Airway management and mechanical ventilation represent the cornerstones of ICU care for critically ill patients. In this chapter we deal with basic concepts and focus on the practical considerations that confront critical care practitioners on a daily basis.

AIRWAY MANAGEMENT

It is essential for critical care specialists to be proficient in securing an airway in a variety of patients and clinical scenarios. Critically ill patients often have hypoxia, acidosis, or hemodynamic instability and poorly tolerate delays in placing an airway. Further, underlying conditions such as intracranial hypertension and myocardial ischemia may be exacerbated by the attempt to secure an airway itself. Compounding the problem are the myriad of comorbid and associated conditions such as vascular disease, cervical fractures, facial trauma, laryngeal edema, and patient combative nature that complicates the situation.

Criteria for Intubation

Although never validated, the decision to establish a definitive airway is based on three general criteria:

1. Failure to protect or maintain airway, e.g., loss of protective airway reflexes in brain injured patients
2. Failure to oxygenate or ventilate, e.g., during cardiopulmonary arrest, acute respiratory distress syndrome (ARDS), septic shock, neuromuscular disease
3. Anticipation of a deteriorating clinical course, e.g., anatomical airway distortion. Serial clinical assessment is requisite to determine the ability of patients to protect their airway.

- The gag reflex does not correlate well with airway protection and is of no clinical value when assessing the need for intubation.
- Arterial blood gases are rarely helpful in the decision to intubate and may lead to faulty decision making.
- The Glasgow Coma Scale (GCS) has been traditionally used in a variety of traumatic and non-traumatic neurologic conditions as a simple tool to gauge airway compromise on serial examinations.
  - A GCS of <8 is associated with severe brain injury and these patients typically require intubation due to loss of protective reflexes.
  - However, the GCS has several limitations and was recently reported to have only moderate degree of interrater reliability in the emergency department.
- Standard pulmonary function testing parameters such as NIF and vital capacity are frequently used to follow the clinical course in patients with neuromuscular disease such as myasthenia gravis and Guillain-Barré syndrome to discern respiratory muscle weakness and the need for intubation.
  - However, abnormalities are frequently subtle and patients may not manifest the usual signs and symptoms of respiratory failure.
  - One retrospective study found that vital capacity is a poor predictor of the need for mechanical ventilation in myasthenia gravis secondary to the erratic nature of the disease.
Sound judgment and clinical decision making are imperative as failure to recognize impending respiratory failure may have life-threatening consequences. If the anticipated clinical course if one of deterioration, it is prudent to err on the side of intubation rather than confronting a disastrous situation of not being able to intubate, oxygenate, or ventilate.

**Rapid Sequence Intubation**

Rapid sequence intubation (RSI) is the cornerstone of emergency airway management. It entails using a specific sequence of drug therapy for rapid induction and paralysis to facilitate placement of an endotracheal tube. The administration of drugs is preceded by preoxygenation. Intubation is ideally performed without bag mask ventilation to limit gastric distension and aspiration. Cricoid pressure (Sellick’s maneuver) is applied to occlude the esophagus. The National Emergency Airway Registry demonstrated that RSI is the most commonly performed intubation technique, with a success rate of greater than 98.5%. Several studies have now demonstrated increased success rates and fewer complications with protocols utilizing RSI compared to traditional intubating techniques. However, one should be aware that not all critically ill patients are candidates for RSI. The most common contraindication to RSI is the predicted difficult airway.

**RSI SEQUENCE**

- **Preparation:** Suction, Tubes, Oxygen, pharmacology, IV access, Connections, Blades, Alternatives, Rescue, Surgery (STOPIC BARS)
- **Preoxygenation:** Administration of 100% oxygen prior to paralysis to replace FRC with oxygen to allow for prolonged apnea without desaturation. It is important to remember that the time to desaturation from 90% to 0% is dramatically less than that from 100% to 90% (Fig. 6.1).
- **Pretreatment:** Agents given to reduce the adverse physiologic effects of laryngoscopy
  - Lidocaine: Suppresses cough reflex and mitigates increase in intracranial pressure (ICP) in response to intubation
  - Opioids: Fentanyl is generally used to attenuate the sympathetic response and prevent blood pressure increases associated with intubation. Also provides analgesia and sedation.
  - Atropine: Used to prevent vagal response in children
  - Defasciculating dose of neuromuscular blockers: Used to prevent fasciculations associated with succinylcholine and prevent associated rises in ICP but the use of this is controversial.
- **Paralysis with induction:** Induction is immediately followed by paralysis. Knowledge of airway pharmacology is paramount (see later).

![Figure 6.1. Time to desaturation in different patient scenarios.](image)
Protection and positioning: Sellick’s maneuver (cricoid pressure to occlude esophagus) to prevent passive aspiration and optimal positioning

Placement with proof: Confirmation of placement with end-tidal CO₂

Postintubation management: Securing the tube, sedation, and mechanical ventilation

RSI is the method of choice to intubate patients with brain injury and raised intracranial pressure as it minimizes the adverse effects associated with intubation.

Airway Pharmacology

Familiarity with the various preinduction, induction, and neuromuscular blocking agents facilitates proper drug selection for the particular clinical situation. Appropriate selection not only increases the likelihood of successful intubation but also decreases the complication rate.

Induction agents (Table 6.1)

Neuromuscular blocking agents (Table 6.2)

- Depolarizing, e.g., succinylcholine
- Nondepolarizing, e.g., vecuronium, rocuronium

Assessment of the Difficult Airway

The American Society of Anesthesiology defines a difficult airway as either difficult to intubate or difficult to ventilate.

Difficult intubation: More than three attempts by an experienced operator or attempts that last more than 10 minutes. The mnemonic LEMON is a useful guide to quickly assess the patients in whom a difficulty airway would be predicted. The elements of this mnemonic are currently being validated by the investigators of the National Emergency Airway Registry project.

- Look externally: External evidence that bag mask ventilation or laryngoscopy would be difficult
- Evaluate the 3-3-2 rule: 3 fingers in the patient’s mouth, 3 fingers from the mentum to hyoid, and 2 fingers from the floor of the mouth to the thyroid notch. These evaluations relate to geometric considerations that predict likelihood of successful laryngoscopy and intubation

Mallampati score: Although not validated for the ICU population, this scoring system predicts difficulty with laryngoscopy on the basis of visualization of posterior pharyngeal elements

Obstruction: Signs and symptoms of upper airway obstruction are a hallmark for difficulty with laryngoscopy

Neck mobility: Limited neck mobility, e.g., with cervical spine trauma will limit an optimum view of the larynx on attempted intubation.

Difficult ventilation: Inability to maintain oxygen saturation above 90% using a face mask for ventilation and 100% inspired oxygen by a trained operator. The various indicators that predict difficult ventilation can be recalled by the mnemonic MOANS:

- Mask seal: Beards and facial trauma are some examples of situations where it is difficult to obtain a good mask seal.
- Obesity/obstruction: For example, pregnant women and patients who have a BMI >26
- Age: Age >55 is associated with a higher risk of difficult ventilation due to loss of upper airway muscle tone.
- No teeth
- Stiffness: Patients who require high ventilation pressure, e.g., ARDS are often difficult to bag mask ventilate.

There is a paucity of studies validating these airway assessment techniques in the ICU population; nevertheless a quick examination of these elements frequently assists in preintubation planning. However, a recent retrospective study indicated that performing an airway assessment in critically ill patients was not possible in approximately 70% of patients presenting to the emergency department. In addition, absence of these features does not guarantee that one will not encounter a difficult airway. So, it is imperative to be prepared for a difficult airway.

Failed Airway

A failed airway is defined as either failure to intubate despite three attempts by an experienced operator or failure to maintain acceptable oxygen saturation during one or more failed attempts at laryngoscopy. If one is unable to intubate and oxygenate, cricothyrotomy should be performed in the vast majority of circumstances.
<table>
<thead>
<tr>
<th>Agent and dosage</th>
<th>Pros</th>
<th>Cons</th>
<th>Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiopental 1.5–5 mg/kg IV push</td>
<td>Rapid onset, Brief duration, Decreases ICP, Anticonvulsant</td>
<td>Decreases blood pressure, Myocardial depression, Respiratory depression, Histamine release, No analgesic effect</td>
<td>Hypotensive patient, Asthmatic patient, Porphyria</td>
</tr>
<tr>
<td>Methohexital 1.5 mg/kg IV</td>
<td>Very rapid onset, Very short duration, Decreases ICP</td>
<td>Decreases blood pressure, Respiratory depression, Seizures (rare), Hypertonus/hiccuping, Laryngospasm, No analgesic effect</td>
<td>Hypotensive patient, Seizure disorder, Porphyria</td>
</tr>
<tr>
<td>Etomidate 0.3 mg/kg IV</td>
<td>No deleterious effect on blood pressure, Minimal depression of respiration, Decreases ICP and IOP</td>
<td>Myoclonic movements, Seizures, Hiccups, Nausea/vomiting, Decreases steroid synthesis, Minor pain on injection, No analgesic effect</td>
<td>Focal seizure disorder (use with caution), Adrenal insufficiency, Should not be used as a continuous IV sedating agent because it depresses steroid synthesis</td>
</tr>
<tr>
<td>Propofol 0.5–2 mg/kg IV</td>
<td>Decreases ICP, Titratable – useful for maintenance sedation, Antiemetic, Anticonvulsant</td>
<td>Decreases blood pressure, Myocardial depression, Respiratory depression, Myoclonic movements, Minor pain on injection, Rare bronchospasm, No analgesic effect</td>
<td>Hypotensive patient, Asthmatic patient (use with caution)</td>
</tr>
<tr>
<td>Ketamine 2 mg/kg IV</td>
<td>“Dissociative” anesthesia without impairing airway reflexes, Analgesia, Amnesia, Bronchodilator, No decrease in blood pressure – useful in hypotensive patients, No significant respiratory depression</td>
<td>Increases ICP, Minimally increases IOP, Increases airway secretions, Laryngospasm, Increases blood pressure, Increases heart rate, Increases muscle tone, Nausea/vomiting, Emergence reactions</td>
<td>Uncontrolled hypertension, Increased ICP, Penetrating eye injury, Glaucoma, Acute URI, CAD/CHF, History of psychosis, Thyroid storm</td>
</tr>
<tr>
<td>Midazolam 0.1–0.3 mg/kg IV</td>
<td>Amnesia anticonvulsant</td>
<td>Delayed onset, Inconsistent effect, Respiratory depression, Hypotension – variable and dose-dependent</td>
<td>Hypotensive patient</td>
</tr>
</tbody>
</table>
Table 6.2. Neuromuscular blocking agents

<table>
<thead>
<tr>
<th>Agent</th>
<th>Dosage</th>
<th>Indications</th>
<th>Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Succinylcholine</td>
<td>1.5 mg/kg IV push</td>
<td>Default paralytic unless contraindications exist</td>
<td>Difficult airway and insecurity about the ability to successfully bag mask ventilate. Family or personal history of malignant hyperthermia. Known hyperkalemia. Certain chronic muscle dystrophies, prior spinal cord injury, prior strokes, any demyelinating diseases. Preexisting tissue injury &gt;3 days prior to RSI. Burns &gt;24 hours prior to RSI. Renal failure with hyperkalemia. Renal failure without hyperkalemia (relative).</td>
</tr>
<tr>
<td>Rocuronium</td>
<td>1 mg/kg IV push</td>
<td>If succinylcholine is contraindicated</td>
<td>Difficult airway and insecurity about the ability to successfully bag mask ventilate. Allergy to neuromuscular blocking drugs.</td>
</tr>
</tbody>
</table>

Airway Management with Increased Intracranial Pressure

Patients with known or suspected increased ICP represent a special population and prevention of secondary brain injury is paramount.

- The process of laryngoscopy and intubation can increase ICP.
- Hypotension from sedative administration or hypovolemia is common.
- Hypoxia can occur during attempts to intubate.
- Cervical spine injuries are found concomitantly with TBI and manipulation of the spine should be avoided.

Careful consideration has to be given to drug selection and technique. RSI is the technique of choice so that the patient is sedated, paralyzed, and the total time taken to intubate is as short as possible. Preinduction medication as described in the preceding text can be given. Induction and paralysis are generally performed with etomidate and succinylcholine, respectively. Difficult airway equipment should always be at hand.

Approach to the ICU Patient

An algorithmic protocol approach to airway management, though never validated in the ICU, has been associated with improved outcomes in the emergency departments as well as field intubations. These algorithms, developed by Wall et al., classify intubation attempts as (1) universal (Fig. 6.2), (2) crash (Fig. 6.3), (3) difficult (Fig. 6.4), and (4) failed (Fig. 6.5). The starting point for every intubation is the universal airway algorithm. The intensivist first determines if the patient is near death or a difficult airway is anticipated. The crash airway or difficult airway algorithms are respectively initiated depending on the circumstance. Failure to oxygenate and intubate leads to the activation of the failed airway algorithm.

Proficiency with handling an airway is an obligatory skill for all intensivists. Extrapolation of the emergency room data supports the practice of adopting an algorithmic approach to airway management and RSI should be the technique of choice for intubation in a vast majority of cases.

MECHANICAL VENTILATION

Mechanical ventilation has been revolutionized by the arrival of sophisticated new technology that now offer a plethora of modes, alarms and monitoring capabilities that facilitate patient safety and patient ventilator synchrony. One should, however, keep in mind that no mode of mechanical ventilation has ever
been shown to be superior to the other in terms of patient outcomes. Most of these studies have looked at oxygenation as an endpoint. In fact, the largest trial to date comparing low versus high tidal volume for ARDS, showed a mortality benefit for patients that were ventilated with low tidal volumes (6 mL/kg). This group of patients had worse oxygenation parameters compared to the group with high tidal volumes.

It is not as important to remember all the modes and variables available on modern ventilators as it is essential to grasp the basic physiologic concepts. There are however nuances, especially when dealing with brain-injured patients and hyperventilation that the intensivist should be familiar with.

- Mechanical ventilation can be delivered invasively or noninvasively.
- There are two basic formats of mechanical ventilation: pressure driven and volume driven. The various modes available generally utilize either of these two formats for breath delivery.
- Each breath in a particular mode then has three phase variables of inspiration: trigger, target, and cycling off criteria.
Breaths can either be mandatory or spontaneous.
Expiration is almost always passive except with specialized modes like high frequency oscillatory ventilation.

Modes of Mechanical Ventilation

**CONTROLLED MECHANICAL VENTILATION**
- All delivered breaths totally controlled by the machine and patient triggering is not possible.
- Breath delivery is in the volume or pressure format.

**ASSIST CONTROL VENTILATION**
- Breath delivery in either the volume or pressure format
- Patient can trigger the ventilator but each breath delivers the set tidal volume or pressure.
- Ventilator senses patient effort by either pressure or flow triggering mechanisms.
  - Volume assist control: Breaths are time or patient triggered, flow targeted, and volume cycled (see Fig. 6.6).
  - The physician sets respiratory rate, flow rate and tidal volume.
Pressures in the system are variable depending on the resistance and compliance of the lungs as well as patient effort. Due to this variability of flow, tidal volumes are variable.

SYNCHRONIZED INTERMITTENT MANDATORY VENTILATION

- CMV breaths are delivered in either the pressure or volume format.
- In between breaths the patient can breathe spontaneously from either a demand valve or continuous flow of gas.
- Mandatory breaths delivered in synchrony with the patient’s efforts, i.e., the unit functions in the assist control mode only during a window of time established by the manufacturer.

- Synchronized intermittent mandatory ventilation (SIMV) may be combined with pressure support, so each spontaneous effort not falling within the specified window is assisted with a
set pressure applied at the airway opening (see Fig. 6.8).

PRESSURE SUPPORT
- Breaths are triggered by patient effort only; there are no mandatory breaths.
- Each breath is patient triggered, pressure targeted, and flow cycled.
- Inspiration is terminated when flow falls to a preset level (usually 25% of peak flow; see Fig. 6.9).
- The physician sets the inspiratory pressure and on the newer generation of ventilators the rise time and termination criteria can be adjusted.
  - Rise time refers to the rate of initial pressurization of the airway.
  - Termination criteria can be manipulated by changing the flow at which the breath terminates.

DUAL-BREATH MECHANICAL VENTILATION
- Closed loop mechanical ventilation that combines both formats to usually guarantee a tidal volume
- Most commonly the physician sets a tidal volume, the inspiratory time, and a maximum pressure.
- Gas delivery for these breaths is in the pressure format.
- The ventilator then by feedback enhancement of breaths tries to deliver the set tidal volume in the specified time at the lowest possible pressure.
For example, VC+ on the Puritan Bennett 840 ventilator or PRVC on the Servo series of ventilators by Siemens.

**Positive End-Expiratory Pressure**

High levels of positive end-expiratory pressure (PEEP) are routinely used to treat ARDS/ALI. However, its effect on brain injured patients remains controversial for the following reasons:

- By increasing mean airway pressure, PEEP may decrease cerebral venous outflow and raise ICP.
- By reducing venous return, PEEP leads to a drop in mean arterial pressure and thereby cerebral perfusion pressure.
- By causing alveolar recruitment, PEEP improves lung compliance and oxygenation leading to beneficial effects.

However, a recent study explored cerebropulmonary interactions and concluded that PEEP leading to alveolar recruitment did not increase ICP but patients with normal respiratory system compliance had an increase in PaCO$_2$, cerebral blood flow, and ICP. A thought provoking editorial accompanied this study and explored the beneficial effect of PEEP in traumatic brain injury. Overall it seems that as long as euolemia is maintained, moderate levels of PEEP are safe in brain-injured patients. Therapy should be tailored to each individual patient with a careful vigil over the ICP, PaCO$_2$, and neurologic status.

**Hyperventilation**

From the standpoint of mechanical ventilation the intensivist should keep the following few things in mind:
If hyperventilation leads to dynamic hyperinflation secondary to insufficient expiratory time, mean airway pressure will increase which may lead to adverse effects on the ICP secondary to impaired venous sinus drainage. PaCO₂ may actually rise secondary to the hyperinflation (see Fig. 6.10).

Using faster flow rates will permit more time for exhalation and will lower the mean airway pressure.

Before beginning hyperventilation careful consideration should be given to factors that can improve CO₂ clearance, such as removing unnecessary excessive dead space in the form of ventilator circuitry, improving respiratory system compliance by draining pleural effusions and ascites, achieving optimum patient ventilator synchrony, and ensuring an unobstructed endotracheal tube.

Noninvasive Ventilation

With dramatic improvements in the patient ventilator interface, noninvasive ventilation (NIV) has become very sophisticated with a variety of modes at the intensivist’s disposal. Bilevel positive airway pressure ventilation (BIPAP) is the most commonly used.

- The ventilator cycles between two different set levels of pressure and the breaths are patient initiated.

- The unique advantage of NIV is the avoidance of complications associated with invasive ventilation.

When used properly in the right patient population, NIV lowers the risk of infection including nosocomial pneumonia and sinusitis, preserves upper airway defenses, and allows patients to vocalize and eat normally.

However, patient selection is the key. NIV should be used as a bridge in patients where the primary process is expected to improve relatively quickly.

- Patients with an inability to handle secretion, loss of upper airway function, hemodynamic instability, and upper gastrointestinal bleeding are better managed with invasive mechanical ventilation.

- The data is most extensive in chronic obstructive pulmonary disease (COPD) exacerbations where the use of NIV has been shown to benefit morbidity and mortality and shorten hospital length of stay, thereby leading to a reduction in associated cost.

- NIV theoretically should benefit patients with neuromuscular disease. However, there is a paucity of data and there have been only two small published trials. The most recent retrospective study examined 9 patients with 11 episodes of acute respiratory failure due to myasthenic crisis. The use of NIV prevented intubation in 7 out of the 11 episodes.

Respiratory failure in the ICU is an exceedingly common entity and patients often require ventilatory support in one form or the other. Familiarity with the physiologic principles underpinning mechanical ventilation will allow the intensivist better manage the patients on mechanical ventilation.
and troubleshoot the common bedside problems that arise.

REFERENCES


