appropriate techniques and skills, an appropriate response to difficulty or failure, and careful planning for tracheal extubation. Skills and human factors together are the key to successful airway management.

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REFERENCES

1. Cook TM, Woodall N, Frerk C, eds. Major complications of airway management in the United Kingdom: report and findings. 4th National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. London: Royal College of Anaesthetists, 2011 (https://www.nationalauditprojects.org.uk/NAP4_home?newsid=463#pt).
2. O'Sullivan E, Laffey J, Pandit JJ. A rude awakening after our fourth 'NAP': lessons for airway management. Anaesthesia 2011;66:331-4.
3. Huitink JM, Cook T. The epidemiology of airway management complications. In: Cook T, Kristensen MS, eds. Core topics in airway management. 3rd ed. Cambridge, England: Cambridge University Press, 2021:22-37.
4. Cook TM. Strategies for the prevention of airway complications — a narrative review. Anaesthesia 2018;73:93-111.
5. Joffe AM, Aziz MF, Posner KL, Duggan LV, Mincer SL, Domino KB. Management of difficult tracheal intubation: a closed claims analysis. Anesthesiology 2019;131:818-29.
6. Schiff JH, Welker A, Fohr B, et al. Major incidents and complications in otherwise healthy patients undergoing elective procedures: results based on 1.37 million anaesthetic procedures. Br J Anaesth 2014;113:109-21.
7. Weiser TG, Haynes AB, Molina G, et al. Estimate of the global volume of surgery in 2012: an assessment supporting improved health outcomes. Lancet 2015;385:Suppl 2:S11.
8. De Jong A, Rolle A, Molinari N, et al. Cardiac arrest and mortality related to intubation procedure in critically ill adult patients: a multicenter cohort study. Crit Care Med 2018;46:532-9.
9. Apfelbaum JL, Hagberg CA, Caplan RA, et al. Practice guidelines for management of the difficult airway: an updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Anesthesiology 2013;118:251-70.
10. Law JA, Duggan LV, Asselin M, et al. Canadian Airway Focus Group updated consensus-based recommendations for management of the difficult airway. Part 1. Difficult airway management encountered in an unconscious patient. Can J Anaesth (in press).
11. Han R, Tremper KK, Kheterpal S, O'Reilly M. Grading scale for mask ventilation. Anesthesiology 2004;101:267.
12. Klock PA Jr. Definition and incidence of the difficult airway. In: Hagberg CA, Artime CA, Aziz MF, eds. Hagberg and Benumof's airway management. 4th ed. Philadelphia: Elsevier, 2018:178-84.
13. Lim KS, Nielsen JR. Objective description of mask ventilation. Br J Anaesth 2016;117:828-9.
14. Cooper RM. Preparation for and management of "failed" laryngoscopy and/or intubation. Anesthesiology 2019;130:833-49.
15. Levitan RM, Heitz JW, Sweeney M, Cooper RM. The complexities of tracheal intubation with direct laryngoscopy and alternative intubation devices. Ann Emerg Med 2011;57:240-7.
16. O'Loughlin EJ, Swann AD, English JD, Ramadas R. Accuracy, intra- and inter-rater reliability of three scoring systems for the glottic view at videolaryngoscopy. Anaesthesia 2017;72:835-9.
17. Kheterpal S, Han R, Tremper KK, et al. Incidence and predictors of difficult and impossible mask ventilation. Anesthesiology 2006;105:885-91.
18. Langeron O, Masso E, Huraux C, et al. Prediction of difficult mask ventilation. Anesthesiology 2000;92:1229-36.
19. Aziz MF, Healy D, Kheterpal S, Fu RF, Dillman D, Brambrink AM. Routine clinical practice effectiveness of the Glidescope in difficult airway management: an analysis of 2,004 Glidescope intubations, complications, and failures from two institutions. Anesthesiology 2011;114:34-41.
20. Aziz MF, Abrons RO, Cattano D, et al. First-attempt intubation success of video laryngoscopy in patients with anticipated

difficult direct laryngoscopy: a multicenter randomized controlled trial comparing the C-MAC D-Blade versus the GlideScope in a mixed provider and diverse patient population. Anesth Analg 2016;122:740-50.
21. Odor PM, Bampoe S, Moonesinghe SR, et al. General anaesthetic and airway management practice for obstetric surgery in England: a prospective, multicentre observational study. Anaesthesia 2020; 76:460-71.
22. Kinsella SM, Winton ALS, Mushambi MC, et al. Failed tracheal intubation during obstetric general anaesthesia: a literature review. Int J Obstet Anesth 2015;24: 356-74.
23. Teoh WH, Mushambi MC. The airway in obstetrics. In: Cook T, Kristensen MS, eds. Core topics in airway management. 3rd ed. Cambridge, England: Cambridge University Press, 2021:185-91.
24. Loong T-W. Understanding sensitivity and specificity with the right side of the brain. BMJ 2003;327:716-9.
25. Pandit JJ, Heidegger T. Putting the 'point' back into the ritual: a binary approach to difficult airway prediction. Anaesthesia 2017;72:283-8.
26. Roth D, Pace NL, Lee A, et al. Airway physical examination tests for detection of difficult airway management in apparently normal adult patients. Cochrane Database Syst Rev 2018;5:CD008874.
27. Detsky ME, Jivraj N, Adhikari NK, et al. Will this patient be difficult to intubate? The rational clinical examination systematic review. JAMA 2019;321:493-503.
28. Law JA, Heidegger T. Structured planning of airway management. In: Cook T, Kristensen MS, eds. Core topics in airway management. 3rd ed. Cambridge, England: Cambridge University Press, 2021:38-49.
29. Yentis SM. Predicting difficult intubation — worthwhile exercise or pointless ritual? Anaesthesia 2002;57:105-9.
30. Moon TS, Fox PE, Somasundaram A, et al. The influence of morbid obesity on difficult intubation and difficult mask ventilation. J Anesth 2019;33:96-102.
31. Saasouh W, Laffey K, Turan A, et al. Degree of obesity is not associated with more than one intubation attempt: a large centre experience. Br J Anaesth 2018;120: 1110-6.
32. Le Fevre PJ, Gough C, Hearne BJ, et al. A trial comparing emergency front of neck airway performance in a novel obese-synthetic neck, meat-modified obese neck and conventional slim manikin. Anaesthesia 2019;74:480-7.
33. Gadd K, Wills K, Harle R, Terblanche N. Relationship between severe obesity and depth to the cricothyroid membrane in third-trimester non-labouring parturients: a prospective observational study. Br J Anaesth 2018;120:1033-9.
34. Mosier JM, Joshi R, Hypes C, Pacheco G, Valenzuela T, Sakles JC. The physiologically difficult airway. West J Emerg Med 2015;16:1109-17.
35. Heidegger T, Hagberg CA. Algorithms for management of the difficult airway. In: Hagberg CA, Artime CA, Aziz MF, eds. Hagberg and Benumof's airway management. 4th ed. Philadelphia: Elsevier, 2018: 203-14.
36. Schäuble JC, Heidegger T. Management of the difficult airway: overview of the current guidelines. Anaesthesist 2018; 67:725-37. (In German.)
37. Crosby ET. An evidence-based approach to airway management: is there a role for clinical practice guidelines? Anaesthesia 2011;66:Suppl 2:112-8.
38. Schaeuble JC, Heidegger T. Strategies and algorithms for the management of the difficult airway: traditions and paradigm shifts 2017. Trends Anaesth Crit Care 2017;13:32-40.
39. Nørskov AK, Rosenstock CV, Wetterslev J, Astrup G, Afshari A, Lundstrøm LH. Diagnostic accuracy of anaesthesiologists' prediction of difficult airway management in daily clinical practice: a cohort study of 188 064 patients registered in the Danish Anaesthesia Database. Anaesthesia 2015;70:272-81.
40. Frerk C, Mitchell VS, McNarry AF, et al. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. Br J Anaesth 2015;115:827-48.
41. Hagberg CA, Artime CA, Aziz MF, eds. Hagberg and Benumof's airway management. 4th ed. Philadelphia: Elsevier, 2018.
42. Fei M, Blair JL, Rice MJ, et al. Comparison of effectiveness of two commonly used two-handed mask ventilation techniques on unconscious apnoeic obese adults. Br J Anaesth 2017;118:618-24.
43. Warters RD, Szabo TA, Spinale FG, DeSantis SM, Reves JG. The effect of neuromuscular blockade on mask ventilation. Anaesthesia 2011;66:163-7.
44. Ikeda A, Isono S, Sato Y, et al. Effects of muscle relaxants on mask ventilation in anesthetized persons with normal upper airway anatomy. Anesthesiology 2012; 117:487-93.
45. Lindsay HA, Cook TM, Russo SG, Hagberg CA. Supraglottic airway techniques: laryngeal mask airways. In: Hagberg CA, Artime CA, Aziz MF, eds. Hagberg and Benumof's airway management. 4th ed. Philadelphia: Elsevier, 2018:328-48.
46. Cook T. Supraglottic airways. In: Cook T, Kristensen MS, eds. Core topics in airway management. 3rd ed. Cambridge, England: Cambridge University Press, 2021:102-21.
47. El-Orbany M, Woehlck H, Salem MR. Head and neck position for direct laryngoscopy. Anesth Analg 2011;113:103-9.
48. Collins JS, Lemmens HJM, Brodsky JB, Brock-Utne JG, Levitan RM. Laryngoscopy and morbid obesity: a comparison of the "sniff" and "ramped" positions. Obes Surg 2004;14:1171-5.
49. Rognås L, Hansen TM, Kirkegaard H, Tønnesen E. Pre-hospital advanced airway management by experienced anaesthesiologists: a prospective descriptive study. Scand J Trauma Resusc Emerg Med 2013; 21:58.
50. Kim J, Kim K, Kim T, et al. The clinical significance of a failed initial intubation attempt during emergency department resuscitation of out-of-hospital cardiac arrest patients. Resuscitation 2014; 85:623-7.
51. Hasegawa K, Shigemitsu K, Hagiwara Y, et al. Association between repeated intubation attempts and adverse events in emergency departments: an analysis of a multicenter prospective observational study. Ann Emerg Med 2012;60(6):749.e2-754.e2.
52. Kerslake D, Oglesby AJ, Di Rollo N, James E, McKeown DW, Ray DC. Tracheal intubation in an urban emergency department in Scotland: a prospective, observational study of 3738 intubations. Resuscitation 2015;89:20-4.
53. Goto T, Watase H, Morita H, et al. Repeated attempts at tracheal intubation by a single intubator associated with decreased success rates in emergency departments: an analysis of a multicentre prospective observational study. Emerg Med J 2015; 32:781-6.
54. Mort TC. Emergency tracheal intubation: complications associated with repeated laryngoscopic attempts. Anesth Analg 2004;99:607-13.
55. Bernhard M, Becker TK, Gries A, Knapp J, Wenzel V. The first shot is often the best shot: first-pass intubation success in emergency airway management. Anesth Analg 2015;121:1389-93.
56. Martin LD, Mhyre JM, Shanks AM, Tremper KK, Kheterpal S. 3,423 Emergency tracheal intubations at a university hospital: airway outcomes and complications. Anesthesiology 2011;114:42-8.
57. Sakles JC, Chiu S, Mosier J, Walker C, Stolz U. The importance of first pass success when performing orotracheal intubation in the emergency department. Acad Emerg Med 2013;20:71-8.
58. Aziz MF, Brambrink AM, Healy DW, et al. Success of intubation rescue techniques after failed direct laryngoscopy in adults: a retrospective comparative analysis from the Multicenter Perioperative Outcomes Group. Anesthesiology 2016;125: 656-66.
59. Aziz MF, Dillman D, Fu R, Brambrink AM. Comparative effectiveness of the C-MAC video laryngoscope versus direct laryngoscopy in the setting of the predicted difficult airway. Anesthesiology 2012;116:629-36.
60. Kaplan MB, Hagberg CA, Ward DS, et al. Comparison of direct and video-assisted views of the larynx during rou-

tine intubation. J Clin Anesth 2006;18:357-62.
61. Brown CA III, Kaji AH, Fantegrossi A, et al. Video laryngoscopy compared to augmented direct laryngoscopy in adult emergency department tracheal intubations: a National Emergency Airway Registry (NEAR) study. Acad Emerg Med 2020;27:100-8.
62. Norris A, Heidegger T. Limitations of videolaryngoscopy. Br J Anaesth 2016;117:148-50.
63. Kleine-Brueggeney M, Greif R, Schoettker P, Savoldelli GL, Nabecker S, Theiler LG. Evaluation of six videolaryngoscopes in 720 patients with a simulated difficult airway: a multicentre randomized controlled trial. Br J Anaesth 2016;116:670-9.
64. Lewis SR, Butler AR, Parker J, Cook TM, Smith AF. Videolaryngoscopy versus direct laryngoscopy for adult patients requiring tracheal intubation. Cochrane Database Syst Rev 2016;11:CD011136.
65. Cabrini L, Landoni G, Baiardo Redaelli M, et al. Tracheal intubation in critically ill patients: a comprehensive systematic review of randomized trials. Crit Care 2018;22:6.
66. Zhao BC, Huang T-Y, Liu K-X. Video laryngoscopy for ICU intubation: a meta-analysis of randomised trials. Intensive Care Med 2017;43:947-8.
67. Huang H-B, Peng J-M, Xu B, Liu G-Y, Du B. Video laryngoscopy for endotracheal intubation of critically ill adults: a systemic review and meta-analysis. Chest 2017;152:510-7.
68. Higgs A, McGrath BA, Goddard C, et al. Guidelines for the management of tracheal intubation in critically ill adults. Br J Anaesth 2018;120:323-52.
69. Heidegger T, Gerig HJ, Ulrich B, Kreienbühl G. Validation of a simple algorithm for tracheal intubation: daily practice is the key to success in emergencies — an analysis of 13,248 intubations. Anesth Analg 2001;92:517-22.
70. Timmermann A, Chrimes N, Hagberg CA. Need to consider human factors when determining first-line technique for emergency front-of-neck access. Br J Anaesth 2016;117:5-7.
71. Rewers M, Chrimes N. Human factors in airway management. In: Cook T, Kristensen MS, eds. Core topics in airway management. 3rd ed. Cambridge, England: Cambridge University Press, 2021:305-15.
72. Marshall SD, Pandit JJ. Radical evolution: the 2015 Difficult Airway Society guidelines for managing unanticipated difficult or failed tracheal intubation. Anaesthesia 2016;71:131-7.
73. Law JA, Duggan LV, Asselin M, et al. Canadian Airway Focus Group updated consensus-based recommendations for management of the difficult airway. Part 2. Planning and implementing safe management of the patient with an anticipated difficult airway. Can J Anaesth (in press).
74. Ahmad I, El-Boghdadly K, Bhagrath R, et al. Difficult Airway Society guidelines for awake tracheal intubation (ATI) in adults. Anaesthesia 2020;75:509-28.
75. Lodenius Å, Maddison KJ, Lawther BK, et al. Upper airway collapsibility during dexmedetomidine and propofol sedation in healthy volunteers: a nonblinded randomized crossover study. Anesthesiology 2019;131:962-73.
76. Heidegger T, Schnider TW. "Awake" or "sedated": safe flexible bronchoscopic intubation of the difficult airway. Anesth Analg 2017;124:996-7.
77. Wong DT, Dallaire A, Singh KP, et al. High-flow nasal oxygen improves safe apnea time in morbidly obese patients undergoing general anesthesia: a randomized controlled trial. Anesth Analg 2019;129:1130-6.
78. Moon TS, Tai K, Kim A, et al. Apneic oxygenation during prolonged laryngoscopy in obese patients: a randomized, double-blinded, controlled trial of nasal cannula oxygen administration. Obes Surg 2019;29:3992-9.
79. Nimmagadda U, Salem MR, Crystal GJ. Preoxygenation: physiologic basis, benefits, and potential risks. Anesth Analg 2017;124:507-17.
80. Benumof JL, Dagg R, Benumof R. Critical hemoglobin desaturation will occur before return to an unparalyzed state following 1 mg/kg intravenous succinylcholine. Anesthesiology 1997;87:979-82.
81. Eskander A, de Almeida JR, Irish JC. Acute upper airway obstruction. N Engl J Med 2019;381:1940-9.
82. Frat J-P, Ricard J-D, Quenot J-P, et al. Non-invasive ventilation versus high-flow nasal cannula oxygen therapy with apnoeic oxygenation for preoxygenation before intubation of patients with acute hypoxaemic respiratory failure: a randomised, multicentre, open-label trial. Lancet Respir Med 2019;7:303-12.
83. Kim HJ, Asai T. High-flow nasal oxygenation for anesthetic management. Korean J Anesthesiol 2019;72:527-47.
84. Heidegger T. Extubation of the difficult airway — an important but neglected topic. Anaesthesia 2012;67:213-5.
85. Popat M, Mitchell V, Dravid R, Patel A, Swampillai C, Higgs A. Difficult Airway Society guidelines for the management of tracheal extubation. Anaesthesia 2012;67:318-40.
86. Sturgess DJ, Greenland KB, Senthuran S, Ajvadi FA, van Zundert A, Irwin MG. Tracheal extubation of the adult intensive care patient with a predicted difficult airway — a narrative review. Anaesthesia 2017;72:248-61.
87. Cooper RM. Extubation and reintubation of the difficult airway. In: Hagberg CA, Artime CA, Aziz MF, eds. Hagberg and Benumof's airway management. 4th ed. Philadelphia: Elsevier, 2018:844-67.
88. Mort TC, Braffett BH. Conventional versus video laryngoscopy for tracheal tube exchange: glottic visualization, success rates, complications, and rescue alternatives in the high-risk difficult airway patient. Anesth Analg 2015;121:440-8.
89. Scottish Courts and Tribunals. Inquiry under the Fatal Accidents and Inquiries (Scotland) Act 1976 into the sudden death of Gordon Ewing. April 2010 (https://www.scotcourts.gov.uk/search-judgments/judgment?id=328e86a6-8980-69d2-b500-ff0000d74aa7).
90. Duggan LV, Law JA, Murphy MF. Supplementing oxygen through an airway exchange catheter: efficacy, complications, and recommendations. Can J Anaesth 2011;58:560-8.
91. Carayon P, Xie A, Kianfar S. Human factors and ergonomics as a patient safety practice. BMJ Qual Saf 2014;23:196-205.
92. Flin R, Fioratou E, Frerk C, Trotter C, Cook TM. Human factors in the development of complications of airway management: preliminary evaluation of an interview tool. Anaesthesia 2013;68:817-25.
93. Schulz CM, Burden A, Posner KL, et al. Frequency and type of situational awareness errors contributing to death and brain damage: a closed claims analysis. Anesthesiology 2017;127:326-37.
94. Crosby ET, Duggan LV, Finestone PJ, Liu R, De Gorter R, Calder LA. Anesthesiology airway-related medicolegal cases from the Canadian Medical Protective Association. Can J Anaesth 2020;68:183-95.
95. Domino KB. Death and brain damage from difficult airway management: a "never event." Can J Anaesth 2021;68:169-74.
96. Yentis S. Of humans, factors, failings and fixations. Anaesthesia 2010;65:1-3.
97. Rall M, Gaba DM, Howard SK, Dieckmann P. Human performance and patient safety. In: Miller RD, ed. Miller's anesthesia. 8th ed. Philadelphia: Elsevier, 2015:106-66.
98. Marshall S. The use of cognitive aids during emergencies in anesthesia: a review of the literature. Anesth Analg 2013;117:1162-71.
99. Scott JA, Heard SO, Zayaruzny M, Walz JM. Airway management in critical illness: an update. Chest 2020;157:877-87.