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EXTUBATION AND CHANGING ENDOTRACHEAL TUBES

Richard M. Cooper

I. INTRODUCTION

Tracheal extubation has received relatively limited critical scrutiny compared with attention to the identification and management of the potentially difficult intubation (DI). Textbooks, reviews, and conferences focusing on the airway frequently ignore this facet of management despite the observation that airway complications are significantly more likely to be associated with extubation than intubation.[14] Many of these "complications" are relatively minor, such as coughing and transient breath-holding, and have little or no impact upon outcome. Some, however, are life threatening. Moreover, some can be predicted and, with proper preparation, morbidity and mortality can be reduced.

The American Society of Anesthesiologists (ASA) Task Force on Management of the Difficult Airway[4,5] and the Canadian Airway Focus Group[67] recommended that each anesthesiologist have a preformulated strategy for extubation of the difficult airway (DA) and an airway management plan for dealing with postextubation hypoventilation. This chapter classifies the complications associated with tracheal extubation (and the exchange of endotracheal tubes), attempts to stratify the risk of extubation (and tube exchange) in various clinical settings, and proposes strategies that may prove helpful in reducing serious complications or death. Low-risk or routine extubation has been reviewed elsewhere[124,192] and is discussed in less detail. It is important to point out that neither the proposed stratification nor the strategies recommended in dealing with intermediate- and high-risk extubations have been validated by controlled, prospective trials. Such trials would be helpful, but it may not be prudent to await their conclusion.

II. RESPIRATORY COMPLICATIONS DURING OR AFTER EXTUBATION

An extubation fails when an attempt to remove a endotracheal tube (ET) is unsuccessful. An ET exchange is unsuccessful when an attempt to replace an ET is unsuccessful. There is no agreed upon time frame; therefore, the reported incidence varies widely. It is reasonable to consider the failed extubation in two different clinical settings: the intensive care unit (ICU), where such failures are relatively common, and the operating room (OR) or postanesthesia care unit (PACU), where they are less frequent.

In the ICU, the ability to predict readiness for endotracheal extubation is imprecise despite a host of predictive criteria.[75,111,183] To minimize the risks, discomfort, and expense of prolonged intubation, a "trial of extubation" is often attempted, not infrequently followed by reintubation. The incidence of required reintubation is on the order of 6% to 25%,[183] depending upon the clinical mix of patients, their critical acuity, pressures stemming from limitations of critical care resources, and the threshold levels for extubation. Compared with routine postoperative patients, intensive care patients are more likely to have failed extubation because neurologic obtundation may leave them unable to protect their airways. In addition, debilitation and impaired mucociliary clearance may interfere with pulmonary toilet, and diminished strength, altered pulmonary mechanics, increased dead space, and venous admixture may result in hypercapnic or hypoxemic respiratory failure.

Although the complications associated with the extubation of postoperative patients may be more frequent than those associated with intubation, they rarely require reintubation. Retrospective studies involving a wide case mix of postsurgical patients show a high degree of concordance regarding the incidence of required reintubation. Combining the results of three large studies involving nearly 50,000 patients, the incidence ranged from 0.09% to 0.19%.[130,186,221] The reintubation rate is significantly higher (1% to 3%) following selected surgical procedures such as panendoscopy[130] and a variety of head and neck procedures.[91,160,173,254,256]

Postoperative reintubation, although infrequent, may represent a considerable challenge for the anesthesiologist. Anatomic distortion may conspire with physiologic instability, incomplete information concerning the patient, or lack of essential equipment, personnel, or expertise, converting a previously easily managed airway to a disaster. As well, a DA adequately managed during a controlled induction is completely different from the DA in an agitated, hypoxemic, and hypotensive patient.

III. CLASSIFICATIONS

A. ROUTINE EXTUBATIONS

The complications of "routine" extubation" are summarized in Table 47-1. Extubation failures for the most part fall into one or more of the following categories: (1) failure of oxygenation, (2) failure of ventilation, (3) inadequate clearance of pulmonary secretions, or (4) loss of airway patency. These are discussed first in general terms, followed by consideration of complications that do not necessarily require reintubation. Lastly, we discuss specific clinical situations in which these problems are more likely to occur. When these occur with a higher frequency, they have been termed intermediate-risk extubations; when reintubation may be problematic, they have been termed high-risk extubations.

1. Hypoventilation Syndromes

One of the first reports from the ASA closed claims study noted that 4% of 1175 closed claims resulted from critical respiratory events in the PACU, the highest proportion being due to inadequate ventilation, in which a large

Table 47-1 **Complications of Routine Extubations**

Failed extubation
Hypoxia
Hypoventilation
Pulmonary toilet
Obstruction
Unintended extubation
Tube entrapment
Hemodynamic changes
Tachycardia or other dysrhythmias
Hypertension
Increased intraocular pressure
Increased intracranial pressure
Coughing, breath-holding
Laryngospasm
Negative-pressure pulmonary edema
Tracheal or laryngeal trauma
Laryngeal edema
Arytenoid dislocation
Vocal fold paralysis
Laryngeal incompetence
Pulmonary aspiration

proportion of the patients died or suffered brain damage.[268]

A wide variety of clinical conditions may give rise to postoperative ventilatory failure. In a large French multicenter prospective survey conducted between 1978 and 1982, involving nearly 200,000 patients, postoperative respiratory depression accounted for 27 of 85 respiratory complications that were life threatening or resulted in serious sequelae. Such complications were responsible for seven deaths and five cases of hypoxic encephalopathy.[248] Rose and colleagues found that 0.2% of 24,000 patients had a respiratory rate of less than 8 breaths/min, as detected by PACU nurses following general anesthesia.[221,222]

Hypoventilation may be mediated centrally at the level of the upper motor neuron, the anterior horn cell, the lower motor neuron, the neuromuscular junction, or the respiratory muscles. Clinical correlates include central sleep apnea, carotid endarterectomy,[259] medullary injuries, demyelinating disorders, direct injury to peripheral nerves, poliomyelitis, Guillain-Barré syndrome, motor neuron disease, myasthenia gravis, and botulism. As well, hypoventilation may result from the loss of lung or pleural elasticity, diaphragmatic splinting caused by abdominal pain or distention, thoracic deformities such as kyphoscoliosis, or multifactorial entities such as morbid obesity and severe chronic obstructive pulmonary disease. Rarely, hypercapnia results from an excess of carbon dioxide production or a marked increase in physiologic dead space.

The residual effects of anesthetic drugs contribute to inadequate postoperative ventilation.[153,116,197] This may be exacerbated by incomplete reversal of neuromuscular blockers,[94] hypocalcemia or hypermagnesemia, or the administration of other drugs, including antibiotics, local anesthetics, diuretics, and calcium channel blockers, which may potentiate neuromuscular blockade.

2. Hypoxemic Respiratory Failure

There are many causes of postoperative hypoxemia, a review of which is beyond the scope of this chapter. Generally, these might occur as a result of hypoventilation, a low inspired oxygen concentration, ventilation-perfusion mismatch, right-to-left shunting, increased oxygen consumption, diminished oxygen transport, or rarely an impairment of oxygen diffusion. Clearly, there are clinical situations in which such events are more likely because of preexisting medical conditions or anesthetic and surgical interventions. If the situation is sufficiently severe, there may be a requirement for continuous positive airway pressure (CPAP) or reintubation and mechanical ventilation.

3. Inability to Protect Airway

ICU or postoperative patients may be unable to protect their airway because of preexisting obtundation, neurologic injury, or the effects of residual anesthesia. Patients may be at an equally high risk for pulmonary aspiration at extubation as they are during intubation. Extubation of patients at increased risk for regurgitation should be delayed if the risks can be lessened by such postponement. Alternatively, turning them on their side, placing them head up (or head down), or reversing residual medications with antagonists should be considered. These measures may not restore airway competence, and lack of resolution may necessitate reintubation.

4. Failure of Pulmonary Toilet

Inadequate clearance of pulmonary secretions may be due to a depressed level of consciousness with impaired airway reflexes, overproduction of secretions, an alteration of sputum consistency leading to inspissation and plugging, impaired mucociliary clearance, or inadequate neuromuscular reserve. These may result in atelectasis or pneumonia with attendant hypoxemic respiratory failure. Alterations in pulmonary mechanics may also lead to hypercapnia, necessitating reintubation.

5. Inadvertent Extubations

Inadvertent extubations may result from movement of or by the patient with an inadequately secured ET.

Intraoperatively, this may occur in prone positioning, when the airway is shared with the surgeon, when the head and neck are extended, when draping obscures the view, or when drapes adherent to the ET or circuit are carelessly removed. In the ICU, this may occur when the patient is repositioned for radiographs or routine nursing care. Fastidious attention to securing the tube, providing support for the circuit, and, when necessary, moving the patient and the tube as an integral unit should help to reduce the frequency of this complication. Self-extubations may occur during emergence from anesthesia when the patient is confused, agitated, or distressed, prompting premature extubation. In the ICU, it may not be possible to know whether a self-extubation is accidental or deliberate, but many of these patients require reintubation[33] and are more likely to exhibit postextubation stridor,[193] and the situation may involve multiple intubation attempts, esophageal intubation, and death.[194,255]

6. Entrapment

The ET may also become entrapped because of an inability to deflate the cuff[161,246] or difficulties with the pilot tube.[129,238] This can occur as a consequence of a crimped pilot tube or defective pilot valve. Fixation of the ET by Kirschner wires,[169] screws,[165] or ligatures[3] and entanglement with other devices[99,132] have been described. Entrapment can also occur during the performance of a percutaneous tracheostomy.[56] Mechanical obstruction of an entrapped tube is a life-threatening complication. As well, partial transection of the ET by an osteotome during a maxillary osteotomy has resulted in the partially cut tube forming a "barb" that caught on the posterior aspect of the hard palate.[229] One report of entrapment had fatal consequences. This involved a Carlens tube that was inadvertently sutured to the pulmonary artery.[83] Lang and coauthors[165] have recommended routine intraoperative testing for ET movement when fixation devices are used in proximity to the airway. Uncertainty about tube movement should prompt fiberoptic examination prior to emergence from general anesthesia.[165]

7. Hypertension and Tachycardia

Transient hemodynamic disturbances accompany extubation in most adults. These responses may be prevented by deep extubation[147] or insertion of a laryngeal mask airway (LMA) prior to emergence[15,198] or attenuated by concurrent medication. Most healthy patients not receiving antihypertensives or other cardioactive drugs exhibit increases in heart rate and systolic blood pressure (BP) of more than 20%.[86] Following coronary artery bypass surgery, these changes tend to be transient, lasting 5 to 10 minutes, and are generally not associated with electrocardiographic evidence of myocardial ischemia.[208] Coronary sinus lactate extraction measurements, however, indicate that among patients with poor cardiac function, extubation can be associated with myocardial ischemia.[264] Patients with inadequately controlled hypertension, carcinoid, pheochromocytoma, hypertension associated with pregnancy, or hyperthyroidism might be expected to display even more marked increases in BP in response to tracheal extubation. The need for specific strategies to attenuate these generally transient changes is dictated by the clinical context. Such strategies, not universally effective, include the use of intracuff,[98,97] intratracheal[245] or intravenous lidocaine,[139,208,239] β-blockers,[86,196,203] and nitrates.

8. Intracranial Hypertension

Endotracheal intubation and suctioning is associated with a rise in intracranial pressure (ICP). It is probable that extubation is associated with comparable or even more marked rises in ICP. There is evidence, albeit contradictory, that intravenous lidocaine[22] and endotracheal lidocaine[42] attenuate this effect.

9. Intraocular Pressure

Madan and colleagues compared the intraocular pressure (IOP) changes of endotracheal intubation and extubation in children with and without glaucoma.[180] They observed significantly greater increases 30 seconds and 2 minutes following *deep* extubation compared with the corresponding times following uncomplicated intubations. These differences were seen in both groups of children. If significant increases in IOP were noted following deep extubation, it is likely that these would have been even higher had extubation occurred following recovery of consciousness. Lamb and coworkers observed similar effects of extubation on IOP in adults, noting that this increase could be prevented by using an LMA rather than an ET.[163]

10. Coughing

Coughing on emergence from general anesthesia is virtually ubiquitous,[151] particularly when an ET is utilized. Surprisingly, Kim and Bishop did not detect a difference between smokers and nonsmokers.[151] In some clinical settings, coughing can be particularly troublesome and may result in serious morbidity. Coughing at extubation may be particularly troublesome in the setting of ophthalmologic, neurologic, tonsil, thyroid, and vascular surgery.

A variety of strategies have been proposed to minimize coughing, including deep endotracheal extubation, the primary use of or conversion to an LMA,[12,154,198] the intravenous or topical application of a local anesthetic to the vocal folds,[239] and the use of intracuff lidocaine.[97,98]

Apart from the aforementioned settings, coughing upon emergence is both common and relatively benign for most patients. As this chapter is being prepared, a respiratory

illness (severe acute respiratory syndrome [SARS]) has emerged with significant transmission to health care workers, particularly those involved with airway management. Currently, there is no specific treatment for SARS and it is associated with considerable morbidity and mortality. This has resulted in a reevaluation of the risks of coughing, at least in a subset of patients. It is premature to speculate upon the long-term and geographic implications of this illness; however, from the perspective of an anesthesiologist in the North American epicenter for SARS, Toronto, Canada,[38,215] coughing upon emergence potentially disperses infected respiratory droplets on those in the patient's vicinity. Currently, this has necessitated a "new normal" protective strategy including appropriate apparel (goggles and/or visor, N95 particulate respirator, gloves, gown, and an air-powered protective respirator hood when SARS is suspected or diagnosed) for those in the patient's vicinity.

11. Glottic Edema

Several of the complications of endotracheal intubation do not become apparent until after extubation occurs. Laryngeal or tracheal trauma may occur despite a good laryngeal view[189] or during awake fiberoptic intubation.[182] Anatomic or functional laryngeal problems are more likely to develop as a consequence of difficult or prolonged intubation attempts.[221] Possible airway injuries include laryngeal edema, laceration, hematoma, granuloma formation, vocal fold immobility, and dislocation of the arytenoid cartilages.[249]

Glottic edema has been classified as supraglottic, retroarytenoidal, and subglottic.[36] Supraglottic edema results in posterior displacement of the epiglottis reducing the laryngeal inlet and causing inspiratory obstruction. Retroarytenoidal edema restricts movement of the arytenoid cartilages, limiting vocal cord abduction during inspiration. Subglottic edema, a particular problem in neonates and infants, results in swelling of the loose submucosal connective tissue, confined by the nonexpandable cricoid cartilage. In neonates and small children, this is the narrowest part of the upper airway and small reductions in diameter result in a significant increase in airway resistance. In children, laryngeal edema is promoted by a tight-fitting ET, traumatic intubation, duration of intubation greater than 1 hour, coughing on the ET, and intraoperative alterations of head position.[156] These investigators found an incidence of 1% in children younger than 17 years. Laryngeal edema should be suspected when inspiratory stridor develops within 6 hours of extubation. Management of laryngeal edema depends upon its severity. Treatment options include head-up positioning, supplemental humidified oxygen, racemic epinephrine, helium-oxygen administration, reintubation, and tracheostomy.

Clinical studies in children and adults, evaluating the role of prophylactic corticosteroids in the prevention of postextubation stridor, have yielded contradictory findings, although the majority fail to identify a benefit from dexamethasone or methylprednisolone administration.[8,70,114,133] It is possible that the benefits of steroids are restricted to high-risk populations and require the administration of multiple doses.[233] In addition, questions remain about the methodology of some of the studies.[174]

An alternative classification has been proposed for laryngotracheal injury following prolonged intubation.[25] Immediate postextubation airway obstruction results from glottic and subglottic granulation tissue, which may swell upon removal of the ET. Posterior glottic and subglottic stenosis related to contracting scar tissue results in increasing obstruction weeks or months following extubation. Benjamin found that fiberoptic evaluation or laryngoscopy with the tube in situ was of limited value. An ET obscures the view of the posterior glottis and subglottis. These lesions were best identified using rigid telescopes with image magnification during general anesthesia. This permitted the anticipation of problems and the development of a management strategy.[25]

12. Laryngospasm

Laryngospasm is a common cause of postextubation airway obstruction, particularly in children.[205] Even in adults, Rose and colleagues found that it accounted for 23.3% of critical postoperative respiratory events.[222] Olsson and Hallen observed an increased incidence among patients presenting for emergency surgery, those requiring nasogastric tubes, and those undergoing tonsillectomy, cervical dilation, hypospadias correction, oral endoscopy, or excision of skin lesions.[205] A variety of triggers are recognized, including vagal, trigeminal, auditory, phrenic, sciatic, splanchnic nerve stimulation, cervical flexion or extension with an indwelling ET, or vocal cord irritation from blood, vomitus, or oral secretions.[217] Laryngospasm involves bilateral adduction of the true vocal folds, the vestibular folds, and the aryepiglottic folds that outlasts the duration of the stimulus. This is protective to the extent that it prevents aspiration of solids and liquids. It becomes maladaptive when it restricts ventilation and oxygenation. The intrinsic laryngeal muscles are the main mediators of laryngospasm. These include the cricothyroids, lateral cricoarytenoids, and the thyroarytenoid muscles. The cricothyroid muscles are the vocal cord tensors, an action mediated by the superior laryngeal nerve. Management of laryngospasm consists of prevention by either extubating at a sufficiently deep plane of anesthesia[147] or awaiting recovery of consciousness. Potential airway irritants should be removed and painful stimulation should be discontinued. If laryngospasm occurs, oxygen by sustained positive pressure may be helpful, although this may push the aryepiglottic folds more tightly together.[228] Very small doses of a short-acting neuromuscular blocker[55,164] with or without reintubation may be necessary.

13. Macroglossia

Massive tongue swelling may complicate prolonged posterior fossa surgery[82,158,162,237] performed in the sitting, prone, or "park bench" position. It may result from arterial, venous, or mechanical compression; have a neurogenic origin; or possibly result from angioneurotic edema. In the ICU setting, it may be seen as a complication of severe volume overload or tongue trauma, particularly when this is further complicated by a coagulopathic state. If this occurs or progresses after extubation, it can lead to partial or complete airway obstruction making reintubation necessary but difficult or impossible.[158] Lam and Vavilala postulated that in most cases, positioning results in venous compression leading to arterial insufficiency and a subsequent reperfusion injury.[162] Alternatively, local compression may cause venous or lymphatic obstruction with resultant immediate but generally milder tongue swelling. The latter form is less severe but more apparent, and extubation is likely to be postponed.

14. Laryngeal or Tracheal Injury

Laryngeal injuries accounted for 33% of all airway injury claims and 6% of all claims in the ASA closed claims database.[80] These range from transient hoarseness to vocal fold paralysis. Even when direct laryngoscopy results in a satisfactory glottic view[189] or intubation is facilitated by fiberoptic instrumentation,[182] airway injury may occur and go unsuspected until the ET is removed. Although airway injuries may be less likely if intubation is easy, this provides no assurance that such injury has not occurred. Indeed, the ASA closed claims analysis revealed that 58% of *airway* trauma and 80% of the *laryngeal* injuries were associated with "nondifficult" intubations.[51,80] (Judging from the closed claims analysis, DIs were more likely to result in *pharyngeal* and *esophageal* injuries.) Tracheal and laryngeal trauma may, however, produce dislocation of the arytenoid cartilages.[249]

Tolley and others described three cases involving two adults and one child.[249] A prematurely born male had required prolonged ventilation for infantile respiratory distress syndrome. At 6 years of age, he came to medical attention for investigation of a weak voice. A unilateral prolapsed arytenoid was noted and was managed with speech therapy. The adults had had difficult and unsuccessful intubations, whereas the child had not. Removal of the ET in one case and the tracheostomy tube in the other case was followed by stridor requiring immediate reintubation or recannulation. Laryngoscopy revealed a unilateral dislocated arytenoid in one case and contralateral vocal cord palsy in the other case. In both cases, an arytenoidectomy was performed. The authors suggested that this complication could be more common than the literature would have us believe. Persistent postextubation hoarseness, a breathy voice, and an ineffective cough should prompt an assessment by an otolaryngologist. The diagnosis is confirmed by endoscopic visualization of an immobile vocal cord associated with a rotated arytenoid cartilage.[177] If the diagnosis is made early, before the onset of ankylosis, it may be possible to manipulate the arytenoid back into position.

Vocal fold paralysis results from injury to the vagus or one of its branches (recurrent laryngeal [RLN] or external division of the superior laryngeal nerves [ex-SLN]) and may resemble arytenoid dislocation or ankylosis. Differentiation may require palpation of the cricoarytenoid joints under anesthesia or laryngeal electromyography.[177] When vocal fold paralysis occurs as a surgical complication, it is usually associated with head and neck, thyroid, or thoracic surgery. The left RLN can also be compressed by thoracic tumors, aortic aneurysmal dilation, left atrial enlargement, or during closure of a patent ductus arteriosus. Occasionally, a surgical cause cannot be implicated. Cavo postulated that an overinflated ET cuff may result in injury to the anterior divisions of the RLN.[47]

The ex-SLN supplies the cricothyroid muscle and is a true vocal cord tensor. The RLN supplies all of the intrinsic laryngeal muscles except the cricothyroid. *Unilateral ex-SLN* results in the retention of adduction but the affected vocal fold is shorter with a shift of the epiglottis and the anterior larynx toward the affected side. This results in a breathy voice but produces no obstruction. *Bilateral ex-SLN* injury causes the epiglottis to overhang, making the vocal folds difficult to visualize. If seen, they are bowed. This produces hoarseness with reduction in volume and range but no obstruction. *Unilateral RLN injury* causes the vocal fold to assume a fixed paramedian position with a hoarse voice. There may be a marginal airway with a weak cough. *Bilateral RLN* results in both vocal folds being fixed in the paramedian position with inspiratory stridor, often necessitating a tracheostomy.[179]

Pharyngeal, nasopharyngeal, and esophageal injuries including perforation, lacerations, contusions, and infections may be associated with difficult laryngoscopy or intubation but may also result from the blind passage of a gum elastic bougie, nasogastric[117] or nasotracheal tube,[230] suction catheter, or transesophageal echo[150] or temperature probe. Unfortunately, recognition of pharyngeal perforation may be delayed, resulting in mediastinitis, retropharyngeal abscess, and death.[263] Following a brief intubation, soft tissue injury resulting in airway obstruction is more likely to result from edema or hematoma than infection. Most of the preceding injuries do not significantly complicate extubation per se. Likewise, laryngeal and tracheal stenoses are serious complications but they are rarely evident at the time of extubation.

15. Airway Injury

Burn patients may have both "intrinsic" and "extrinsic" airway injuries. Circumferential neck involvement is an example of an extrinsic injury. Smoke inhalation or thermal injuries are examples of intrinsic injuries. Burn patients

are at particular risk for requiring reintubation. They are known to exhibit bronchorrhea and have impairment of mucociliary clearance and local defenses, laryngeal and supraglottic edema, increased carbon dioxide production, and progressive acute respiratory distress syndrome (ARDS). Carbon monoxide may also diminish their level of consciousness and thus their ability to protect their airway. Kemper and associates reported on the management of 13 burn patients younger than 15 years, 7 of whom exhibited postextubation stridor. Treatments with helium and oxygen resulted in lower stridor scores than those of patients treated with an air-oxygen mixture.[149] They found that 11 of 30 extubated burn victims required treatment for stridor after extubation, consisting of racemic epinephrine, helium-oxygen, reintubation ($n = 5$), or tracheostomy ($n = 1$). The absence of a cuff leak was considered to be the best predictor of failure, with a sensitivity of 100% and a positive predictive value of 79%.[149]

A variety of conditions may lead to airway edema severe enough to encroach on the ET, preventing leakage of expired gas around the deflated cuff. If tissue swelling is sufficiently severe, it may result in airway obstruction following extubation. These conditions include generalized edema, angioneurotic edema, anaphylaxis, deep neck infections, pemphigus, and epidermolysis bullosa. The most common situation probably occurs in the ICU after prolonged intubation. Adderley and Mullins described the cuff leak test to evaluate children with croup.[1] This was performed by deflating the ET cuff, occluding the tube, and assessing air movement around the tube. Kemper and coworkers concluded that the cuff leak test was the best predictor of successful extubation in a pediatric burn and trauma unit.[148] Fisher and Raper found the test to be sensitive but not specific for predicting stridor, necessitating reintubation.[103] Others have measured the cuff leak volume as the difference between inspiratory and expiratory tidal volumes during assist-control ventilation, following cuff deflation.[88,193] Both studies found the cuff leak volume to be predictive of postextubation stridor. Efferen and Elsakr found that 8 of 45 patients exhibited stridor, 4 of whom required reintubation.[88] In another study involving 88 adult medical ICU patients (100 intubations), 6 patients exhibited stridor, 3 of whom required reintubation. They observed a significantly lower cuff leak in patients who subsequently developed stridor, concluding that this measurement was the best predictor of the presence or absence of stridor.[193]

Using the same protocol as Miller and Cole, Engoren evaluated 561 consecutive patients following cardiothoracic surgery.[92] The majority of their patients (79%) were extubated within 24 (median 12) hours. Only three patients exhibited stridor, two of whom were managed medically with racemic epinephrine. All three patients had cuff leak volumes much higher than the threshold of 110 mL proposed by Miller and Cole. None of the patients with cuff leak volumes less than 110 developed stridor, leading Engoren to conclude that this test was not reliable in his population.

Using absolute cuff leak volumes and determining the percentage of tidal volume leaked, Sandhu and colleagues[226] observed that adult trauma patients who developed stridor or needed reintubation had been intubated for a significantly greater length of time. This was confirmed in another study involving adult patients in a combined medical-surgical ICU.[72] Cuff leaks of less than 10%[226] or 15.5% of tidal volume[72] identified patients at risk for developing stridor or requiring reintubation with a specificity of 72% to 96%. Sandhu and colleagues observed stridor in nearly 12% of their patients, 6 of 13 of whom required reintubation. De Bast and coauthors found that a low leak volume and intubation greater than 48 hours had a positive predictive value of 37%. They also found that patients with a high cuff leak had a very high probability of not developing laryngeal edema.[72]

Jaber and coworkers[141] prospectively studied the extubations of 112 consecutive adult medical-surgical ICU patients. The extubation failure rate was 10% and the incidence of postextubation stridor was 12%. They identified a threshold cuff leak volume of 130 mL and 12% of the inspiratory tidal volume with an associated specificity of 85% and 95%, respectively.

All of these studies have identified a group of patients with a small cuff leak who can be successfully extubated, although there may be a greater probably of requiring reintubation. The optimal strategy to manage this relatively common problem has not been determined. Persistence with endotracheal intubation may worsen laryngotracheal injury, subject the patient to greater discomfort, and have considerable economic or resource implications. Tracheostomy, on the other hand, may be unnecessary in a significant proportion of patients. Reintubation in the ICU is associated with significant morbidity and mortality,[75,194] particularly if it cannot be achieved easily. The following approach seems reasonable regarding patients in an intensive care setting: if the previous intubation is known to have been easy, no new factors have intervened to complicate laryngoscopy, and experienced personnel are and will remain immediately available, it may be sound to extubate a patient in the absence of a large cuff volume leak. If there is any doubt about the ease of reintubation, either a tube exchanger may be employed (see later) or a tracheostomy should be performed. Patients with little or no cuff leak prior to extubation should be monitored very closely.

In view of the discrepant findings of Engoren[92] versus Sandhu[226] and De Bast,[72] it would be helpful to know the significance of the absence of a cuff leak in the immediate postoperative period. Venna and Rowbottom[256] described 180 patients who had undergone upper cervical spinal surgery, deemed by the surgeon to be at high risk for postoperative swelling. They elected not to extubate patients if they failed (unspecified) extubation criteria,

which included demonstration of a cuff leak and the absence of significant upper airway edema on laryngoscopy. This strategy resulted in an average extubation time of 33.5 hours, with 12 patients (6.6%) developing postextubation stridor and breathing problems, 5 of whom required reintubation. Interestingly, the average time from extubation to required reintubation was 14.6 hours and the resultant duration was 6 days. Two deaths occurred as a result of an inability to reintubate. This suggests that such patients warrant careful postoperative monitoring if they fulfill criteria for extubation. Furthermore, reliance on these criteria alone may fail to identify patients who require but cannot be successfully reintubated.

16. Postobstructive Pulmonary Edema

Severe airway obstruction from any cause may complicate extubation and lead to postobstructive or negative-pressure pulmonary edema.[207] This occurs when a forceful inspiratory effort is made against a closed glottis, generating large negative intrapleural pressures promoting venous return. It may also result in a rightward shift of the interatrial and interventricular septa, raising left atrial and ventricular pressures. In turn, this can promote transudation of fluids into the pulmonary interstitial and alveolar spaces. In some instances, there may also be a permeability defect with exudative fluid and inflammatory cells.[79,107,121,135,168]

In adults, this generally occurs in patients with upper airway tumors, severe laryngospasm, or rarely bilateral vocal cord palsy,[78] whereas in children it occurs most commonly as a complication of croup or epiglottitis.[166] The onset may be within minutes of the development of airway obstruction. It generally resolves with relief of obstruction and supportive treatment for pulmonary edema.

B. INTERMEDIATE- AND HIGH-RISK EXTUBATIONS

Although the preceding complications may follow a routine extubation, the need to reintubate is more likely to occur with intermediate-risk extubations. In contrast to the high-risk extubations, they are more easily dealt with. Bag-mask ventilation or reintubation, if required, should not pose a particular challenge. The intermediate-risk patient, for example, may have a preexisting medical condition[172] such as Wegener's granulomatosis or sarcoidosis that results in airway obstruction. They may undergo surgical procedures that are associated with an increased risk of postoperative airway obstruction. Chronic pulmonary or cardiac disease may compromise spontaneous ventilation and necessitate intubation. The patient with an ineffective cough or increased secretions may have a need for pulmonary toilet. An obtunded patient may be unable to protect his or her airway. A more complete list of intermediate- and high-risk extubations is provided in Table 47-2.

As previously mentioned, the high-risk designation applies to settings in which replacement of a removed ET

Table 47-2 **Intermediate- and High-Risk Extubations**

Inability to Tolerate Extubation
Hypoxemia
Low FIO_2
Ventilation-perfusion abnormality
Right-to-left shunt
Increased oxygen consumption
Decreased oxygen delivery
Impaired pulmonary diffusion
Hypoventilation
Central sleep apnea
Severe chronic obstructive pulmonary disease
Residual volatile anesthesia
Residual neuromuscular blockade
Preexisting neuromuscular disorders
Diaphragmatic splinting
Relative hypoventilation
Excess CO_2 production
Increased dead space
Failure of pulmonary toilet
Obtundation
Pulmonary secretions
Bronchorrhea
Tenacious secretions
Impaired mucociliary clearance
Loss of airway patency (see Table 47-3)
Obstructive sleep apnea
Tongue
Tumor
Swelling (macroglossia)
Hematoma
Paradoxical vocal cord motion
Laryngeal edema
Bilateral RLN paralysis
Intrinsic airway swelling
Extrinsic airway compression
Tracheomalacia or bronchomalacia
Difficulty Reestablishing Airway
Known difficult airway
Multiple attempts required
Need for alternative airway adjunct (e.g., FOB)
Limited access
Cervical immobility (or instability)
Intermaxillary fixation
"Guardian suture"
Limited resources
Personnel or expertise
Equipment
Airway injury
Thermal or inhalation injury

FOB, fiberoptic bronchoscope; RLN, recurrent laryngeal nerve.

may be reasonably expected to be difficult, complicated, or unsuccessful. *Reintubation is potentially and fundamentally different from the original intubation* because it is likely to occur in an urgent or emergent setting, with limited information and equipment. The patient is more likely to be hypoxic, acidemic, agitated, or hemodynamically unstable, and the procedure may be done in haste. A preemptive strategy is appropriate in the management of such patients.

1. Clinical Settings (Table 47-3)

a. Paradoxical Vocal Cord Motion

Perhaps the most interesting and quintessential example of intermediate-risk extubation is paradoxical vocal cord motion (PVCM). The probable need for reintubation is very high, although it is not necessarily difficult to accomplish. This is an uncommon (or rarely diagnosed[191]) and poorly understood condition, frequently mistaken for refractory asthma[126] or recurrent laryngospasm.[115,190] Endoscopy reveals the cause of upper airway obstruction to be vocal fold adduction on inspiration.[10,54,242,251]

Table 47-3 **Clinical Settings for Intermediate- and High-Risk Extubations**

Paradoxical vocal cord motion
Airway instrumentation (diagnostic laryngoscopy or rigid bronchoscopy)
Thyroid surgery Hematoma or swelling Nerve injury (RLN or ex-SLN) Tracheomalacia
Maxillofacial surgery
Deep neck infections
Cervical spine surgery
Carotid endarterectomy
Posterior fossa surgery
Tracheal resection
Preexisting airway obstruction Parkinson's syndrome Rheumatoid arthritis Epidermolysis bullosa Pemphigus
Tracheomalacia or bronchomalacia

Ex-SLN, external branch of the superior laryngeal nerve; RLN, recurrent laryngeal nerve.

Hammer and colleagues[122] described a 32-year-old woman with recurrent episodes of stridor, sometimes associated with cyanosis, despite normal flow-volume loops and pulmonary function tests. The diagnosis of PVCM was made endoscopically and managed with "relaxation techniques." Following preoperative sedation, topical lidocaine, and bilateral SLN blocks, she underwent an awake fiberoptic intubation. At the conclusion of her surgery, extubation was performed when she was fully awake; however, sustained inspiratory stridor ensued, resulting in reintubation. A subsequent attempt the following day confirmed inspiratory vocal fold adduction and a tracheostomy was required for 58 more days. Michelsen and Vanderspek[191] described recurrent postextubation stridor complicating a cesarean section. General anesthesia was reestablished and laryngoscopic examination showed appropriate vocal fold motion until consciousness resumed.

PVCM, in and of itself, imposes no special requirements for intubation. The abnormality is functional rather than anatomic. Most authors have advised that speech therapy, psychotherapy, hypnosis, and calm reassurance are helpful, but such is not always the case.[126] Some reports have recommended electromyographically guided botulinum toxin injection into the thyroarytenoid muscle for recalcitrant cases. The optimal anesthetic management of these patients is not known. Regional anesthesia avoids airway intervention but does not ensure that a condition that may be stress related will not occur. Familiarity with this condition, calm reassurance when there is prior suspicion, and perhaps deep extubation seem prudent. This author has cared for a patient precisely fitting the description of the typical patient—a young, female, health care worker with a prior history of postextubation stridor requiring repeated reintubations.[126] Extubation was performed under deep propofol sedation, an LMA was inserted, and the upper airway was observed endoscopically with spontaneous respiration. The airway was widely patent and normal, functionally and anatomically. As the sedation was reduced and consciousness was regained, the false and true vocal folds increasingly constricted, obstructing the laryngeal inlet and resulting in stridor. Tracheal extubation was accomplished by very gradually reducing the propofol infusion.

b. Laryngoscopic Surgery

Mathew and colleagues[186] looked at 13,593 consecutive PACU admissions between 1986 and 1989. Twenty-six of these patients (0.19%) required reintubation while in the PACU; 7 of the 26 had undergone ear, nose, and throat (ENT) procedures. All these patients required reintubation related to airway obstruction.

Patients undergoing laryngoscopy and panendoscopy (laryngoscopy, fiberoptic bronchoscopy, and esophagoscopy) are at an increased postoperative risk for airway obstruction and are approximately 20 times as likely to require reintubation as those having a wide variety of

other surgical procedures.[130] Reviewing the records of 324 diagnostic laryngoscopies and 302 panendoscopies, Hill and coauthors found that patients who had undergone laryngeal biopsy were at the greatest postoperative airway risk. Thirteen of 252 (5%) patients required reintubation, most within 1 hour of extubation. Twelve of 13 had undergone laryngeal biopsy. Most of these patients had chronic obstructive pulmonary disease, and their need for reintubation was attributed largely to this. They did not state whether their patients had received topical anesthesia or vasoconstrictors. They had not received prophylactic steroids, although the value of this adjunct is not well established.[130]

Robinson prospectively studied 183 patients having 204 endoscopic laryngeal procedures.[219] Seven patients had tracheostomies prior to or subsequent to their surgery because of "high-risk" airways. Two of the remaining patients developed postoperative stridor, one of whom required reintubation and the other a delayed tracheostomy. Indirect laryngoscopy, carried out 4 to 6 hours following surgery, revealed mucosal hemorrhage or laryngopharyngeal swelling in 32% of cases. The patients undergoing tracheostomy were not described, and it is possible that the low incidence of reintubation resulted from an aggressive approach to preemptive tracheostomy.[186]

c. Thyroid Surgery

A variety of injuries following thyroidectomies have been described. Lacoste and colleagues retrospectively reviewed the records of 3008 patients who underwent thyroidectomies between 1968 and 1988.[160] The RLN had been identified intraoperatively in 2427 of these patients. Indirect laryngoscopy was performed on the third or fifth postoperative day. Postoperatively, the RLN was found to be damaged in 0.5% of patients with benign goiters and 10.6% of patients with thyroid cancer. *Unilateral recurrent laryngeal nerve palsy* was observed in 1.1% of patients. Three patients had bilateral RLN palsy and required tracheostomy. Six of a total of 16 deaths during the first 30 postoperative days were attributed to respiratory complications. One death occurred following failed intubation related to a deviated, constricted trachea. A second death was due to difficulties performing a tracheostomy. Two deaths resulted from aspiration or pneumonia, possibly related to RLN dysfunction.

These authors reviewed published reports with at least 1000 patients in which postoperative laryngoscopy was performed. The incidence of permanent nerve palsies with benign goiters was 0.5 per 100 operations. This was more common in substernal goiters (4%) and thyroid cancer (9%). In the latter group, it is sometimes necessary to sacrifice the nerve to achieve an adequate resection. It remains to be determined whether methods of intraoperative RLN monitoring will reduce this complication.[128,131] Although bilateral RLN palsy is rare, thyroidectomy is the leading cause of this injury. The external branch of the superior laryngeal nerve, supplying the cricothyroid muscle that tenses the vocal folds, is believed to be vulnerable during thyroid dissection; however, the frequency of this injury is unknown.[160]

Local *hemorrhage* or *hematoma* occurred postoperatively in 0.1% to 1.1% of the patients in the literature review and in 0.36% of the patients cared for by Lacoste and colleagues.[160] These occurred from 5 minutes to 3 days postoperatively. Reexploration within the first day was required only twice. Airway obstruction may result from significant laryngeal and pharyngeal edema and wound evacuation may be of limited value in the relief of airway obstruction.[34] The prophylactic placement of surgical drains probably reduces the incidence of this complication. Rarely, wound evacuation may result in a significant improvement of the airway obstruction.[43]

d. Carotid Endarterectomy

Neck swelling or hematoma formation after carotid endarterectomy may be relatively common. When defined radiographically, it occurs frequently and to an alarming degree.[46] When defined by a need for postoperative reintubation or exploration, the incidence is 1% to 3%.[232] Kunkel and others described 15 patients who developed *wound hematomas* following carotid endarterectomy.[159] Eight of these were evacuated under local anesthesia. In six of seven cases in which general anesthesia was induced, difficulties arose with airway management, resulting in two deaths and one patient with severe neurologic impairment.

O'Sullivan and coauthors described six patients with airway obstruction after carotid endarterectomy.[204] Five of these patients had been taking antiplatelet drugs preoperatively. They found that stridor was not relieved by wound evacuation. Of particular importance, the administration of muscle relaxants made manual mask ventilation virtually impossible and intubation was complicated by marked glottic or supraglottic edema. Cyanosis and extreme bradydysrhythmias or asystole occurred in four patients. Although the authors endorsed Kunkel's recommendation of the use of local anesthetic infiltration for wound evacuation, they felt that much of the airway compromise was related to edema from venous or lymphatic congestion. They emphasized that the degree of external swelling may lead one to underestimate the internal oropharyngeal edema.

Munro and coworkers described four patients with post–carotid endarterectomy airway obstruction.[195] The early signs (voice changes) were relatively subtle with rapid clinical deterioration when stridor developed. Two patients suffered respiratory arrest and were intubated blindly. These authors argued that the time course favored venous and lymphatic congestion as the mechanism of injury. Carmichael and associates compared pre– and post–carotid endarterectomy computed tomography (CT) scans in 19 patients.[46] These demonstrated significant

swelling of the retropharyngeal space and a reduction of the anteroposterior and transverse airway diameter, particularly at the level of the hyoid. Compared with preoperative CT scans, the calculated volume reduction averaged 32% ± 7% for extubated patients. Patients requiring postoperative endotracheal intubation showed a significantly greater volume reduction of 62% ± 9% ($P < .025$). A subsequent study by this group failed to demonstrate any clinical benefit from the prophylactic administration of dexamethasone.[138]

Accelerated carotid atherosclerosis may occur after cervical irradiation. Airway obstruction after carotid surgery occurred in two of five such patients described by Francfort and colleagues.[106] The mechanisms of obstruction included supraglottic and glottic edema in one patient and periglottic trauma in the other patient. Cervical irradiation may further complicate reintubation if the tissues are indurated and noncompliant.

Bilateral vocal cord[254] and bilateral *hypoglossal nerve palsies*[173] have been described after staged bilateral carotid endarterectomies. In the latter case, the first procedure, performed under regional anesthesia, had been complicated by a wound hematoma resulting in numbness over the anterior neck and diminished sensation in the C2 and C3 distribution. The subsequent endarterectomy, done 4 weeks later under deep cervical plexus block with subcutaneous infiltration, caused intraoperative airway obstruction and asystole. The airway was secured, but recurrent attempts at extubation resulted in persistent obstruction related to bilateral hypoglossal nerve palsy.

e. Maxillofacial Surgery and Trauma

Maxillary and mandibular surgery produces conspicuous and often worrisome swelling. Anxiety regarding postoperative care may be heightened by limited airway access, fear that airway intervention may disrupt the surgical repair, and anecdotal reports of near misses or actual fatalities. As many of these patients are young and otherwise healthy, undergoing elective surgery for functional or cosmetic improvement, there may also be anxiety and fear of litigation. It is speculative whether this results in more or less aggressive care.

Although clearly all of these concerns mandate special care (see later), deaths rarely occur. Beed and Devitt reviewed the charts of 461 perioperative deaths reported to the coroner between 1986 and 1995 in Ontario, Canada.[24] They found only one death associated with orthognathic surgery, although they were unable to determine how many such cases had been performed. They were unable to determine the frequency or to identify nonlethal complications. Meisami and others performed postoperative magnetic resonance imaging (MRI) scans approximately 24 hours following maxillary or mandibular surgery, or both, in 40 patients.[188] Despite the significant facial swelling seen in almost all the patients, none exhibited soft tissue swelling from the base of the tongue to the glottis.

Complete airway obstruction following elective orthognathic surgery, although rare, has been reported. Dark and Armstrong described a single case involving a young woman who underwent seemingly uneventful mandibular and maxillary osteotomies with submental liposuction.[69] Immediately following extubation, she developed airway obstruction requiring reintubation. Repeated fiberoptic examination and CT imaging showed severe and extensive edema from the tongue to the trachea, maximal at the level of the hyoid. By the fourth postoperative day, a cuff leak was detected and the patient was successfully extubated over a tube exchanger.

Maxillofacial injuries are generally the result of unrestrained occupants of motor vehicles encountering an unyielding dashboard, windshield, or steering wheel. Gunshot wounds or physical altercations also cause maxillofacial injury. Airway obstruction is a primary cause of morbidity and mortality in these patients.[211] These patients may have a fractured larynx or tracheal disruption and not survive to admission to hospital. Those with less life-threatening injuries are likely to present with a full stomach, and many have associated head and neck injuries such as lacerations, loose or avulsed teeth, intraoral fractures, or fractures extending into the paranasal sinuses, the orbit, or through the cribriform plate. As well, there may be instability of the cervical spine or damage to the neural axis. Injuries to the lower face raise the possibility of a laryngeal fracture.

Intermaxillary fixation may be part of the surgical plan, necessitating a nasal intubation or a surgical airway. Timing of tracheal extubation is complex. It must take into consideration such factors as the patient's level of consciousness, the patient's ability to maintain satisfactory gas exchange, and the integrity of protective airway reflexes. In addition, consideration must be paid to the difficulties originally encountered in securing the airway and an evaluation of whether reintubation would be easier or more difficult as a consequence of surgery and resuscitation. The lack of guidance from the literature makes communication between anesthesiologist, surgeon, and intensivist essential. Intermaxillary fixation requires that wire cutters be immediately available and that personnel know which wires to cut, should this prove necessary. A fiberoptic bronchoscope, provisions for an emergency surgical airway, and the required expertise should be immediately available at the time of extubation. Many would advocate that fiberoptic airway evaluation be performed prior to extubation, although assessment may be limited to supraglottic structures and exclusion of tube entrapment. Ideally, extubation should be accomplished in a "reversible" manner, permitting oxygenation, ventilation, and reintubation should this prove necessary (see "Extubation Strategies" in Section IV of this Chapter).

f. Deep Neck Infections

Infections involving the submandibular, sublingual, submental, and retropharyngeal fascial spaces present a

significant airway management challenge, whether intubation is achieved for surgical drainage or for protection during medical management. The literature is unclear about the indications for preoperative or postdrainage tracheostomy, although clearly a surgical airway is required if efforts to intubate are unsuccessful or constitute a serious risk of rupturing the abscess. Potter and colleagues retrospectively compared the outcomes of 34 patients in whom a tracheostomy was performed and 51 patients who remained intubated following surgical drainage.[214] All patients had undergone surgical drainage for impending airway compromise and required airway support postoperatively. It was not always evident to the investigators why a particular strategy was chosen. Airway loss occurred more commonly in the intubated patients, but this was not statistically significant. Two deaths occurred, one resulting from an unplanned extubation and the other from postextubation laryngeal edema and inability to reestablish the airway. Interestingly, the latter patient was noted to have a cuff leak prior to extubation and developed signs of obstruction 30 minutes after the ET was removed. If a decision is made to manage the patient without a tracheostomy, great care must be taken to ensure proper timing of extubation and the immediate provision of equipment and expertise to attend to potential complications. It is improbable that drainage will result in immediate airway improvement, and reintubation or an emergent surgical airway, if required, may be complicated by edema, tissue distortion, and urgency.

g. Cervical Surgery

Lehmann and coauthors described a patient with advanced rheumatoid arthritis (RA) who underwent a posterior occipitocervical fusion.[170] Complete airway obstruction occurred immediately following extubation, and neither bag-mask ventilation nor attempts at reintubation were successful. Following a successful surgical airway, fiberoptic examination revealed massive hypopharyngeal edema. The patient succumbed to hypoxic encephalopathy.

Emery and associates studied the records of 133 patients who underwent cervical corpectomies.[91] Seven (5.3%) required postoperative reintubation. Three had had DIs because of limited access or cervical immobility. The patients had undergone an anterior approach to achieve a three-level vertebral body and disc resection with bone grafting. This surgical approach requires tracheal and esophageal retraction to permit exposure. Drains were placed and all patients were immobilized by halo vest or a rigid head-cervical-thoracic orthosis. Three of the patients were extubated in the OR and four were extubated at 12 to 91 hours postoperatively. Reintubation was immediately necessary in one case, within 30 minutes in two cases, and within 2 to 23 hours in four cases. Reintubation was required because of severe hypopharyngeal and supraglottic edema in four patients, but the indication was not specified in the other three. Five of the reintubations had no serious sequelae; these patients were extubated within 2 to 8 days. One patient required a cricothyrotomy, but delay resulted in hypoxic encephalopathy and death. The other patient was reintubated but developed and succumbed to severe adult respiratory distress syndrome. The risk factors identified by Emery and colleagues included a smoking history, moderate or severe preoperative myelopathy, extensive multilevel decompression with prolonged surgery, and tissue retraction.[91] The authors recommend 1 to 3 days of elective intubation postoperatively, determination of the presence of a cuff leak, and direct laryngoscopy at extubation.

Sagi and coworkers conducted a retrospective chart review of 311 anterior cervical procedures.[224] In this series, 6.1% of patients had airway complications, but only six (1.9%) required reintubation. Most of these complications were attributed to pharyngeal edema. Risk factors included increased intraoperative bleeding, prolonged surgery (more than 5 hours), and exposure of more than three vertebral bodies, particularly when these included C2, C3, or C4. Reviewing the literature, these workers identified an airway complication rate of 2.4% (from 1615 cases), with 35 patients requiring reintubation or tracheostomy. On average, those requiring reintubation did so at 24 hours.

Venna and Rowbottom reviewed the records of 180 patients who had undergone a variety of cervical surgical procedures.[256] On the basis of the Emery study, they had made the decision to keep high-risk patients intubated until they met specified criteria including a demonstrable cuff leak and absence of significant airway edema on laryngoscopy. The average time to extubation was 33.5 hours. Despite the delay and the aforementioned criteria, 12 patients (6.6%) demonstrated postextubation stridor and breathing difficulties and 5 (2.7%) required reintubation. Two patients required tracheostomy, and two deaths occurred related to airway obstruction and unsuccessful reintubation.

Epstein and coworkers developed a collaborative protocol involving the neurosurgeon and anesthesiologist, with the specific intention of avoiding reintubations.[93] Although their study involved only 58 patients, these were high-risk, lengthy procedures involving several cervical levels and significant blood loss. All patients remained electively intubated overnight and underwent fiberoptic airway examination prior to considering extubation. The majority of patients were extubated the day following surgery; however, three remained intubated until day 7. Only one patient required reintubation. This reintubation rate was essentially the same as that observed by Emery and colleagues, but it appears that Epstein's cohort underwent higher risk surgery.

Wattenmaker and others studied patients with RA (see later) undergoing posterior cervical spine procedures.[262] Their primary objective was to compare direct laryngoscopic and flexible fiberoptic intubation with respect to perioperative airway complications. This study

retrospectively reviewed 128 consecutive posterior cervical procedures in patients with RA, comparing the methods of securing the airway. Overall, upper airway obstruction, characterized by stridor, occurred in 9 of 128 patients, 1 of 70 patients intubated fiberoptically, and 8 of 58 patients intubated "nonfiberoptically" (direct laryngoscopy or blind nasotracheal technique). Five patients (all in the nonfiberoptic group) required emergency reintubation, which proved very difficult, with two near fatalities and one death. Although the two groups were similar with regard to age, gender, American Rheumatology Association classification, ASA physical status, the duration of surgery and anesthesia, fluid balance, and postoperative immobilization, there were significant differences in time to extubation. Seven of the patients could not be intubated fiberoptically and were therefore intubated by a nonfiberoptic technique. The patients were not randomly assigned to different methods, criteria for the method of intubation and techniques were not described, all patients were intubated awake, and the study was carried out over an 11-year period.[60] Although it is not possible to draw firm conclusions from this study, there was a high incidence (7%) of postextubation stridor and difficult or failed reintubations, regardless of the intubation technique.

h. Posterior Fossa Surgery

Posterior fossa surgery can cause injury to cranial nerves, bilateral vocal cord paralysis, brain stem[237] or respiratory control center injury,[11] and macroglossia. Howard and colleagues described a patient with a recurrent choroid plexus papilloma involving the fourth ventricle.[136] Preoperatively, the patient displayed bulbar dysfunction. His extubation on the first postoperative day was complicated by complete airway obstruction, hypoxia, and a seizure. Following neuromuscular blockade, laryngoscopy revealed mildly edematous, abducted vocal cords. Following reintubation and elective tracheostomy, fiberoptic examination showed the vocal folds in a neutral position. For the following month, the tracheostomy was retained because of periodic breathing. This patient demonstrated central apnea and bulbar dysfunction with hypoglossal paralysis and unopposed vocal fold adduction. Artru and others described a patient with a cerebellar mass, severe papilledema, and bulbar signs.[11] Postoperatively, despite recovery of consciousness and strength, the patient remained apneic and ventilatory support was required for 7 days. The authors cautioned that the dorsal pons and medulla are the sites of the cardiovascular and respiratory centers that control hemodynamics and ventilation. They are also host to several of the cranial nerve nuclei. Damage to these areas can result from edema, disruption, ischemia, or compression and may result in a loss of respiratory drive or airway obstruction.

Dohi and coworkers described a patient who developed bulbar signs including bilateral vocal cord paralysis following excision of a recurrent cerebellopontine angle tumor.[78] Negative-pressure pulmonary edema developed as a consequence of a bilateral, presumably central RLN injury and a tracheostomy was required until recovery, 3 months later. During the initial intubation, the glottis could not be seen by direct laryngoscopy and blind intubation was performed. There were three unsuccessful extubations requiring reintubation, the details of which were not described. However, 5 minutes *following* the first reintubation, the arterial partial pressure of oxygen (Pa_{O_2}) was 36 and the Pa_{CO_2} was 64. Such "trials of extubation" are life threatening and unjustifiable.

i. Stereotactic Surgery/Cervical Immobilization

Stereotactic neurosurgery is finding increasing applications. The head frames may prevent proper positioning for laryngoscopy and physically interfere with the insertion of the laryngoscope. Patients in cervical immobilization devices for spinal cord protection may also be undergoing high-risk surgical procedures. Careful planning for their extubation is critical because reintubation may be difficult and surgical access may be virtually impossible. Full recovery of strength and consciousness, persistence of respiratory drive, the presence of a cuff leak, and the absence of significant tongue swelling are the prerequisites for extubation. Several of the strategies described subsequently (LMA with or without fiberoptic laryngeal examination or extubation over a tube exchanger) should be given serious consideration.

j. Tracheal Resections

Patients with moderate or severe tracheal stenosis may come for surgical tracheal resection. These patients generally have tracheal stenosis, frequently secondary to prolonged intubation. Some may have compromised preoperative respiratory function. Following an end-to-end anastomosis, the surgeon may elect to place a "guardian suture" from the chin to the chest, maintaining the head and neck in flexion and thereby minimizing traction on the suture lines[209,212] (Fig. 47-1). The preference is for early extubation to avoid positive pressure and the presence of a foreign body in the airway. A cough-free extubation is highly desirable, as is avoidance of a need for reintubation, which, if required, could prove very challenging. Strategies are discussed in the following sections.

k. Airway Obstruction—Preexisting Medical Conditions

Parkinson's syndrome. Susceptibility to aspiration is common among patients with Parkinson's disease (PD) and is the most common cause of death. Dysphonia, most frequently hypophonia, is also common and occurs in approximately 90% of patients with PD. Several neurodegenerative diseases have some features in common with PD, which include dysphonia, and these patients may exhibit bilateral abductor vocal fold paresis. Typically, their symptoms progress insidiously, are not

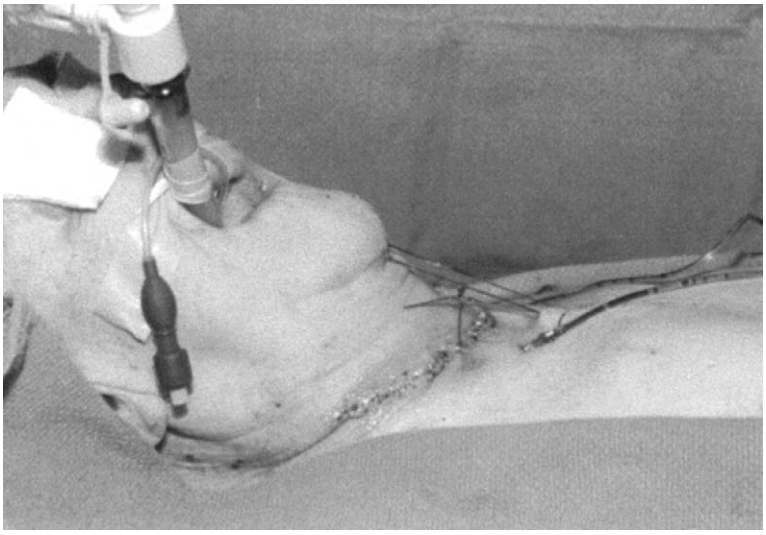

Figure 47-1 This patient has undergone a cricotracheal resection. Cervical extension is restricted by a chin-to-chest guardian suture. The patient has been extubated and a laryngeal mask airway has been introduced, prior to reversal of neuromuscular blockade or awakening. This reduces coughing on emergence, allowing the gradual recovery and assessment of spontaneous respiratory while minimizing cough and the potential distraction of the surgical anastomosis.

recognized by the patient, and may be associated with nocturnal stridor. These features resemble obstructive sleep apnea by polysomnography. Interestingly, many such patients may benefit from nocturnal CPAP or bilevel positive airway pressure.[37] Blumin and Berke described seven patients, only one of whom presented for surgery. This patient underwent a transurethral prostate resection under general anesthesia and 2 weeks after surgery returned with biphasic stridor necessitating an emergent tracheostomy. It is unclear that there was any relationship between the surgery or anesthesia and subsequent airway obstruction.

Vincken and coworkers studied 27 patients with extrapyramidal disorders.[258] Twenty-four had flow-volume loops, many of which demonstrated saw-toothed oscillations. Fiberoptically, they observed oscillations with rhythmic (4 to 8 Hz) or irregular movements of the glottis and supraglottic structures. Ten patients exhibited intermittent upper airway obstruction. Four patients had stridor or dyspnea. The authors believed that the upper airway was the primary site of involvement. In a subsequent report, they observed symptomatic improvement with levodopa, despite persistence of the oscillatory pattern on flow-volume loops.[257]

Easdown and colleagues described a patient with PD who had a respiratory arrest 60 hours following surgery.[87] Prior to that event, the patient had episodic desaturation, labored breathing, and progressive hypercapnia in the absence of tremor or rigidity. His condition improved following intubation. This patient's antiparkinsonian medications had not been resumed postoperatively, and the authors speculated that upper airway obstruction secondary to withdrawal from levodopa/carbidopa was either causative of or contributory to this event. Fitzpatrick described a patient who developed airway obstruction and acute respiratory acidosis requiring intubation *preoperatively* because of withholding his antiparkinsonian medications while he was being fasted.[105] The authors emphasized the importance of continuing with these medications throughout the perioperative period.

Liu and others described airway obstruction during induction of anesthesia.[175] Despite being unable to visualize the larynx, they attributed this to laryngospasm. Nonetheless, the obstruction resolved with awake, blind nasal intubation but recurred 24 hours later upon extubation. At that point, fiberoptic examination showed inspiratory vocal fold adduction, necessitating reintubation. It is unclear whether they were observing manifestations of PD or PVCM; however, extubation was uneventful 24 hours later after increasing the dosage of levodopa/carbidopa.

Backus and coauthors described a patient who became aphonic, developed stridor, and suffered a respiratory arrest shortly after taking cough medication.[19] After being weaned from mechanical ventilation, she was extubated and upper airway obstruction recurred with vocal fold apposition. Four days later, the patient extubated herself with no further complications. The authors interpreted this "spontaneous" laryngospasm as a manifestation of PD. Others have noted upper airway dysfunction, airflow limitation, and bilateral abductor vocal cord paralysis in association with PD. The first episode may not have been spontaneous but rather a consequence of aspiration of the cough medicine. Nonetheless, there remains a possibility that such patients are more susceptible to laryngospasm, whether spontaneous or induced by glottic stimulation.

Rheumatoid arthritis. Autopsy studies suggest that 30% to 50% of patients with RA have significant cervical spine involvement. *Cervical subluxation* has been reported to occur clinically in 43% to 86% of such patients[119] and may represent a serious neurologic risk during intubation.[117,201] In addition, these patients may have a restricted range of cervical motion, narrowed glottic aperture, limited mouth opening because of involvement of their

temporomandibular joints (TMJs), micrognathism, laryngeal deviation, and cricoarytenoid and cricothyroid involvement.[262,155] Kohjitani and colleagues retrospectively described four patients undergoing bilateral TMJ replacement, three of whom had glottic erythema and swelling at endoscopy, three had obstructive sleep apnea, and three experienced laryngospasm at intubation and following extubation.[155] *TMJ involvement* may result in loss of ramal height and micrognathia with or without ankylosis and associated obstructive sleep apnea.

Cricoarytenoid arthritis. Its consequences have long been recognized in the anesthesia and general medical literature.[48,109,146,176,235] Although RA is the most common cause of this condition, it may also be seen in association with bacterial infections, mumps, diphtheria, syphilis, tuberculosis, Reiter's syndrome, ankylosing spondylitis, systemic lupus erythematosus, gout, progressive systemic sclerosis, and others.[171] Cricoarytenoid involvement is often unsuspected until airway obstruction occurs during induction or following extubation. Indeed, Bamshad and coauthors described airway obstruction from neck manipulation alone, severe enough to necessitate tracheostomy.[20] They described another patient in whom attempts at intubation were unsuccessful, resulting in the surgery being aborted. Four hours later, the patient "suddenly" experienced a respiratory arrest requiring a cricothyroidotomy.

Keenan and coworkers described tracheal deviation, laryngeal rotation, and anterior angulation as well as vocal fold adduction seen fiberoptically and on CT scans.[146] This "tracheal scoliosis" was presumed to be due to loss of vertical height and asymmetric bone erosions.

Dysphonia, dyspnea, or stridor may be misinterpreted or obscured by other features of the disease. Kolman and Morris described a patient who developed severe recurrent airway obstruction following extubation, despite an easy atraumatic intubation performed by direct laryngoscopy.[157] At laryngoscopy, the vocal folds appeared white, thickened, and poorly mobile despite complete reversal of neuromuscular blockade. An urgent ENT consultation confirmed the diagnosis of paramedian vocal cord fixation secondary to cricoarytenoid arthritis. The glottic inlet was severely narrowed, necessitating a tracheostomy under local anesthesia. Decannulation was achieved after 1 month. Complete airway obstruction is a well-described but fortunately an infrequent complication, despite involvement of the cricoarytenoids in 26% to 86% of patients with RA.[155,157] This disarticular joint can be affected like any other joint with inflammation, pannus formation, cartilaginous or ligamentous erosion, joint space obliteration, ankylosis, and fibrosis. Chronic cricoarytenoid arthritis may be mistaken for asthma or chronic bronchitis, with symptoms of dyspnea, hoarseness, or stridor. At laryngoscopy, the mucosa may be rough and thick and the vocal chink is narrowed. Although airway obstruction occurs most commonly in patients with long-standing RA having polyarticular and systemic involvement, laryngeal stridor has been described as the sole manifestation of this disease.[118]

The combination of a potentially unstable cervical spine, difficult direct laryngoscopy, and the risk of postextubation airway obstruction makes the patient with RA the prototype of the high-risk extubation. Several authors have recommended postponing extubation until the patient is wide awake. Unfortunately, this provides increased protection against nothing other than laryngospasm and aspiration. In addition, the prevailing wisdom is that patients with limited mouth opening and a potentially unstable cervical spine should be intubated with a flexible fiberscope.[262] This method involves the blind passage of the ET through the cords, which may be traumatic,[60,182] particularly in the presence of preexisting cricoarytenoid arthritis. Regional anesthesia should be considered as an alternative to general anesthesia when appropriate. When intubation cannot be avoided, proposed extubation strategies include a preemptive tracheostomy or a method that increases the "reversibility" of extubation. Neither strategy has been prospectively evaluated in this population. These are discussed in detail under "Extubation Strategies."

Epidermolysis bullosa. This rare condition, with more than 25 described variations, results in separation of layers of skin and mucous membranes with fluid accumulation caused by a deficiency in intercellular bridges.[266] Shearing forces are particularly damaging and may result in separation, bullous formation, hemorrhage and healing by scar formation, and subsequent tissue contraction. Laryngeal involvement is extremely rare, and tracheal bullae have never been reported.[41] A retrospective report involving 33 patients undergoing 329 surgical procedures identified no postoperative airway problems, although microstomia was noted in 13 of the patients.[142] Giant oropharyngeal bullae and profuse bleeding from a ruptured oral bulla and a large fibrosing supraglottic bulla have, however, been reported to cause airway obstruction.[102]

Pemphigus. Pemphigus embraces a group of rare immunologically mediated vesiculobullous diseases (vulgaris, foliaceus, pemphigoid, and others), which frequently involve mucous membranes. Ninety percent of patients with vulgaris have oromucosal involvement at some point.[266] Most lesions heal without scarring unless they become secondarily infected. Microstomia is not a feature. Management of such patients is similar to that of patients with epidermolysis bullosa. Severe upper airway obstruction secondary to cicatricial laryngeal pemphigoid has been reported,[81,90,267] although this complication appears to be uncommon.[181]

Tracheomalacia. Tracheomalacia is a dynamic airway obstruction resulting from loss of the cartilaginous tracheal support. Clinically, it should be considered when

unexpected inspiratory obstruction is identified. The diagnosis may be confirmed fiberoptically during spontaneous breathing. The negative intrathoracic pressure of inspiration results in partial collapse of the affected segment. Diagnosis may also be confirmed by CT[9] or MRI scans.[100] This may be congenital[185] or result from vascular compression,[252] be caused by an intrathoracic goiter (see later), or develop as a consequence of prolonged intubation. The latter is presumably related to cuff-induced erosion of the tracheal cartilage with or without extension to the membranous trachea. The severity of the dynamic obstruction is proportional to the inspiratory force. Thus, a distressed patient is more likely to exhibit severe symptoms. Positive pressure or bypassing the lesion with an ET provides relief while further management options are considered. These might include medical management, surgical resection, or placement of a stent.[265] Additional suggestions for the extubation of a patient with suspected tracheomalacia are proposed later.

Relapsing polychondritis. Relapsing polychondritis is a rare, multisystem disease characterized by episodic inflammation of cartilaginous structures resulting in tissue destruction.[134] Laryngeal and tracheal tract involvement occurs in approximately half of the patients. This usually occurs early in the course of the disease and may be manifested by complaints of hoarseness, nonproductive cough, shortness of breath, and stridor. Upper airway obstruction is usually diffuse and may progress to involvement of the glottis, subglottic area, trachea, and bronchial cartilages. Histologically, there is evidence of perichondral inflammation and replacement of cartilage by fibrous tissue, manifesting in inflammatory swelling and progressive destruction of cartilage. The clinical manifestations range from bronchorrhea and recurrent pneumonia to airway collapse. Medical management consists of steroids, nonsteroidal anti-inflammatory drugs, and immunosuppressants, but these are of variable benefit. Surgical management consists of external airway splinting or self-expanding metallic stents. These patients may present for fiberoptic bronchoscopy, tracheostomy, tracheal or nasal reconstruction, aortic valve replacement, or stent placement.[35,44,104,127,252] Airway collapse following extubation should be anticipated and may be effectively dealt with by CPAP.[2,253]

Obstructive sleep apnea syndrome. Obstructive sleep apnea (OSA) correlates positively with age and obesity, both of which are becoming increasingly prevalent. It has been estimated that 80% to 95% of patients with OSA are undiagnosed.[28] OSA syndrome also appears to be associated with difficulty in mask ventilation,[167] laryngoscopic intubation,[53,96,218] and accelerated arterial oxygen desaturation.[29] The risk of airway obstruction following surgery has been noted to be increased for patients with OSA,[216] with an incidence of life-threatening postextubation obstruction of 7 of 135 (5%) patients.[96] Rapid desaturation, difficult mask ventilation, and difficult direct laryngoscopy[144] make this a particularly high-risk setting. It is essential that such a patient be fully awake, recovered from neuromuscular blockade, and have a sustained spontaneous respiratory rate; that nasal CPAP be available or routinely implemented[143,216,218]; and that consideration be given to extubation over a tube exchanger.[28] (These strategies have been associated with better outcomes, and anecdotal comparisons are very compelling but they have not been subjected to controlled, randomized trials.)

A variety of surgical procedures have been employed to treat OSA including uvulopalatopharyngoplasty (UPPP), midline glossectomy, mandibular advancement, limited mandibular osteotomies with genioglossal advancement, and hyoid bone suspension.[244] Pepin and colleagues published a critical analysis of the literature related to the risks and benefits of surgical treatment of snoring and OSA.[210] They identified "at least five deaths" following UPPP and drew attention to the fact that few studies have adequate numbers to allow conclusions to be drawn regarding their outcome. In addition, fewer than half of the studies commented on the frequency of complications. Haavisto and Suonpaa retrospectively reviewed 101 UPPP procedures and found an early postoperative respiratory complication rate of 10%.[120] Ten of 11 patients required reintubation, with one death resulting from airway obstruction.

UPPP surgery was introduced to deal with retropalatine collapse. However, in approximately half of the adult patients with OSA, obstruction occurs at the retrolingual pharynx. Tongue suspension is one of several approaches introduced to manage the latter group of patients.[57] This involves the placement of an anchoring screw in the geniotubercle and the attachment of a suture through the base of the tongue. Szokol and associates described a morbidly obese patient with OSA in whom such a procedure was performed.[244] Both laryngoscopy and bag-mask ventilation had been difficult. At the conclusion of the procedure, the patient was fully awake, able to sustain a head lift for 5 seconds, demonstrated a negative inspiratory pressure of 40 cm H_2O, and was extubated. Stridor was noted immediately, and bag-mask and LMA ventilation was ineffective. Attempts to reintubate the patient were unsuccessful, necessitating a cricothyrotomy. Subsequent direct laryngoscopy showed a markedly swollen epiglottis and grossly edematous laryngeal and hypopharyngeal tissue. The patient developed negative-pressure pulmonary edema and a tracheostomy was performed 2 days later because of persistent swelling. Tracheal decannulation occurred uneventfully 2 weeks later. The authors speculated that airway manipulation during the surgery was the cause of this patient's swelling. They did not consider that the swelling may have resulted from or at least been worsened by repeated attempts at laryngoscopy.

Laryngeal incompetence. Laryngeal function may be disturbed for at least 4 hours after tracheal extubation.[45]

Immediately following extubation, 8 of 24 (33%) patients aspirated swallowed radiopaque dye; five showed radiologic evidence of massive aspiration. Four hours following extubation, 4 of 20 (20%) patients aspirated, 3 massively. At 24 hours, the rate was reduced to 5%. In this study, patients had been intubated for 8 to 28 hours during and following cardiac surgery. Although the authors did not observe a relationship with duration of intubation (8 to 28 hours), it is unclear whether the presumed laryngeal incompetence occurs with a brief duration of intubation or is more severe or common with more prolonged intubation. The mechanism of laryngeal incompetence was postulated to be primarily sensory because patients who aspirated dye did not cough.

Residual neuromuscular paralysis is a common problem in postoperative patients and may result in hypoventilation, hypoxemia, and pharyngeal and laryngeal dysfunction or increase the risk of pulmonary aspiration.[71,252] Pharyngeal function was impaired in conscious volunteers receiving a continuous infusion of vecuronium and resulted in laryngeal penetration of contrast medium proportional to the degree of blockade.[95] Relaxation of the upper esophageal sphincter was also noted. None of the volunteers coughed or demonstrated respiratory symptoms. Berg and colleagues noted a higher incidence of postoperative pulmonary complications (pulmonary infiltrate or atelectasis, or both, associated with cough, sputum, or shortness of breath) among patients randomly assigned to receive a long-acting versus intermediate-acting neuromuscular blocker.[32] It is intriguing to speculate on how residual neuromuscular blockade may contribute to "laryngeal incompetence."

Pulmonary aspiration of gastric contents. Although gastroesophageal reflux (GER) is increasingly diagnosed, the recognition of perioperative pulmonary aspiration has not changed in recent decades.[200,260] Many factors in addition to GER may predispose a patient to aspiration, including emergency surgery, pain, obesity, narcotics, nausea, ileus, pregnancy, some surgical positions, depressed level of consciousness, inadequate depth of anesthesia, postoperative drowsiness, and residual neuromuscular blockade, yet clinically important aspiration is uncommonly identified. Prior to intubation, difficult bag-mask ventilation may result in gastric distention. This may be further complicated if laryngoscopy proves difficult because this may delay securing the airway and repeated laryngoscopic attempts may cause edema, thereby decreasing the glottic opening. Clearly, aspiration can cause serious morbidity and death.[200,206,260] In a multicenter, prospective study looking at major complications associated with anesthesia, aspiration was identified in 27 of 198,103 general anesthetics resulting in 4 deaths and 2 cases of anoxic encephalopathy.[248] Aspiration may also result from obtundation or conditions that impair vocal cord apposition (e.g., vocal cord paralysis, residual neuromuscular blockade, and granulomata).

Although the majority of incidents of aspiration seem to occur at induction, a significant number occur during maintenance and recovery periods.[152] Numerous strategies have been described to reduce the risk at induction, but relatively little information is available on how best to prevent this later on. Postoperative nausea, delayed gastric emptying, residual neuromuscular blockade, relaxation of the esophageal sphincters, decreased level of consciousness, gagging on an ET, and impaired laryngeal competence may all make emergence from anesthesia and tracheal extubation as problematic as induction. At present, it is not possible to offer evidence-based recommendations on an extubation strategy to reduce aspiration. It would seem logical to minimize the preceding contributing factors—postoperative nausea and vomiting, residual neuromuscular blockade, decreased level of consciousness and associated diminished protective airway reflexes, and perhaps gastric evacuation. We do not know whether gastric decompression reduces aspiration, although a well-seated ProSeal LMA (PLMA) may[61,184] or may not[63] offer some protection from aspiration. Nonetheless, with the present body of information, it is not appropriate to recommend specifically the use of this device in a patient recognized to be at increased risk for aspiration.

2. Previous Difficulties Encountered

Multiple attempts at laryngoscopy by experienced personnel, a need for alternative airway management techniques because of failure of direct laryngoscopy, and a history of prior difficulty prompting the primary use of such an alternative technique represent settings in which the need for reintubation may be problematic. Under urgent or emergent circumstances, methods that had previously been successful may not be available or appropriate. The required equipment, necessary skills, or time required to perform alternative techniques may not be available. Uncertainty regarding the probable success of laryngoscopy may appropriately result in reluctance to administer paralytic and sedating drugs that may actually make laryngoscopy easier, yet result in an apneic patient who can be neither ventilated nor intubated. Thus, knowledge of prior difficulties may result in intubation conditions that are less favorable to success. Awake flexible fiberoptic bronchoscopy generally requires a dry field for visualization and adequate topical anesthesia. Blood and secretions in the airway or an agitated, hypoxic patient makes such a technique less likely to be successful.

3. Limited Access

Limited access to the airway is exemplified by (1) intermaxillary fixation; (2) severe cervical restriction, instability, or immobilization; and (3) the chin-to-chest guardian suture to prevent traction tracheal resection. In each case, there may be additional risks related to oxygenation,

ventilation, airway obstruction, or pulmonary toilet. For example, following cervical fixation, the patient may also have macroglossia or supraglottic edema. A patient requiring tracheal resection may be unable to clear blood or secretions from the airway.

C. HIGH-RISK EXTUBATIONS

We have previously defined a high-risk extubation as a situation wherein reestablishing a lost airway, be it due to failure of oxygenation, ventilation, pulmonary toilet, or loss of patency, is likely to be difficult or impossible without significant risk. Many of the preceding clinical examples (e.g., OSA, RA, anterior cervical surgery, intermaxillary fixation) represent a high risk because reintubation may be challenging. In addition, the clinical "playing field" may not be level at all hours of the day. The immediate availability of highly trained primary and support personnel, equipment, and the relevant clinical information may be problematic at night or during periods of intense activity. As previously mentioned, the consultants of the ASA Task Force on Management of the Difficult Airway[5] and the Canadian Airway Focus Group[66] both recommended a preformulated strategy for extubation of the DA. Patients at risk for hypoventilation, hypoxemia, and loss of airway patency have been discussed at length. The remainder of this chapter is related to specific extubation strategies.

IV. EXTUBATION STRATEGIES

To the extent that any of the high-risk extubation conditions exist or are anticipated, it behooves the clinician to consider a strategy that does not cut off access to the airway (Table 47-4). Ideally, such a strategy should permit the continued administration of oxygen or the ability to ventilate a failing patient even while the airway is being reestablished. Such objectives are consistent with the ASA Task Force[5] and Canadian Airway Focus Group[67] recommendations.

The extubation risk stratification is largely based upon intuition, anecdotal reports, and limited clinical series. It is hoped that the proposed classification and strategies will become broader and deeper with time. Because the majority of patients—even those at high risk—are successfully extubated, it is essential that any proposed strategy entail less risk than simply removing the ET and hoping for the best. It should also involve minimal discomfort, at an acceptable cost; and facilitate oxygenation, ventilation, and reintubation.

A. DEEP VERSUS AWAKE EXTUBATION?

Extubations may be performed before or after recovery of consciousness. Deep extubation ordinarily would involve the prior reversal of neuromuscular blockade and resumption of spontaneous ventilation. Its purported advantage is the avoidance of the adverse reflexes associated with extubation, such as hypertension, dysrhythmias, coughing, laryngospasm, and increased IOP or ICP. The fundamental disadvantage of deep extubation is the patient's inability to protect the airway against obstruction and aspiration. If it is improperly executed, laryngospasm and its attendant complications are more likely to occur. Although not having to await the recovery of consciousness may accelerate OR turnover, the exhalation of unscavenged volatile anesthetic agents may result in occupational health and safety issues. A significant proportion of American anesthesiologists practice the technique, at least some of the time, yet there are very few data in adults comparing the safety of deep versus awake extubation.[68] Koga and colleagues compared three small groups of adult patients, extubated deep, awake, or extubated deep following the insertion of an LMA.[154] Straining occurred in a high (but comparable) proportion of patients whether the ET was removed prior or subsequent to recovery of consciousness. Deep extubation followed by LMA insertion (isoflurane 2% to 3%) is discussed subsequently. Deep extubation is contraindicated when mask ventilation was found or is likely to have become difficult, the risk of aspiration is increased, endotracheal intubation had been difficult, or airway edema is likely.

Table 47-4 **Extubation Strategies**

Deep (versus awake) extubation
Substitution of an LMA
Extubation over FOB
Substitution of and LMA combined with FOB
Use of gum elastic bougie or Mizus obturator
Jet stylet
TTX or JETTX (Sheridan-RCI)
CAEC (Cook Critical Care)
ETVC (CardioMed Supplies)
Double-lumen tube exchanges
Nasal-oral conversions

CAEC, Cook airway exchange catheter; ETVC, endotracheal ventilation catheter; FOB, fiberoptic bronchoscope; JETTX, jet ventilation/tracheal tube exchanger; LMA, laryngeal mask airway; TTX, tracheal tube exchanger.

B. EXTUBATION WITH LARYNGEAL MASK AIRWAY

Upon emergence from general anesthesia, most patients tolerate an LMA with less coughing and changes in IOC, ICP, and BP (see Fig. 47-1).[40,108,154,163] Silva and Brimacombe substituted an LMA for the ET in a small series of patients while they were still asleep and paralyzed

following completion of neurosurgical procedures.[234] Muscle relaxation was then reversed and the anesthetic was discontinued. The LMAs were removed when the patients resumed spontaneous ventilation and obeyed commands. None of the 10 patients coughed, and changes in the rate-pressure product were minimal. The authors concluded that the technique might prove useful in patients undergoing other types of surgical procedures. They stressed that this substitution should be performed only by those skilled in LMA insertion. Patients must be at a sufficient depth of anesthesia or coughing, breath holding, laryngospasm, and the very pressor responses this substitution is intended to avoid may occur. Bailey and others recommended that the LMA be inserted prior to removal of the ET, with the purported advantage of not risking loss of the airway following tracheal extubation.[77,154] Compared with deep tracheal extubation followed by Guedel airway insertion, there was a lower incidence of coughing and requirement for airway manipulation.[77] Koga and coworkers compared this technique with deep and awake tracheal extubation. As previously mentioned, they observed no difference in recovery conditions between patients in whom the ET was removed either deep or awake; however, they noted a significant improvement in recovery conditions when the LMA substitution was performed. This technique might be useful in patients undergoing procedures in which coughing, straining, and intraocular, intracranial, and BP changes could be particularly detrimental. Patients at risk for aspiration are not protected. Furthermore, patients difficult to intubate by laryngoscopy are probably poor candidates for this technique because airway patency cannot be guaranteed after the LMA substitution.

ET exchange using an LMA has also been described. Asai described a patient who had had a difficult endotracheal intubation further complicated by rupture of the ET cuff.[13] He introduced a 7.0-mm ET over a fiberoptic bronchoscope and passed these through an unmodified size 5 LMA Classic, extending the length of the ET with a second ET inserted into the proximal end of the replacement tube. A smaller LMA would have necessitated cutting of the aperture bars or use of a smaller ET. Stix and coworkers modified an intubating LMA (ILMA) by removing the epiglottic elevator bar.[241] They used this to convert from a double-lumen tube (DLT) to a single-lumen ET. In addition, they employed a 14 Fr jet ventilation tube exchanger (type unspecified) through the tracheal lumen of the DLT. Had the intubation through the ILMA proved unsuccessful, this would have provided a means of oxygenating and ventilating that could be used as a stylet for the replacement ET.

Matioc and Arndt proposed another approach.[187] They wished to substitute an ET for a No. 5 PLMA, despite a grade II view as seen through the LMA.[39] Using an Arndt Airway Exchange Catheter Set (Cook Critical Care, Bloomington, IN), they introduced a fiberoptic bronchoscope through the PLMA into the trachea. A 144-cm guidewire (Amplatz extra stiff) was passed through the fiberoptic bronchoscope and the latter was removed. A No. 11 Fr 70-cm Cook airway exchange catheter (see later) was introduced over the guidewire and the PLMA was removed. The replacement ET was then advanced over the exchange catheter.

A simpler approach using a ventilation/exchange bougie (Aintree Intubation Catheter, Cook Critical Care) has been described. This can be used with a COPA (cuffed oropharyngeal airway, Mallinckrodt)[125] or an LMA Classic.[213] There are several advantages of this technique. It can be used to facilitate conversion from an unmodified LMA to an oral ET of adequate size. It affords sufficient length that the LMA can be removed with minimal risk of losing the airway. The Aintree Intubation Catheter fits tightly to the insertion cord of the fiberoptic bronchoscope and in turn to the ET, thereby reducing the size discrepancy that often results in difficult glottic passage. The catheter can be used as a conduit for manual or jet ventilation during an exchange. An LMA Classic, inserted as a rescue device (cannot intubate, cannot ventilate), can facilitate safe tube exchange without the need for an ILMA.

C. EXTUBATION OR REINTUBATION OVER FIBEROPTIC BRONCHOSCOPE OR LARYNGOSCOPE

In situations with the possibility of tube entrapment, extubation over a fiberoptic bronchoscope (FOB) can detect and potentially avert a disastrous outcome. With a spontaneously breathing patient, extubation over a bronchoscope provides the opportunity of visually assessing the trachea and laryngeal anatomy and function. This can be very helpful in the patient suspected of having tracheomalacia, vocal cord paresis, or PVCM. It also permits the assessment of supraglottic structures.[74] In this author's experience, such opportunities are maximized by reassuring the patient, judicious sedation, an antisialagogue, and the use of an auxiliary Yankauer sucker for oral secretions. The FOB is placed above the carina and the cuff is slowly deflated to minimize coughing. The ET is slowly withdrawn into the oropharynx with subsequent, very gradual withdrawal of the FOB to the supraglottic region. Once the patient is comfortable, the FOB is further withdrawn to a position just above the vocal cords. Even with such a deliberate technique, the exercise is frequently frustrated by excessive secretions, coughing, swallowing, or poor tolerance with insufficient opportunity to visualize the structures of interest.

If the technique is successful, it may enable the anticipation of complications. When significant abnormalities are noted, a decision must be made whether to reinsert the ET or withdraw the FOB immediately and manage the patient with agents such as corticosteroids (see earlier), racemic epinephrine, or helium-oxygen.[148,149] This technique is not a practical way of performing a trial

of extubation, in part because such a trial lasts only seconds or minutes.

Hudes and coauthors described two patients who had had DIs and required tube exchange.[137] This was accomplished by the prior removal of the plastic connector on the original tube, mounting the new tube over a bronchoscope, advancement of the FOB, and withdrawal of the original tube. This tube was then filleted with a scalpel blade and peeled off to allow the replacement tube to be advanced. They claimed to have achieved this in 20 and 30 seconds. In this author's opinion, such a technique is awkward and places the patient, the FOB, and the operator's fingers in jeopardy.

Others have used the FOB to change ETs. Rosenbaum and colleagues placed a bronchoscope through the opposite nostril of a patient with an existing but inadequate nasotracheal tube.[223] Watson endorsed the use of an FOB to exchange ETs, citing the advantages of minimal sedation, risk of aspiration, hemodynamic embarrassment, and uncertainty about tube placement.[261] His technique involved passing the "loaded" FOB alongside the existing ET. He had used such a technique successfully in 13 of 15 attempts. Dellinger considered the FOB to offer the least likelihood of reintubation failure, suggesting a "cumbersome" technique that places the preloaded bronchoscope alongside the ET to be replaced and subsequent advancement of the FOB.[74] The existing tube is removed and the new tube is advanced. He suggested that if the bronchoscope could not be advanced, it should be positioned just above the vocal folds and the existing tube withdrawn from the trachea followed by reintubation. Admittedly, this risks loss of the airway.

There can be no more certain means of exchanging an ET than performing this operation with continuous visual control. Andrews and Mabey described the use of a WuScope (Achi Corporation, Fremont, CA and Asahi Optical, Tokyo, Japan) to perform a tube exchange.[6] Their patient had previously had a DI related to morbid obesity and limited head extension. He was also suffering from severe ARDS. A WuScope allowed successful glottic visualization, permitting the insertion of a suction catheter anterior to the existing nasotracheal tube. The latter was withdrawn and the replacement oral ET was easily advanced over the suction catheter with minimal interruption of mechanical ventilation. In this author's opinion, the visual control possible with a WuScope (or presumably a Bullard Scope [Circon, Santa Barbara, CA], Upsher UltraScope [Mercury Medical, Clearwater, FL], or videolaryngoscope) is preferable to the blind passage of an ET over an FOB or tube exchanger. A hollow tube exchanger, however, would have permitted jet ventilation if desaturation or difficulties with tube advancement had occurred. The author has had personal experience performing tube exchanges under direct vision using the Bullard laryngoscope and the GlideScope (Saturn Biomedical, Burnaby, BC).

D. EXTUBATION WITH LARYNGEAL MASK AIRWAY ± BRONCHOSCOPE

Extubation of a DA over an FOB or with an LMA has the limitations referred to previously. The combination of these devices, however, offers significant advantages. Replacement of an ET with an LMA provides an excellent means of performing a fiberoptic assessment of glottic and subglottic anatomy and function. After the substitution is performed and with the patient under anesthesia or a suitable degree of sedation, muscle relaxation can be reversed and spontaneous ventilation be allowed to resume. An FOB is then be passed through an LMA, and dynamic vocal fold movement and appearance can be assessed while concentrations of oxygen and volatile agents (if necessary) can be controlled. The view is also protected from oral secretions and inadequate ventilation can be supplemented. The presence of PVCM or tracheomalacia can be evaluated, although both may be minimal if the patient is deeply anesthetized.

This technique is useful in patients with recurrent postextubation stridor or those at risk for static or dynamic tracheal stenosis. The author frequently employs this technique in patients undergoing thyroidectomies when either tracheomalacia or vocal fold paralysis is suspected.

E. EXTUBATION OVER GUM ELASTIC BOUGIE/METTRO-MIZUS OBTURATOR

Finucane and Kupshik described an awake blind nasal intubation in a patient with cervical instability.[101] After confirming correct placement and neurologic integrity, anesthesia was induced, at which point they discovered that the nasotracheal tube cuff had been damaged. They used the 63-cm-long, 4-mm outer diameter (OD) plastic sleeve from a brachial central venous catheter as a stylet and performed a tube exchange without difficulty. Others have used a gum elastic bougie to achieve similar objectives.[21,76,220,250]

Cook Critical Care has designed the METTRO (Mizus ET replacement obturator) for the replacement of endotracheal and tracheostomy tubes (Fig. 47-2). It is available in two sizes, 70 cm (7.0 Fr) for replacement of ETs as small as 3 mm and 80 cm long (19 Fr) to pass through tubes 7 mm or larger. It is a single-use, flexible, radiopaque, solid device with a tapered tip. It bears distance markings. Early package inserts had instructed the user to advance this until resistance is encountered. Such a recommendation can result in coughing, discomfort, hypertension, and tachycardia. (Tracheal perforation has been reported using different devices but following similar recommendations.[73,231])

The smaller airway obturator has been used to maintain airway access during 22 tracheostomies and for "tentative extubations" in seven patients.[18] The authors preferred the smaller caliber device because there was minimal discomfort of the patient during tube exchanges and it was "unobtrusive" during surgical tracheostomies.

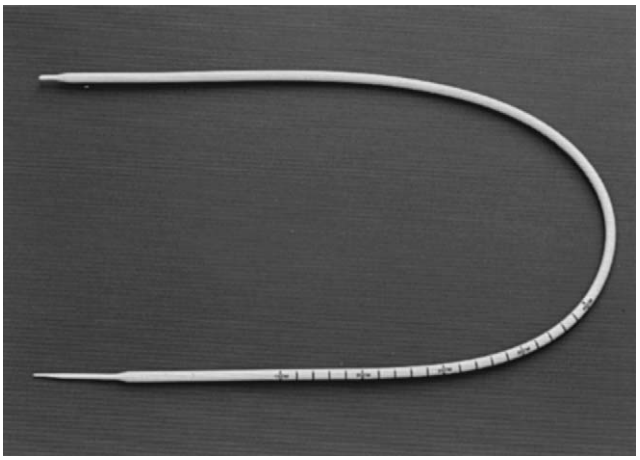

Figure 47-2 The METTRO (Mizus endotracheal tube replacement obturator, Cook Critical Care) is a solid device, tapered at the end. It is available in two diameters (7 and 19 Fr) and two lengths (70 and 80 cm). (Courtesy of Cook Critical Care.)

The obturator was removed when it was apparent that the patient was unlikely to require reintubation. In their experience, the 19 Fr obturator was not conducive to spontaneous breathing. Chipley and colleagues used a METTRO in an obese patient with a fractured occipital condyle recovering from respiratory failure.[52] They left this in place for 48 hours, removing it when extubation appeared to be successful. They also described the use of the obturator to stimulate coughing, although this may have been ill advised given the previously cited complication of tracheal perforation.

F. CONCEPT OF JET STYLET

The ubiquitous nasogastric tube has been used as an exchange catheter,[240] but these devices are specifically formulated to become softer as they are warmed. Such thermolability is not likely to be a desirable attribute for a tube exchanger.

Bedger and Chang coined the term "jet stylet" to refer to a self-fashioned long (65 cm) plastic catheter with a removable 15-mm adapter for connection to an anesthesia machine or jet injector.[23] They created three side ports cut into the distal 5 cm to minimize catheter whip during jet ventilation. They used their stylet for the extubation or reintubation of 59 patients. It also functioned "adequately" in the patients in whom it was used for jet ventilation and oxygen insufflation. Although no complications were encountered in this series, the same authors, in an earlier report, described tension pneumothoraces in 3 of 600 patients ventilated at 15 pounds per square inch through a 3.5-mm (OD) pediatric chest tube.[50] This "stylet" had been used to provide airway access and ventilation during direct laryngoscopy. They speculated that the pneumothoraces might have resulted from endobronchial migration of the catheter. They did not consider the possibility that barotrauma occurred as a result of jet ventilation against apposed vocal cords as their patients were recovering from neuromuscular blockade.

G. COMMERCIAL TUBE EXCHANGERS

There are now a number of commercial products that incorporate many of the features described by Bedger and Chang.[23] These are long, hollow catheters that may include connectors for jet or manual ventilation, or both. Most have distance and radiopaque markers. They also have end or distal side holes, or both. They can be introduced through an existing ET, permitting its withdrawal. Oxygen insufflation or jet ventilation can be provided through the tube exchanger. Respiratory monitoring can also be achieved by connection to a capnograph. Spontaneous breathing may take place around the device. In most reports, these have been tolerated well enough that they can be left in situ until it is probable that reintubation will not be required. Even with the catheter in place, most patients are able to talk or cough. If reintubation or a tube exchange is required, this can be facilitated with gentle laryngoscopy, not necessarily to reveal the glottis but to retract the tongue. Reintubation using a tube exchanger is similar to intubation over an FOB, and the difference of diameters between the tube exchanger and the advancing ET may predict the relative ease of tube advancement. If resistance is encountered, ET rotation may successfully release the tube from the pyriform fossa or arytenoid cartilage.

These devices are consistent with the ASA Task Force[5] and Canadian Airway Focus Group[67] recommendations regarding the extubation of the DA. They increase the probability that a reintubation will succeed; should difficulty be encountered, the device provides a means whereby oxygen by insufflation or ventilation, if necessary, can be accomplished while alternative techniques are explored. This may be thought of as a reversible extubation. With the device in place, other options can be pursued, including an evaluation of the benefits of helium-oxygen or the inhalation of racemic epinephrine. Knowing that the patient is satisfactorily oxygenated (and ventilated), additional information, equipment, or expertise can be recruited. There are differences between these commercial products—and such differences may be important—but they are far less important than the concept of the reversible extubation. In this author's opinion, reintubation of the high-risk patient may have a low likelihood of being required, but it must have a high probability of being successful. The differences between the devices are now detailed.

1. Tracheal Tube Exchanger

The most basic commercial tube exchanger is the Sheridan TTX (Hudson Respiratory Care Incorporated, Temulca, CA) (Fig. 47-3). These are available in four

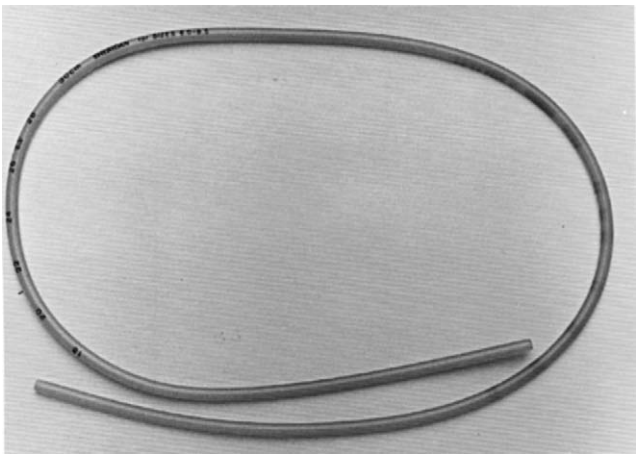

Figure 47-3 The tracheal tube exchanger (Sheridan TTX, Hudson, RCI) is a simple catheter with no proximal or distal modifications. These devices are available in four diameters and two lengths. If the device is to be used for ventilation, it must be adapted by the user. There are no distal side ports, which makes jet injection potentially hazardous. (From Cooper RM: The difficult airway—II. Anesthesiol Clin North Am 13:683-707, 1995.)

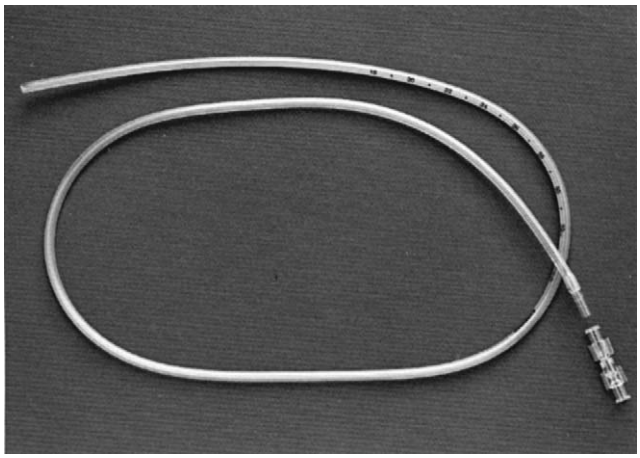

Figure 47-4 The Sheridan JETTX (Hudson, RCI) is essentially a modification of the tracheal tube exchanger (TTX), being 100 cm in length, featuring a proximal adapter for jet ventilation, and having a single distal end hole. As with the TTX, this is likely to result in catheter whip and might increase the risk of jet injection injury. (From Cooper RM: Extubation and changing endotracheal tubes. In Benumof JL [ed]: Airway Management: Principles and Practice, 1st ed. St. Louis, Mosby, 1996, pp 864-885.)

diameters (2.0, 3.3, 4.8, and 5.8 mm OD) and two lengths (56 and 81 cm). The smallest can be inserted into ETs as small as 2.5 mm inner diameter (ID). They are firm (durometry of 85 shore) although thermolabile and therefore subject to softening with heat. They are frosted to minimize drag and have a radiopaque stripe and distance markings. There are no side holes, nor are there connectors.

Benumof has described the combined use of a TTX and FOB in replacing a 7.0-mm nasotracheal tube with a 8.0-mm orotracheal tube in a patient with halo fixation.[26] Benumof has also described modifications of the TTX to enable jet ventilation, although these must be prepared in advance and may be somewhat difficult to disassemble when the original ET is being off-loaded. Consequently, the manufacturer has produced an alternative product referred to as the Sheridan JETTX exchanger (Fig. 47-4). This is a longer device (100 cm) but available in only a single size, suitable for ETs greater than 6.5 mm ID. It incorporates a proximal slip-fit connector that can be Luer-locked to a jet ventilator. As with the TTX, there is only a single distal end hole.

2. Cook Airway Exchange Catheters*

Cook Critical Care has developed a family of hollow stylets, known as airway exchange catheters (CAECs) (Fig. 47-5). These are available in French sizes 8.0, 11, 14, and 19 mm corresponding to 2.7, 3.7, 4.7, and 6.33 mm ODs, respectively. The 8 Fr CAEC is 45 cm in length and the others are 83 cm long. The smallest can be used with a 3 mm ID ET. These devices are radiopaque and have distance markings between 15 and 30 cm from the distal end. There are two distal side holes and an end hole. Proximally, there are two types of connectors, secured and released by a patented Rapi-Fit adapter. These were designed for easy adapter removal as the ET is being off-loaded and subsequent reattachment for ventilation while the new tube is being introduced. A secure

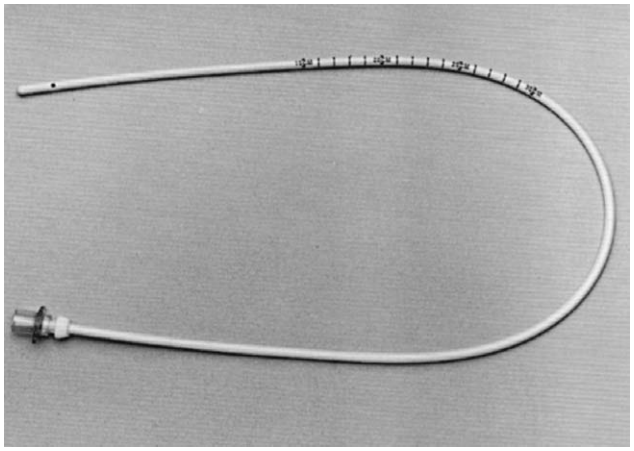

Figure 47-5 The Cook airway exchange catheters (Cook Critical Care) are available in four diameters and two lengths. They are radiopaque and have distance markings at each centimeter throughout the working length. Proximally, there is a Rapi-Fit adapter that can be easily and securely added or removed. They are packaged with both 15-mm and jet ventilation connectors. Distally, there are an end hole and two side holes. (Courtesy of Cook Critical Care.)

*The author served as a consultant to Cook in the development of this product.

Luer-Lok fitting is available for jet ventilation and a 15-mm connector for manual ventilation. The length and inner diameters (1.6 to 3.4 mm) make manual ventilation with a resuscitation bag possible but impractical because resistance is so high. The 15-mm Rapi-Fit connector serves primarily as a means of connecting the exchange catheter to an oxygen source. During jet ventilation, the paucity of distal side holes potentially increases catheter whip and the risk of barotrauma.[89] Loudermilk and others used the 11 Fr, 83 cm CAEC in 40 high-risk adult extubations, 3 of which required reintubation. This was easily performed with each attempt. The exchange catheters were also used for oxygen insufflation. All but one patient tolerated the device, and dislodgement occurred in one patient.[178]

Atlas and Mort examined the relationship between the diameter of the two larger CAECs and tolerance as well as the ability to phonate and cough.[17] It is unclear whether their patients were randomly assigned to specific sizes of catheters. Phonation and discomfort were similar in both groups with only 3 of 101 patients experiencing significant discomfort. Cough effort tended to be reduced in the larger sized CAEC, but this did not achieve significance. Atlas also looked at a larger tube exchanger (JEM 400 ET Changer, Instrumentation Industries, Bethel Park, PA), which it was reasoned would have a higher degree of success as a tube exchanger. This device has an OD of 6.35 mm and is said to be stiffer. Atlas adapted the JEM 400 using the Rapi-Fit connector from the CAEC 19-83 to enable jet ventilation.[16] This device, however, has only a single end hole and is not recommended for jet ventilation (see later).

As previously mentioned (see METTRO-Mizus obturator), the manufacturer originally had recommended insertion of the CAEC until resistance was encountered, presumably at the carina. Such a recommendation was ill advised as it could result in tracheal injury or barotrauma, particularly if used for ventilation. The instructions now clearly state that the distal end of the CAEC should be aligned with the distal end of the ET or preferably 2 to 3 cm proximal to the carina.

3. Endotracheal Ventilation Catheter*

This device is manufactured by CardioMed Supplies (Gormley, ON, Canada) of a hybrid plastic (Fig. 47-6). It is 85 cm in length and has an OD and ID of 4 and 3 mm, respectively. It has a radiopaque stripe along its entire length and distance markings at 4-cm intervals. Proximally, it has a male hose barb with a threaded adapter welded into the catheter. These attachments have been constructed so as not to restrict the catheter's inner diameter. The threaded adapter connects to an easily removed Luer-Lok adapter. Distally, it is blunt ended with one end hole and eight helically arranged side holes to minimize catheter whip and jet ventilation pressures (see later). Studies by the manufacturer indicate no significant softening over time at body temperature. This is desirable for a product that may remain in situ and be required to serve as a stylet. A metal guidewire is available to provide additional stiffness, but the author has not found this to be necessary.

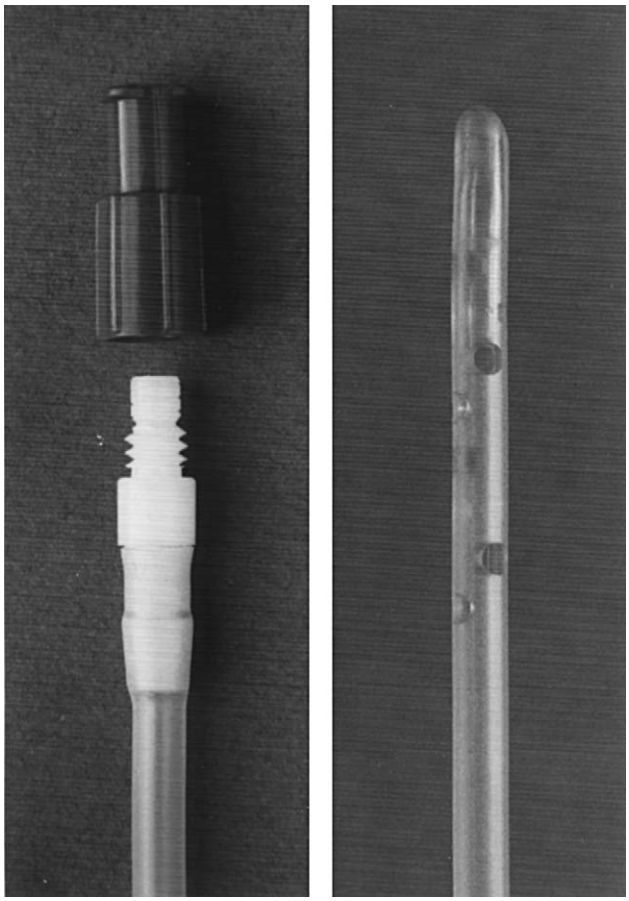

Figure 47-6 The endotracheal ventilation catheter (ETVC, CardioMed Supplies) is available in one length (85 cm) with an outer diameter of 4 mm. It is nonthermolabile and has a radiopaque stripe along its length. There are distance markings every 4 cm. Proximally, there is a welded plastic adapter with a threaded Luer-Lok adapter for jet ventilation **(A)**. Distally, there are an end hole and eight helically arranged side holes **(B)**. These minimize catheter whip and reduce the jet injection pressure. A removable metal stylet is available for additional stiffening. (From Cooper RM, Cohen DR: The use of an endotracheal ventilation catheter for jet ventilation during a difficult intubation. Can J Anaesth 41:1198, 1994.)

The endotracheal ventilation catheter (ETVC) was designed to facilitate reversible extubation.[65] It has been used by the author in at least 500 patients, the first 202 of whom have been reported.[62] Although the ETVC had been used to facilitate reintubation, in the majority of cases this was not required. In the original series, reintubation

*This device was designed by the author, who has no financial interest in CardioMed Supplies Inc. but has received limited royalties from sales of the ETVC.

or tube exchange was performed in 32 of 202 uses (16%), a figure very similar to that reported by Loudermilk and coworkers.[178] In both series, the ETVC[62] and the CAEC,[178] respectively, had been used mostly to maintain airway access. The ETVC was also used for oxygen insufflation (31 patients), jet ventilation (45), and postextubation capnography (54).

Reintubation was successful in 20 of 22 attempts. One failure occurred with a softer prototype. The second failure resulted when an inexperienced and unsupervised operator attempted a tube exchange. Difficulty was occasionally encountered advancing the ET through the glottis, similar to that experienced when using an FOB to intubate.[145] Rotation of the ET usually remedied this situation. Many of the early patients in whom the ETVC was used had undergone orthognathic surgery or had been difficult to intubate. Early in our experience, the majority of the orthognathic surgery patients had postoperative intermaxillary fixation. In some cases, tube exchanges were necessitated by damaged cuffs or inadequate tube length.

Oxygen insufflation was achieved by connecting the male component of the ETVC to an oxygen flow meter with 2 to 4 L/min flow, titrated to the arterial saturation. *Jet ventilation* is discussed later. The ETVC has also been used to facilitate intubation when the glottis could be seen only through a rigid bronchoscope.

Complications included barotrauma, intolerance, unintended dislodgment, and tracheal penetration. Barotrauma is discussed in the next section. *Intolerance* occurred in 2 of 202 patients (generally because of carinal irritation) and in 1 patient recently recovered from status asthmaticus. Patients' intolerance should prompt a reassessment of the depth of insertion. If the depth is clinically or radiographically appropriate and the ETVC continues to be required, tolerance can generally be achieved by instilling lidocaine through the ETVC. Most patients, including those with reactive airways, have tolerated the ETVC without difficulty. *Dislodgment* occurred when the ETVC was inadequately secured or the patient "tongued" the catheter out. Tracheal or bronchial *perforation* with different instrumentation has been described previously.[73,231] In our case, it occurred in a patient with obstructing, proliferative tracheal papillomatosis and a chronic tracheostomy. A rigid prototype catheter was inserted alongside the tracheostomy, penetrating the posterior tracheal wall. Jet ventilation resulted in fatal barotrauma. *Aspiration* and *laryngospasm* have not been observed.

H. EXCHANGE OF DOUBLE-LUMEN TUBES

Generally, DLTs are selected for procedures requiring lung isolation. Although the resistance through a larger sized DLT does not preclude postoperative ventilation or weaning, it may be desirable to replace this with a single-lumen tube, particularly if care is to be transferred to an area where familiarity is lacking. The DLT may also have to be changed because of damage to a cuff or because the initial tube was of an inappropriate size. Such a substitution can often be achieved by direct laryngoscopy. While the larynx is in view, the DLT is withdrawn and immediately replaced with a single-lumen tube. Occasionally, this cannot be accomplished.[27] Whether tube substitution is single-to-double, double-to-single, or double-to-double lumen tube, the requirements are similar and the previously mentioned tube exchangers may not be sufficiently long or firm.[64,123]

Hudson RCI manufactures a DLT exchanger known as the Sheridan ETX Exchanger (catalog number 5-24105). This device is 100 cm in length and was designed for use with the Sheri-Bronch 35 to 41 Fr DLT. It has one distal end hole. There are distance markings and "tracheal" and "bronchial" markings to indicate when the distal tip of the ETX is at the opening of the distal lumen. This device lacks a connector for manual ventilation and the manufacturer recommends against the use of jet ventilation.

Cook Critical Care provides "extra firm" tube exchangers in 11 and 14 Fr sizes, which are 100 cm long and were designed primarily for the exchange of double-lumen ETs (designation C-CAE-11.0-100-DLT-EF and CAE-14.0-100-DLT-EF). These devices have ODs of 3.7 and 6.3 mm, respectively.

I. CONVERSION FROM NASAL TO ORAL

Blind or fiberoptically assisted nasal intubation is sometimes performed when oral approaches are difficult or not possible. The nasal tube may have to be converted to an oral one because of complications or intended surgery. Unless circumstances have changed making laryngoscopy now feasible, it is unlikely that conversion from nasal to oral can be achieved under direct visual control. Fiberoptic conversion, flexible[247] or rigid[7] may be possible as described previously (see "Extubation or Reintubation over Fiberoptic Bronchoscope or Laryngoscope" in Section IV. C). Occasionally, the required equipment is not available, the glottis cannot be visualized, or the patient must be ventilated throughout the exchange. This has been achieved using a variety of techniques.

Gabriel and Azocar described a patient in halo fixation in whom the connector was detached and the nasotracheal tube was advanced deeper into the trachea.[110] The tube was then grasped close to the uvula with forceps and digitally extracted through the mouth. Novella used a Sheridan TTX to perform a nasal-to-oral conversion in a patient with Klippel-Feil syndrome who first underwent orthognathic surgery and a subsequent septorhinoplasty.[202] Following the completion of the orthognathic surgery, the TTX was inserted into the nasal ET and the latter was withdrawn. The TTX was then grasped with two Magill forceps, the caudal one used to stabilize the

catheter and the cephalad one to withdraw the proximal end out of the mouth. An oral tube was then "railroaded" over the TTX. Cooper described a similar maneuver in a patient in whom oral fiberoptic intubation could not be accomplished; however, fiberoptic nasal intubation was achieved.[58] He passed an ETVC through the existing nasal tube and removed the latter. The ETVC was then stabilized with caudal Magill forceps and withdrawn through the mouth with the cephalad forceps. Oxygen insufflation was provided through the ETVC, which was then used to thread an oral tube into the trachea. In the latter case, oxygen desaturation was thereby avoided, although the procedure was easily and quickly accomplished.

J. CONVERSION FROM ORAL TO NASAL

During efforts to convert from an oral to a nasal ET, Sumiyoshi and coworkers used negative-pressure ventilation during the tube exchange.[243] Their patient was in a halo and chest cast because of a cervical injury and laryngoscopy had been unsuccessful. An attempt to introduce a 4.8-mm FOB adjacent to the existing tube (with a tube exchanger through it) was unsuccessful. A subsequent effort involved a 3.5-mm FOB and a 7 Fr Mizus obturator using negative pressure to achieve ventilation. A smaller hollow tube exchanger might have been successful and could have avoided the risk of negative-pressure pulmonary edema resulting from both an ET and FOB occupying a small glottic opening.[59] Smith and Fenner performed an oral-to-nasal conversion using a 4.0-mm (OD) FOB, which they inserted through the glottis, anterior to an oral tube.[236] The latter was withdrawn and a nasal tube was advanced over the FOB.

Dutta and colleagues had been unable to intubate a sedated child orally or nasally using a flexible FOB.[84] Oral intubation was achieved by direct laryngoscopy assisted by a stylet, but nasal placement was required for the intended surgical procedure. An FOB was inserted through the nose and retrieved through the mouth. Its distal end was threaded through the oral ET to the level of the carina. The bronchoscope was retroflexed and both were withdrawn through the naris. Such a maneuver seems fraught with danger to both patient and equipment. Salibian and coworkers, facing a similar problem, advanced a CAEC (11-83) through the nose, retrieving it from the mouth.[225] They then inserted this into the existing oral ET, providing oxygen insufflation. The oral ET was then withdrawn into the mouth, where it was filleted with a scalpel and torn away. A nasal tube was then successfully advanced over the CAEC. This, too, was a high-risk maneuver for patient, bronchoscope, and the operator's fingers. Interestingly, the authors did not mention whether any special precautions were taken at the time of extubation.

A far simpler technique was described by Nakata and Niimi employing a Patil two-part intubation catheter (Cook Critical Care).[199] This intubation-extubation device consists of two components that can be screwed together at its midpoint (see Fig. 47-6). The distal segment was introduced into the existing oral ET. The proximal part was introduced through the nose and retrieved through the mouth. The oral tube was then removed, the two parts were connected, and the Rapi-Fit jet adapter was connected. Jet ventilation was provided. The entire assembly was then used as a stylet and the replacement nasal tube was successfully advanced.

V. JET VENTILATION THROUGH STYLETS

The preceding sections stressed the importance of being able to supplement oxygenation during a tube exchange. In most circumstances, a patient's oxygen content can be adequately sustained with insufflation, obviating the need for high-pressure jet ventilation. If oxygen requirements are high prior to a tube exchange, equipment should be immediately available to provide jet ventilation. In its simplest form, this equipment consists of a manually cycled, Venturi-type jet ventilator with a Luer-Lok adapter and an in-line pressure-reducing valve (Fig. 47-7).[30] The objective of jet ventilation is to correct life-threatening hypoxemia, not to normalize arterial blood gases. Although the achievement of normal $Paco_2$ may be attainable, the risks probably exceed the benefits. Barotrauma, in some cases fatal, has occurred through such misguided objectives.

A. IN VITRO STUDIES

Transtracheal jet ventilation by means of an intravenous catheter or intratracheal ventilation using a stylet or tube exchanger has been advocated in the management of the cannot intubate, cannot ventilate patient.[5,31] In general, the *inspiratory volume* depends upon the driving pressure, injection time, the respiratory compliance and resistance, and the resistance of the tube exchanger. The latter is determined by the device's inner diameter and length. The *expiratory volume* depends on the exhalation time, the elastic recoil of the lungs, and the airway resistance.[30,85] Mismatch between inspiratory and expiratory volumes can have serious consequences.

In vitro studies using jet stylets have been conducted to determine flow, pressure, and entrainment characteristics. Using an in vitro model, with three sizes of Sheridan TTX catheters, Dworkin and colleagues measured the inspiratory and expiratory flows resulting from 50 psi injection as the simulated upper airway resistance, lung compliance, gas flow rate, and injection times were varied.[85] The upper airway resistance was determined by the effective tracheal diameter, which they defined as a computed difference between the OD of the TTX and tracheal diameter. They simulated upper airway obstruction by using various sizes of ET adapters, ranging from 11 to 3.5 mm ID, in the proximal airway. The gas flows

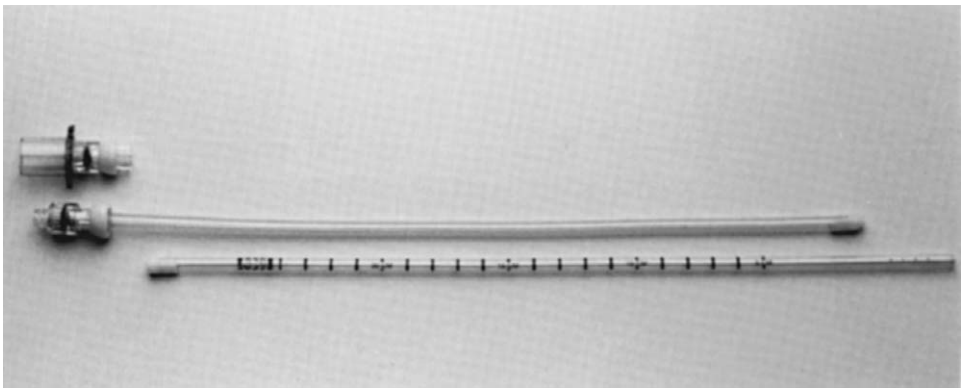

Figure 47-7 The Patil two-part intubation catheter (Cook Critical Care, Bloomington, IN). It is 63 cm in length with an outer diameter of 6.0 mm (18 Fr) and an inner diameter of 3.4 mm. Proximally, it accommodates a Rapi-Fit adapter with both a 15-mm connector and a Luer-Lok jet adapter. Distally, there is a total of eight side holes. At its midpoint, there is threading to enable the two halves to be separated or assembled to achieve its full length. (From Cooper RM: The difficult airway—II. Anesthesiol Clin North Am 13:683-707, 1995.)

through the large, medium, and small tube exchangers, when connected to a pressure source of 50 psi, were 63, 33, and 12 L/min, respectively. In their model, if the difference between the tracheal and TTX diameters resulted in an effective tracheal diameter that was greater than 4 to 4.5 mm, air trapping did not occur. Because increased upper airway resistance and reduced effective tracheal diameter resulted in larger tidal volumes, they concluded that jet ventilation through a long catheter, positioned close to the carina, caused little Venturi effect. Such ventilation was not greatly dependent upon air entrainment. Placement of the catheter close to the carina may ensure a higher oxygen concentration (by reducing room air entrainment), but it also increases the risk of distal catheter migration and barotrauma.

In another in vitro model, calculations based on oxygen dilution and direct measurement using a pneumotachograph revealed that air entrainment accounted for 0% to 31% of the inspired volume.[112] The largest TTX and "lung compliance" resulted in the greatest entrainment. These authors used a high driving pressure (50 psi), long inspiratory time (1 second), and brief expiratory time (1 second). Even within a low-compliance system, the large TTX was associated with excessive tidal volumes.

Prolonging expiratory time reduces the minute ventilation by reducing the respiratory rate. This technique still exposes the lungs to potentially injurious tidal volumes. An alternative approach would be to reduce the driving pressure. Gaughan and others assessed the tidal volumes and air entrainment in a model lung with a range of compliance sets, ventilated by high and low flow regulators through 14 and 16 g intravenous catheters.[113] Their high-flow regulator, at steady state, produced flow rates of 320 L/min at 100 psi, whereas the low-flow regulator produced flows up to 15 L/min at 9 to 5 psi. Intravenous catheters, because of their short length, offer considerably less resistance to flow. Their proximity to the upper airway also results in greater air entrainment (15% to 74%). Both high- and low-flow regulators allowed adequate minute ventilation in the setting of normal tracheal and bronchial diameters and normal compliance. The authors recommended that during transtracheal jet ventilation, when low-flow regulators were used, an inspiratory/expiratory ratio of 1:1 should be used because it yields the greatest minute ventilation. Although this observation is undoubtedly true, it remains to be determined whether such minute volumes are either clinically necessary or safe.[30,64]

B. IN VIVO STUDIES

Chang and coworkers provided intraoperative jet ventilation using a 3.5-mm chest tube as a jet catheter.[50] Ventilating with 15 psi at 10 to 16 breaths/min, they continued until spontaneous ventilation was deemed adequate. The patient was recovered and was noted to have a left pneumothorax that the authors attributed to catheter migration and unilateral ventilation. They mentioned that they had encountered three cases of pneumothoraces and one pneumoperitoneum in approximately 600 such procedures. The authors drew attention to the importance of catheter placement and advised that even brief airway obstruction can result in barotrauma. However, they failed to mention that vocal fold apposition as recovery occurs may promote such a complication. In a subsequent paper, the same authors stated that the "jet stylet" had been used for the ventilation of six patients resulting in normocarbia and adequate ventilation.[23]

Egol and associates described pneumothoraces or a pneumoperitoneum in three patients using a variety of delivery devices and driving pressures.[89] These included an 18 Fr suction catheter at 50 psi, a nasogastric sump tube at 20 psi (inspiratory time = 30%), and a fiberoptic

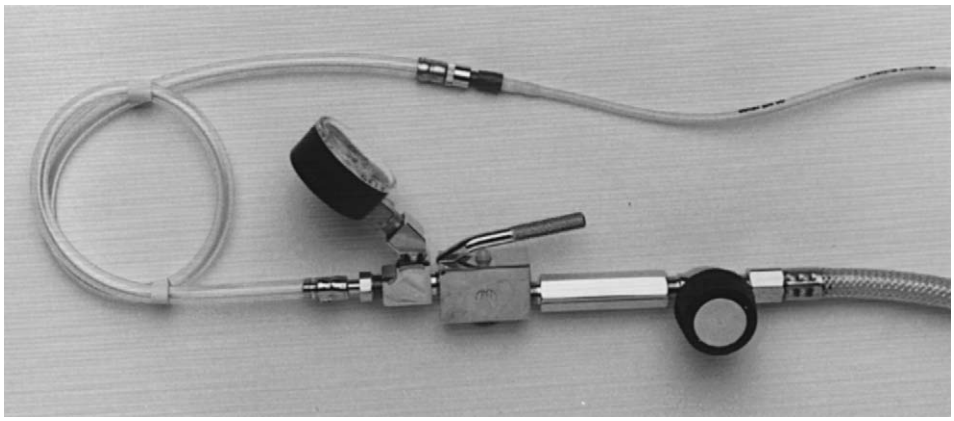

Figure 47-8 An endotracheal ventilation catheter is connected to a hand-held jet injector. The Rapi-Fit adapter or the JETTX device could be similarly attached. A pressure-reducing valve enables the operator to select a driving pressure that yields adequate chest expansion while minimizing the risk of barotrauma. (From Cooper RM, Cohen DR: The use of an endotracheal ventilation catheter for jet ventilation during a difficult intubation. Can J Anaesth 41:1196-1199, 1994.)

laryngoscope at 40 psi. They attributed the barotrauma observed to incorrect catheter placement, ventilation during phonation, and possible direct mucosal penetration from jet injection. They examined the relationship between the number of distal side holes in the tube exchanger and the pressure at the catheter tip. The more side holes at a given driving pressure, the lower the pressure at the catheter tip. They recommended vigilance regarding the location of the catheter tip (avoidance of direct mucosal contact, insertion into orifices where exhalation may be restricted, and securing the catheter to minimize migration); advocated for catheters with multiple side holes, the use of small-diameter jet catheters to minimize the resistance to exhalation, and the use of the minimal effective driving pressure; and encouraged the development and use of an effective pressure sensor and pressure cutoff device.

As previously mentioned, the ETVC has an end hole and eight distal side holes. Its use to provide jet ventilation during general anesthesia with muscle relaxation on 45 occasions was described.[62] Its attachment to a hand-held jet ventilator with a pressure-reducing valve is illustrated in Figure 47-8. Between 1991 and 1993, Irish and colleagues used this device with a driving pressure of 50 psi in anesthetized and paralyzed patients undergoing percutaneous tracheostomies.[140] They observed barotrauma in one patient. Arterial blood gases in 12 consecutive critically ill patients revealed (mean ± SD) a pH of 7.37 ± 0.09, Pa_{CO_2} 45.5 ± 10.8, and Pa_{O_2} 256 ± 126. In a subsequent report, a patient ventilated for 90 minutes at only 20 psi developed a pneumothorax.[64] Chan and Manninen also described the use of the ETVC to provide jet ventilation.[49] After performing a fiberoptic intubation in a patient with an unstable cervical spine, they discovered that the cuff of the ET had been damaged. They inserted an FOB through the other nostril and advanced this through the cords, anterior to the original ET. They then passed an ETVC through the original ET and provided three breaths of jet ventilation at 50 psi. The patient developed a pneumothorax. Unfortunately, they used a high driving pressure through an exchange catheter that may have been too deeply inserted in the setting of a significantly reduced effective tracheal diameter (partial cuff deflation, 6-mm ET, and FOB passing through the vocal cords).

These cases reinforce the general principles previously stated. The need for jet ventilation should always be weighed against its possible risks. It should be immediately available and used when there is evidence of a deterioration in a patient's oxygenation. An in-line pressure-reducing valve should be used and ventilation should begin with the lowest pressure capable of producing adequate chest expansion. The duration of inspiration should be minimized while the duration of exhalation is determined by observing the return of the thoracic diameter to its preinspiratory position. The depth of catheter insertion should be far enough from the carina that distal migration does not occur but not so proximal that jet ventilation results in the catheter's ejection from the glottis. Multiple distal side holes reduce both catheter whip and the distal catheter pressure during jet ventilation. Finally, every effort must be taken to minimize expiratory resistance.

VI. SUMMARY

Successful airway management does not end with endotracheal intubation. Although respiratory complications are more common at extubation than during intubation, the majority of these are relatively minor and do not result in a need for reintubation. However, such a need cannot always be predicted. Reintubation could prove to be difficult and dangerous in a variety of circumstances, discussed in detail. Accordingly, the ASA Task Force and

the Canadian Airway Focus Group have recommended that each anesthesiologist have a preformulated strategy for extubation of the DA. This chapter proposes a risk stratification scheme in an effort to identify patients in whom special extubation precautions might be of benefit. A variety of strategies are presented, although generally the benefits of these have not been subjected to rigorous evaluation. The concept of a reversible extubation using a tube exchanger has been presented. When such a device is used as a stylet, it does not provide a guarantee that reintubation will succeed. Carefully used, however, it should enhance patients' safety by providing oxygen insufflation and jet ventilation while other avenues are explored.

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