Atelectasis is a frequent complication seen in the ICU. Concern over prolonged atelectasis is that it may worsen hypoxemia through shunting and may predispose the patient to nosocomial pneumonia. Traditionally, the treatment of atelectasis in ICU patients has focused on suctioning with adjuncts such as chest physiotherapy and bronchoscopy. Recently, newer modalities such as kinetic beds, therapy with mucolytic agents, mechanical vibration therapy delivered through hand-held devices, and vests to manage atelectasis have been added to the physician’s armamentarium. However, little research has been aimed at helping the practitioner choose among the disparate therapies for their patients. This review seeks to answer the following three questions focusing specifically on the role of bronchoscopy in the treatment of acute atelectasis in the ICU:
1. Is bronchoscopy effective in resolving atelectasis?
2. Is bronchoscopy superior to other means of resolving atelectasis?
3. Is bronchoscopy safe in these critically ill patients?

**Materials and Methods**

We performed a MEDLINE search from 1966 to July 2002 and a search of the PubMed database using the terms bronchoscopy, atelectasis, ICU, and critical illness. Bibliographies of identified articles were reviewed for further references. We excluded non-English language and nonhuman studies. Review articles were examined for their bibliographies. Original research was then systematically evaluated.

**Is Bronchoscopy Effective?**

The use of bronchoscopy for atelectasis and for clearing retained secretions has become commonplace in the ICU over the last 30 years. For example, in a review by Lindholm and colleagues, they investigated 52 patients who had undergone 71 fiberoptic bronchoscopy (FOB) procedures in ICUs in Sweden and Pittsburgh. Sixty-six percent of their patients were receiving mechanical ventilation at the time of the FOB, although no other patient information was provided. When secretions were seen on FOB, then 43 of 53 patients (81%) demonstrated improvement on the follow-up chest radiograph (CXR). If secretions were not seen on FOB, then only 4 of 18 patients (22%) demonstrated improvement.

In 1977, a report from the University of Kansas studied 43 bronchoscopic lavages in six patients who were receiving mechanical ventilation with atelectasis seen on a CXR. No obvious mucus plugs were observed during FOB. They found that after 81% of the bronchoscopic lavages there was a significant increase in the PaO2/PaO2 ratio. Furthermore, they were able to demonstrate an increase in static lung compliance after 63% of their procedures. They argued that lavage adds to bronchoscopy in cases of atelectasis without obvious central plugging.

In one of the larger studies of bronchoscopy for atelectasis, Stevens et al. studied 297 FOBs that had been performed in 223 ICU patients. They defined improvement as a decrease in the alveolar-arterial oxygen gradient or improved aeration on examination or CXR at 24 h. Of the 118 patients in whom bronchoscopies were performed for atelectasis demonstrated on a CXR, 93 (79%) improved. However, of the 70 patients in whom bronchoscopy was performed for retained secretions, only 31 (44%) improved following the procedure.

**Table 1—Case Series of FOB for Atelectasis**

<table>
<thead>
<tr>
<th>Study/Year</th>
<th>FOBs, No.</th>
<th>Patient Characteristics</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindholm et al/1974</td>
<td>71 in 52 patients with CXR opacities</td>
<td>66% mechanically ventilated, diagnoses not provided</td>
<td>If secretions seen: 43/53 (81%) resolved; if no secretions: 4/18 (22%) resolved</td>
</tr>
<tr>
<td>Weinstein et al/1977</td>
<td>43 with lavage in 6 patients with CXR atelectasis or retained secretions</td>
<td>Medical ICU patients receiving ventilation</td>
<td>35/43 (81%) improved PaO2/PaO2; 27/43 (63%) improved lung compliance</td>
</tr>
<tr>
<td>Stevens et al/1981</td>
<td>118 for atelectasis, 70 for retained secretions</td>
<td>Patients in ICUs, 65% were ventilated, diagnoses not provided</td>
<td>93/118 (79%) of those with atelectasis and 31/70 (44%) of those with retained secretions had improvement in P(A-a)O2 or resolution on CXR or improved aeration on examination</td>
</tr>
<tr>
<td>Snow and Lucas/1984</td>
<td>35 for lobar atelectasis, 9 for subsegmental atelectasis</td>
<td>Surgical ICU patients, 46% were ventilated</td>
<td>31/35 patients (89%) with lobar atelectasis had radiographic improvement; 5/9 patients (56%) with subsegmental atelectasis</td>
</tr>
<tr>
<td>Olopade and Prakash/1989</td>
<td>90 for atelectasis and retained secretions</td>
<td>Surgical and medical ICU patients, 76% were ventilated</td>
<td>17/90 patients (19%) improved either in oxygenation or on CXR</td>
</tr>
</tbody>
</table>

*P(A-a)O2 = alveolar-arterial oxygen pressure difference.
Snow and Lucas\textsuperscript{5} documented their experiences in the surgical ICU of Case Western Reserve Hospital. They performed 76 bronchoscopies on 51 patients, with 35 performed due to lobar atelectasis and 8 performed due to subsegmental atelectasis. Those patients with lobar atelectasis fared significantly better, with 89\% achieving resolution on follow-up CXR compared with 56\% of those with subsegmental atelectasis.

Finally, Olopade and Prakash\textsuperscript{1} looked retrospectively at the experience of FOB for atelectasis in the Mayo Clinic ICU. Ninety bronchoscopies were performed for atelectasis and retained secretions. Interestingly, only 17 patients (19\%) had an improvement in either oxygenation or CXR by 72 h. It is not entirely clear why the Mayo Clinic experience was inferior to those of the other studies. The authors suggested that in their ICU, stable surgical patients with atelectasis are taken to the operating room for bronchoscopy, and thus were not included in their analysis. Furthermore, they stated that their patients might be “sicker” than others, however, objective criteria were not provided to confirm this contention.

Across numerous series, bronchoscopy has been shown to be moderately effective in removing retained secretions and improving atelectasis, with a wide range of success rates (19 to 89\%) depending on the characteristics of the subgroups analyzed. The studies suggest that a subgroup of patients with lobar atelectasis may respond better than those with retained secretions or subsegmental atelectasis. This is likely because these are the patients that presumably have large central plugs that can be removed by bronchoscopy. Additionally, these studies have suggested that BAL may be of additional benefit for clearing more distal mucous plugs. However, most of the studies did not state whether BAL was added to bronchoscopy \textit{a priori}, so the additional benefits seen in the series by Weinstein et al\textsuperscript{4} using pulmonary lavage cannot be confirmed. Unfortunately, all of these series are hampered by large variations in the study populations. Additionally, these series did not scrutinize other methods of airway clearance, such as chest physiotherapy, which limits the conclusions that can be drawn about the benefits of bronchoscopy as a treatment of atelectasis.

Some authors have advocated the use of insufflation in addition to standard bronchoscopy for the treatment of atelectasis (Table 2). The idea of insufflation is based conceptually on the idea that while mucus plugs may lead to atelectasis, their removal may not be sufficient to correct the defect. Instead, some authors advocate the addition of high pressures to overcome the high critical opening pressure and reduced lung compliance of the atelectatic lung. The idea was first introduced in 1974 by Bowen et al\textsuperscript{6} when they described using a balloon-cuffed rigid bronchoscope. They fitted a rigid bronchoscope with a balloon cuff, the bronchoscope then was positioned either in the main or lobar bronchus of the affected lung, and the cuff was inflated. An attached anesthesia bag was subsequently inflated to 50 to 75 cm H\textsubscript{2}O for 5 to 10 s. This was repeated several times until reexpansion of the lung was seen. They were successful in lung reexpansion in 15 of 15 patients.\textsuperscript{6}

Later, a new technique utilizing a balloon-tipped catheter through a flexible bronchoscope was introduced.\textsuperscript{7} Some groups also designed a cuffed bronchoscope that could be designed to isolate the affected bronchi and to deliver high pressures distal to the bronchoscope.\textsuperscript{8,9}

Tsao et al\textsuperscript{10} described a simpler method of lung insufflation through a flexible bronchoscope. They attached a three-way adaptor to the suction port of a bronchoscope. One port was used to introduce room air from an ambu bag, and the other port was used to connect a pressure gauge that was used to monitor peripheral airway pressure during insufflation. The bronchoscope then was wedged into each segment or subsegment of the collapsed lung, and room air was rapidly insufflated into the segment to a pressure of 30 cm H\textsubscript{2}O, or 10 cm H\textsubscript{2}O higher than previous airway pressure, and was maintained for 1 to 2 min.

### Table 2—Case Series of Insufflation Added to FOB

<table>
<thead>
<tr>
<th>Study/Year</th>
<th>Procedure</th>
<th>Patients</th>
<th>FOBs, No.</th>
<th>Success Rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowen et al\textsuperscript{6}/1974</td>
<td>Balloon cuffed rigid bronchoscope</td>
<td>Postbronacotomy</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Millen et al\textsuperscript{6}/1978</td>
<td>Balloon cuffed flexible bronchoscope</td>
<td>An acute quadriplegia postangiogram and paraplegic with pneumonia</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Lee and Wright\textsuperscript{7}/1981</td>
<td>Swan-Ganz catheter through a flexible bronchoscope</td>
<td>ICU patients</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Harada et al\textsuperscript{8}/1983</td>
<td>Balloon cuffed flexible bronchoscope</td>
<td>Surgical ICU patients</td>
<td>15</td>
<td>93</td>
</tr>
<tr>
<td>Tsao et al\textsuperscript{10}/1990</td>
<td>Wedged flexible bronchoscope</td>
<td>Medical and surgical ICU patients</td>
<td>14</td>
<td>86</td>
</tr>
<tr>
<td>Haenel et al\textsuperscript{1}1/1992</td>
<td>Wedged flexible bronchoscope</td>
<td>Surgical ICU patients</td>
<td>17</td>
<td>82</td>
</tr>
<tr>
<td>Van Heerden et al\textsuperscript{2}/1995</td>
<td>Wedged flexible bronchoscope</td>
<td>Medical and surgical ICU patients</td>
<td>10</td>
<td>70</td>
</tr>
</tbody>
</table>
They performed this procedure 14 times and had complete resolution of atelectasis on CXR immediately 12 of those times. Of the two patients whose lungs did not reexpand immediately, the condition of one eventually resolved with chest therapy and the other responded to a repeat bronchoscopy with insufflation. No complications were noted.

This procedure was utilized in two other studies with equally good success. Haenel et al\(^\text{11}\) used a similar apparatus to deliver oxygen-enriched gas to a pressure of 40 cm H\(_2\)O. They noted partial or complete reexpansion in 14 of their 17 patients (82%). The complications that they observed were mild hypotension with premedication in one instance and a rise in the intracranial pressure (ICP), which quickly returned to baseline, in another. Finally, another group in the Netherlands replicated the procedure and accomplished lung reexpansion in 7 of 10 patients (70%) without any complications.\(^\text{12}\)

Another alternative approach with selective insufflation is the use of a 7.5F balloon-tipped catheter with a wire without bronchoscopy that is guided under fiberosscopic into the affected subsegmental bronchi.\(^\text{13}\) Air then was delivered several times through a 60-mL syringe (pressure not monitored). Eighteen patients underwent the procedure, of whom 15 patients experienced full lung expansion and 3 had partial expansion with no complications. The authors thought that the benefit of this technique over others was that the balloon could be placed more distally and the insufflation could be more localized, decreasing the dispersion of pressure to unaffected parts of the lung, which may actually worsen the pressure on the atelectatic area, causing it to remain closed.

Thus, insufflation may be of additional benefit to bronchoscopy. However, the estimates of resolution are similar to those with bronchoscopy alone, and, since few if any of these studies performed bronchoscopy alone first and proceeded to insufflation only when that failed, we cannot be certain that there is truly a significant benefit. Furthermore, although no complications were seen in these series, there are at least theoretical concerns for real complications such as pneumothorax or dissection of forced air into vessels leading to air embolism. Given these possible risks, the additional benefit of these techniques needs further study.

**Is Bronchoscopy More Effective Than Other Techniques for Airway Clearance?**

Multiple other modalities have been advocated for the prevention and treatment of atelectasis, the most common of which is chest physiotherapy. However, the components of chest physiotherapy that are most effective have been debated. One study\(^\text{14}\) found that chest percussion and postural drainage did not add significantly to the efficacy of deep breathing and coughing for the treatment of acute atelectasis. Another study\(^\text{15}\) compared hyperinflation and suctioning alone to the addition of vibrations and positioning, and found that these increased the resolution rate from 8 to 60%. The mechanisms for delivering the percussion and positioning have become increasingly sophisticated with the addition of hand-held vibration devices, theravests, and kinetic beds with percussion capability. The effects of the positioning and percussion of the kinetic bed has been studied by Raoof et al. They randomized patients to either a kinetic bed with a 45\(^\circ\) rotation on either side and 20 min of percussion delivered mechanically every 4 h vs manual repositioning and chest percussion every 2 h by the nursing staff. They found that 14 of 17 patients (83%) with the combined kinetic and percussion therapy had some degree of resolution of atelectasis, as opposed to 1 of 7 patients (14%) in the standard-therapy group. Of note, they stated that the control group did not receive therapy every 2 h as ordered, but the actual frequency of treatments was not provided.

Given that chest therapy at least with the addition of vibration and probably positioning is effective in treating atelectasis to approximately the same degree as seen with bronchoscopy, is one superior to the other? Only one study has addressed this question. Marin et al\(^\text{17}\) performed a randomized controlled trial of an aggressive chest physiotherapy regimen vs bronchoscopy with lavage for the treatment of acute atelectasis. They took 31 consecutive inpatients with a variety of medical and surgical diagnoses with acute lobar atelectasis and randomized 14 of those patients to emergent bronchoscopy and then chest therapy every 4 h for 48 h and 17 of those patients to chest therapy alone every 4 h and a bronchoscopy at 24 h if the atelectasis had not improved. Their chest therapy regimen started with deep breathing to total lung capacity for 3 min or multiple inflations of 1 to 2 L with an anesthesia bag if the patients were intubated. Then either coughing or tracheal suctioning was performed. Finally, the patients used a saline solution nebulizer followed by 4 min of chest percussion therapy and postural drainage to the involved area. They found no significant difference in the rate of atelectasis resolution with bronchoscopy vs chest therapy at either 24 or 48 h. In fact, the improvement noted immediately after bronchoscopy was the same as that seen with the initial chest percussion therapy. For both groups, approximately 80% of volume loss on the CXR was restored by 24 h. They did find, however, that the
presence of air bronchograms on the initial CXR predicted significantly delayed resolution of atelectasis by either method.

**Is Bronchoscopy Safe in Critically Ill Patients?**

There are several ways that bronchoscopy might adversely affect the critically ill patient. Studies have examined the effects of FOB on respiratory mechanics, blood gas levels, the cardiovascular system, and ICP.

Lindholm et al\(^{18}\) studied the cardiorespiratory effects on bronchoscopy in a variety of patients. A subgroup of 35 patients who were receiving mechanical ventilation was evaluated. Intratracheal pressure readings measured at the end of the bronchoscope were shown to have higher inspiratory pressures (range, 18 to 60 cm H\(_2\)O; mean \([\pm SD]\), 33.7 ± 11.5) that remained positive at the end of expiration. These measurements of positive end-expiratory pressure were > 18 cm H\(_2\)O in eight patients and as high as 35 cm H\(_2\)O in one patient. The investigators calculated a significant decrease in cross-sectional area when passing a bronchoscope through an endotracheal tube. For example, a 5.7-mm diameter bronchoscope through an 8.0-mm endotracheal tube reduces the cross-sectional area by 66%. The elevated airway pressures during inspiration combined with high positive end-expiratory pressure may place a patient at an increased risk for barotraumas.

Matsushima et al\(^{19}\) studied the respiratory mechanics of 30 patients undergoing bronchoscopy, with half of the procedures performed on intubated patients through an 8.0-mm endotracheal tube. As seen in Figure 1, vital capacity during bronchoscopy falls as less ventilation is delivered to the patient. Forced residual capacity, however, increases due to incomplete exhalation.\(^{19}\) These counterbalancing forces may explain why hypoxemia often is not profound during the procedure. However, once the bronchoscope is removed, the functional residual capacity falls but the vital capacity remains transiently lower, and thus oxygenation may paradoxically worsen after the procedure is complete. Not noted in the Figure 1, but seen in their study, was a rather dramatic decrease in the midexpiratory phase of forced expiratory flow, which remained low post-procedure, raising a question about the induction of bronchospasm with bronchoscopy.

In the same study by Lindholm et al\(^{15}\) that was noted above, the effects of changes in respiratory mechanics on arterial blood gas levels were demonstrated. Significant decreases in PaO\(_2\) can been seen during bronchoscopy, and this decline was especially more pronounced as the duration and amount of suctioning was increased. Additionally, the PaCO\(_2\) demonstrated a corresponding increase during the procedure. The authors noted that the hypoxemia eventually normalized back to baseline in all patients but that it took 15 min to normalize in patients with healthy lungs and several hours in those patients with parenchymal disease (Fig. 2). The PaCO\(_2\) was even slower to normalize (not shown).

Also notable in this study was the 50% rise in cardiac output seen during bronchoscopy.\(^{18}\) Other authors have corroborated this finding. In a prospective study by Trouillet et al\(^{20}\) of bronchoscopy in 107 ICU patients receiving mechanical ventilation, there was a 40 to 50% average rise in heart rate. Systolic BP significantly decreased after sedation prior to the

---

**Figures**

**Figure 1.** Changes in pulmonary function with bronchoscopy. Functional residual capacity (FRC) increases, while vital capacity (VC) decreases. Alveolar oxygen concentration decreases during the procedure but returns to near normal after the procedure. Adapted from Matsushima et al.\(^{19}\)

**Figure 2.** Tidal volumes and alveolar oxygen concentrations fall during bronchoscopy but return to near normal by 15 min postprocedure. Adapted from Lindholm et al.\(^{15}\)
start of the procedure and then significantly increased during the bronchoscopy itself.\textsuperscript{20} The combination of increases in cardiac output, heart rate, and BP all combine to increase myocardial oxygen demand and raise the possibility of inducing cardiac ischemia in patients who are at risk. One study\textsuperscript{21} looked at ECG tracings during bronchoscopy and found that 17\% of patients $>$ 50 years of age had ST-segment changes that were consistent with ischemia during the procedure, although all patients were asymptomatic.

Early studies demonstrated marked elevations of ICP during bronchoscopy.\textsuperscript{3} One recent study confirmed this, noting elevations of ICP in 81\% of patients with ICP monitors in place from an average of 12 mm Hg to as high as 38 mm Hg.\textsuperscript{22} These changes were all transient and occurred despite heavy sedation, paralysis, and tracheal anesthesia. Unfortunately, this sedation did not allow mental status examinations, so the clinical significance of brief rises in ICP was not demonstrated.

These physiologic perturbations can be large, but are they clinically significant? What is the incidence of morbidity and mortality from bronchoscopy in critically ill patients? Given the uncertainty of the utility of bronchoscopy and the natural history of atelectasis, we cannot determine that the morbidity and mortality in these patients had bronchoscopy not been performed. Combining seven of the larger series of bronchoscopies in ICU settings, no deaths occurred in 1,150 procedures.\textsuperscript{1} Complications did, however, occur. Trouillet et al\textsuperscript{20} studied a mixture of 107 medical and postsurgical patients who were receiving mechanical ventilation and were undergoing bronchoscopy because of a suspicion of the presence of nosocomial pneumonia. The authors excluded those patients with severe hypoxemia (ie, \( P_{aO_2} < 60 \text{ mm Hg} \) on a fraction of inspired oxygen of $\geq 0.8$), hypotension (ie, systolic BP, $< 85 \text{ mm Hg}$) or an endotracheal tube of $< 7.0 \text{ mm}$. They then followed hemodynamic and respiratory measurements during bronchoscopy to look for complications. Their procedures lasted an average of 120 $\pm$ 41 s. Thirty-three percent of their patients experienced a fall in \( P_{aO_2} \) of $> 30\%$, and 6\% had major arrhythmias (tachyarrhythmias, four patients; bradycardia, one patient; multiform ventricular arrhythmia, one patient). These estimates are similar to those reported in older studies.\textsuperscript{1,23}

CONCLUSIONS AND RECOMMENDATIONS

Bronchoscopy for atelectasis appears to be effective in patients who demonstrate lobar or segmental atelectasis. It is likely to be a less effective modality in patients who exhibit subsegmental atelectasis or air bronchograms on CXRs. Drawing further conclusions about its use is not justified given the lack of consistency in study designs. There is not enough evidence to determine whether bronchoscopy is more effective than alternate mechanisms of airway clearance in the intubated ICU patient, as only Marini and colleagues\textsuperscript{17} directly compared bronchoscopy to an alternate method of clearance. Their study demonstrated that the results of bronchoscopy may be equivalent to those of an aggressive chest physiotherapy regimen.

There are a paucity of data regarding other methods of airway clearance in the ICU patient population. Therapy with mucolytic agents, percussion vests, kinetic beds, and bronchoscopy with insufflation all await further study. We believe that these studies are necessary given that bronchoscopy in critically ill patients is not without risk. The effects of bronchoscopy in the critically ill patient include worsened hypoxemia, hypercapnia, elevation of end-inspiratory pressure and end-expiratory pressure, and hemodynamic instability. Worsening of cardiac ischemia and elevations of ICPs have been demonstrated. The clinical significance of these changes has not been adequately assessed.

Although bronchoscopy is a commonly performed procedure for the treatment of atelectasis in the ICU, the literature does not support its indiscriminate use. Success rates in the most favorable patient populations may reach 79 to 89\%. However, those patients with subsegmental disease have significantly lower success rates that may not justify its use. Additional studies are needed to further delineate the proper role of bronchoscopy in the ICU.

REFERENCES