and systems that independently affect mortality.[40] On the contrary, upper airway obstruction can occur in less compromised patients and, by itself, does not appear to increase the likelihood of adverse outcomes.[41] Another hypothesis to account for this difference in outcome is that patients who fail trials of extubation because of airway obstruction are reintubated earlier than those who fail because of intrinsic respiratory complications,[41] and time to reintubation after failure has been found to be an independent predictor of hospital mortality.[13,24]

Interestingly, in the NAP4 study only 1 of the 36 airway management complications reported in ICU patients occurred at the time of tracheal extubation. It is not possible to calculate the incidence of these events because a reliable estimate of the number of patients managed in ICUs in the same 1-year observation period is missing. This is a limitation of the ICU portion of the study, which is otherwise an extremely interesting and useful source of information on major complications of airway management and clinical practices in anesthesia and intensive care at a national level.[43–45] However, other investigations show that tracheal reintubation, either after failed extubation or failed weaning, is a much more common occurrence in the ICU than in the postoperative setting.[25] Moreover, unplanned extubation occurs in 5% to 15% of ICU intubated patients and is associated with increased ICU morbidity and mortality.[40]

CONDITIONS AND PROCEDURES AT INCREASED RISK FOR EXTUBATION FAILURE AND DIFFICULT AIRWAY MANAGEMENT

Conditions such as obesity, OSA,[6,46–48] major head/neck and upper airway surgery,[6,28,35,49,50] obstetric,[51] and cervical spine procedures[52–56] carry significantly increased risks of extubation failure and are frequently associated with difficult airway management.

Obesity and OSA

The Centers for Disease Control and Prevention define obese individuals as those with a body mass index >30 kg/m^2.[57] In the United States, the "heaviest" Western Country, the prevalence of obesity was 34% in 2008.[58] OSA is a syndrome characterized by periodic, partial, or complete obstruction of the upper airway during sleep.[59] Up to 71% of morbidly obese patients are affected by OSA.[60] Expert recommendations and practice guidelines for the perioperative management of the obese and OSA patients largely overlap.[46–48,59]

Obese patients have a higher incidence of difficult mask ventilation,[61–63] increased risk of pulmonary aspiration, airway obstruction, and rapid oxygen desaturation after anesthesia induction.[48] Difficult intubation has been reported in 7.5% of morbidly obese patients.[64] In reports investigating major airway complications, the prevalence in obese patients is often higher than in the general population. Sixty-five of the 156 (42%) perioperative airway events in the 2005 ASA Closed Claim data analysis (data from 1985 to 1999)[1] and 77 of 184 (42%) complications in the NAP4 report[6] involved obese patients. In the time periods corresponding to the ASA Closed Claim and NAP4 data collections, prevalence of obesity in the United States ranged between 10% and 25%[c] (from 1985 to 1999); and in England, the prevalence of obesity was 22% for men and 24% for women (2009 data).[d] According to recent studies, this relatively high prevalence does not necessarily result in increased hospital stay and higher mortality,[65–67] especially for the subgroup of moderately obese patients.[68] However, these statistics do suggest that obese patients present a higher risk of airway management-related complications compared with the general population. Important postoperative concerns in the management of both obese and OSA patients include: (1) increased susceptibility to the respiratory-depressant effects of opioids and anesthetics; (2) increased risk of hypoxia that may require the use of continuous positive airway pressure treatment; (3) attention to patient positioning, which should be "nonsupine"; and (4) appropriate monitoring for early detection of respiratory and cardiovascular impairment (such as continuous pulse oximetry, capnography, and telemetry).[46–48,59]

Of note, in OSA patients undergoing upper airway surgery for the treatment of OSA, the incidence of postoperative airway complications, including obstruction leading to severe oxygen desaturation, may be as high as 5%.[46,69]

Head and Neck Pathology, Maxillofacial and Major Neck and Upper Airway Surgery

In the presence of head and neck pathology and after maxillofacial and major neck surgery, rates of tracheal reintubation between 0.7% and 11.1% have been reported.[29,35] This also applies to endoscopic upper airway surgery, after which 4.2% of the patients whose tracheas were extubated in the OR needed to be reintubated in the PACU.[28]

In the NAP4 report, 72 of the 184 adverse airway events (39.1%) involved patients with acute or chronic head and neck pathologies. Of these 72, 55 events were anesthesia-related (41.3% of the 133 anesthesia-related events), and the rest occurred in the ICU and emergency department. Of the 55 anesthesia-related events, 13 (23.6%) occurred at the time of tracheal extubation or during the recovery period. These adverse events in patients with head and neck pathologies accounted for 34.2% of all events during emergence or recovery.[6]

Patients with active head and neck pathology, or who have undergone surgical or radiation treatment for head and neck cancer, are also at an increased risk of adverse airway events when presenting for other types of surgeries. In a 4-year observational study on prediction of impossible mask ventilation and outcomes, Kheterpal et al.[63] examined more than 50,000 attempts at mask ventilation over more than 94,000 anesthetics and found that neck radiation changes were the most significant clinical predictor of impossible mask ventilation. Besides critical difficulties with mask ventilation, radiation therapy induces extreme neck rigidity and modification of normal airway anatomy that may cause significant difficulty with tracheal intubation and makes it extremely challenging to perform an emergency

[c] Available at: http://www.cdc.gov/obesity/data/trends.html. Accessed on November 27, 2011.

[d] NHS, the Information Centre: Statistics on Obesity, Physical Activity and Diet: England, 2011. Available at:http://www.ic.nhs.uk/statistics-and-data-collections/health-and-lifestyles/obesity. Accessed on November 27, 2011.

tracheostomy. Moreover, postradiation airway edema, that may be worsened by impaired lymphatic drainage after neck dissection, is a contributory risk factor for postextubation laryngeal obstruction in this group of patients.[70]

Obstetrics

In an analysis of anesthesia-related maternal deaths in Michigan from 1985 to 2003, Mhyre et al.[51] found that all anesthesia-related deaths from airway obstruction or hypoventilation (5 events) took place during emergence and recovery and not during the induction of general anesthesia. In contrast, in the NAP4 report, all airway-related adverse events in pregnant women (4 cases) involved emergency cesarean deliveries and occurred at the time of tracheal intubation.[6] It is difficult to reconcile the different findings in the 2 reports, especially because of insufficient information about the environment in which the events occurred and the lack of details about the clinical management of these cases. However, the known frequent prevalence of obesity and airway edema among pregnant women[71] suggests the necessity of an appropriate strategy to prevent airway-related complications in this group at any stage of the anesthetic management.

Rheumatoid Arthritis

In patients with rheumatoid arthritis (RA), traumatic tracheal intubation due to decreased neck mobility and anatomical abnormalities has been considered a potential contributory cause of postextubation airway obstruction. The prevalence of laryngeal involvement in RA ranges from 13% to 75% in clinical studies and between 45% and 88% in postmortem studies.[72] Patients with RA may have deviation of the larynx causing difficulty at intubation;[73] arthritis of the cricoarytenoid joints that may present as a life-threatening airway obstruction;[72,74–76] and laryngeal rheumatoid nodules that may be worsened by microtrauma and may contribute to airway obstruction.[72]

In 1994, Wattenmaker et al.[77] suggested that fiberoptic intubation should be the method of choice in patients with advanced RA (as defined by the decision to proceed with surgical spine stabilization) to avoid excessive manipulation of the airway during direct laryngoscopy that may have a critical role in the development of postextubation airway obstruction.[77] Future studies should compare the safety and facility of video-assisted laryngoscopy techniques in RA patients, because these techniques were not available at the time of the initial study.

Cervical Spine Surgery

Airway obstruction after anterior cervical spine surgery is a known complication that may cause extubation failure. Patients who have undergone anterior cervical spine surgery are at risk of airway compromise both immediately after tracheal extubation at the end of surgery, and for several hours after the surgical procedure (up to 48 hours). Indeed, airway complications after tracheal extubation are particularly insidious in this group of patients, and may occur also in patients who have been kept intubated overnight after surgery, to avoid complications from slow formation of retropharyngeal hematomas.

In 2 different studies, patients experiencing extubation failure after anterior cervical spine surgery required tracheal reintubation between 0[52] and 24 hours[53] after extubation. In a retrospective chart review of 311 anterior cervical procedures, Sagi et al.[53] found that airway complications occurred in 6% of cases, a third of which required tracheal reintubation. The authors identified the following as predictors of increased risk of postoperative airway complications: length of surgery >5 hours; surgical exposure of >3 vertebral levels that include C2, C3, or C4; and blood loss ≥300 mL. Considering the potential for the development of delayed respiratory complications, the authors suggested continued close respiratory monitoring of these patients for up to 48 hours postoperatively.[53]

Overflexion of the cervical spine has been shown to be a possible cause of upper airway obstruction after posterior cervical spine surgery.[54–56] The mechanism of this rare but extremely serious complication will be discussed below, in the causes and mechanisms of extubation failure section. RA is an additional risk factor for the development of upper airway obstruction after cervical spine surgery.[56]

CAUSES AND MECHANISMS OF EXTUBATION FAILURE

Causes of postextubation upper airway obstruction are heterogeneous and can be classified on the basis of the anatomical segment of the airway involved, the predisposing clinical conditions, and the underlying pathophysiologic mechanism.

Pharyngeal Obstructions

Loss of pharyngeal patency is common in obese and OSA patients. This is due to a combination of mechanisms, the main one being the "anatomical mismatch between the craniofacial bony enclosures and the amount of soft tissue."[66] The second mechanism is a reduction in the longitudinal tension of the pharyngeal wall causing collapse of the airway. Pharyngeal wall tension is thought to depend mainly on traction exerted by the trachea moving caudally during inspiration (bigger tidal volumes causing more caudal traction). The decreased traction on the trachea caused by a reduced lung volume expansion in anesthetized obese/OSA patients would then cause upper airway collapse.[45,66,78–80] Shallow breathing and lung atelectasis are common contributing factors to upper airway closure in morbidly obese patients after general anesthesia and surgery.

Formation of a retropharyngeal hematoma is a known complication after anterior cervical spine surgery and a life-threatening cause of airway obstruction.[53] Accumulation of airway secretions associated with impaired cough reflex or reduced cough strength[14,18,81,82] is a common additional cause of pharyngeal obstruction in ICU patients (see below).

Laryngeal Obstructions

Edema of the larynx is a frequent cause of postextubation airway obstruction.[6,32,37] Causes include multiple intubation attempts, upper airway and major neck surgery,[35,77] upper airway trauma and burns,[41] prone or Trendelenburg intraoperative positioning,[6] fluid overload,[83] prolonged tracheal intubation,[32] and long-term effects of neck radiation.[70]

While edema of the tongue and pharyngeal structures is easily assessed by direct vision or direct laryngoscopy, laryngeal edema may be more difficult to assess and quantify in the presence of an ETT. However, although the presence of an ETT may prevent optimal visualization of the airway,[32,36,84] if the tube is small compared with the size of the airway, as frequently indicated in upper airway surgery, examination of the degree and anatomical distribution of edema may be extremely helpful in guiding tracheal extubation.[10,34,85] The "degree" of edema is not easily defined as a specific amount of tissue swelling and attempts to develop a "measure of the degree of edema" resulted in moderate levels of agreement among observers.[86] Nevertheless, a case-by-case assessment of the disproportion between upper airway diameters, within the finite limits of their bony and cartilaginous enclosures and the swollen mucosa, may predict situations at risk of postextubation upper airway obstruction.[87]

Flexible laryngoscopy or video-assisted laryngoscopy to detect airway edema before extubation may be useful in selected situations[10,87] (Table 3).

In ICU patients evaluated by fiberoptic endoscopic examination after extubation, edema of the vocal cords but not of the false vocal folds and arytenoids was associated with stridor, impaired vocal cord mobility, and need for reintubation.[88]

Laryngospasm is caused by contraction of the adductor muscles of the vocal cords, causing complete obstruction of the glottic opening. It is a protective airway reflex, activated by liquids or other substances entering the glottic space. Factors associated with its occurrence in adults are not completely clear, although some risk factors, such as smoking and obesity, have been identified.[33,89] In adults, laryngospasm during emergence may occur at a rate of up to 7.5%, and even more frequently in the postextubation phase of procedures on the upper airway.[90,91] Use of laryngeal mask airways in adults has been advocated to reduce postextubation respiratory complications such as coughing, desaturation,[92] and laryngospasm.[93,94] Interestingly, use of a laryngeal mask airway in children has been associated with an increased risk of laryngospasm,[95] especially after recent upper respiratory tract infections.[96]

Laryngospasm may be complicated by negative pressure pulmonary edema (NPPE). Young and healthy male patients appear to be at increased risk for NPPE, and this complication has a prevalence of approximately 0.1% in the postoperative period.[97–100] Although relatively rare, NPPE is a very serious complication that may lead to tracheobronchial and alveolar hemorrhage.[98] The reported mortality rate due to NPPE ranges between 2% and 40%, with higher mortality rates associated with delayed diagnosis, or underlying ventricular dysfunction or valvular pathology.[91,101]

Vocal cord paralysis secondary to recurrent laryngeal nerve (RLN) injury is another cause of laryngeal obstruction that frequently follows cervical and intrathoracic surgical procedures. Unilateral paralysis is asymptomatic more than 50% of the time,[102] whereas bilateral vocal cord paralysis presents immediately after extubation with stridor and airway obstruction, and may be a life-threatening event. Thyroid surgery is the most common cause of bilateral vocal fold immobility. Nonthyroid surgeries are the main cause of iatrogenic unilateral vocal cord paralysis.[102,103] The incidence of temporary RLN palsy after thyroid operations is 9.8%, and the incidence of permanent RLN palsy is 2.3%.[104] Reported rates of RLN injury vary greatly in the literature, depending on the method and timing of laryngeal examination. During thyroid surgery, the role of nerve monitoring in identifying the laryngeal nerve, thereby preventing postoperative vocal cord paralysis, is controversial.[102,105–107] As a tool to predict postoperative vocal cord function, this technique has been shown to be highly effective at correctly predicting normal nerve function, but it has a low predictive value for nerve injury (positive predictive value 40% and negative predictive value 100%).[105]

Postoperative Bleeding

Formation of hematoma compressing the upper airways externally or of clots obstructing the airway internally may depend not only on surgical factors, but also on hypocoagulability secondary to medical conditions or to drug effects. Antiplatelet and nonsteroidal anti-inflammatory drugs are associated with increased risk of perioperative bleeding,[108] but other commonly prescribed drugs and over-the-counter supplements can also impact surgical bleeding; these side effects may not be adequately known to prescribers. For example, selective serotonin reuptake inhibitors and venlafaxine have been reported to increase the risk of upper gastrointestinal tract bleeding[109] and, possibly, the risk of surgical bleeding.[110] In at least 1 case reported in the literature, abnormal bleeding after an oral surgical procedure led to airway compromise in a patient taking a selective serotonin reuptake inhibitor combined with nonsteroidal anti-inflammatory drugs.[111] In addition, a variety of dietary herbal supplements (such as gingko biloba, saw palmetto, and garlic) have been associated with excessive perioperative bleeding.[112]

Presence of Masses and Lesions

Masses and lesions obstructing or compressing the airway are well-known causes of difficult airway management. Occasionally, patients with mediastinal masses will undergo procedures for diagnostic purposes or surgery outside of the mediastinum. In such cases, the mass may cause compression on the airway before and after the procedure, requiring special precautions both at anesthesia induction and tracheal extubation, such as maintenance of head-up position as much as possible, the use of short-acting anesthetics, avoidance of muscle relaxants, and preservation of spontaneous ventilation.[113] Additionally, substernal and mediastinal masses may be difficult to evaluate and may cause unexpected postdecannulation airway collapse, preventing successful extubation.[114]

Effects of Drugs Administered in the Perioperative Period

Neuromuscular blocking drugs, anesthetics, and opioids may have deleterious effects on respiratory drive, muscle strength, and airway patency. Consequences of these effects on postoperative respiratory adverse events have been investigated extensively.

In a recent review on the clinical implications of residual neuromuscular block, Murphy and Brull[115] report an incidence of this condition that varies widely among studies (2%–64%). In this review, the impact of residual neuromuscular block on pharyngeal and airway muscle function, hypoxic ventilatory drive and subjective weakness is extrapolated from studies in healthy volunteers. In volunteer studies, the effects of neuromuscular blocking drugs may be better separated than in clinical studies from the effects of other drugs that may contribute to respiratory depression and airway obstruction in the postoperative period.

The following effects have been found to correlate with train-of-4 ratios <0.9 (0.7–0.9): impairment of pharyngeal coordination and force of contraction;[116,117] increased risk of aspiration;[117] reductions in upper airway volumes;[118] impairment of upper airway dilator muscle function;[118] decreased inspiratory air flow;[119] upper airway obstruction;[119] impaired hypoxic ventilatory drive;[120–122] and profound symptoms of muscle weakness.[123]

The review also examined large-scale, database-derived investigations assessing risk factors for anesthetic-related adverse outcomes that demonstrated an association between neuromuscular blocking drug use, residual paralysis, and increased perioperative severe morbidity and mortality.[124,125] Observational and randomized clinical studies were also considered, confirming that postoperative respiratory events, including airway obstruction, are the most common adverse outcomes associated with residual paralysis.[115]

In the general surgical patient population, tracheal reintubation due to depressive effects of opioids is uncommon in a monitored postoperative environment. Lee et al.,[31] in an analysis of a quality assurance database of 152,939 cases over a 5-year period (107,317 cases performed under general anesthesia), identified 191 reintubations, of which only 9 (4.71%) were classified as secondary to "excessive opioids" administration. However, it is not known how many patients in this population were rescued from opioid overdose with naloxone and/or noninvasive mask ventilation, thereby preventing the need for tracheal reintubation. Identification of all cases of opioid-related respiratory depression would have allowed the assessment of the role of monitoring and timely treatment of respiratory depression in preventing reintubation. It is, in fact, recognized that, in the absence of adequate monitoring of vital variables, in-hospital use of opioids is associated with increased mortality due to undetected upper airway obstruction and central apnea.[126,127] For inpatients receiving postoperative opioids, the routine use of pulse oximetry may prevent adverse outcomes from opioid-related respiratory depression. If supplemental oxygen is administered, the use of capnography to detect hypoventilation has been advocated.[e]

Populations at particularly high risk of respiratory depression and upper airway collapse after anesthesia and administration of opioids are obese/OSA patients[46,48,59,128] and patients who have undergone oral and maxillofacial surgery.[85,129] In the context of maxillofacial surgery, other factors may further increase the risk of airway obstruction, such as the presence of oral swelling, bleeding inside the airway and/or the use of intermaxillary surgical fixation that may prevent easy access to clear blood and secretions from the upper airway.

Specific Mechanisms of Airway Obstruction After Cervical Spine Surgery

Pharyngeal edema, vocal cord paralysis, and hematoma formation[52,53,56] are known causes of airway obstruction after anterior cervical spine surgery. Cerebrospinal fluid leak,[130] angioedema,[131] and graft or plate dislodgement[132,133] are less frequent complications of cervical spine procedures.[56]

Upper airway obstruction after posterior fusion of the cervical spine in an overflexed position has been described.[54–56] In this particular clinical situation, the mechanism of obstruction seems to depend on the narrowing of the pharyngeal space by the overflexion fixation of the cervical spine, rather than the presence of pharyngeal edema. Pharyngeal stenosis and resulting airway obstruction are corrected with surgical revision of the fixation angle.

Cough Strength and Endotracheal Secretions in ICU Patients

Inadequate cough[14,81] and excessive airway secretions[18] may also lead to loss of airway patency and extubation failure, particularly in ICU patients. In the absence of other causes of airway obstruction, upper airway patency relies on the ability to maintain the airway clear of secretions, owing to a balance between cough strength and amount and thickness of respiratory secretions. Cough strength has been found to be a more reliable predictor of extubation outcome than the amount of endotracheal secretions, also due to the difficulty in standardizing the method to quantify secretions[14] (Table 1).

CURRENT RECOMMENDATIONS

A "preformulated strategy for extubation of the difficult airway" has been recommended at least since the publication of the ASA Practice Guidelines for Management of the Difficult Airway in 1993.[9] The Practice Guidelines, updated in 2003, suggest that:

"The preformulated extubation strategy should include

1. A consideration of the relative merits of awake extubation versus extubation before the return of consciousness.
2. An evaluation for general clinical factors that may produce an adverse impact on ventilation after the patient has been extubated.
3. The formulation of an airway management plan that can be implemented if the patient is not able to maintain adequate ventilation after extubation.
4. A consideration of the short-term use of a device that can serve as a guide for expedited reintubation."

Of note, with the exception of tube exchangers to guide and expedite reintubation in the presence of a difficult airway,[9,10,25,94,134] no other specific tool or procedure to increase safety at extubation has gained wide acceptance or has been routinely adopted in clinical algorithms.

[e] "No Patient Shall Be Harmed By Opioid-Induced Respiratory Depression" in APSF Newsletter Fall 2011. Available at: http://www.apsf.org/newsletters/html/2011/fall/01_opioid.htm. Accessed on December 15, 2011.

Table 1. Proposed Methods to Evaluate Endotracheal Secretions and Cough Strength

Assessment of amount of endotracheal secretions
Amount of secretions[18] (single observer method)
Patients classified as producing no, mild, moderate, or abundant endotracheal secretions on the basis of personal observations. (reported PPV 96% for successful extubation in the no/mild secretions group)[a]
Frequency of suction[18]
>every 2 h versus < every 2 h. (PPV for successful extubation in the suction > every 2 h group = 98%)[a]
Assessment of cough strength
Semiobjective scale of cough strength[18] (single observer method)
0—no cough on command,
1—audible movement of air through the endotracheal tube but no audible cough,
2 —weakly (barely) audible cough,
3 —clearly audible cough,
4—stronger cough,
5—multiple sequential strong coughs.[a]
White card test (WCT)[18] (single observer method)
White file card 1–2 cm from the end of the endotracheal tube.
Patients asked to cough, up to 3–4 times. If any wetness appears on the card, it is classified as a positive WCT result (reported PPV 88% for successful extubation).[a]
Voluntary cough peak expiratory flow (PEF)[81]
Patients are asked to cough into a peak flowmeter placed in series with the endotracheal tube.
Head positioned at 30°–45° and patients coached to cough through the endotracheal tube spirometer.
The best of 3 attempts is recorded as the cough PEF.
PEF <60 L/min correlates with 5 times increased risk of unsuccessful extubations and 19 times increased risk of in-hospital death.[b]
Involuntary cough peak flow (CPFi)[14]
Induced by removing the T-piece and dripping 2 mL of normal saline into the endotracheal tube at the end-inspiratory point, with the patient in a head-up position at 45° from the horizontal.
T-piece and flow sensor are reconnected to the endotracheal tube as soon as possible.
Patients observed continuously until their breathing becomes smooth and regular.
The maximum expiratory flow value detected by the hand-held respiratory monitor is recorded as the involuntary CPF.
CPFi cutoff of 58.5 L/min resulted in a positive predictive value of the test of 93% to predict successful extubation in patients with CPFi >58.5 L/min.[c]

[a] Khamiees et al. 2001:[18] 91 adult medical cardiac intensive care unit (ICU) patients who passed an spontaneous breathing trial (SBT). Results from this group on the relation between the volume of secretions and success at extubation have not been replicated by a group that found that neuro ICU patients with "thick" secretions were more likely to fail extubation.[82] The "white card test" has not shown to be helpful in other publications other than the original paper in which it was presented. However, it represents an interesting attempt to quantify cough strength and is shown in the Table for its historic value.
[b] Smina et al. 2003:[81] 95 critically ill patients admitted to a medical ICU who had successfully passed an SBT.
[c] Su et al. 2010:[14] 150 adult ICU patients who had passed an SBT.

Table 2. "Awake" Versus "Asleep" Extubation: Pros and Cons[3,10,94]

Fully awake extubation
Pros = complete recovery of airway protective reflexes and effective spontaneous breathing are present and may increase safety margin in the presence of possible difficult reintubation.
Cons = active protective airway reflexes may lead to increased risk of rebleeding at the site of neck/upper airway surgery (increased venous pressure and straining on surgical wound).
Caveats = if patient is awake but NOT calm and cooperative, safe extubation procedures (e.g., flexible laryngoscopy, positioning of tube exchanger) may be extremely difficult.
"Asleep" extubation (= before return of consciousness)
Regular and effective spontaneous breathing must be present.
Pros = patient still partially anesthetized avoids coughing and fighting ventilator which may lead to increased risk of rebleeding (e.g., at the site of neck/upper airway surgery) due to increased venous pressure and straining on sutures.
Cons = lack/decrease of protective airway reflexes may lead to increased risk of aspiration and airway obstruction.
Caveats = easy intubation and mask ventilation are important prerequisites; the risk of laryngospasm is increased if extubation is performed during transition between deeply anesthetized and awake state.

There are reasons why recommendations relative to safe extubation have not been easily translated into clinical practice, as opposed to what occurred in the development of difficult intubation strategies and algorithms. Many reliable anatomical and functional predictors of inability to perform effective mask ventilation and intubation have been identified, and algorithms have been created in which key decision elements are quite easy and quick to assess; for instance, the question "is facemask ventilation adequate?" can be answered easily by a trained anesthesiologist. Advanced airway tools and techniques have been found to be effective in improving success rates of intubation and in the prevention and rescue of airway compromise. Moreover, when intubation and mask ventilation fail, this is immediately recognized as a dangerous clinical situation and can be effectively treated according to a validated difficult airway algorithm.

Evaluating potential risks of airway obstruction after extubation in a patient whose airway is still protected is a more subtle task. Providers may know that their patients' trachea had been difficult to intubate, and prepare an

Table 3. Evaluation of General Clinical Factors That May Have an Adverse Impact on Ventilation After Tracheal Extubation: Identification of Situations At-Risk

Risk factor for extubation failure	Predisposing conditions	Pre-extubation test	Sensitivity/Specificity PPV/NPV	References	Comments
Upper airway edema	Airway manipulation (difficult intubation, upper airway/ neck surgery) s/p neck radiation prone/ Trendelenburg positioning Trauma/upper airway burns Prolonged intubation Fluid overload	Cuff-leak test Visual assessment (direct or indirect laryngoscopy at the end of the surgical procedure, before extubation; laryngeal ultrasound also proposed)	Cuff-leak test discrimination power is highly variable depending on method and cutoff chosen; (see also Table 5)	De Backer 2005[136] Zulian et al. 1989[85] Dark and Armstrong 1999[34] Krohner 2003[137] Popat et al. 2012[10] Ding et al. 2006[138]	The Cuff-leak test may be coupled with laryngoscopy (direct, video-assisted or fiberoptic) to increase the ability to predict extubation failure; Value of laryngeal ultrasound is still to be determined.
Vocal cord paralysis	Neck and thoracic surgery; Traumatic intubation	Cuff-leak test Intraoperative Recurrent Laryngeal Nerve Monitoring (RLNM) by surgeon	PPV 40% NPV 100% (see above and Table 5 for comments on cuff-leak test)	Cernea et al. 2012[105]	Intraoperative RLNM accurately predicts intact RLN, less reliable in predicting injury.
Upper airway bleeding	Transoral surgery Airway/oral trauma	Visual assessment (laryngoscopy) Airway suction	N/A	NAP4 report[a]	
Residual neuromuscular blockade	Use of neuromuscular blocking drugs (NMBDs)	Clinical tests: inability to smile, swallow, speak; head and leg lift >5 s; general weakness; hand grip, tongue depressor test. Qualitative (visual or tactile) assessment of a response to peripheral nerve stimulation Quantitative (AMG, KMG, and EMG) neuromuscular monitoring tests to confirm TOF ratio >0.9	Clinical tests of neuromuscular function cannot reliably exclude residual paralysis unless TOF ratios are <0.5; The reliability of qualitative methods is low; Quantitative methods are more sensitive than both of the above.	Brull and Murphy 2010[139]	Intermediate-acting NMBDs can reduce the risk of residual paralysis compared with long-acting NMBDs. Complete recovery of neuromuscular function is more likely when antagonists are administered >15–20 min before extubation and at TOF count of 4 (this does not apply to sugammadex)
Increased secretions and cough strength (ICU patients; see also Table 1 for details)	Upper and lower airway pathologies	White card test; Determination of amount of secretions on the scale: "no, mild, moderate, abundant"; Involuntary cough peak flow (CPFi) Voluntary cough peak expiratory flow (PEF)	PPV 88%–96% to predict successful extubations with no/ mild secretion CPFi : PPV 93% to predict successful extubation if CPFi >58.5 L/min PEF <60 L/min = X 5 risk of unsuccessful extubation (95% confidence interval, 1.6–17.5).	Khamiees et al. 2001[18] Smina et al. 2003[81] Su et al. 2010[14]	Methods of determination of "abundance of secretions" are subjective

PPV = positive predictive value; NPV = negative predictive value; N/A = not appropriate; TOF = train-of-4; AMG = acceleromyography; KMG = kinemyography; EMG = electromyography; ICU = intensive care unit.
[a] http://www.rcoa.ac.uk/nap4

Table 4. Evaluation of General Clinical Factors That May Produce an Adverse Impact on Ventilation After Tracheal Extubation: Optimization of Medical Management

1. Use of steroids to prevent and treat laryngeal edema has been advocated both in the perioperative and ICU settings with a variety of protocols producing different results (see notes), but remains a controversial practice.[15,140,a]
2. Reversal of nondepolarizing neuromuscular block needs to be confirmed (gold standard quantitative measure of TOF ratio > 0.9);[115,139]
3. Careful consideration should be given to the head position: extubation in the left lateral head-down position is the position least likely to be associated with aspiration; head-up and upright position may be indicated in obese/OSA patients.[10,47,48,59,94]
4. Preoxygenation with 100% oxygen should always be performed before extubation.[10,94]
5. Consideration should be given to techniques that minimize stimulation and activation of airway reflexes during emergence such as administration of lidocaine, remifentanil infusion, and avoidance of tactile stimulation.[10,94,141]

Lidocaine, applied topically on the larynx or instilled through the ETT, may reduce coughing and the hemodynamic response to extubation. Intavenous lidocaine (1 mg/kg) may be an alternative, but is probably less effective.[94] Risk of aspiration when attenuating upper airway reflexes should be weighed against benefits.

Pros and cons of opioid administration (blunting airway reflexes versus depressing respiratory drive) should be evaluated, especially in obese/OSA patients.

6. When indicated, mainly in an ICU setting, adequate weaning parameters must also be confirmed with a spontaneous breathing trial before extubation.[142]
7. Postextubation airway obstruction due to edema may be relieved by nebulized racemic epinephrine.[10]
8. Use of helium-oxygen mixtures decreases the inspiratory effort in the presence of acute upper airway obstructions; when using these mixtures, benefits should be weighed against the decreased FIO_2.[10]

ICU = intensive care unit; TOF = train-of-4; OSA = obstructive sleep apnea; ETT = endotracheal tube.

[a] Clear benefits have only been demonstrated in selected groups of "high risk" patients (see below). Scheduled administration of intravenous steroids (mainly dexamethasone and methylprednisolone) is a common practice in the intraoperative and postoperative period of many upper airway, maxillofacial and neck surgeries and is considered beneficial in this setting.[137] Application of local steroids in the retropharyngeal space before wound closure has also been proposed to reduce prevertebral soft tissue swelling after anterior cervical discectomy and fusion.[143] Planned administration of steroids before extubation reduces the occurrence of laryngeal edema and may prevent reintubation in critically ill ICU patients.[32,36] In a large meta-analysis of randomized controlled trials, Jaber et al.[37] conclude that the administration of steroids to prevent postextubation stridor and reintubation is beneficial for critically ill patients considered at "high risk" on the basis of a cuff-leak test (leak <110 mL or <25% of the measured TV with cuff inflated—Table 5 for details on cuff-leak test), and only if steroids are administered at least 4 h before extubation. Also importantly, steroids will reduce inflammatory edema but not mechanical edema secondary to venous obstruction.[10]

Table 5. Quantitative Methods of Performing the "Cuff-Leak Test" and Proposed Cutoff Values

Proposed methods

With patient in assisted-controlled ventilation mode, to guarantee constant delivery of TV:

(a) Measurements of expiratory tidal volumes after 6 complete respiratory cycles with the ETT cuff deflated.[144]

(b) Measurements of expiratory tidal volumes with cuff deflated, ONLY at the end of the end-inspiratory pause.[145]

Method (b) was created for research purposes to evaluate the impact of factors influencing the inspiratory component of the leak on the total leak. Not proven to be clinically superior to the other method.[136,145]

Proposed cutoff values for leak (leak volume above which it is considered "safe" to extubate)

10%–25 % of the TV that was measured before cuff deflation (100 × [ETVci–ETVcd]/ETVci).[84,146,147]

OR

110–130 mL (adult population).[84,144,148]

The value of a cuff-leak test in predicting postextubation airway obstruction is quite controversial.[134,136,140,147,148] Results obtained with validated quantitative methods have been considered more reliable than those obtained with qualitative methods.[32,84,144,146,147] However, sensitivity and specificity of this test vary greatly in different patient populations, and higher or lower cutoff values may apply to different clinical situations. Choice of higher cutoff values, minimizing the risk of false negatives (negative result = presence of adequate leak), may be valuable in patients in whom difficult tracheal intubation is expected. Lower cut offs, thus reducing the risk of false positive (positive result = no or insufficient leak detected), may be preferred to minimize the risk of unnecessary prolonged intubation.[136] In a systematic review and meta-analysis, Ochoa et al.[149] concluded that while a negative result is not necessarily reassuring, a positive cuff-leak test should alert the clinician of a high risk of upper airway obstruction. In addition, the validity of this test as a predictor of extubation failure has been found to be higher in ICU patients ventilated for at least 48 h than for elective surgical patients and shorter ventilation times[136,147,148] and the association of a positive cuff-leak test and stridor was significantly associated with extubation failure.[82]

TV = tidal volume; ETT = endotracheal tube; ETVci = exhaled TV with cuff inflated; EVTcd = exhaled TV with cuff deflated; ICU = intensive care unit.

extubation strategy as the "logical extension of the difficult intubation strategy."[9] However they may fail to recognize situations in which factors related to surgery and anesthesia changed an initial "easy airway" into a difficult one, or created the conditions for postextubation airway obstruction. Moreover, extubation failure may not occur immediately after tracheal extubation and, without appropriate monitoring, may remain undetected until the loss of airway has resulted in a severe adverse outcome.

Our search has confirmed that many predictors of extubation failure can and should be identified before extubation (the statement "extubation . . . should always be an elective process"[10] is true, probably with the sole exception of an airway fire scenario), and that strategies and tools are available to improve extubation outcomes in the presence of difficult airways and/or high risk of postextubation airway obstruction.

In 2006, a panel of experts of the French Society of Anesthesia and Intensive Care (Société Française d'Anesthésie et de Réanimation) gathered in a conference on "Difficult intubation" and formulated a series of criteria for extubation considered "at risk" on the basis of the limited evidence available. In 2008, Francon and other members of the panel published the "Difficult extubation: Extubation criteria and management of risk situations," a review aimed to expand the issues discussed at the Conference. An "Extubation algorithm for high risk situations" is included, which is mainly based on the use of an AEC that is left in place for up to 1 hour after extubation if oxygen saturation is satisfactory (SpO_2 >90%). The AECs may be used as a

Table 6. Formulation of an Airway Management Plan That Can Be Implemented if the Patient Is not Able to Maintain Adequate Ventilation After Extubation

1. A suitable environment for a protected tracheal extubation must guarantee immediate availability of appropriately trained personnel and airway management equipment (e.g., oxygen source, suction, AEC, oral and nasopharyngeal airways, supraglottic ventilation devices, endotracheal tubes of different sizes, variety of laryngoscopes and fiberoptic scope).[6,10]
2. Consider potential role of capnography in the early detection of airway obstruction.[6,10,51,127,a]
3. Guidelines for airway management of obese/OSA patients uniformly recommend careful planning for postoperative monitoring and discharge,[47,48,59] which may include (re)-initiation of CPAP therapy in postanesthesia care unit, as indicated.
4. Extubation setting is critical in upper airway, maxillofacial and neck surgery. A multidisciplinary approach and close cooperation between the surgical and anesthesia teams are essential.[6,10,49,50,b]

Possibility to "implement an airway management plan" rests on the ability to timely detect high risk situations and the immediate availability of personnel and tools necessary to implement the rescue strategy.

[a] Lack of appropriate postoperative monitoring seemed to be one of the major determinants of adverse respiratory outcomes at end of anesthesia in the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society (NAP4) report[6] and in Mhyre et al.'s[51] report on the series of anesthesia-related maternal deaths in Michigan, 1985–2003, 5 of which took place during emergence and recovery and were due to airway obstruction or hypoventilation. In this report, the authors state that "system errors played a role in the majority of cases. This point is particularly important as lapses in postoperative monitoring and inadequate supervision by an anesthesiologist seemed to contribute to more than half of the deaths."[51]

[b] Complex head and neck patients and surgeries often require ad hoc strategies. As an example, Moore et al.[50] propose leaving the patient intubated for 24 h after oral cavity free flap reconstruction, and removing the tube in an intensive care setting after a course of IV steroids. In selected patients, this approach may avoid the necessity of a tracheostomy, allowing faster recovery of the physiologic respiratory function.[50] Cameron et al.[49] created a "tracheostomy scoring system" to guide airway management after major head and neck surgery. Applying this system, patients could be assigned, depending on their score, to elective extubation in the operating room at the end of the procedure, elective overnight ventilation via an endotracheal tube, or elective ventilation via tracheostomy. This scoring system requires validation but is an interesting systematic approach to postoperative airway management in this high risk population.[49]

AEC = airway exchange catheter; OSA = obstructive sleep apnea; CPAP = continuous positive airway pressure.

Table 7. Use of Airway Exchange Catheters (AECs)

1. Commonly used and recommended model and sizes: Cook AEC catheters 11 F and 14 F (Cook Critical Care, Bloomington, IN),[10,25,35,94] compatible with tracheal tubes of internal diameters >4 and 5 mm, respectively.[10] These sizes are large enough to provide adequate support in case of reintubation, and thin enough to be well tolerated by patients.
2. The catheter should be semirigid as opposed to rigid to minimize trauma. Hollow catheters are preferred, as they offer the ability to insufflate oxygen and/or ventilate through their lumen.[10,22,25,35,94,150–152]
3. Oxygen insufflation and jet ventilation through AEC may be associated with significant risk of barotrauma and should be reserved to selected life-threatening situations and administered by expert providers (an alternative source of oxygenation should be preferred whenever possible even with an AEC in place).[10,153]
4. Suggested depth of insertion is equal to the depth of the tip of the endotracheal tube (ETT) in place, generally about 20–22 cm orally or 27–30 cm nasally.[35] Appropriate depth of insertion of the catheter well above the carina and administration of local anesthetic through the AEC[10] can help minimize patient discomfort.
5. During reintubation over an AEC, use of advanced laryngoscopy (video-assisted or optical) has been suggested to improve visibility of the periglottic structures and facilitate advancement of the ETT into the trachea.[154]
6. Most common complications associated with AEC use: pneumothorax (unilateral or bilateral, with or without subcutaneous emphysema), pneumoperitoneum and pneumomediastinum, hypoxia during airway management and unintended esophageal misplacement leading to gastric perforation.[153,155–157]
7. There is disagreement on how long an AEC should be left in place after extubation (risks/benefits), and on the utility of this device in assisting reintubation in different clinical scenarios.

The use of a device similar to the modern airway exchange catheter (AEC) to facilitate reintubation in patients at risk for difficult reintubation had been proposed since 1979, when Choby et al.[150] proposed the use of an "appropriately sized catheter" through the ETT placed nasally to suction secretions and leave in place as a guide over which to remove the ETT during extubation of patients with intermaxillary fixation. The authors suggested that "When … the patient is not breathing sufficiently or is obstructed the catheter inside the trachea serves 1) to oxygenate by continuously insufflating oxygen through the catheter 2) as a guide for reintubation without removing the dental fixation." Ever since this first report many other authors have proposed the use of similar techniques and devices at extubation with the same indications.[151] These observations have lead to the development and use of the modern hollow AEC.[22,25,35] With this device Mort[25] reports an overall success rate at reintubation of 92 % (87% at first attempt) in intensive care unit (ICU) patients with "difficult airway."

1. The Sheridan TTX tracheal tube exchanger, (Sheridan Catheter Corp, Argyle, NY) and the Endotracheal Ventilation Catheter (CardioMed, Lindsay, Ontario, Canada) are other examples of hollow endotracheal tube exchangers.

2. Nonhollow catheters have also been proposed to facilitate reintubation (e.g., the Mettro Mizus Endotracheal Tube Replacement Obturator, Cook Critical Care; Bloomington, IN), however the use of hollow catheters, that allow oxygen insufflation or ventilation, has been generally widely favored and recommended.[10,22,25,35,94,150–152]

3. In a recent review on efficacy, complications and recommendations on the use of AEC, Duggan et al.[153] report that oxygen insufflation and even more jet ventilation through AEC may be associated with significant risk of barotrauma, and caution against use of AEC to administer oxygen in the absence of proven benefits of its use over the use of standard oxygen therapies. In the context of rapid decompensation of a patient with an AEC in situ, the authors convincingly suggest that priority should be given to attempt reintubation over attempting oxygenation and ventilation through the lumen of the catheter.[153]

4. The recently published Difficult Airway Society extubation guidelines suggest that "an AEC should never be inserted beyond 25 cm in an adult patient,"[10] but this obviously refers to the depth marked at the lips, in a patient intubated orally, and does not apply to nasally intubated patients.

7. There have been reports that maintaining the catheter in place for several hours,[25,35] even up to 72 h[22] in situations at risk for delayed complications, is safe and well tolerated by most patients. The guiding principle should be to leave the catheter in place as long as it is necessary to rule out complications that may lead to reintubation.

Use of AEC has not been found helpful in every investigated clinical scenario. In a simulated scenario of immobilized cervical spine created using a manual in-line axial stabilization, Kim et al.[158] did not confirm the adequate performance of an 11 F AEC in facilitating reintubation and do not recommend this method to maintain airway access after extubation in adult patients with cervical immobility or instability.

means of oxygenation, and reintubation or jet ventilation if saturation decreases below 90%.

Leaving the AECs in place for a maximum of 1 hour after extubation and adopting a cutoff Sp_{O_2} of 90% for satisfactory oxygenation seem arbitrary choices and definitely not indicated for all types of patients and clinical scenarios. However, recommendations concerning the importance of predicting situations at risk and planning accordingly, optimizing the patients' medical conditions and demanding the presence of an expert physician when difficulties with extubation are expected, are reasonable, and widely applicable in clinical practice.[135]

The recently published DAS extubation guidelines[10] follow in the same path and provide clinicians with pragmatic algorithms that apply to low-risk and at-risk situations in which difficulty with oxygenation, ventilation, and airway management may be expected.[f]

The main argument in favor of providing guidelines on the basis of a pragmatic approach and expert opinions is that high quality evidence generated by prospective randomized trials may not always be available, generalizable, or relevant to clinical practice.[12] The major weakness of the DAS guidelines is the lack of stringent criteria to diagnose situations and to guide decisions. The key question, "is it safe to remove the tube?" that is central to the at-risk algorithm, can be a difficult one, and the answer is left to the intuition of the individual provider, as is the challenge to make the "appropriate choices" and to select the suitable "advanced techniques" to apply with "meticulous attention to detail."

Pending further studies evaluating outcomes of specific interventions and strategies leading to the validation of widely accepted guidelines for the extubation of the difficult airway and extubation at risk, the reviewed literature supports the adoption of a series of practices that are consistent with the ASA Practice Guidelines for Management of the Difficult Airway (Tables 2–7).

CONCLUSION

Extubation failure may lead to severe outcomes, particularly in the presence of a difficult airway. Situations at risk for postextubation airway complications are frequently recognizable. Patients at risk may be identified by medical history, physical examination, and pre-extubation assessment of variables that predict airway patency and airway competence, but reliable diagnostic tests and predictors are still largely missing. Postextubation complications may be prevented or mitigated by preemptive optimization of the patients' medical conditions, careful timing and logistics of the extubation process, preparation for urgent or emergent tracheal reintubation (including routine use of AECs in case of extubation of difficult airways), and adequate level of postextubation monitoring and care.

DISCLOSURES

Name: Laura F. Cavallone, MD.
Contribution: This author participated in study design, research and analysis of the literature, and manuscript preparation.

[f] Available at: http://www.das.uk.com/guidelines/guidelineshome.html. Accessed on April 30, 2012.

Attestation: Laura F. Cavallone, MD approved the final manuscript.
Name: Andrea Vannucci, MD, DEAA.
Contribution: This author participated in study design, research and analysis of the literature, and manuscript preparation.
Attestation: Andrea Vannucci, MD, DEAA approved the final manuscript.
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