Flexible Bronchoscopy

YATIN B. MEHTA and MICHAEL A. Jantz

INTRODUCTION

Flexible bronchoscopy is an essential diagnostic and therapeutic tool in the intensive care unit (ICU). Potential indications for flexible bronchoscopy in the ICU include airway management (intubation, changing of endotracheal tubes (ETTs), and extubation); diagnosis of respiratory infections, parenchymal lung disease, acute inhalational injury, or airway injury from intubation or chest trauma; and treatment of hemoptysis, atelectasis, foreign bodies, obstructing airway lesions, and bronchopleural fistulae (BPFs). From a diagnostic standpoint, flexible bronchoscopy can identify the etiology of hemoptysis and the cause of pulmonary infection.

Compared with rigid bronchoscopy, flexible bronchoscopy offers enhanced visualization of the proximal and distal airways, is associated with fewer complications, and can be performed at the bedside, averting the need for general anesthesia and operating room resources. However, for management of massive hemoptysis, difficult-to-extract foreign bodies, bronchoscopic laser resection, and benign or malignant obstruction of the trachea or bilateral mainstem bronchi, rigid bronchoscopy may be the procedure of choice.

Both fiberoptic and video bronchoscopes are utilized for flexible bronchoscopy in the ICU. Video bronchoscopy allows for better resolution of the image because of the greater number of pixels on the charge-coupled device for image acquisition. In contrast, the resolution of the traditional fiberoptic bronchoscope is determined by the diameter of the optical fibers and seems to have reached its technologic limit. With the video bronchoscope, as well as with attachment of a camera head to the fiberoptic bronchoscope, observation by multiple parties is possible, which decreases the possibility of missed findings and facilitates teaching and education. Compared with video bronchoscopes, the fiberoptic bronchoscope is less expensive, although improper use and care can result in broken optical fibers and thus higher repair costs over time.

PROCEDURE

General Considerations

In nonintubated patients, flexible bronchoscopy can be performed by the transnasal or transoral route with a bite block. In the mechanically ventilated patient, gas exchange abnormalities may occur due to the bronchoscope occupying a significant portion of the internal diameter of the ETT (1). This reduction in the cross-sectional area of the ETT may lead to hypoventilation, hypoxemia, and air trapping with intrinsic positive end-expiratory pressure (auto-PEEP). The outer diameter of the bronchoscope should be at least 2 mm smaller than the lumen of the ETT to minimize these effects. As most adult bronchoscopes have an outer diameter of 5 to 6 mm, an 8-mm ETT is generally recommended for performing bronchoscopy safely in the intubated patient. A pediatric bronoscope with an outer diameter of 3 to 4 mm should be used if the ETT is smaller.

Informed consent for the procedure should be obtained prior to starting bronchoscopy. Enteral feeding or oral intake should be discontinued for 4 hours before and 2 hours after the procedure. Patients with asthma should receive bronchodilators prior to bronchoscopy. Platelet counts and coagulation studies should be obtained in those patients with risk factors for bleeding if the bronchoscopic procedure will include biopsies. In the ICU setting, most patients will be monitored with a continuous electrocardiogram, pulse oximetry, and intra-arterial blood pressure or intermittent cuff blood pressure every 3 to 5 minutes. End-tidal CO₂ monitoring use is recommended if deep sedation or general anesthesia is used to facilitate the procedure and in patients where intracranial pressure is being tightly regulated (2).

Equipment for reintubation and bag–valve–mask ventilation should be readily available, and suctioning equipment, including Yankauer and endotracheal catheters, should be accessible at the bedside. In addition to sedatives and analgesics, resuscitation medications should also be on hand. It is prudent to have materials for chest tube thoracostomy located in the ICU.

Topical Anesthesia

Topical anesthesia is typically used to suppress the gag reflex and coughing, thereby reducing the dose of sedation needed during the procedure. Commonly used topical anesthetic agents before and during bronchoscopy include lidocaine (1%–10%), benzocaine (20%), and tetracaine (1%). In general, use of benzocaine and tetracaine is discouraged due to higher risk of drug-induced methemoglobinemia (3). Lidocaine is the most commonly used topical anesthetic due to its efficacy in suppressing cough, short half-life, wide safety margin, and minimal tissue toxicity (4). It is available in different preparations, including gel, solution, and spray, and at concentrations ranging from 1% to 10%. For nonintubated patients, topical anesthesia of the nares and oropharynx can be achieved with lidocaine jelly and nebulized or sprayed lidocaine. The tracheal and bronchial mucosa is anesthetized with 1% lidocaine solution. In intubated patients, the 1% lidocaine can be administered through the ETT or through the working channel of the bronchoscope after insertion into the ETT. Lidocaine is absorbed through the mucous membranes and achieves peak serum concentrations in 20 to 30 minutes that are similar to that of intravenous administration. The total dose of lidocaine should not exceed 3 to 4 mg/kg. Patients with advanced age or cardiac or hepatic insufficiency have reduced clearance of lidocaine, and thus the dose should not exceed 2 to 3 mg/kg. The use of lidocaine should be kept to a minimum if samples for culture are to be obtained, as bacteriostatic lidocaine...
preparations may decrease culture yields. Although transcriocid or transtracheal injection of topical anesthetic and local nerve block are effective in suppressing cough, their use is discouraged due to invasive nature and need for special training. The administration of antisialagogues, such as atropine or glycopyrrolate, has been recommended in the past to reduce secretions and prevent bradycardia, although recent studies suggest no benefit from use of these drugs and their use is discouraged (5).

**Sedation and Analgesia**

Sedation is a continuum of altered consciousness levels. For nonintubated patients, minimal sedation (anxiolysis) and moderate sedation (conscious sedation) are utilized. Deep sedation is typically reserved for intubated patients although it can be administered with the assistance of monitored anesthesia care.

Benzodiazepines are preferred class of drugs to achieve conscious sedation due to antianxiety effects, antegrade amnesia, and sedation through suppression of gamma-aminobutyric acid. Midazolam is the preferred agent due to its quick onset of action, rapid peak effect, and relatively shorter duration of action. Dose adjustments may be needed in elderly and in patients with advanced liver disease due to slower clearance. Opioids are commonly used in combination with benzodiazepines due to analgesic and cough suppressant properties. Randomized trials have shown that the combination is safe without any major clinically relevant adverse effects and achieves better comfort, tolerance, and improved cough control when compared with benzodiazepines alone (6). Fentanyl is the most commonly used opioid due to rapid onset of action and short elimination half-life. Alfentanil is another opioid alternative that has immediate onset of action and shorter elimination half-life when compared to fentanyl. Meperidine has also been used for bronchoscopy, although clearance is decreased with hepatic and renal failure, and accumulation of a toxic metabolite, normeperidine, may cause seizures. Newer agents such as dexmedetomidine, a selective alpha-2 receptor agonist has been shown to be effective for procedural sedation during bronchoscopy but requires additional agents such as benzodiazepines or opioids to achieve sedation and it is used less commonly in the intensive care setting (7).

Deep sedation with propofol may also be used in intubated patients and patients with adjunctive airway support (8); advantages include rapid onset and offset of action, with the potential disadvantage of drug-induced hypotension. Fospropofol is found to be safe and efficacious and can be titrated to a predictable level of moderate sedation, however due to conversion to propofol it requires similar level of monitoring as propofol (9). Ketamine, a noncompetitive NMDA receptor antagonist has been used in flexible bronchoscopy in pediatric patients however it is used less frequently in adults. It has an advantage of being potent bronchodilator and analgesic, but increased salivation and secretions and emergence delirium limits the usage especially as a single agent (10). The type and level of sedation required depend on the clinical status. Nonintubated patients, particularly with borderline oxygenation and ventilation or with central airway obstruction, should likely receive anxiolysis or moderate sedation. Unstable hypoxic patients with acute respiratory distress syndrome (ARDS) and patients with brain injury may require deep sedation, or even neuromuscular blockade, to safely perform the procedure (11).

**Mechanical Ventilation**

In mechanically ventilated patients, a special swivel adapter, with a perforated diaphragm through which the bronchoscope is passed, is used to prevent loss of delivered tidal volumes (12). As previously noted, bronchoscopy in the mechanically ventilated patient may cause hypoxemia, hypoventilation, generation of auto-PEEP, and potential barotrauma. The lumen of the ETT should be 2 mm larger than the external diameter of the bronchoscope. Decreases in delivered tidal volumes will occur during pressure-limited, time-cycled ventilator modes, as well as when flow-limited, volume-cycled breaths become pressure limited. To reliably ensure tidal volume delivery, volume-cycled breaths should be used during bronchoscopy. Because the increase in peak pressure is dissipated along the ETT and does not represent an increased risk for barotrauma, the peak pressure limit on the ventilator can be significantly elevated to ensure delivery of tidal volume. The high peak pressures seen during bronchoscopy are not reflective of pressures distal to the ETT. The problem with high peak pressures is ventilator pressure limiting, resulting in decreased effective tidal volume. Decreasing inspiratory flow rate decreases peak pressures and pressure limiting, but may paradoxically increase predisposition to auto-PEEP by decreasing the expiratory time. Set tidal volumes may need to be increased by 40% to 50% in some patients to achieve adequate tidal volumes. Barotrauma and hypotension may occur if the bronchoscope-added expiratory resistance leads to auto-PEEP. Some authors advocate reducing set PEEP or discontinuing PEEP prior to bronchoscopy (1). The fraction of inspired oxygen (FiO2) should be increased to 1.0 prior to and during the procedure to ensure adequate oxygenation. Exhaled tidal volumes should be monitored during the procedure. The bronchoscope should be withdrawn periodically to allow for adequate ventilation; prolonged suctioning through the bronchoscope can decrease delivered tidal volumes and oxygenation.

**Bronchoalveolar Lavage**

Bronchoalveolar lavage (BAL) allows for sampling of cellular and noncellular components from the lower respiratory tract. The tip of the bronchoscope is wedged into a distal airway, and sterile, nonbacteriostatic saline solution is instilled through the bronchoscope and then aspirated with the syringe or suctioned into a sterile trap. Aliquots of 20 mL to 60 mL are generally used. Infusions of 120 mL to 240 mL are needed to ensure adequate sampling of secretions in the distal respiratory bronchioles and alveoli (13–15). Aspiration of aliquots by syringes in a serial fashion allows for detection of progressively bloodier aliquots, which strongly suggests the presence of alveolar hemorrhage. The first aliquot of aspirated fluid is likely to contain a significant amount of material from the proximal airways. As such, some authors recommend discarding this aliquot or analyzing the aliquot separately from the remainder of the fluid (13). In patients with emphysema, collapse of the airways with negative pressure during aspiration or suctioning may limit the amount of fluid obtained. The very small fluid return in these patients may contain only diluted material from the proximal bronchi rather than the alveoli, and thus may give rise to false-negative results (16). Suctioning prior to having the bronchoscope in the appropriate wedged position should be minimized to avoid contamination with upper airway secretions and potential false-positive results.
In addition to quantitative bacterial cultures for the diagnosis of ventilator-associated pneumonia (VAP), BAL samples may also be sent for cytology, antigen tests, and polymerase chain reaction (PCR) tests, which provide additional information for the diagnosis of noninfectious and infectious etiologies of pulmonary disease as compared to the protected specimen brush (PSB).

**Protected Specimen Brush**

The PSB is used to obtain a lower respiratory tract specimen for microbiology that is not contaminated by organisms in the proximal airways. The PSB consists of a retractable brush within a double-sheathed catheter that has a distal dissolvable plug occluding the outer catheter (17, 18). After the tip of the bronchoscope is positioned in the desired area, the catheter is advanced through the working channel and situated 1 to 3 cm beyond the distal end of the bronchoscope to prevent collection of secretions pooled around the distal end of the bronchoscope. The inner cannula containing the brush is advanced to eject the distal plug, and the brush is then advanced into the desired subsegment under direct visualization. Once the sample is obtained, the brush is retracted into the inner cannula, the inner cannula is then withdrawn into the outer sheath, and the entire catheter is removed from the bronchoscope. The distal ends of the outer and inner cannula are wiped with alcohol, cut with sterile scissors, and discarded. The brush is advanced beyond the remaining portion of the inner cannula, cut with sterile scissors, and placed in 1 mL of nonbacteriostatic sterile saline or transport media.

**Quantitative Bronchoalveolar Lavage and Protected Specimen Brush Cultures**

Specimens for culture should be rapidly processed to prevent a decrease in patient viability or contaminant overgrowth. The BAL sample should be transported in a sterile, leak-proof container. The initial aliquot, which is thought to be representative of proximal airway secretions, should be discarded or analyzed separately from the remaining pooled fractions. It is recommended that specimens for microbiologic analysis be processed within 30 minutes, although refrigeration can be used when the specimens cannot be immediately processed (13, 19). The specimens should be processed according to clearly defined protocols (20). Pathogens are present in lower respiratory tract secretions, at concentrations of at least \(10^4\) to \(10^6\) colony forming units (CFU)/mL, in patients with pneumonia, while contaminant bacteria are present at concentrations of less than \(10^4\) CFU/mL (21, 22). The diagnostic thresholds proposed for BAL and PSB are based on these concentrations with \(10^4\) CFU/mL for BAL, which collects 1 mL of secretions in 10 to 100 mL of saline and represents \(10^3\) to \(10^5\) CFU/mL, which is considered supportive of the diagnosis of VAP. Similarly, the concentration of \(10^3\) CFU/mL for PSB, which collects 0.001 to 0.01 mL of secretions in 1 mL of saline, is considered supportive of the diagnosis of VAP.

**Transbronchial and Endobronchial Biopsies**

Histologic samples of lung parenchyma may be obtained with transbronchial lung biopsies. In patients with diffuse or localized parenchymal diseases, transbronchial lung biopsies may be useful and offer a less invasive option to open lung biopsy. It should be noted, however, that for some interstitial lung diseases and pulmonary vasculitides, transbronchial biopsy specimens are inadequate to make a definitive diagnosis. The major risks of transbronchial biopsies are bleeding and pneumothorax. The risk of pneumothorax is higher when performing transbronchial biopsies in the mechanically ventilated patient (23). Fluoroscopy may not be required to perform transbronchial biopsies in mechanically ventilated patients with diffuse parenchymal disease; however, if available, use of fluoroscopy is recommended to minimize the risk of a life-threatening pneumothorax. A chest radiograph should be obtained in all critically ill or mechanically ventilated patients after transbronchial lung biopsy.

Samples of bronchial mucosa and endobronchial abnormalities may be obtained with endobronchial biopsies. Transbronchial and endobronchial biopsies may be sent for bacterial, mycobacterial, and fungal cultures as indicated, in addition to histology.

**CONTRAINDICATIONS**

Only a few absolute contraindications to flexible bronchoscopy exist in critically ill patients. Flexible bronchoscopy should not be performed in the absence of informed consent, if trained personnel are not available, if adequate oxygenation cannot be maintained during the procedure, if unstable cardiac conditions are present, or if uncontrolled bronchospasm is present (24, 25). The inability to normalize the platelet count and coagulation parameters if biopsy or PSB is planned is a relative contraindication. Airway inspection and BAL may likely be done safely despite thrombocytopenia or coagulopathy unless the abnormalities are profound. The general recommendation is that the platelet count should be at least 50,000 cells/µL if biopsies are going to be performed. Performing biopsies or PSB in patients on aspirin can be safely accomplished however, discontinuation of potent antiplatelet agents such as clopidogrel, prasugrel, and ticagrelor for 5 to 7 days is recommended due to significant increase in risk of bleeding (26). Likewise, the following agents should be held for an appropriate period of time before performing biopsies or PSB based upon drug half-life: heparin infusions; low–molecular-weight heparinoids (at full anticoagulation dosage); fondaparinux (at full anticoagulation dosage); factor Xa inhibitors such as apixaban, rivaroxaban, and edoxaban; and direct thrombin inhibitors such as dabigatran, argatroban, bivalirudin, and desirudin. Patients with uremia, which causes a functional platelet defect, are at increased risk for hemorrhage with biopsy procedures (27). Patients with pulmonary hypertension have also been noted to be at risk for greater bleeding with transbronchial biopsies. Patients with stable COPD may safely undergo flexible bronchoscopy. Sedation during the procedure should be used cautiously, and the possibility of supplemental oxygen-induced hypoventilation should be considered.

Patients with increased ICP should be carefully monitored during flexible bronchoscopy. Bronchoscopy has been noted to increase ICP by at least 50% in 88% of patients with head trauma, despite the use of deep sedation and paralysis (11). Cerebral perfusion pressure may not change, however, due to concurrent increases in mean arterial pressure during bronchoscopy. Despite an increase in ICP, no significant neurologic abnormalities are inadequate to make a definitive diagnosis.
Complications were noted in studies of patients with severe head trauma or space-occupying lesions who were undergoing flexible bronchoscopy (2,11,28). In spite of these observations, caution is warranted in performing bronchoscopy in patients with markedly elevated ICP.

**COMPPLICATIONS**

With appropriate care, flexible bronchoscopy is an extremely safe procedure. The incidence rate of major complications ranges from 0.08% to 0.15%, and the mortality rate ranges from 0.01% to 0.04%. Minor complications (e.g., vasovagal reaction, fever, bleeding, nausea, and vomiting) occur in as many as 6.5% of these patients (29–31). Flexible bronchoscopy in mechanically ventilated patients has the potential for life-threatening complications including hypoxemia, hypercapnia, barotrauma, cardiac arrhythmias, myocardial ischemia, intracranial hypertension, local anesthetic toxicity, and pulmonary hemorrhage. Careful patient selection, meticulous preparation before the procedure, and vigilant physiologic monitoring during the procedure limit complications and mortality. The characteristics of high-risk patients are summarized in Table 38.1.

A prospective clinical trial in critically ill, mechanically ventilated patients with ARDS provides important information with regard to the safety of BAL in this patient population. Careful attention was directed toward maintenance of minute ventilation and the limitation of auto-PEEP during the procedure. Severe hypoxemia and hypotension were seen in 4.5% and 3.6% of patients, respectively. No significant reduction occurred in postprocedure pulmonary function, such as static compliance or PaO2/FiO2 ratio. No deaths were attributed to the procedure. The incidence of pneumothorax was 0.9% (1 of 110 patients) (32).

These results are in contrast to other investigators who have shown the potential for significant decline in oxygenation, which can persist for up to 2 hours after the procedure (33). In healthy patients, the arterial partial pressure of oxygen (PaO2) may decline by 20 to 30 mmHg during flexible bronchoscopy (33). In critically ill patients, the decrement in PaO2 can exceed 30 to 60 mmHg (34,35). In a more recent study of bronchoscopy in critically ill patients, hypoxemia was observed in 29 of 147 procedures (19.7%) (36). The greater the amount of normal saline instilled for lavage during bronchoscopy, the more frequent the hypoxemia—seen in as many as 23% of patients—and the longer its duration, up to 8 hours (37,38). Hypoxemia- and hypercapnia-induced increased sympathetic tone can result in dysrhythmias, myocardial ischemia, hypotension, and cardiac arrest.

Bronchoscopy-associated hypoxemia may be minimized by providing 100% oxygen during the procedure, shortening bronchoscopy time, and frequently withdrawing the bronchoscope from the airway to allow adequate ventilation. Adequate tidal volume delivery should be monitored by observing chest excursions and exhaled tidal volumes in patients undergoing mechanical ventilation. Tidal volume and flow rates must be adjusted to provide adequate ventilation (1,33,39).

Complications associated with the administration of sedation, analgesia, and topical anesthesia include hypotension and allergic reactions, as well as hyperventilation, and hypoxemia from oversedation and respiratory depression. The overzealous use of local anesthetic agents within the airways has potential for toxicity with the rapid uptake of these agents into the systemic circulation from the bronchial mucosa (40). Lidocaine is the most commonly used airway anesthetic. The risks of toxicity are decreased with total doses of less than 4 mg/kg of body weight. The duration of airway anesthesia induced by lidocaine is approximately 20 to 40 minutes. Lidocaine in excessive doses can cause sinus arrest and atrial ventricular block, especially in patients with underlying heart disease. Other potential adverse reactions include respiratory arrest, seizures, laryngospasm, and, rarely, hypersensitivity reactions. Although not as commonly used for topical anesthesia, benzocaine has been associated with the development of methemoglobinemia (41). For reversal of benzodiazepine sedation, flumazenil, a competitive antagonist at GABA receptor, in the dose of 0.2 mg every 60 seconds up to 1 mg can be used. Naloxone is the competitive opioid antagonist which can be used for reversal of opioid-induced respiratory depression. Typical dose of naloxone is 0.1 to 0.2 mg, which can be repeated in every 2-minute interval. Ready availability of these agents is essential if bronchoscopy is being performed under conscious sedation.

Although rarely associated with bronchoscopy, dysrhythmias are more likely to occur in critically ill patients (42). Major cardiac dysrhythmias occur in 3% to 11% of all patients undergoing bronchoscopy. Hypoxemia is the major risk factor for the development of dysrhythmias (43,44).

Laryngospasm (in the nonintubated patient) or bronchospasm can occur in any patient undergoing flexible bronchoscopy, but are more common in patients with pre-existing reactive airway disease. Preoperative bronchodilator therapy significantly reduces the risk of bronchoscopy-induced bronchospasm in most patients with reactive airway disease (45).

Although transbronchial biopsy is a relatively safe procedure in patients with normal hemostasis and pulmonary vascular pressures, it is associated with a 2.7% and 0.12% risk of morbidity and mortality, respectively (46). Hemorrhage (more than 50 mL of blood) is more likely to occur in patients who undergo transbronchial biopsy; risk factors for hemorrhage include thrombocytopenia, coagulopathy, uremia, and pulmonary hypertension. Transbronchial biopsy should be restricted

<table>
<thead>
<tr>
<th>TABLE 38.1</th>
<th>Characteristics of Increased-Risk Patients for Bronchoscopy on Mechanical Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulmonary</strong></td>
<td>PaO2 &lt; 70 mmHg with FiO2 &gt; 0.70</td>
</tr>
<tr>
<td><strong>Cardiac</strong></td>
<td>Recent myocardial infarction (&lt; 48 hrs)</td>
</tr>
<tr>
<td><strong>Coagulopathy</strong></td>
<td>Platelet count &lt; 20,000 cells/μL</td>
</tr>
<tr>
<td><strong>Central nervous system</strong></td>
<td>Increased intracranial pressure</td>
</tr>
</tbody>
</table>

FiO2, fraction of inspired oxygen; PEEP, positive end-expiratory pressure.
to nonuremic patients with platelet counts greater than 50,000 cells/μL and prothrombin times and activated partial thromboplastin times less than twice that of controls (29,46,47). The incidence rate of bronchoscopy-related hemorrhage in normal hosts approaches 1.4%. In immunocompromised hosts, the rate of hemorrhage ranges from 25% to 29%, while hemorrhage occurs in as many as 45% of uremic patients (29,48,49). Administration of desmopressin, 0.3 μg/kg, can reverse the uremic effect on platelet function, although no controlled study evaluating the safety of performing transbronchial biopsies after treatment with desmopressin exists (50). Pneumothorax occurs in fewer than 5% of nonventilated patients undergoing transbronchial biopsy. Tube thoracotomy is required in approximately half of these patients (29). A major risk factor for pneumothorax is positive pressure ventilation, especially if PEEP is used. Rates of pneumothorax after transbronchial lung biopsy in mechanically ventilated patients have been reported up to 7% and 23% (23,51,52). Fluoroscopic guidance may diminish the risk of pneumothorax. No patient should undergo bilateral transbronchial biopsy procedures during the same bronchoscopy session because of the small risk of bilateral pneumothorax.

Postbronchoscopy fever occurs in as many as 16% of patients. Bronchoscopy-related pneumonia is rare, occurring in fewer than 5%, and bacteremia is exceedingly rare (53,54). In general, endocarditis prophylaxis is not required with flexible bronchoscopy (55).

Neurosurgical patients are at risk for intracranial hypertension as a result of bronchoscopy-induced elevation of intrathoracic pressure, arterial hypertension, and hypercapnia. Bronchoscopy-associated cough or retching must therefore be avoided. Deep sedation with or without neuromuscular blockade may be utilized if bronchoscopy is deemed necessary.

### Diagnostic and Therapeutic Bronchoscopy

#### Airway Management

Flexible bronchoscopy can provide an efficient and effective means to secure a difficult airway, change an ETT, and inspect an airway during extubation (56,57). Endotracheal intubation can be technically difficult in select patient groups (Table 38.2). Intubation using flexible bronchoscopy under topical anesthesia, with or without conscious sedation, is an important technique in these patients with compromised airways, particularly if the airway is obstructed or if the trachea is extrinsically compressed by a mediastinal mass. Spontaneous ventilation keeps the airway open and assists the bronchoscopist in locating the glottis when airway anatomy is distorted (56,58). Bronchoscopic examination of the airway also identifies the nature of the obstructed airway and helps to plan for additional therapeutic maneuvers to relieve the airway obstruction.

Bronchoscopic endotracheal intubation can be performed using either a nasal or oral approach. With the nasal approach, after preparation of the nasal mucosa with a local anesthetic such as lidocaine and a mucosal vasoconstrictor such as 1% phenylephrine, the bronchoscope is passed through the nares and situated directly above the glottic opening. It is then passed into the trachea and the ETT is passed over the bronchoscope into the trachea. The major limitation of this approach in many ICU patients with concomitant abnormalities of coagulation is epistaxis and the potential for sinusitis with prolonged nasal intubation. The development of epistaxis can significantly impair the bronchoscopic examination and can seriously hamper subsequent nasal or laryngoscopic attempts at intubation. Other difficulties associated with nasal intubation include adenoid dislocation and difficulty passing the ETT in patients with a limited diameter of the nares.

Oral flexible bronchoscopic intubation effectively avoids these difficulties associated with nasal intubation. Topical anesthesia of the oropharynx is achieved with spraying of 4% lidocaine. Translaryngeal injection of 3 mL of 4% lidocaine through the cricothyroid membrane to provide topical anesthesia to the larynx and trachea, in addition to lidocaine sprays

<table>
<thead>
<tr>
<th>TABLE 38.2 Factors Associated with Difficult Endotracheal Intubations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anatomic</strong></td>
</tr>
<tr>
<td>Short muscular neck</td>
</tr>
<tr>
<td>Receding mandible</td>
</tr>
<tr>
<td>Prominent upper incisors</td>
</tr>
<tr>
<td>Microglossia</td>
</tr>
<tr>
<td>Limited mandible movement</td>
</tr>
<tr>
<td>Large breasts</td>
</tr>
<tr>
<td>Cervical rigidity</td>
</tr>
<tr>
<td><strong>Congenital abnormalities</strong></td>
</tr>
<tr>
<td>Absence of nose</td>
</tr>
<tr>
<td>Choanal atresia</td>
</tr>
<tr>
<td>Macroglossia</td>
</tr>
<tr>
<td><strong>Infectious</strong></td>
</tr>
<tr>
<td>Bacterial retropharyngeal abscess</td>
</tr>
<tr>
<td>Epiglottitis</td>
</tr>
<tr>
<td>Diphtheria</td>
</tr>
<tr>
<td>Infectious mononucleosis</td>
</tr>
<tr>
<td>Croup</td>
</tr>
<tr>
<td>Leprosy</td>
</tr>
<tr>
<td><strong>Noninfective inflammation</strong></td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
</tr>
<tr>
<td>Instability of cervical spine</td>
</tr>
<tr>
<td>Cervical fixation</td>
</tr>
<tr>
<td>Temporomandibular disease</td>
</tr>
<tr>
<td>Cricoarytenoid disorders</td>
</tr>
<tr>
<td>Hypoplastic mandible</td>
</tr>
<tr>
<td>Ankylosing spondylitis</td>
</tr>
<tr>
<td><strong>Neoplasia</strong></td>
</tr>
<tr>
<td>Laryngeal papillomatosis</td>
</tr>
<tr>
<td>Stylohyoid ligament calcification</td>
</tr>
<tr>
<td>Laryngeal carcinoma</td>
</tr>
<tr>
<td>Mediastinal carcinoma</td>
</tr>
<tr>
<td><strong>Trauma</strong></td>
</tr>
<tr>
<td>Mandibular fracture</td>
</tr>
<tr>
<td>Maxillary fracture</td>
</tr>
<tr>
<td>Laryngeal and tracheal trauma</td>
</tr>
<tr>
<td>Mediastinal carcinoma</td>
</tr>
<tr>
<td><strong>Endocrine</strong></td>
</tr>
<tr>
<td>Obesity</td>
</tr>
<tr>
<td>Acromegaly</td>
</tr>
<tr>
<td>Thyromegaly</td>
</tr>
</tbody>
</table>
to the oropharynx, is favored by some practitioners although use is discouraged due to the invasive nature and need for special training. Others favor a “spray as you go” technique, with injection of lidocaine through the working channel of the bronchoscope to provide laryngeal and tracheal topical anesthesia. Alternatively, nebulization of 6 to 8 mL of 4% lidocaine is used for topical anesthesia in some institutions (56). A bite block should be in place to prevent scope damage from the patient biting. In some patients, the use of an oral intubating airway, such as the Williams Airway Intubator, the Ovassapian Airway, or the Berman Airway, may be helpful in successfully intubating the patient with a difficult airway (59). The oral intubating airway directs the flexible bronchoscopy past the tongue and directly over the larynx, facilitating endotracheal intubation. Use of these airways in the completely awake patient with inadequate topical anesthesia may be problematic due to gagging and vomiting. This is less of a problem in the sedated or unconscious patient. After exposure of the vocal cords, the bronchoscope is passed into the trachea and the ETT is then passed over the bronchoscope into the airway. In some patients, the ETT impinges on laryngeal structures despite the smooth entrance of the bronchoscope into the trachea. In this situation, the ETT may be withdrawn back over the bronchoscope, rotated 90 degrees clockwise or counterclockwise to change the position of the tube bevel relative to the larynx, and readvanced during inspiration (56). Mild to moderate conscious sedation may be used in some patients to improve patient comfort and tolerance of oral or nasal bronchoscopic intubation. Great caution should be taken in patients with highly compromised airways, however, and sedatives may need to be completely avoided.

In addition to the oral intubating airway, other airway adjuncts have been used in combination with the flexible bronchoscope for intubation of patients with a difficult airway. A special facial mask with a diaphragm for the bronchoscope has been developed for the critically ill and for use in the operating room (60). The mask is useful for bronchoscopic intubation in sedated or comatose patients with limited respiratory reserve, providing a tight seal for assisted ventilation during the procedure. The intubating laryngeal mask airway (LMA) has also been used successfully in combination with the flexible bronchoscope (61).

Flexible bronchoscopy allows for ETT changes in patients with ETT cuff leaks, inadequate ETT internal diameters, and nasotracheal tube–associated sinusitis. Before bronchoscopy, the oropharynx should be suctioned thoroughly. For oral tracheal intubation, the ETT should be shortened 2 to 3 cm at its proximal end and advanced over the bronchoscope before its placement in the pharynx. The bronchoscope tip is advanced to the level of the cuff of the existing ETT, and secretions are aspirated through the suction channel. If necessary, the cuff is deflated and the bronchoscope advanced into the tracheal lumen. The ETT is then withdrawn with the cuff fully deflated, the bronchoscope tip advanced to the carina, and the new ETT advanced over the bronchoscope into the trachea. Adequate positioning of the tube 3 to 4 cm proximal to the carina is confirmed by visual inspection, and the cuff is inflated. After intubation, a chest radiograph is not required to confirm adequate placement of the ETT (62). Tube changes by the oral or nasal routes are possible. Contralateral nasal reintubation, however, may be difficult because of the lateral displacement of the septum by the existing nasotracheal tube.

Percutaneous dilatational tracheostomy (PDT) has become a well-accepted method for performing bedside tracheostomy in the ICU. While not universally used, flexible bronchoscopy is routinely used in performing PDT (63). Bronchoscopy facilitates proximal positioning of the ETT prior to introducing the guidewire needle into the trachea, reducing the risk of ETT impalement by the needle, and facilitates reintubation if the ETT is dislodged out of the airway. Bronchoscopic visualization ensures that the guidewire needle is introduced in the appropriate interspace in a midline position and that the needle does not penetrate the membranous posterior tracheal wall, thereby decreasing the risk of misplacement of the tracheostomy tube and creation of a false paratracheal passage. Bronchoscopy also provides feedback to the operator during dilator passage so that pressure on the posterior wall is minimized and the potential for posterior wall tears is reduced.

Flexible bronchoscopy can be extremely useful in the placement of a double-lumen ETT. If a right-sided tube is used, adequate positioning of the tube with the tracheal port proximal to the carina and bronchial port proximal to the right upper lobe orifice can be confirmed by using a small-diameter (3.5-mm outer diameter) flexible bronchoscope to inspect the airway through each lumen (64,65). Positioning of left-sided tubes is not as problematic given the longer length of the left mainstem bronchus relative to the right mainstem bronchus and less likelihood of obstructing the left upper or left lower lobe. In general, bronchoscopic confirmation of proper bronchial port positioning should be performed after all double-lumen ETT intubations, given the significant rate of malpositioning with a blind technique (66).

Flexible bronchoscopy provides an excellent opportunity to inspect the airways at the time of extubation in patients at risk for airway compromise, including those intubated for inhalation injury, trauma, subglottic stenosis, and laryngeal edema. The bronchoscope is advanced through the ETT to its most distal aspect, and the ETT and bronchoscope are withdrawn slowly together to allow inspection of the airway. If bronchoscopy confirms persistent mucosal edema or airway obstruction, the ETT can be readvanced over the bronchoscope into the tracheal lumen and secured, with extubation postponed until a later time.

Atelectasis

Segmental or lobar atelectasis presents radiographically as a parenchymal density associated with a combination of shift of an interlobar fissure, crowding of vessels or bronchi, ipsilateral mediastinal shift, or elevation of the diaphragm. Complete lung atelectasis will produce opacification of the hemithorax and usually ipsilateral mediastinal shift. Atelectasis is most commonly due to mucus plugging; however, in patients who do not improve after chest physiotherapy, endobronchial obstruction due to endobronchial tumor, foreign body, or blood clot should be excluded by bronchoscopy. Predisposing conditions for mucus plugging and atelectasis include inadequate inspiratory effort (pain, sedation, and muscle weakness), immobility, obesity, excessive airway secretions, pre-existing airway disease, and endobronchial obstructing lesions. Lobar or whole lung atelectasis produces hypoxemia by right-to-left vascular shunting and ventilation/perfusion mismatching. The clinical significance of atelectasis is directly related to its extent and to the pre-existing pulmonary reserve of the patient.

Much of the evidence supporting the role of flexible bronchoscopy in the treatment of atelectasis is anecdotal. Success
rates for bronchoscopy range from 19% to 89% (67). One randomized trial comparing bronchoscopy to aggressive chest physiotherapy and nebulizer therapy found no advantage for bronchoscopy, although the study methodology has been criticized (68–70). Patients with whole lung or lobar atelectasis tend to respond better than those with segmental atelectasis. With the exception of large, obstructing central artery mucous plugs, the radiographic response to successful removal of secretions is delayed from 6 to 24 hours. Therapeutic bronchoscopy is, in general, indicated for patients with life-threatening whole lung or lobar atelectasis and for patients who have not responded to chest physiotherapy measures. Chest physiotherapy should be continued after successful bronchoscopy to prevent new airway obstructions. Instillation of saline or a dilute 10% solution of acetylcysteine through the working channel may help to clear thick, tenacious secretions. Acetylcysteine is a bronchial irritant, however, and may exacerbate bronchospasm in patients with reactive airway disease. Typically 10 to 20 mL aliquots of saline are used as the irrigant to facilitate clearing of mucous plugs. If saline irrigation fails, then instillation of acetylcysteine or rhDNase (Pulmozyme) may be considered (71–73). In some patients, holding continuous suction while withdrawing the bronchoscope through the ETT allows removal of large mucous plugs that cannot be suctioned directly through the working channel. Extremely tenacious mucous plugs may require the use of biopsy forceps or a foreign body basket to be successfully extracted. Blood clots may similarly be removed with saline irrigation. Instillation of acetylcysteine may be helpful in more difficult to remove blood clots. The use of biopsy forceps or a foreign body basket may be needed to remove blood clots that cannot be removed with irrigation and suction extraction.

Selective intrabronchial insufflation by the flexible bronchoscope, preceded by suctioning of mucus from large airways, has been used in patients with refractory atelectasis (67). One study in a surgical ICU using air insufflation for lobar collapse reported an overall effectiveness of 82%, with 92% effectiveness when collapse was less than 72 hours’ duration (74). Although only minor clinically insignificant complications have been described, selective positive pressure insufflation does carry the potential risk of barotrauma (75–77).

### Hemoptysis

Flexible bronchoscopy plays a central role in the evaluation of hemoptysis. Bronchoscopy should be considered in all critically ill patients with hemoptysis, regardless of the degree of hemoptysis, to localize the site of bleeding and attempt to determine the underlying etiology. Localization of the site of bleeding is important to guide temporizing therapy such as angiographic embolization and definitive therapy such as surgical resection. Early rather than delayed bronchoscopy should be performed to increase the likelihood of localizing the source of bleeding. Bronchoscopy performed within 48 hours of bleeding onset successfully localized bleeding in 34% to 91% of patients, depending on the case series, as compared to successful localization in 11% to 52% of patients if bronchoscopy was delayed (78). Bronchoscopy performed within 12 to 24 hours may provide an even higher yield.

Massive hemoptysis is defined as expectoration of blood exceeding 200 to 1,000 mL over a 24-hour period, with expectoration of greater than 600 mL in 24 hours as the most commonly used definition (79). In practice, the rapidity of bleeding and ability to maintain a patent airway are critical factors, and life-threatening hemoptysis can alternatively be defined as the amount of bleeding that compromises ventilation. Only 3% to 5% of patients with hemoptysis have massive hemoptysis, with the mortality rates approaching 80% in various case series. Most patients who die from massive hemoptysis do so from asphyxiation secondary to airway occlusion by blood and blood clots, not exsanguination. The causes of massive hemoptysis are listed in Table 38.3. Infections associated with bronchiectasis, tuberculosis, lung abscess, and necrotizing pneumonia are commonly responsible for the

<table>
<thead>
<tr>
<th>TABLE 38.3 Potential Causes of Massive Hemoptysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neoplasm</strong></td>
</tr>
<tr>
<td>Bronchogenic cancer</td>
</tr>
<tr>
<td>Metastasis (parenchymal or endobronchial)</td>
</tr>
<tr>
<td>Carcinoid</td>
</tr>
<tr>
<td>Leukemia</td>
</tr>
<tr>
<td><strong>Infectious</strong></td>
</tr>
<tr>
<td>Lung abscess</td>
</tr>
<tr>
<td>Bronchiectasis</td>
</tr>
<tr>
<td>Tuberculosis</td>
</tr>
<tr>
<td>Necrotizing pneumonia</td>
</tr>
<tr>
<td>Fungal pneumonia</td>
</tr>
<tr>
<td>Septic pulmonary emboli</td>
</tr>
<tr>
<td>Mycetoma (aspergilloma)</td>
</tr>
<tr>
<td><strong>Pulmonary</strong></td>
</tr>
<tr>
<td>Bronchiectasis</td>
</tr>
<tr>
<td>Cystic fibrosis</td>
</tr>
<tr>
<td>Sarcoïdosis (fibrocavitary)</td>
</tr>
<tr>
<td>Diffuse alveolar hemorrhage</td>
</tr>
<tr>
<td>Airway foreign body</td>
</tr>
<tr>
<td><strong>Cardiac/vascular</strong></td>
</tr>
<tr>
<td>Mitral stenosis</td>
</tr>
<tr>
<td>Pulmonary embolism/intraction</td>
</tr>
<tr>
<td>Arteriovenous malformation</td>
</tr>
<tr>
<td>Bronchoarterial fistula</td>
</tr>
<tr>
<td>Ruptured aortic aneurysm</td>
</tr>
<tr>
<td>Congestive heart failure</td>
</tr>
<tr>
<td>Pulmonary arteriovenous fistula</td>
</tr>
<tr>
<td><strong>Iatrogenic-traumatic</strong></td>
</tr>
<tr>
<td>Blunt or penetrating chest trauma</td>
</tr>
<tr>
<td>Tracheal/bronchial tear or rupture</td>
</tr>
<tr>
<td>Tracheoinnominate artery fistula</td>
</tr>
<tr>
<td>Bronchoscopy</td>
</tr>
<tr>
<td>Pulmonary artery rupture from Swan–Ganz catheter</td>
</tr>
<tr>
<td>Endotraacheal tube suctioning trauma</td>
</tr>
<tr>
<td><strong>Hematologic</strong></td>
</tr>
<tr>
<td>Coagulopathy</td>
</tr>
<tr>
<td>Disseminated intravascular coagulation</td>
</tr>
<tr>
<td>Thrombocytopenia</td>
</tr>
<tr>
<td><strong>Drugs/toxins</strong></td>
</tr>
<tr>
<td>Anticoagulants</td>
</tr>
<tr>
<td>Antiplatelet agents</td>
</tr>
<tr>
<td>Thrombolytic agents</td>
</tr>
<tr>
<td>Crack cocaine</td>
</tr>
</tbody>
</table>
massive bleeding. Other common causes include bronchogenic carcinoma, mycetoma, invasive fungal diseases, chest trauma, cystic fibrosis, pulmonary infarction, coagulopathy, and alveolar hemorrhage due to granulomatous polyangiitis (Wegener granulomatosis) and Goodpasture syndrome.

Airway patency must be ensured in patients with massive hemoptysis. While preparing for intubation and bronchoscopy, the patient may be positioned in the lateral decubitus position with the bleeding side down. Most patients with massive hemoptysis will require intubation and mechanical ventilation. While intubation generally preserves oxygenation and facilitates blood removal from the lower respiratory tract, the ETT may become obstructed by blood clots with inability to oxygenate and ventilate the patient. The largest possible ETT should be inserted to allow for use of bronchoscopes with a 2.8- to 3.0-mm working channel for more effective suctioning and to allow for better ventilation with the bronchoscope in the airway for prolonged periods of time. In severe cases, the mainstem bronchus of the nonbleeding lung can be selectively intubated under bronchoscopic guidance to preserve oxygenation and ventilation from the normal lung.

Some authors have recommended the use of a double-lumen ETT to isolate the normal lung and permit selective intubation. While double-lumen ETTS have been used successfully in the airway management of massive hemoptysis, there are a number of potential pitfalls. First, placement of a double-lumen ETT is difficult for less experienced operators, particularly with a large amount of blood in the larynx and oropharynx. Second, the individual lumens of the ETT are significantly smaller than a standard ETT and are at significant risk of being occluded by blood and blood clots. Lastly, positioning of the double-lumen ETT and subsequent bronchoscopic suctioning of the distal airways require a small pediatric bronchoscope with working channels of 1.2 to 1.4 mm. Adequate suctioning of large amounts of blood and blood clots through such bronchoscopes is extremely problematic. In one series of 62 patients with massive hemoptysis, death occurred in four of seven patients managed with a double-lumen ETT due to loss of tube positioning and aspiration (80). Related to this rationale, the use of double-lumen ETTS for airway management in massive hemoptysis is not recommended. As an alternative to selective mainstem bronchial intubation or intubation with a double-lumen ETT, an ETT that incorporates a bronchial blocker, such as the Univent tube, may be used.

Endobronchial tamponade with flexible bronchoscopy can prevent aspiration of blood into the contralateral lung and preserve gas exchange in patients with massive hemoptysis. Endobronchial tamponade can be achieved with a 4-French Fogarty balloon-tipped catheter. The catheter may be passed directly through the working channel of the bronchoscope or the catheter can be grasped by biopsy forceps placed through the working channel of the bronchoscope prior to introduction into the airway. The bronchoscope and catheter—when the latter is held in place adjacent to the bronchoscope by the biopsy forceps—are then inserted as a unit into the airway. Care must be taken not to perforate the catheter or balloon by the forceps. The catheter tip is inserted into the bleeding segmental orifice, and the balloon is inflated. If passed through the suction channel, the proximal end of the catheter is clamped with a hemostat, the hub cut off, and a straight pin inserted into the catheter channel proximal to the hemostat to maintain inflation of the balloon catheter. The clamp is removed, and the bronchoscope is carefully withdrawn from the bronchus with the Fogarty catheter remaining in position, to provide endobronchial hemostasis (81–83). The catheter can safely remain in position until hemostasis is ensured by surgical resection of the bleeding segment or bronchial artery embolization. Right heart balloon catheters have been used in a similar fashion (84). A modified technique for placement of a balloon catheter has been described using a guidewire for insertion. A 0.035-in soft-tipped guidewire is inserted through the working channel of the bronchoscope into the bleeding segment. The bronroscope is withdrawn, leaving the guidewire in place. A balloon catheter is then inserted over the guidewire and placed under direct visualization after reintroduction of the bronchoscope (85). The use of endobronchial blockers developed for unilateral lung ventilation during surgery may hold promise for management of massive hemoptysis in tamponading bleeding and preventing contralateral aspiration of blood (86). The Arndt endobronchial blocker is placed through a standard ETT and directly positioned with a pediatric bronchoscope. Suctioning and injection of medications can be performed through the lumen of the catheter after placement. The Cohen tip-deflecting endobronchial blocker is also placed through a standard ETT and directed into place with a self-contained steering mechanism under bronchoscopic visualization. At this time, there is limited published experience with these blockers in the setting of massive hemoptysis, although the authors have successfully used them for this application. The prolonged use of endobronchial blockers may cause mucosal ischemic injury and postobstructive pneumonia and their use beyond 24 to 48 hours is discouraged.

Additional bronchoscopic techniques may be useful as a temporizing measure in patients with massive hemoptysis. Bronchoscopically administered topical therapies such as iced sterile saline lavage or topical 1:10,000 or 1:20,000 epinephrine solution may be helpful (87). Direct application of a solution of thrombin or a fibrinogen–thrombin combination solution has been used (88). The use of bronchoscopy-guided topical hemostatic tamponade therapy using oxidized regenerated cellulose mesh has recently been described (89). Although anecdotal, one of us (MJ) has had success with topical application of 5 to 10 mL of a 1-mEq/mL (8.4%) sodium bicarbonate solution.

For patients who have hemoptysis due to endobronchial lesions, particularly endobronchial tumors, hemostasis may be achieved with the use of neodymium-yttrium-aluminum-garnet (Nd:YAG) laser phototherapy, electrocautery, or cryotherapy via the bronchoscope.

**Diagnosis of Ventilator-Associated Pneumonia**

For the diagnosis of VAP, the use of bronchoscopic modalities remains controversial and is often institution dependent. Although commonly attributed to pneumonia, the chest radiographic finding of alveolar infiltrates in the ICU patient can represent a broad differential diagnosis, requiring a wide range of therapies. The use of standard clinical criteria for the diagnosis of pneumonia such as new pulmonary infiltrates, hypoxemia, leukocytosis or leukopenia, fever, and pathogenic bacteria in respiratory secretions has been associated with a significant rate of misdiagnosis (90). Bacterial colonization of the upper airways and ETT can confound the reliability of the
Gram stain and cultures from tracheal aspirates obtained in the intubated patient. Concern about the inaccuracy of clinical approaches to the diagnosis of VAP and the possibility of antibiotic overprescribing with a clinical strategy has led some investigators to postulate that bronchoscopic methods such as PSB and BAL would improve the diagnosis of VAP and treatment outcomes (21,22).

The methodology for performing PSB and BAL quantitative cultures is outlined in a previous section of this chapter. PSB and BAL should be performed in the most abnormal segment as determined by radiographic studies or where endobronchial abnormalities are most pronounced. Alternatively, samples may be obtained from the right lower lobe, as this is the most commonly affected area on autopsy studies. A quantitative culture result of more than 10^4 CFU/mL is considered diagnostic for pneumonia with BAL, while more than 10^5 CFU/mL is considered diagnostic for pneumonia with PSB. An evidence-based review of 23 prospective studies of BAL in suspected VAP showed a sensitivity of 42% to 93% with a mean of 73% ± 18%, and a specificity of 45% to 100% with a mean of 82% ± 19% (91). In 12 studies, the detection of intracellular organisms in 2% to 5% of recovered cells was used to diagnose pneumonia, with a mean sensitivity of 69% ± 20% and a specificity of 75% ± 28% (91). An advantage of looking for intracellular organisms is the ability to obtain information of high predictive value in a rapid time frame without waiting for the results of cultures to define the presence of pneumonia, although not the specific identity of the etiologic pathogen (90).

In a review of studies evaluating PSB, the sensitivity ranged from 33% to 100% with a median sensitivity of 67%, while the specificity ranged from 50% to 100% with a median specificity of 95% (92). It is unclear if BAL is superior to PSB or vice versa in the diagnosis of VAP. In a meta-analysis of 18 studies on PSB (795 patients) and 11 studies on BAL (435 patients), there was no difference in the accuracy of the two tests (93). BAL does offer an advantage in that additional microbiologic tests beyond routine bacterial cultures, as well as cytologic analysis, can be performed on the sample if an infectious process is suspected other than typical bacterial pneumonia. PSB may potentially have a greater complication rate compared with BAL, but this has not been formally compared.

Despite studies of BAL and PSB showing a greater accuracy than tracheal aspirates, the routine use of bronchoscopy for establishing the diagnosis of VAP remains controversial (90,94). This controversy is in part due to critiques in study methodologies and in part due to some studies showing a benefit in patient outcomes while others have not. One prospective, nonrandomized study noted a difference in mortality between patients managed with an invasive bacteriologic strategy (19%) versus those managed with a clinical strategy (35%) (95). One large, prospective randomized trial did show an advantage to the quantitative bronchoscopic approach when compared with a clinical approach in a multicenter study of 413 patients suspected of having VAP. Compared with patients managed clinically, those receiving invasive management had a lower mortality rate on day 14 (16% vs. 25%; p < 0.02), but not on day 28, and lower mean sepsis-related organ failure assessment scores on days 3 and 7. At 28 days, the quantitative culture group had significantly more antibiotic-free days (11 ± 9 vs. 7 ± 7 days; p < 0.001), but only a multivariate analysis showed a significant difference in mortality (hazard ratio 1.54; 95% confidence interval [CI] 1.10–2.16) (96). No differences in mortality were observed in three randomized single-center studies when invasive techniques (PSB and/or BAL) were compared with either quantitative or semiquantitative endotracheal aspirate culture techniques (97–99). However, these studies included few patients (58, 83, and 95, respectively), and antibiotics were continued in all patients, even those with negative cultures, thereby negating one of the potential advantages of the bacteriologic strategy. A meta-analysis of these randomized controlled trials noted that an invasive approach did not alter mortality (odds ratio 0.89, 95% CI 0.56–1.41), although invasive testing affected antibiotic utilization (odds ratio for change in antibiotic management after invasive sampling 2.85, 95% CI 1.45–5.59) (100).

Performing microbiologic cultures of pulmonary secretions for diagnostic purposes after initiating new antibiotic therapy can lead to false-negative results and is likely of little value regardless of the manner in which the secretions are sampled. Studies have demonstrated that culture positivity at 24 and 48 hours after the onset of antimicrobial treatment is markedly diminished (101,102). The decrease in positive cultures after initiation of antibiotic therapy appears to affect PSB more so than BAL. If patients have been treated with antibiotics but did not have a change in antibiotic class prior to bronchoscopy for a suspected new episode of VAP, the yield of BAL and PSB appears to be similar to that in patients who have not received antibiotics (103). If an invasive bronchoscopy strategy is used to establish a diagnosis of VAP, BAL, PSB, or both should be performed prior to administration of antibiotics or administration of new antibiotics if the patient was previously on antimicrobial therapy.

### Diagnosis of other Respiratory Infections

Flexible bronchoscopy is an essential modality in evaluating the critically ill, immunocompromised patient with pulmonary infiltrates. These patients are at risk for fungal, viral, protozoal, mycobacterial, and atypical bacterial pulmonary infections. Critically ill patients who have no underlying immunocompromised condition, such as acquired immunodeficiency syndrome (AIDS), leukemia, neutropenia, hematopoietic stem cell/bone marrow transplant, or solid organ transplant, may also develop respiratory infections other than bacterial pneumonias, such as fungal and viral infections. In addition to these patients, those who present with acute respiratory failure and apparent community-acquired pneumonia, but fail to respond appropriately to antibiotic therapy, may benefit from bronchoscopy to evaluate for more unusual infections and noninfectious causes of acute respiratory failure with infiltrates. Bronchoscopy is not recommended for routine community-acquired pneumonia.

BAL, as compared to PSB, provides the opportunity for more extended microbiologic studies and for cytology and additive value of PSB to BAL is likely minimal. It is unclear if the addition of transbronchial biopsy to BAL improves diagnostic accuracy in all immunocompromised patients with pulmonary infiltrates but it potentially has a role in lung transplant recipients and recipients of hematopoietic stem cell transplants. Transbronchial biopsy may increase the yield for the diagnosis of infectious etiologies such as invasive viral and fungal infections, and may assist in establishing an alternate noninfectious cause of infiltrates in these patients (104–106).
The benefits versus risks, including life-threatening pneumothorax and bleeding, need to be individualized in the critically ill immunocompromised patient.

In immunocompromised and critically ill patients who are suspected to have an atypical infection, BAL fluid should be sent for cytopathology to evaluate for viral cytologic changes, as well as for fungal organisms and Pneumocystis jirovecii. Alternatively, Papanicolaou, Giemsa, toluidine blue O, or direct fluorescent antibody staining may be used for detection of Pneumocystis.

For Pneumocystis in AIDS patients, BAL has a sensitivity rate in diagnosing Pneumocystis pneumonia of approximately 85% to 90%, and for transbronchial biopsy, the diagnostic yield approaches 87% to 95%. When BAL and transbronchial biopsy are performed in AIDS patients with Pneumocystis pneumonia, the diagnostic yield is 95% to 98% (107–110). Given the high yield of BAL and the potential risk of transbronchial biopsy in critically ill patients, transbronchial biopsy is not recommended in AIDS patients for diagnosing Pneumocystis. In immunocompromised patients without HIV, the yield of BAL is lower, and transbronchial biopsies to establish a diagnosis may be required. Although not used routinely in clinical practice, PCR for Pneumocystis on BAL specimens may increase diagnostic rates (111).

The criteria for proven fungal disease except for endemic mycoses, based upon the European Organization for Research and Treatment of Cancer/National Institute of Allergy and Infectious Diseases Mycoses Study Group (EORTC/MSG) criteria, rely upon visualization of fungal organisms on histopathologic or cytopathologic specimens or culture positivity from a normally sterile site (112). The criteria for probable invasive fungal disease except for endemic mycoses, in addition to radiographic criteria, include detection of mold on BAL/PSB cytology or culture. For the diagnosis of pulmonary fungal infections in immunocompromised patients, BAL fluid should be sent for fungal stains and cultures in addition to cytology stains. However, BAL cytology, microscopic examination, and culture tend to have low sensitivity. As noted, demonstration of fungal organisms on transbronchial lung biopsies is diagnostic of invasive fungal diseases, however, many patients with hematologic malignancies and recipients of hematopoietic stem cell transplants will not be candidates for transbronchial biopsies due to thrombocytopenia; the utility of biopsies in these patient populations is controversial. If transbronchial biopsies are obtained, the samples should be sent for culture in addition to histology. Some fungi, such as Mucor and Rhizopus, are difficult to grow in culture, and diagnosis relies on BAL cytology or biopsy specimens. Aspergillus is the most commonly encountered pulmonary fungal infection; BAL cytology and culture are diagnostic in approximately 50% to 60% of cases of invasive pulmonary aspergillosis. The diagnostic yield from BAL appears to be increased with the use of galactomannan antigen and PCR testing in small studies (113–115), however, a recent large single-center prospective cohort showed poor sensitivity and specificity of BAL galactomannan assay in diagnosis of invasive fungal diseases (116). Although duration of antifungal treatment prior to bronchoscopy has not been reported in all studies, the use of mold-active antifungal therapy for 2 to 3 days prior to bronchoscopy may decrease the sensitivity of BAL galactomannan (117,118). The presence of [1,3]-beta-D-glucan in BAL may be suggestive of pneumocystis, but the low positive predictive value limits its use in the diagnosis of invasive fungal pneumonia (119). Antigen testing for histoplasmosis and blastomycosis on BAL samples is now available (120).

To evaluate for viral infections, multiplex PCR is available and widely used for a comprehensive panel of respiratory viruses and atypical bacteria including Legionella pneumophila, Chlamydia pneumoniae, Mycoplasma, and Bordetella pertussis, and has significantly improved in detection of a pathogen (121,122). BAL cytology may demonstrate characteristic intracytoplasmic inclusions, but sensitivity is lacking. Immunofluorescence and PCR for cytomegalovirus (CMV) may be performed on BAL specimens (123).

If there is suspicion for tuberculosis or nontuberculous mycobacteria, BAL samples should be sent for acid-fast bacillus stains and mycobacterial culture. BAL samples of sputum smear-negative patients with tuberculosis are smear positive in 12% to 42% of patients and culture positive in 66% to 95% (124). In one-third to one-half of initially sputum smear-negative patients, bronchoscopy specimens yield the only positive source of mycobacterial tuberculosis (125–127). Nucleic acid amplification testing (NAAT) on BAL specimens for detection of mycobacterial tuberculosis and nontuberculous mycobacterial infection is routinely used in some institutions (128,129). NAAT for the diagnosis of tuberculosis is very sensitive and specific in patients with BAL smear-positive samples. In a meta-analysis of NAAT on BAL samples that are smear negative, the pooled sensitivity was 54% (130). Thus, a negative NAAT on a BAL sample that is smear negative does not exclude the diagnosis of tuberculosis.

For atypical bacterial infections, additional stains and cultures may be required. Legionella requires specific culture media; a direct fluorescence antibody stain is also available for Legionella. Some laboratories utilize specific media if Nocardia is suspected, and this agent can often be identified with a combination of Gram stain and modified Ziehl–Neelsen stains, and are observed as delicately branched, weakly gram-positive, variably acid-fast bacilli. Methenamine silver stains may demonstrate the organisms in tissue specimens.

**Diagnosis of Noninfectious Pulmonary Infiltrates**

Although most helpful in excluding infectious etiologies for pulmonary infiltrates in ICU patients, bronchoscopy with BAL and/or transbronchial biopsy may be able to establish the etiology of noninfectious infiltrates in some patients (131,132). In some cases, surgical lung biopsy will be required to make a definitive diagnosis. The appearance of the BAL and a cell count and differential on the BAL fluid can be helpful in suggesting a diagnosis. A bloody BAL that does not decrease, or increases in the degree of blood return with serial fluid aliquots, is diagnostic of alveolar hemorrhage. This can be confirmed with iron staining that demonstrates hemosiderin-laden alveolar macrophages. BAL fluid that has a milky or whitish, cloudy appearance with flocculent debris that settles to the bottom of the container is suggestive of pulmonary alveolar proteinosis. Additional support for this diagnosis is provided with a positive periodic acid–Schiff (PAS) stain. The diagnosis of pulmonary alveolar proteinosis can be confirmed with transbronchial or surgical lung biopsy. A BAL with a differential count greater than 25% eosinophils is virtually diagnostic...
of eosinophilic lung disease. In the patient with acute respiratory failure, this finding will most commonly be due to acute eosinophilic pneumonia, although parasitic lung infections such as strongyloidiasis rarely have a similar presentation. A finding of over 25% lymphocytes on BAL differential is suggestive of sarcoidosis, hypersensitivity pneumonitis, drug reaction, or viral infection.

Transbronchial biopsy can confirm the above diagnoses in most cases. In addition, transbronchial biopsy may be able to establish other noninfectious diagnoses of pulmonary infiltrates in the ICU including idiopathic interstitial pneumonia and graft versus host disease (GvHD) in stem cell or bone marrow transplant patients, leukemic infiltrates, drug-induced pneumonitis, bronchiolitis obliterans organizing pneumonia/cryptogenic organizing pneumonia (BOOP/COP), bronchoalveolar carcinoma, lymphangitic carcinomatosis, and acute rejection after lung transplantation.

**Traumatic Airway Injury**

The classic signs of tracheobronchial disruption include shortness of breath, massive subcutaneous emphysema, persistent pneumothorax despite chest tube insertion, and a large air leak after tube thoracostomy. On occasion, however, only subtle signs exist, even in the presence of significant injury. Flexible bronchoscopy should be performed early in any patient with chest trauma in whom airway injury may have occurred (133). Signs and symptoms of tracheobronchial injury are listed in Table 38.4. Tracheobronchial disruption rarely occurs as an isolated injury (134); a history of a rapid deceleration injury, such as a motor vehicle accident with the patient’s chest striking the steering wheel or dashboard, is typical. The pathogenesis of tracheobronchial rupture in blunt chest trauma is caused by shearing, wrenching, or compressive forces, acting alone or in concert. Rapid deceleration results in shearing forces, acting predominantly at the distal trachea near the carina where the relatively fixed trachea joins the more mobile distal airways (135,136). If the trachea and mainstem bronchi are crushed between the chest wall and vertebral column and the glottis closed, airway pressure suddenly increases, and resultant rupture of the airway may occur (134).

In patients with tracheal or bronchial disruption, early bronchoscopy can reliably detect the site of airway injury (137–142). Prompt diagnosis and surgical correction of tracheobronchial disruption produces a better outcome, as delay in diagnosis is usually detrimental to the patient (134). Patients with partial tracheal or bronchial disruption may be relatively asymptomatic and present with a paucity of physical findings. Delays in diagnosis unfortunately are common and have been associated with decreased frequency of successful repair. Failure to diagnose disruption may result in a delayed stricture formation at the site of injury, resulting in dyspnea, distal atelectasis, and chronic recurrent infections.

If an airway injury is suspected, flexible bronchoscopy should be performed through an ETT prepositioned on the bronchoscope to assess tracheal or bronchial disruption. If a persistent BPF exists because of proximal airway trauma, the cuff of the ETT sometimes can be positioned just distal to the rupture site and inflated, and adequate ventilation can be established before surgical repair. Cervical tracheal rupture is less common than rupture of the intrathoracic trachea. Cervical tracheal rupture, however, may be more difficult to diagnose once the patient is intubated because of the proximal location of the tear, and may itself be an impediment to intubation (143).

### Bronchopleural Fistula

In patients who are not candidates for surgical management of a BPF, flexible bronchoscopic techniques may offer alternative methods for closure of the BPF. Detection of a proximal BPF due to stump breakdown after lobectomy or pneumonectomy or a BPF due to bronchial dehiscence is usually relatively straightforward, as these abnormalities can be directly visualized. In the setting of a BPF due to a rent or tear on the lung periphery, locating the bronchial segment that provides ventilation to that area of the lung can be more difficult. Several techniques can be employed by bronchoscopy to localize the proximal endobronchial site of the fistulous tract. Occasionally, air bubbles can be seen emanating from the segmental bronchus. Washing the suspected segment with normal saline and coughing may accentuate the bubbling. A balloon-tipped catheter, such as a Fogarty catheter or a single-lumen right heart catheter, can be passed through the working channel of the bronchoscope and selectively positioned in suspect segmental bronchial orifices that lead to the peripheral fistula. After positioning the catheter in the suspect segment, the balloon is inflated to occlude the orifice, and the bronchoscopist then looks for cessation of bubbling in the water seal chamber of the pleural drainage unit (137). The lack of bubbling after balloon inflation confirms that the bronchial segment has been occluded and allows the BPF to heal.

Successful endobronchial occlusion of BPFs has been reported with cyanocrylate-based tissue adhesives (Histoacryl, Bucrylate), fibrin sealants (Tissseal, Hemaseal, thrombin plus fibrinogen or cryoprecipitate), synthetic hydrogel (Coseal) (144), absorbable gelatin sponge (Gelfoam), vascular occlusion coils, doxycycline and blood, Nd:YAG laser, silver nitrate, and lead shot (145–147). The agent initially seals the leak by acting as a plug and subsequently induces an inflammatory process with fibrosis and mucosal proliferation permanently sealing the area. Of these techniques, the uses of cyanocrylate tissue adhesives and fibrin sealants have been most widely reported.

Airway stents may be used to cover and seal the fistula in selected patients, depending on the location of the fistula. BPFs...
due to breakdown of a stump after lobectomy or pneumonec- 
tomy or bronchial dehiscence after lung transplantation or 
bronchoplastic procedures are the most amenable to successful 
closure with airway stenting. More recently, the successful 
closure of BPFs using bronchoscopic placement of endobronchial 
valves designed for emphysema has been described (148–150).

**Foreign Body Removal**

Risk factors for foreign body aspiration include age younger 
than 3 years, altered consciousness, trauma, and disordered 
wallowing mechanisms. Although occurring less frequently 
in adults than in children, tracheobronchial foreign bodies are 
problematic in adults (151,152). Patients may present with 
dyspnea, coughing, wheezing, or stridor. Foreign body aspira-
tion may be relatively occult with no obvious history for aspir-
ration. Radiographically, there may be evidence of atelectasis, 
bronchiectasis, or recurrent pneumonitis.

Bronchoscopy to remove an aspirated foreign body should 
be performed by an experienced bronchoscopist. For pediat-
ric patients, the foreign body may be successfully extracted 
via flexible bronchoscopy. For most situations, however, the 
rigid bronchoscope remains the instrument of choice in young 
children and infants (152). In adults, flexible bronchoscopy 
has clearly been shown to be an effective diagnostic and 
therapeutic tool in cases of suspected foreign body aspira-
tion (151,153,154). Several extraction devices are available 
for use through the flexible bronchoscope (155). Biopsy for-
ceps, graspers, and foreign body baskets are most commonly 
employed. Large foreign bodies may be extracted by applying 
continuous suction and withdrawing the bronchoscope with 
the foreign body adhered to the tip of the scope. Compared 
with rigid bronchoscopy, flexible bronchoscopy offers an 
enhanced visualization of the more peripheral airways, can 
be performed at the bedside, and averts the need for general 
anesthesia and operating room facilities. Occasionally, com-
bined flexible and rigid bronchoscopy are required to enhance 
retrieval of the foreign body.

**Inhalation Injury**

Exposure to fire or smoke in an enclosed environment puts the 
patient at risk for thermal airway injury. Patients with singed 
nasal hairs, facial burns around the nose or mouth, oral/naso-
pharyngeal burns, carbonaceous sputum, or hoarseness should 
be suspected of having an upper airway injury. Stridor, whee-
zing, or other manifestations of upper airway symptomatol-
ogy may imply impending ventilatory failure. In patients with 
suspected inhalation injury, flexible bronchoscopy should be 
performed early by an experienced bronchoscopist to iden-
tify evidence of thermal airway injury. Flexible bronchoscopy 
allows direct examination of the supraglottic and infraglottic 
areas. The need for intubation should be anticipated and an 
ETT placed over the bronchoscope before examining the air-
ways. If intubation is deemed necessary, the bronchoscope can 
function as a guide for ETT placement. Serial examinations may 
be necessary in patients with apparent minimal thermal airway 
injury on initial evaluation (156). Signs indicating impending 
airway obstruction include inflammation, edema, ulceration, 
or hemorrhage of the upper airway mucosa (156–159).

By using flexible bronchoscopy, inhalation injury can be 
classified into acute, subacute, and chronic phases. In the acute 
stage, upper airway obstruction from mucosal edema and 
respiratory failure from pulmonary edema and hemorrhage 
are the main characteristics. Soot deposition in the airways and 
carbon monoxide poisoning also may be found. The subacute 
stage, which lasts from hours to several days, is manifested 
by necrosis of the tracheobronchial mucosa, hemorrhagic trac-
heal bronchitis, persistent pulmonary edema with or without 
hemorrhage, and secondary infection. Scarring and stenosis of 
the tracheobronchial tree with formation of granulation tis-
sue, as well as bronchiectasis due to bronchiolitis obliterans, 
are the hallmarks of the chronic stage. Flexible bronchoscopy 
may offer significant utility in identifying these three stages of 
significant injury (160).

In the intubated patient, repeat airway examination by 
bronchoscopy may be necessary before extubation to ensure 
airway patency and resolution of the supraglottic or laryngeal 
edema. The ETT can be withdrawn over the bronchoscope 
while inspecting the airway mucosa and replaced if the airway 
is compromised (161).

**Acute Upper Airway Obstruction**

Causes of upper airway obstruction include epiglottitis, bilat-
eral vocal cord paralysis, laryngeal edema, and foreign body. 
In the pediatric patient, subglottic stenosis secondary to croup 
should also be considered. Flexible bronchoscopy can be 
helpful to make a diagnosis in these circumstances. Flexible 
bronchoscopy may be particularly helpful for diagnosis and 
therapeutic intubation in upper airway obstruction after burn 
and smoke inhalation injury and trauma to the face and neck. 
The flexible bronchoscope affords immediate direct visualiza-
tion of the upper airway and, if performed with an ETT placed 
over the bronchoscope, affords visualization and guidance for 
endotracheal intubation. If epiglottitis is suspected, it may be 
prudent to perform bronchoscopy in the surgical suite, with 
the surgical team available for emergency tracheostomy in case 
of failure. When performing bronchoscopic intubation in sus-
pected upper airway obstruction, the nasotracheal approach 
may be preferable because the turbinates offer stabilization 
and a more controlled approach to the area of acute airway 
obstruction (162). Flexible bronchoscopic intubation in upper 
airway obstruction may be performed in the sitting position 
with decreased posterior displacement of the epiglottis over 
the compromised upper airway as compared with laryngo-
scopic examination in the supine position. If foreign body 
obstruction is known or suspected as the cause of the upper 
airway obstruction, rigid bronchoscopy may be the bronchos-
copy method of choice.

**Central Airway Obstruction**

Patients may develop impending or acute respiratory failure 
due to central airway obstruction from primary lung cancer 
or metastatic malignancies. Treatment for malignant airway 
obstruction from endoluminal tumor has typically consisted 
of Nd:YAG laser photoresection and metal or silicone stent 
placement, although endobronchial electrocautery or argon 
plasma coagulation has more recently been used in lieu of 
the Nd:YAG laser (163–165). Other modalities such as cryo-
therapy, photodynamic therapy, and brachytherapy have been 
used to treat malignant airway obstruction; however, there is 
a delay in airway patency after treatment with these therapies
and, as such, they may be less satisfactory in treating the patient with acute respiratory failure who would benefit from immediate airway patency. Airway obstruction from extrinsic tumor compression is typically treated with placement of metal or silicone stents.

Patients may also develop respiratory failure from benign causes, most commonly previous intubation or tracheostomy tube placement, causing a cicatrical stenosis with or without granulation tissue. Obstructive fibronidal tracheal pseudomembrane (OFTP) is reported to be a thick tubular rubber-like whitish pseudomembrane which usually develops at the site of previous ETT cuff and can result in acute upper airway obstruction after extubation (166). It is thought to be the precursor of tracheal ischemic injury by some and may result in postintubation tracheal stenosis. Flexible bronchoscopy is key to the diagnosis of OFTP. Reinflation and suction may be effective in removal of OFTP but rigid bronchoscopy may be needed for mechanical ablation in severely dyspneic patients (166). Patients who have an indwelling tracheostomy tube may also develop a fibrous stenosis or granulation tissue just beyond the tip of the tracheostomy tube, thereby causing airway obstruction. The granulation tissue may be resected with laser electrocautery therapy. The stenosis may be dilated with a rigid bronchoscope or balloon dilatation catheters. In selected patients, silicone stents may be placed after dilation. In general, metal stents should not be used for tracheal stenosis due to a higher complication rate and difficulty in removing the stent should problems develop.

**Status Asthmaticus**

The usefulness of bronchoscopy in patients with status asthmaticus is the subject of controversy (39,167). Success has been reported with bronchial lavage in patients with obstructive airway disease who could not be weaned from ventilatory support (168,169). Bronchial lavage may benefit selected mechanically ventilated patients with thick, tenacious secretions who are unresponsive to aggressive bronchodilator therapy (71,170). Mucous plugs impacted in airways may result in hypoventilation, hypoxemia, and air trapping with intrinsic positive end-expiratory pressure (auto-PEEP). The outer diameter of the bronchoscope should be at least 2 mm smaller than the lumen of the ETT to minimize these effects.

**Key Points**

- Bronchoscopy in the intubated patient may cause hypoventilation, hypoxemia, and air trapping with intrinsic positive end-expiratory pressure (auto-PEEP).
- End-tidal CO₂ monitoring use is recommended in patients where intracranial pressure is being tightly regulated.
- For bronchoscopic assisted intubation, the use of an oral intubating airway, such as the Williams Airway Intubator, the Ovassapian Airway, or the Berman Airway, may be helpful in successfully intubating the patient with a difficult airway.
- Bronchoscopy should be considered in all critically ill patients with hemoptysis, regardless of the degree of hemoptysis, to localize the site of bleeding and attempt to determine the underlying etiology.
- For the diagnosis of VAP, the use of bronchoscopic modalities remains controversial and is often institution dependent.
- A quantitative culture result of more than 10⁴ CFU/mL is considered diagnostic for pneumonia with BAL, while more than 10⁵ CFU/mL is considered diagnostic for pneumonia with PSB.
- A bloody BAL that does not decrease, or increases in the degree of blood return with serial fluid aliquots, is diagnostic of alveolar hemorrhage.
- Flexible bronchoscopy should be performed early in any patient with chest trauma in whom airway injury may have occurred.
- In patients with suspected inhalation injury, flexible bronchoscopy should be performed early by an experienced bronchoscopist to identify evidence of thermal airway injury.

**References**


