CHEST
Official publication of the American College of Chest Physicians

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Chest 2005;127;1397-1412
DOI 10.1378/chest.127.4.1397

Airway Management of the Critically Ill Patient*

Rapid-Sequence Intubation

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Advances in emergency airway management have allowed intensivists to use intubation techniques that were once the province of anesthesiology and were confined to the operating room. Appropriate rapid-sequence intubation (RSI) with the use of neuromuscular blocking agents, induction drugs, and adjunctive medications in a standardized approach improves clinical outcomes for select patients who require intubation. However, many physicians who work in the ICU have insufficient experience with these techniques to adopt them for routine use. The purpose of this article is to review airway management in the critically ill adult with an emphasis on airway assessment, algorithmic approaches, and RSI. ***(CHEST 2005; 127:1397–1412)***

Key words: airway management; ICU; induction agents; intensivist; intubation; neuromuscular blocking agents; rapid-sequence intubation; respiratory failure

Abbreviations: NMBA = neuromuscular blocking agent; RSI = rapid-sequence intubation; $\dot{V}O_2$ = oxygen uptake

The ability to place a secure airway in a variety of patients and clinical circumstances represents an obligatory skill for critical care physicians. In the ICU, these skills are regularly tested by the susceptibility of critically ill patients to hypoxic injury when emergency intubation is required. These patients typically have varying degrees of acute hypoxemia, acidosis, and hemodynamic instability when intubation is required, and tolerate poorly any delays in establishing an airway.[1] Associated conditions, such as intracranial hypertension, myocardial ischemia, upper airway bleeding, or emesis can be aggravated by the intubation attempt itself. And many critically ill patients, especially elderly patients, have a high frequency of comorbid conditions and underlying vascular disease that may further increase the risk for myocardial or cerebral ischemia when intubation attempts are prolonged.[2]

Unfortunately, multiple factors complicate rapid stabilization of the airway for critically ill patients in the ICU. Patients who require emergency intubation frequently become combative during intubation attempts. Conditions that complicate assisted ventilation and airway intubation, such as supraglottic edema, may go undetected before airway placement attempts. Also, critical care physicians cannot always count on having the most highly skilled members of the nursing and respiratory therapy staff on duty to assist with difficult intubations.

All of these factors warrant the standardization of the approaches used for emergency intubation in the ICU to ensure proper airway placement. Emergency medicine physicians have adopted algorithmic approaches for airway assessment and for rapid-sequence intubation (RSI) as the primary approach for emergency airway management.[3,4] RSI is the nearly simultaneous administration of a potent induction agent with a paralyzing dose of a neuromuscular blocking agent (NMBA). When applied by skilled operators for appropriately selected patients, RSI increases the success rate of intubation to 98%

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Manuscript received April 14, 2004; revision accepted August 31, 2004.

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while reducing complications.[4–15] Moreover, adjunctive medications incorporated into the RSI algorithm reduce the physiologic pressor response to endotracheal intubation, which can induce cardiovascular complications. The present review outlines these standardized approaches for airway assessment and RSI with the intent of widening the use of these techniques in the ICU setting.

Airway Assessment

The American Society of Anesthesiology defines a *difficult airway* by the existence of clinical factors that complicate either ventilation administered by face mask or intubation performed by experienced and skilled clinicians. *Difficult ventilation* has been defined as the inability of a trained anesthetist to maintain the oxygen saturation > 90% using a face mask for ventilation and 100% inspired oxygen, provided that the preventilation oxygen saturation level was within the normal range.[16] *Difficult intubation* has been defined by the need for more than three intubation attempts or attempts at intubation that last > 10 min.[16] This latter definition provides a margin of safety for preoxygenated patients who are undergoing elective intubation in the operating room. Such patients in stable circumstances can usually tolerate 10 min of attempted intubation without adverse sequelae. Critically ill patients with preexisting hypoxia and poor cardiopulmonary reserve, however, may experience adverse events after shorter periods of lack of response to ventilation or intubation.[1,2,17] Schwartz and coworkers[1] reported that 3% of hospitalized critically ill patients die within 30 min of emergency intubation, and as many as 8% of intubation attempts result in an esophageal placement. Li and coworkers[7] have demonstrated that complications occur in up to 78% of patients requiring emergency intubation. The incidence of esophageal intubation and aspiration ranged from 8 to 18%, and 4 to15%, respectively.[1,7] Identification of the difficult airway before initiating intubation attempts, therefore, has heightened importance in the ICU.

Examination of the airway to predict difficulties with face mask ventilation and intubation is an essential component of the preoperative assessment of patients who are scheduled for elective surgery. Multiple approaches exist to identify patients with a difficult airway. Unfortunately, the utility of these airway assessment methods has not been adequately evaluated in critically ill patients who undergo urgent intubation. Moreover, a recent retrospective analysis by Levitan and coworkers[18] has indicated that performing a thorough airway assessment of a critically ill patient in the emergency department is often not feasible in 70% of patients. Nevertheless, intensivists who are skilled in intubation should have an understanding of these techniques to allow their application when it is practical to do so.

Assessment for Difficult Ventilation

Both anatomic and functional factors can interfere with the use of a face mask for ventilation. Anatomic factors include abnormalities of the face, upper airway, lower airway, and thoracoabdominal compliance (Table 1). Obesity represents an important

Table 1—*Anatomic Factors Associated With Difficult Ventilation**

Anatomic Location	Airway Issue	Intervention
Face	Facial wasting; facial hair; edentulous snoring history	Patient positioning: sniffing position, and/or jaw thrust; ensure proper fit of mask to face; variety of different mask sizes; oropharyngeal and nasopharyngeal airways; team ventilation, with one person "bagging" while the other person ensures a proper seal; leave the dentures in while ventilating the patient
Upper airway	Abscess; hematoma; neoplasm; epiglottitis	Assist ventilation and avoid neuromuscular paralysis; awake intubation, possible fiberoptic with double set up for cricothyrotomy; call for help if an upper airway obstruction is suspected
Lower airway	Reactive airways	Preinduction administration of bronchodilators, nitrates, and diuretics
	Airspace disease Pneumonia ARDS Pulmonary edema Hemo/pneumothorax	PEEP valve for oxygenation in pulmonary edema, ARDS, and pneumonia; decompress a pneumothorax if you are going to apply positive pressure ventilation
Thorax-abdomen	Ascites; obesity; hemoperitoneum; abdominal compartment syndrome	Use of a bag-valve-mask with a PEEP valve may help oxygenation and ventilation

*PEEP = positive end-expiratory pressure.

anatomic barrier to successful face-mask ventilation.[19] Obese patients experience an increased risk of arterial oxygen desaturation due to difficulties with face mask ventilation and intubation because of redundant oral tissue, decreased respiratory system compliance due to chest and diaphragmatic restriction, and cephalomegaly, which interferes with proper face-mask placement.[20]

Altered mental status with loss of airway tone is the most common functional hindrance to assisted ventilation.[21] Critical illness and medications commonly used in the ICU, such as sedatives, NMBAs, and opioids, produce increased upper airway resistance by relaxing the muscles of the soft palate.[22,23] Because the soft palate rather than the tongue is the site of obstruction, ventilation is assisted by a jaw thrust or head tilt, the placement of either a nasopharyngeal or oropharyngeal airway, and the application of positive-pressure assisted ventilation. Conversely, inadequate sedation, saliva levels, and oropharyngeal instrumentation can precipitate laryngospasm, which can result in an obstructed airway. This involuntary spasm of the laryngeal musculature may be ablated with positive-pressure ventilation, suctioning of secretions, cessation of airway manipulation, and jaw thrust. Severe instances may require neuromuscular blockade.

Assessment for Difficult Intubation

Multiple methods exist to identify patients who are at risk for difficult intubations in the operating room. Unfortunately, no studies have assessed their utility for patients in the ICU.

The Mallampati classification system,[24] as modified by Samsoon and Young,[25] is a widely utilized approach for evaluating patients in the preoperative setting. This system predicts the degree of anticipated difficulty with laryngoscopy on the basis of the ability to visualize posterior pharyngeal structures (Fig 1). The Mallampati class is devised by having patients sit up, open their mouth, and pose in the "sniffing position" (*ie*, neck flexed with atlantoaxial extension) with the tongue voluntarily protruded maximally while the physician observes posterior pharyngeal structures. A tongue blade is not used. A Mallampati class of I or II predicts a relatively easy laryngoscopy. A Mallampati class > II indicates an increased probability of a difficult intubation and the need for specialized intubation techniques.

The Mallampati system has an application in the ICU, however, for the evaluation of mentally alert patients who require elective intubation for procedures. Critically ill patients with altered mental status or acute respiratory failure are unlikely to cooperate with the procedure. In approaching such patients, the evaluation of the oropharyngeal cavity with a tongue blade or laryngoscope allows the intensivist who is familiar with the Mallampati system to assess the patient to some degree for a difficult intubation and also provides an opportunity to detect any obvious signs of upper airway obstruction.[26]

Other factors that predict a difficult intubation include a mouth opening < 3 cm (*ie*, two fingertips), a cervical range of motion of < 35° of atlantooccipital extension, a thyromental distance of < 7 cm (*ie*, three finger breadths), large incisor length, a short, thick neck, poor mandibular translation, and a narrow palate (*ie*, three finger breadths).[27–31] Models developed by multivariate analysis have incorporated multiple clinical factors to derive highly accurate predictive models (sensitivity, 86.8%; specificity, 96.0%) for identifying difficult intubations among patients who are undergoing elective intubations in the operating room.[32] Because the incidences of both difficult laryngoscopy (1.5 to 8.0%) and failed intubation (0.1 to 0.3%) are low in the operating

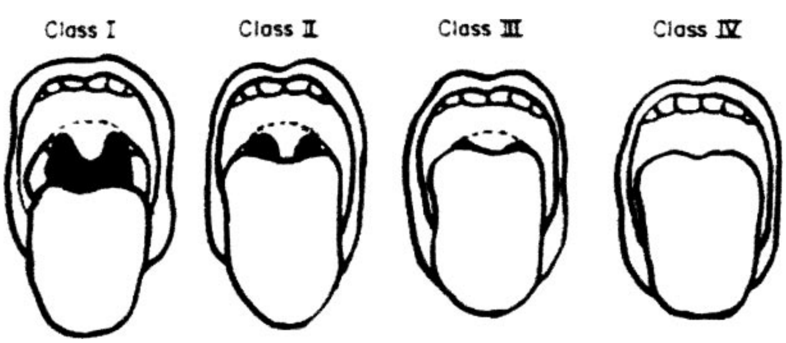

Figure 1. Mallampati classification for grading airways from the least difficult airway (I) to the most difficult airway (IV). Class I = visualization of the soft palate, fauces, uvula, and anterior and posterior pillars; class II = visualization of the soft palate, fauces, and uvula; class III = visualization of the soft palate and the base of the uvula; and class IV = soft palate is not visible at all.

room with expert anesthesiologists working with patients from the healthy population, these models have a high negative predictive value (99.7%) but a low positive predictive value (30.7%).[32–34] Their routine use in the operating room, therefore, has questionable cost-effectiveness. Although the incidence of difficult intubations is higher in the ICU, these multivariate predictive models have not been tested in that setting. In the emergency department, nearly 70% of patients undergoing RSI have either altered mental status or cervical spine collars in place that prevent the assessment of these predictive factors.[18] Consequently, no data support the value of these predictive models for routine use of RSI in the ICU to identify patients who will experience a difficult or failed intubation.

Despite the absence of validation studies to demonstrate the utility of airway assessment techniques to identify patients who will experience difficult intubations in the ICU, a quick examination of the patient for functional and anatomic factors has been shown to be predictive in the operating room setting and can assist preintubation planning.

Advanced Airway Pharmacology

Advanced airway management requires the selection of appropriate drugs for a particular clinical situation. Proper drug selection facilitates laryngoscopy, improves the likelihood of successful intubation, attenuates the physiologic response to intubation, and reduces the risk of aspiration and other complications of intubation by a factor of 50 to 70%.[35–38] Depending on the clinical circumstances, the intensivist may utilize a combination of preinduction agents, an induction agent, and a paralytic agent.

Preinduction Drugs

Stimulation of the airway with a laryngoscope and endotracheal tube presents an extremely noxious stimulus,[39] which is associated with an intense sympathetic discharge resulting in hypertension and tachycardia (called the *pressor response*). The physiologic consequences of this pressor response are well-tolerated by healthy persons undergoing elective intubation. A hypertensive response, however, may induce myocardial and cerebrovascular injury in critically ill patients with limited reserves for adequate tissue oxygenation.[2] Moreover, critically ill patients who require emergent intubation experience hypoxia, hypercarbia, and acidosis, which induce an extreme sympathetic outflow that is associated with tachycardia, labile BP, and an increased myocardial contractility.[40] Attenuation of these physiologic stresses after the placement of an airway may unmask relative hypovolemia and/or vasodilation, which result in postintubation hypotension.[40] Endotracheal intubation also can provoke bronchospasm and coughing that may aggravate underlying conditions, such as asthma, intraocular hypertension, and intracranial hypertension. Patients who are at risk for adverse events from airway manipulation benefit from the use of preinduction drugs, which include opioids, lidocaine, β-adrenergic antagonists, and non-depolarizing neuromuscular blockers (Table 2).

Opioids have a long history of use in anesthesia because of their analgesic and sedative effects. Fentanyl is commonly used because of its rapid onset of action and short duration of action. Fentanyl blunts the hypertensive response to intubation (40% incidence of hypertensive response compared with 80% in control subjects),[41] although it has only marginal effects on attenuating tachycardia.[41,42] Derivatives of fentanyl, sufentanil and alfentanil, are more effective than fentanyl at blunting both the tachycardic and hypertensive responses to intubation.[42–45] Fentanyl and its derivatives can occasionally cause rigidity of the chest wall. This idiosyncratic reaction appears to occur more commonly with higher doses and rapid injections. Studies in rats[46] and case reports in adults[47,48] have suggested that opioid-induced chest wall rigidity may be reversed by treatment with IV naloxone, although some patients in our experience may require neuromuscular blockade.

Caution is advised when using opioids in patients who are in severe shock states. Opioids can block the sympathetic compensatory response to hypotension, resulting in cardiovascular collapse.

Lidocaine, a class 1B antiarrhythmic drug, has been used to diminish the hypertensive response, to reduce airway reactivity, to prevent intracranial hypertension, and to decrease the incidence of dysrhythmias during intubation.[49–51] Demonstrated effectiveness for these end points, however, has varied among reports,[50,52,53] and no evidence has clearly established that lidocaine improves outcomes in terms of a lower incidence of myocardial infarction or stroke. North American physicians use lidocaine more commonly as a preinduction agent for patients who are at risk of elevated intracranial pressure compared with physicians in Europe.[52] To be most effective, lidocaine should be administered 3 min prior to intubation at a dose of 1.5 mg/kg.

Esmolol is a rapid-onset, short-acting, cardioselective β-adrenergic receptor-site blocker that effectively mitigates the tachycardic response to intubation with an inconsistent effect on the hypertensive response.[41,42,54–56] However, most studies,[41,54,56] but not all,[53] have indicated that esmolol is more effective than lidocaine or fentanyl in reducing the pres-

Table 2—*Preinduction Agents Used for RSI*

Drug	Dosage	Onset	Duration	Indications	Cautions
Fentanyl	2–3 μg/kg slow IV push over 1–2 min	Almost immediate	0.5–1 h	Primary preinduction agent that provides sedation and analgesia in hemodynamically stable patients with the following: coronary artery disease; hypertensive emergencies; arterial aneurysms and dissections; cerebrovascular accidents; and intracranial/intraocular hypertension	Hypotension; masseter and chest wall rigidity if bolus injected; bradycardia with large bolus doses
Lidocaine	1.5 mg/kg IV 2–3 min before intubation	45–90 s	10–20 min	As with fentanyl; asthma; COPD; often used in conjunction with fentanyl	Hypotension
Esmolol	2 mg/kg IV	2–10 min	10–30 min	Synergistic with fentanyl; most commonly used for neurosurgical patients with raised intracranial pressures; limited but growing experience in isolated head trauma in the emergency department	Bradycardia; hypotension; increased airway reactivity
Rocuronium at a defasciculating dose	0.06 mg/kg	1–2 min	< 5–10 min	Elevated intracranial/intraocular pressure; prevention of succinylcholine-induced myalgia	Avoid doses > 0.06 mg/kg because a paralytic effect may occur.

sor response. The combined use of esmolol (2 mg/kg) and fentanyl (2 μg/kg) has a synergistic effect for reducing both the tachycardia and hypertension associated with tracheal intubation and laryngeal manipulation.[35,41] Caution is needed with the use of esmolol in trauma victims and other patients who are at risk for hypovolemia and may require a tachycardic response to maintain BP.

Some protocols for RSI recommend the use of a subparalytic preinduction dose of a non-depolarizing neuromuscular blocking drug for patients with suspected raised intracranial or intraocular pressure (*eg*, those with acute traumatic brain injury) who will receive succinylcholine during induction for intubation.[42,57] Succinylcholine can cause fasciculations that may promote transient intracranial hypertension, hyperkalemia, and postintubation myalgia. A low "defasciculating dose" dose (*ie*, one tenth of the intubation dose) of a non-depolarizing NMBA, such as rocuronium, has been recommended[58–60] to prevent fasciculations and a succinylcholine-induced rise in intracranial pressure. One systematic literature review,[57] however, found no evidence that pretreatment with a defasciculating dose of competitive neuromuscular blockers in patients with acute brain injury is beneficial. The available studies were limited by weak designs and small sample sizes, so a positive effect has not yet been excluded. Level II evidence exists that pretreatment before succinylcholine administration lowers intracranial pressure in patients undergoing neurosurgery for brain tumors.[57] It is not the practice of the authors, however, to use a subparalyzing dose of rocuronium or any other non-depolarizing muscle relaxant as an adjunctive premedication because of the limited evidence for efficacy.

Induction Agents

Induction agents are used to facilitate intubation by rapidly inducing unconsciousness. Familiarity with a range of induction drugs is important because the specific clinical circumstance dictates the appropriate induction method (Table 3). Agents that are indicated for patients with respiratory failure may be contraindicated in other clinical settings. Intensivists should, therefore, avoid using a single standardized induction approach.

Etomidate is a nonbarbiturate hypnotic agent that is used for the rapid induction of anesthesia. This imidazole derivative has a rapid onset of action and a short half-life. It predictably does not affect BP. Etomidate has cerebral-protective effects by reducing cerebral blood flow and cerebral oxygen uptake

($\dot{V}O_2$). It does not, however, attenuate the pressor response that is related to intubation or provide analgesia.

Adverse effects of etomidate include nausea, vomiting, myoclonic movements, lowering of the seizure threshold in patients with known seizure disorders, and adrenal suppression.[43,49,61–63] Etomidate, even after a single bolus dose, inhibits cortisol production in the adrenal gland at various enzymatic levels and reduces adrenal responsiveness to exogenous adrenal corticotrophin hormone for up to12 h.[49,64] Deleterious effects of etomidate-induced adrenal suppression have not been established after a single induction dose.

Because of its rapid onset, short half-life, and good risk-benefit profile, etomidate has become the primary induction agent for emergency airway management. It is especially useful for patients with hypotension and multiple trauma because it does not alter systemic BP.

Propofol is a rapid-acting, lipid-soluble induction drug that induces hypnosis in a single arm-brain circulation time. The characteristics of propofol include a short half-life and duration of activity, anticonvulsive properties, and antiemetic effects. Propofol reduces intracranial pressure by decreasing intracranial blood volume and decreasing cerebral metabolism.[65,66] These mechanisms may underlie the improved outcomes with the use of propofol that have been demonstrated in patients with traumatic brain injury who are at risk of raised intracranial pressure.[42,63,67]

At doses that induce deep sedation, propofol causes apnea and produces profound relaxation of laryngeal musculature. This profound muscular relaxation effect allows propofol, when used in combination with a non-depolarizing NMBA (rocuronium) or opioids (remifentanil or alfentanil) to produce intubation conditions that are similar to those obtained with succinylcholine.[68–71] However, we continue to favor its use with succinylcholine to ensure adequate intubating conditions. Propofol facilitates RSI, to a greater degree than etomidate, because it provides a deeper plane of anesthesia, thereby attenuating any effects of incomplete muscle paralysis.[38]

The most important adverse effect of propofol is drug-induced hypotension, which occurs by reducing systemic vascular resistance and, possibly, by depressing inotropy.[63] Hypotension usually responds to a rapid bolus of crystalloid fluids and can be prevented by expanding intravascular volume before giving propofol or by pretreating patients with ephedrine.[72] Some patients with allergies to soy or eggs may experience hypersensitivity reactions to propofol. Propofol has no analgesic properties.

For hemodynamically stable patients who have

Table 3—*Drugs Used for Induction**

Drug	Dosage	Onset	Duration	Indications	Cautions
Etomidate	Stable, 0.3 mg/kg IVP, unstable, 0.15 mg/kg IVP; onset, 30 s	30–60 s	3–5 min	Multitrauma; existing hypotension	Inhibits cortisol synthesis; decreases focal seizure threshold
Propofol	Stable, 2 mg/kg IVP; unstable, 0.5 mg/kg IVP; onset, 30 s	9–50 s	3–10 min	Isolated head injury; status epilepticus	Hypotension; lecithin allergy
Thiopental	Stable, 3 mg/kg IVP; unstable, 1.5 mg/kg IVP; onset, 30 s	30–60 s	5–30 min	Normotensive; normovolemic before barbiturate therapy for status epilepticus or control of intracranial hypertension	Bronchospasm; hypotension; poor availability because of controlled drug status
Ketamine	2 mg/kg IVP	1–2 min	5–15 min	Asthma/COPD	Head injury; ischemic heart disease; hypertensive emergencies
Scopolamine	0.2–0.4 mg IVP	10 min	2 h	Uncompensated shock	Tachycardia

*IVP = IV push.

either a contraindication to succinylcholine or receive non-depolarizing neuromuscular blockers for paralysis, propofol may be the induction agent of choice. Many clinicians use propofol as an induction drug for patients with isolated head injury or status epilepticus.

Ketamine, a phencyclidine derivative, is a rapidly acting dissociative anesthetic agent that has potent amnestic, analgesic, and sympathomimetic qualities. Ketamine acts by causing a functional disorganization of the neural pathways running between the cortex, thalamus, and limbic system.[49] It does so by selectively inhibiting the cortex and thalamus while stimulating the limbic system. Ketamine is also a unique induction agent because it does not abate airway-protective reflexes or spontaneous ventilation.[49]

The central sympathomimetic effects of ketamine can produce cardiac ischemia by increasing cardiac output and BP, thereby increasing myocardial $\dot{V}O_2$. Patients can experience "emergence phenomena" as they resurface from the dissociative state induced by ketamine. This frightening event, characterized by hallucinations and extreme emotional distress, can be attenuated or prevented with benzodiazepine drugs. Because ketamine is a potent cerebral vasodilator, intracranial hypertension is a contraindication for its use. Other side effects include salivation and bronchorrhea, both of which can be prevented with the administration of an anticholinergic agent such as glycopyrrolate or scopolamine.

The bronchodilator properties of ketamine make it suitable for patients with bronchospasm due to status asthmaticus or COPD. No outcome studies exist, however, to demonstrate improved outcomes in these clinical settings. The sympathomimetic effects of ketamine warrant avoiding its use in patients with acute coronary syndromes, intracranial hypertension, or raised intraocular pressure.

Sodium thiopental is a thiobarbiturate with a rapid 30-s onset of action and a short half-life. Its use for RSI is limited because it is a controlled substance and propofol has similar characteristics. Barbiturates in general decrease cerebral $\dot{V}O_2$, cerebral blood flow, and intracranial pressure. They are associated, however, with hypotension secondary to the inhibition of CNS sympathetic outflow, which results in decreased myocardial contractility, systemic vascular resistance, and central venous return.[63,73] Hypovolemia accentuates barbituate-induced hypotension. Sodium thiopental, therefore, should not be used as an induction agent in patients who have hypovolemic or distributive shock. The central sympatholytic effect induced by barbiturates has a positive effect in its blunting of the pressor response to intubation.[58,74,75]

Barbituates cause allergic reactions in 2% of patients, and also induce laryngospasm, hypersalivation, and bronchospasm.[63] Just as barbiturates are generally not used in the ICU for sedation purposes, they are not used to the same extent for emergency airway management. Sodium thiopental is rarely used in the ICU for emergency intubation, although it has applications for normotensive, normovolemic patients who have status epilepticus or require intubation prior to entering barbiturate coma for the control of intracranial hypertension.

Scopolamine is a muscarinic anticholinergic agent with a short half-life that has sedative and amnestic effects, but no analgesic properties. It can cause tachycardia but otherwise produces no hemodynamic consequences.[74] Scopolamine induces less tachycardia, however, compared with other available muscarinic agents (*eg*, atropine and glycopyrrolate).[49] This hemodynamic profile makes scopolamine a preferred induction agent for patients with uncompensated shock when RSI is used. Adverse effects include psychotic reactions in addition to tachycardia and occur related to the dose administered.[49] Scopolamine causes profound papillary dilation, complicating neurologic evaluations.

NMBAs

NMBAs are used to facilitate laryngoscopy and tracheal intubation by causing profound relaxation of skeletal muscle. There are two classes of NMBAs, depolarizing and non-depolarizing (Table 4). Both classes act at the motor end plate. These drug classes differ in that depolarizing agents activate the acetylcholine receptor, whereas non-depolarizing agents competitively inhibit the acetylcholine receptor. NMBAs have no direct effect on BP.

Depolarizing Agents: Succinylcholine

Succinylcholine, a depolarizing NMBA, is a dimer of acetylcholine molecules that causes muscular relaxation via activity at the motor end plate.[74] Succinylcholine acts at the acetylcholine receptor in a biphasic manner. It first opens sodium channels and causes a brief depolarization of the cellular membrane, noted clinically as muscular fasciculations.[49] It then prevents acetylcholine-medicated synaptic transmission by occupying the acetylcholine receptor. Succinylcholine is enzymatically degraded by plasma and hepatic pseudocholinesterases.[76]

Succinylcholine is the most commonly administered muscle relaxant for RSI, owing to its rapidity of onset (30 to 60 s) and short duration (5 to 15 min).[76] Effective ventilation may return after 9 to 10 min. The effects of succinylcholine on potassium balance

Table 4—*Neuromuscular Blocking Agents*

Drug	Dosage	Onset, s	Duration, min	Indications	Cautions
Succinylcholine	1.5 mg/kg IV push	30–60	5–15	Use as default paralytic agent unless there is contraindication	Contraindications: personal or family history of malignant hyperthermia; likely difficult intubation or mask ventilation; known uncontrollable hyperkalemia; myopathy; chronic neuropathy/stroke; denervation illness or injury after > 3 d; crush injury after > 3 d; sepsis after > 7 d; severe burns after > 24 h Caution: chronic renal insufficiency
Rocuronium	High dose: 1 mg/kg IV push	45–60	45–70	When succinylcholine is contraindicated	Predict difficult intubation and ventilation; allergy to aminosteroid neuromuscular blocking agents

and cardiac rhythm represent its major complications. It can also induce malignant hyperthermia.[77]

Most reports[76,78,79] of deaths, secondary to succinylcholine-induced hyperkalemia, involve children with previously undiagnosed myopathies who underwent surgery. Although deaths related to succinylcholine-induced hyperkalemia are rare, cardiac arrest has been reported.[80–83] Three studies[84–86] of adult patients have reported that the mean values of serum potassium levels for the study populations before and after an intubating dose of succinylcholine changed by as little as −0.04 mmol/L to as much as 0.6 mmol/L.

The hyperkalemic effect may be exaggerated in patients with subacute or chronic denervation conditions (*eg*, congenital or acquired myopathies, cerebrovascular accidents, prolonged pharmacologic neuromuscular blockade, wound botulism, critical illness polyneuropathy, corticosteroid myopathies, and muscle disuse atrophy), burns, intraabdominal infections, sepsis, and muscle crush injuries.[81,83,87–91] The exaggerated hyperkalemic response is mediated through the up-regulation of skeletal muscle nicotinic acetylcholine receptors.[88] Acute rhabdomyolysis can produce hyperkalemia, which is aggravated by the effects of succinylcholine, through mechanisms of drug-induced increases in muscle cell membrane permeability.[83,88,92]

A personal or family history of malignant hyperthermia represents an absolute contraindication to succinylcholine therapy, which may trigger a hyperthermic response. Patients who experience masseter spasm on induction with either thiopental or fentanyl are at an increased risk of developing malignant hyperthermia when treated with succinylcholine.[93,94] Other contraindications that require special precautions include denervation of muscles due to underlying neuromuscular diseases or injury to the CNS, myopathies with elevated serum creatine kinase values, sepsis after the seventh day, narrow-angle glaucoma, cutaneous burns, penetrating eye injuries, hyperkalemia, and disorders of plasma pseudocholinesterase. Succinylcholine may be used safely within 24 h of experiencing acute burns,[95–97] and within 3 days of experiencing acute denervation syndromes and crush injuries.[97–100] The drug should be used with caution in patients with preexisting chronic renal insufficiency, although a literature review[101] has indicated that succinylcholine may be used safely in this setting in the absence of other risk factors for drug-induced hyperkalemia. Such patients must be closely monitored for severe hyperkalemia.

Succinylcholine-associated dysrrhythmias are mediated by postganglionic muscarinic receptors and preganglionic sympathetic receptors. Bradydysrrhythmias are most commonly observed, with rare reports of asystole and ventricular tachyarrhythmias. Most instances occur in pediatric patients or in adults after the use of multiple doses of succinylcholine.[76,102,103] Dysrrhythmias may be prevented in adults by premedication with a vagolytic dose of atropine (0.4 mg IV) prior to repeating a dose of succinylcholine.[75,76]

Succinylcholine may cause an increase in intragastric pressure, presumably because of drug-induced muscular fasciculation. Aspiration usually does not occur by way of this effect because of a coincident increase in tone of the esophageal sphincter.[104,105] Succinylcholine increases both intraocular and intracranial pressure, but these effects are transient and clinically unimportant.[106,107] Patients should receive succinylcholine only if adequate face-mask ventilation can be achieved if intubation fails.

Because of the extensive risks associated with the use of succinylcholine in critically ill patients, some intensivists have argued that its role in the ICU is obsolete.[108] We believe that its superiority to other available neuromuscular blocking drugs (*infra vida*) warrant its use in patients without risk factors for adverse events. Its use requires extensive education of critical care physicians to ensure their understanding of the contraindications for use of the drug. One survey study[109] observed that there was a poor understanding among critical care physicians of the risks of succinylcholine for patients with critical illness polyneuropathy.

Succinylcholine is given in a dose of 1.5 mg/kg for intubation because a lower dose may induce relaxation of the central laryngeal muscles before peripheral musculature. This circumstance may promote aspiration and complicate intubation by relaxing laryngeal muscles and promoting glottic incompetence, while leaving masseter muscle function intact.[49] A recent study,[110] however, suggests that comparable intubation conditions for surgical patients undergoing elective intubation can be achieved after 0.3, 0.5, or 1.0 mg/kg succinylcholine when induced with propofol or fentanyl. These lower doses allow a more rapid return of spontaneous respiration and airway reflexes.[110] In the absence of such data for critically ill patients who require urgent intubation, we continue to recommend the use of succinylcholine, 1.5 mg/kg, for RSI.

Non-Depolarizing NMBAs

Non-depolarizing NMBAs provide an alternative to succinylcholine for RSI. Rocuronium, an aminosteroid drug, has a short onset of action (1 to 2 min) and an intermediate duration of action (45 to 70 min).

A systematic review[68] compared relative outcomes with the use of succinylcholine for intubation to those with the use of rocuronium. This study concluded that the use of succinylcholine produced superior intubation conditions compared to that of rocuronium (0.6 mg/kg) when rigorous standards were used to define the term *excellent conditions* (relative risk of poor conditions with rocuronium use, 0.87; 95% confidence interval, 0.81 to 0.94; n = 1,606). The two agents had similar efficacy when less rigorous definitions were used to define *adequate intubation conditions*. No differences were found, however, if propofol was used for induction, or if the dose of rocuronium was 1.0 mg/kg. The use of this higher dose of rocuronium prolongs the duration of paralysis. The success rate of intubation was similar for both rocuronium and succinylcholine under all of the study conditions.[68]

The effects of non-depolarizing blocking drugs can be reversed using acetylcholinesterase inhibitors, such as neostigmine or edrophonium, and vagolytic doses of glycopyrolate or atropine. The only absolute contraindication to the use of rocuronium is allergy to aminosteroid neuromuscular drugs. Extreme caution should be exercised in selecting appropriate patients for its use. Patients for whom intubation appears likely to be difficult may experience hypoxia if face mask ventilation is unsuccessful during the prolonged period of drug-induced paralysis (45 to 70 min) before intubation can be achieved.

Airway Management in the ICU

In 1993[16] and again in 2003,[111] the American Society of Anesthesiologists task force on difficult airways published guidelines for the management of difficult airways in the operating room. The application of these structured approaches to airway management appears to have decreased closed claims costs in anesthesia.[112] The guidelines are widely endorsed by anesthesiologists, with 86% stating that they use the algorithms in their clinical practice.[113] These particular algorithms, however, have limited applicability to the ICU because they rely on preoperative assessment and exercise the option of delaying surgery in the operating room if it appears that intubation will be overly difficult.

Although not validated, algorithms reported by Walls and coworkers[114] provide a standardized approach to emergency airway management. Such algorithmic approaches for emergent intubation that appropriately select patients for RSI have demonstrated improved outcomes in both emergency department and field intubation settings.[5–13,15] Emergency medicine practitioners who utilize airway management protocols that incorporate RSI experience airway failures with a need to progress to emergency cricothyrotomy in only 0.5% of intubations.[5,6] The National Emergency Airway Registry II,[6] a data bank of 7,712 intubations, has demonstrated that RSI is the most common technique of intubation with a success rate $> 98.5\%$. These results contrast with the 18% incidence of failed intubation in the absence of RSI reported by Li and coworkers.[7] This prospective study compared complications arising from intubation utilizing paralytic agents within an RSI protocol to intubations those arising from intubations without the use of NMBAs. Esophageal intubations and airway trauma occurred with greater frequency in the group that did not receive RSI (18% vs 3%, respectively, and 28% vs 0%, respectively).[7]

The intubation algorithms modified from Walls and coworkers[114] (Figs 2–5) classify intubation attempts into the following categories: (1) universal;

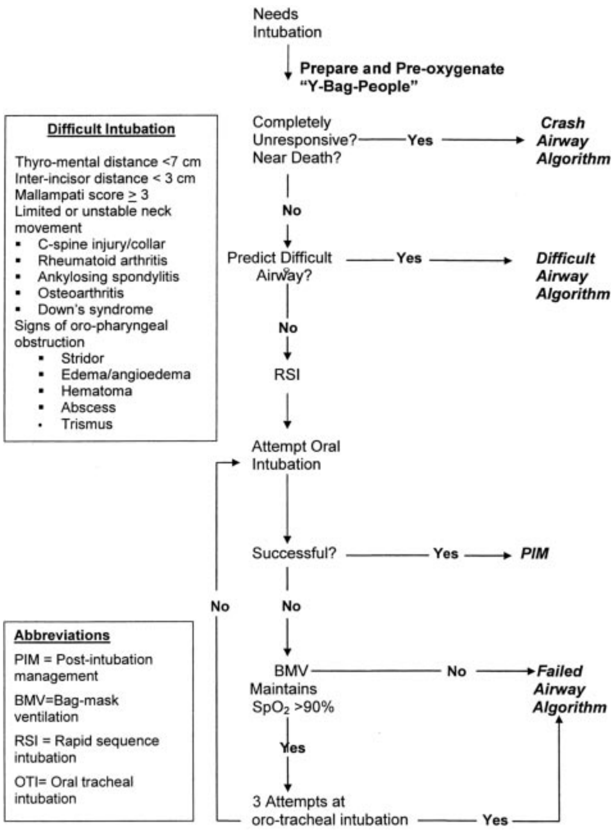

FIGURE 2. Universal airway algorithm. BNTI = blind nasotracheal intubation.

(2) crash; (3) difficult; and (4) failed. The universal algorithm (Fig 2) is the beginning point for intubation for all patients. The initial assessment requires the intensivist to determine whether the patient is unresponsive or near death, or whether a difficult airway appears likely. The former requires activation of the crash airway algorithm (Fig 3), and the latter activation of the difficult airway algorithm (Fig 4). The absence of any of these conditions allows the physician to initiate RSI.

Failure to intubate a patient with three or more attempts directs the intensivist to the failed airway algorithm (Fig 5). This algorithm calls for immediate assistance in preparation for emergency criciothyroidotomy if measures to oxygenate or intubate the patient have failed. Success with the use of these algorithms requires the presence of personnel who are skilled in the specialized techniques needed to manage a difficult airway and failed intubation. These algorithms can serve as a training curriculum for preparing critical care physicians to manage airways in the ICU.

RSI

As described above, RSI is a critical element in the establishment of a secure airway during emergency intubation. First developed to facilitate intubation in the operating room and to reduce the risks of aspiration for patients with full stomachs, RSI has been adopted by emergency physicians and is now being used for intubating patients in the field. Studies[4–15] have demonstrated increased intubation success rates and decreased complications with airway protocols that utilize RSI compared with those using traditional intubation techniques.

Several factors underlie the improved outcomes with RSI. Preoxygenation reduces the need for face-mask ventilation in preparation for intubation, and thereby decreases the risks for gastric insufflation and the aspiration of stomach contents. The use of a potent induction agent with a neuromuscular blocking drug allows the airway to be rapidly controlled, further reducing the risk of aspiration. The use of adjunctive medications in appropriate clinical settings can reduce the pressor response and other physiologic consequences of laryngoscopy and tracheal intubation. Table 5 presents an example of the authors' typical RSI protocol.

Not all critically ill patients are candidates for RSI, however. The presence of severe acidosis, intravas-

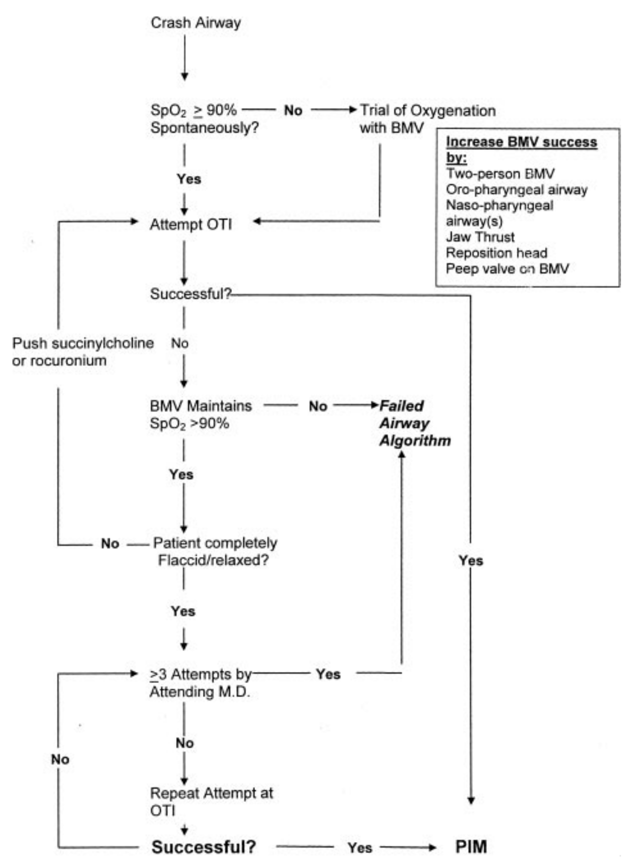

FIGURE 3. Crash airway algorithm. See Fig 2 for abbreviations not used in text.

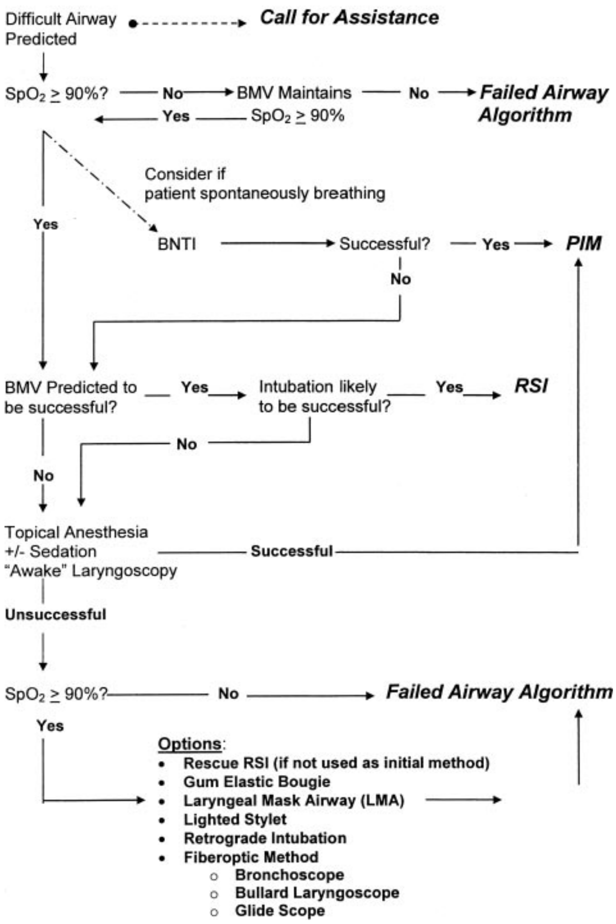

FIGURE 4. Difficult airway algorithm. BNTI = blind nasotracheal intubation.

cular volume depletion, cardiac decompensation, and severe lung injury may complicate the administration of preinduction and induction agents, which may result in vasodilation and hypotension. Acute lung injury may prevent an adequate response to preoxygenation efforts. Such patients require crash intubation and usually tolerate intubation attempts without extensive premedication because of the presence of depressed consciousness.

The general sequence of RSI consists of the "six P's," as follows: preparation, preoxygenation, premedication, paralysis, passage of the endotracheal tube, and postintubation care. Preparation begins when the clinician identifies the need for intubation. A period of 5 to 10 min before intubation allows for the evaluation of the patient for signs of a difficult airway, as described above, and for the preparation of the equipment. Among the various mnemonics that are used to assist preparation, the phrase "Y BAG PEOPLE?" (Table 6) allows physicians to recall the essential elements of the preparatory phase and emphasizes the need to avoid positive-pressure face mask ventilation whenever possible.

Preoxygenation, also termed *alveolar denitrogenation*, is performed with the patient breathing 100% oxygen through a nonrebreather mask for 5 min. Mentally alert patients are asked to perform eight deep breaths to total lung capacity. Alveolar denitrogenation creates a reservoir of oxygen in the lung that limits arterial desaturation during subsequent intubation attempts. The use of positive-pressure ventilation administered by face mask is reserved for patients who cannot achieve adequate oxygenation while breathing 100% oxygen by nonrebreather mask.

Premedication entails the use of drugs to provide sedation and analgesia, and to attenuate the physiologic response to laryngoscopy and intubation. Two to three minutes before the patients undergoes

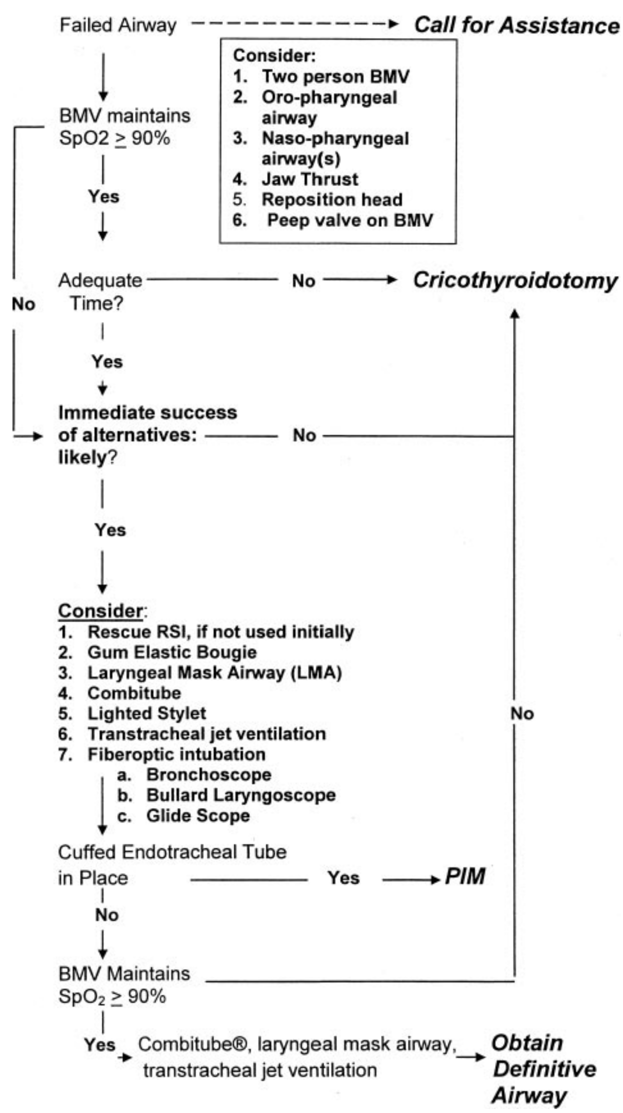

FIGURE 5. Failed airway algorithm. See Fig 2 for abbreviations not used in text.

Table 5—*Schematized Example of an RSI*

Time − 10 min (Prepare)	Time − 5 min (Preoxygenate)	Time − 2 min (Pretreat)	Time 0 (Paralysis)	Time + 30–45 s (Pass the Tube)	Time + 45 s (Postintubation Management)
Predict difficult intubation: stop if not RSI candidate Hypotensive patient: 1. Good vascular access 2. Vasopressors readily available We use as needed Phenylephrine 10 mg in 100 mL NS (100 μg/mL)—and give 1 mL aliquots prn Or Ephedrine, 5–10 mg boluses as needed	Provide 100% with nonrebreather mask or BVM	Suspected intracranial hypertension, myocardial ischemia, or hypertensive emergency. Fentanyl with or without lidocaine (more commonly we use fentanyl alone)	Induction: 1. Etomidate (default induction agent) or 2. Propofol or 3. Ketamine or 4. Scopalamine	Intubate Observe ETT pass between vocal cords If problems with visualization remember to "BURP" 1. Backwards 2. Upward, and 3. Rightward 4. Pressure on the thyroid cartilage	Confirm placement after inflation of cuff: 1. Auscultate abdomen, then hemithoraces for air entry 2. Detect $ETco_2$ color change or waveform 3. Reassess oxygenation status 4. Once ETT placement confirmed, cease Sellick maneuver 5. Secure tube
Mnemonic "Y BAG PEOPLE"	No PPV unless patient's Spo_2 < 90% If PPV required, then provide cricoid pressure (Sellick maneuver)	Asthma lidocaine	Sellick maneuver with administration of induction agent		Consider placement of OGt or NG Post ETI, ABG analysis and CXR
If patient is hypotensive, ensure good vascular access, and have available drugs		It is not our practice to use defasciculating doses of rocuronium or other nondepolarizing NMBAs	Neuromuscular blockade: 1. Succinylcholine or 2. Rocuronium	If patient $Spo_2 < 90\%$ during attempt, stop and provide PPV and oxygenation until $Spo_2 > 90\%$	As many of the drugs used in RSI have short half-life consider continued sedation with or without paralysis

*ABG = arterial blood gas; SCI = spinal cord injury; BVM = bag-valve-mask ventilation; CXR = chest radiograph; $ETco_2$ = end-tidal CO_2; ETI = endotracheal intubation; NG = nasogastric tube; OG = orogastric tube; PPV = positive-pressure ventilation; SPo_2 = pulse oximetry oxygen saturation; ETT = endotracheal tube.

Table 6—*Preparation for Intubation Mnemonic*

Mnemonic	Description
Y	Yankauer suction
B	Bag-valve-mask
A	Access vein
G	Get your team, get help if predict a difficult airway
P	Position patient (sniffing position if no contraindications) and place on monitor
E	Endotracheal tubes and check cuff with syringe
O	Oxygen, oropharyngeal airway available
P	Pharmacy: draw up adjunctive medications, induction agent, and neuromuscular blocker
L	Laryngoscope and blades: ensure a variety and that they are working
E	Evaluate for difficult airway: look for obstruction, assess thyromental distance < 3 finger breadths, interincisor distance < 2 finger breadths, neck immobilization

laryngoscopy, a combination of drugs individualized to a patient's needs and clinical circumstances is administered (Table 2).

The induction and neuromuscular blocking drugs are administered immediately after the patient achieves adequate preoxygenation and receives the preinduction medication. An assistant performs the Sellick maneuver (*ie*, cricoid pressure) to prevent passive aspiration and reduce gastric insufflation if the patient is receiving positive-pressure ventilation by face mask. If the patient vomits, cricoid pressure should be released and the patient should be log-rolled to allow dependent suctioning of the pharynx.

Although many emergency physicians use etomidate as their primary induction drug, other drugs have specific advantages in certain clinical settings (Table 3). The selection of a neuromuscular blocking drug also depends on clinical circumstances, as previously described. Succinylcholine provides safe and effective neuromuscular blockade for most patients. Rocuronium may be a more appropriate choice for patients if there are contraindications or concerns about the use of succinylcholine.

Forty-five seconds to 1 min after induction and paralysis, the adequacy of paralysis is assessed by checking mandibular mobility. Resistance to motion indicates incomplete paralysis, which requires that the patient start to receive oxygen again, with reassessment of relaxation taking place in 15 to 30 s.

Once the patient is relaxed, laryngoscopy is performed and the vocal cords visualized. Visualization of the vocal cords and the glottic opening may be improved by placing pressure on the thyroid cartilage in a backward, upward, and rightward direction (the mnemonic "BURP" or backwards, upwards, right, and pressure).[8] If laryngoscopy is not immediately successful and the patient's oxygen saturation level falls to < 90%, assisted ventilation is initiated with a bag-valve-mask device and cricoid pressure to oxygenate and ventilate the patient before attempting laryngoscopy again. After successful tracheal intubation and cuff inflation, the confirmation of intubation is required.

The goal in the immediate postintubation period is to confirm correct tracheal intubation, and the adequacy of oxygenation and ventilation. Epigastric auscultation followed by auscultation of both hemithoraces in the axillas assists in assessing for an esophageal or mainstem intubation. The rise and fall of the chest and the maintenance or improvement of oxygenation should be noted. The measurement of end-tidal CO_2 by either a colorimetric or waveform device has become a necessary step in confirming tracheal intubation. Once satisfied that the endotracheal tube is in the trachea, cricoid pressure may be released. The cuff is then rechecked, and the endotracheal tube is secured to the patient. A postintubation chest radiograph and arterial blood gas assessment should be obtained. Many of the induction agents and succinylcholine have a short duration of action. Thus, sedation should be considered at this point.

Conclusion

Advanced airway management is an obligatory skill for critical care physicians to acquire. The adoption of algorithmic approaches and RSI by anesthesiologists and emergency medicine physicians has improved the success rates for the emergency intubation of unstable patients and has decreased the number of complications related to airway control.[3,4] Although limited outcomes data exist for the use of these techniques in the ICU, similarities of patients and conditions with the emergency setting warrant the adoption of algorithmic approaches and RSI as the standard mode of intubation for critically ill patients. RSI requires a thorough understanding of the physiology of intubation, and of the various drugs used for induction and paralysis in addition to careful patient selection. The standardization of intubation efforts with well-conceived algorithms requires a regimented approach that is similar to that employed for cardiopulmonary resuscitation. The training of critical care physicians requires greater attention to teaching these advanced airway management skills, more collaboration between anesthesiologists and critical care physicians to promote these skills,[4] and careful monitoring for adverse events and outcomes to improve patient selection for the various intubation approaches that are available.[115]

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