Chest Physical Therapy for Patients in the Intensive Care Unit

Chest physical therapy is used in the intensive care unit (ICU) to minimize pulmonary secretion retention, to maximize oxygenation, and to reexpand atelectatic lung segments. This article reviews how chest physical therapy is used with patients who are critically ill. A brief historical review of the literature is presented. Chest physical therapy treatments applicable to patients in the ICU are discussed. Postural drainage, percussion, vibration, breathing exercises, cough stimulation techniques, and airway suctioning are described in detail, with current references. The importance of patient mobilization is emphasized. The advantages of chest physical therapy over therapeutic bronchoscopy also are discussed. Two patient examples are used to demonstrate the beneficial effects that may be obtained with chest physical therapy. Following the removal of retained secretions, arterial oxygenation and partial pressure of arterial oxygen/fraction of inspired oxygen concentration ratios improved, and atelectasis resolved without the negative hemodynamic side effects of therapeutic bronchoscopy. Physical therapists trained in the ICU can safely perform chest physical therapy with the majority of patients who are critically ill. [Ciesla ND. Chest physical therapy for patients in the intensive care unit. Phys Ther. 1996; 76:609–625.]

**Key Words:** Airway suctioning, Breathing exercises, Bronchial hygiene, Cardiopulmonary, Chest physical therapy, Cough, Intensive care units, Postural drainage, Thorax.

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The purpose of this article is to review the role of chest physical therapy in the intensive care unit (ICU). Treatments are described and critiqued for utility in the ICU. The ICU is a unique environment, and patients are frequently mechanically ventilated and have multiple invasive lines and drainage tubes that are needed to optimize hemodynamic status. Pulmonary artery, intracranial, and central venous pressures are routinely monitored. Chest physical therapy is often necessary due to retained secretions following intubation and immobility. Some physicians advocate volume-controlled mechanical ventilation or mandatory synchronized intermittent ventilation, whereas others recommend pressure support and pressure control modes. In my experience, mobilization of patients treated with intermittent positive pressure ventilation and ventilator adjustments are permitted before or during chest physical therapy to enable them to tolerate turning and mobilization.

Chest physical therapy usually consists of postural drainage, percussion, vibration, coughing and cough stimulation techniques, breathing exercises, suctioning, and patient mobilization. In my experience, mobilization that includes side-to-side turning, transfer training, and ambulation while ventilating the patient with a manual resuscitator bag (MRB) usually minimizes the need for postural drainage with manual techniques. The forced-expiration technique, active cycle of breathing, positive expiratory pressure, autogenic drainage, and use of a flutter valve are newer airway clearance techniques that appear to be beneficial for cooperative patients with chronic sputum-producing diseases such as cystic fibrosis. The focus of this article is the adult patient in the ICU who is frequently intubated, receiving supplemental oxygen, and unable to follow complex instructions. Breathing exercise techniques, therefore, for patients with less acute chronic sputum-producing disease are not discussed.

**Historical Review**

Studies of chest physical therapy did not occur until the 1950s when Palmer and Sellick and Thoren studied 352 patients following gastrectomy, hernia repair, and cholecystectomy. These authors demonstrated that postural drainage, percussion and vibration, breathing exercises, and coughing were more effective at reducing postoperative pulmonary complications including atelectasis and pneumonia than either no treatment or breathing exercises alone.

The study of the effects of chest physical therapy on arterial oxygenation, oxygen consumption, total lung/thorax compliance, cardiac output, and airway resistance was possible in the 1970s due to the routine use of mechanical ventilation and hemodynamic monitoring. Mackenzie et al demonstrated radiological improvement without hypoxemia in 47 patients with multiple trauma who received chest physical therapy and were mechanically ventilated with positive end-expiratory pressure (PEEP). The fraction of inspired oxygen concentration (FIO₂) was not altered during chest physical therapy for these patients. Chest physical therapy improved lung/thorax compliance in 42 patients with atelectasis, pneumonia, lung contusion, and adult respiratory distress syndrome (ARDS) who were mechanically ventilated following trauma. Airway resistance was unchanged immediately following and for 2 hours after chest physical therapy. Mackenzie and colleagues concluded, therefore, that chest physical therapy most likely affects the small airways rather than large airways in adult patients with traumatic injuries. Even in patients with unstable vital signs following severe multiple trauma, chest physical therapy has been shown to assist in the resolution of left lower-lobe atelectasis and to improve arterial oxygenation. Investigators also have noted that suctioning decreases the saturation of venous oxygen (Svo₂) due to increased oxygen consumption when there is an inadequate increase in cardiac output. Klein et al demonstrated an increase in cardiac output with chest physical therapy, which returned to baseline within 15 minutes of the procedure.

Only two research groups have examined the effect of chest physical therapy on the resolution of acute primary pneumonia. Outcome variables included duration of fever, radiographic clearing, hospital stay, and mortality. Graham and Bradley demonstrated no difference in the resolution of pneumonia for 27 patients treated with intermittent positive pressure breathing (IPPB) and chest physical therapy compared with a control group of 27 patients. Britton and colleagues studied 177 patients. Outcomes were the same for the control group, which received advice on deep breathing and coughing, and for the study group, in which postural drainage, manual techniques, and breathing exercises were used. In both studies, the majority of patients received antibiotics. Patients with nosocomial pneumonia, however, were not included in either study. Patients who were intubated, patients who had undergone thoracic or upper abdominal surgery,
Clinical examination and data gained from ventilation-perfusion scans, computerized tomography, magnetic resonance imaging, and portable radiographs are used to determine an indication for chest physical therapy. Monitoring in the ICU and pulse oximetry allow continuous assessment of patients' vital signs and oxygen saturation before, during, and after treatment. Unfortunately, because studies evaluating treatment techniques are limited, clinicians have frequently extrapolated the outcomes from studies of patients with chronic disease or patients who are mobile to patients in the ICU who are immobilized and mechanically ventilated. For example, Sutton and colleagues studied eight patients with copious sputum production (five patients with bronchiectasis, two patients with chronic bronchitis, and one patient with cystic fibrosis) who were not in the ICU and concluded that tracheobronchial clearance is unaffected by adding vibration shaking or percussion to postural drainage with the forced-expiration technique. Early ambulation following gallbladder and cardiac surgery has almost eliminated the need for chest physical therapy in these patients unless comorbidities are present. Whether the positioning therapy recommended by Dean and colleagues contributes to the resolution of acute atelectasis is unknown. The resolution of acute atelectasis (37%–83%) demonstrated with postural drainage and manual techniques, however, has been shown to be equally as effective as therapeutic bronchoscopy for the treatment of acute lobar atelectasis and has been studied in the ICU. The use of chest physical therapy without regard to the patient population or condition for which it is prescribed, and with no standard definition of treatment components, has led, in my opinion, to numerous negative reports on the efficacy.

### Efficacy of Chest Physical Therapy in the Intensive Care Unit

The efficacy of chest physical therapy can be determined by a reduction in the incidence of pulmonary infection or an improvement in pulmonary function. The mortality rate from nosocomial pneumonia remains high and ranges from 30% to 60%. Other benefits of chest physical therapy may include decreased duration of mechanical ventilation and prevention of tracheostomies—benefits that reduce cost and shorten hospital stays.

The diagnosis of pneumonia in the critical care setting is difficult. The clinical criteria used to diagnose pneumonia include the presence of fever, purulent sputum, leukocytosis, a Gram stain showing many polymorphonuclear cells and a single morphologically distinct organism, and a new pulmonary infiltrate on chest radiograph. Patients in the ICU meeting these criteria may respond to chest physical therapy without antimicrobial therapy. Joshi and colleagues studied 39 patients with trauma (32 patients were intubated) who met the criteria for diagnosis of pneumonia, at which time chest physical therapy was initiated. Within 3 days of chest physical therapy, 31 of the 39 patients showed complete or partial clearing of pulmonary infiltrates and did not require antimicrobial therapy. Overuse of antibiotics can result in toxicity, emergence of resistant strains of bacteria, superinfections, and increased hospital costs. For some patients in the ICU, the response to chest physical therapy can differentiate the diagnosis of atelectasis from pneumonia and can be used to determine which patients require antimicrobial therapy.

Although activities in the ICU, including chest physical therapy, have been reported to increase metabolic rate up to 35%, the use of short-acting narcotics usually diminishes any associated hemodynamic instability. The importance of an increase in oxygen consumption and carbon dioxide production, which return to baseline within 15 minutes, is questionable. Therefore, most patients in the ICU who tolerate turning will tolerate the positioning necessary for chest physical therapy.

### Indications for Treatment

Many authors have described the inappropriate use of chest physical therapy. For example, the American Association of Respiratory Care’s clinical practice guideline for postural drainage considers recent spinal surgery, rib fractures, and bronchopleural fistulas to be contraindications for postural drainage. This approach may be a result of prescribing therapy without a clear-cut indication for treatment (Tab. 1) or of the health care provider not having the training to position the patient with neurologic and orthopedic injuries or the skills to assess the patient’s breath sounds, vital signs, and ability to cough. I believe that the patient’s level of mobility is

### Table 1.

<table>
<thead>
<tr>
<th>Indications for Chest Physical Therapy</th>
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<tr>
<td>Evidence of retained secretions (blood or sputum) not removed by suctioning, coughing, and turning</td>
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<tr>
<td>Radiological evidence of acute atelectasis or infiltrate</td>
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<td>Decrease in PaO&lt;sub&gt;2&lt;/sub&gt; or SpO&lt;sub&gt;2&lt;/sub&gt; as a result of secretion retention</td>
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<tr>
<td>Prophylactic Use</td>
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<td>Acute neurological diseases affecting the innervation of the intercostal, diaphragmatic, or abdominal muscles</td>
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<tr>
<td>Smoke inhalation</td>
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<td>Acute moderate to severe brain injury</td>
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often not considered in the initial patient assessment by non-physical therapists. I have found that patients who adequately clear secretions with side-to-side turning, mobilization, and suctioning do not need postural drainage with manual techniques. In my experience, chest physical therapy is frequently administered to both lungs without directing therapy to the anatomic area of lung involvement, is not continued until secretions reach the upper airway, or is not terminated when the patient stops producing secretions. The presence of chronic sputum-producing lung diseases, with the exception of cystic fibrosis, does not warrant chest physical therapy unless another indication for treatment (Tab. 1) or recurrent pneumonia is present.

**Chest Physical Therapy Components**

Mucociliary activity and an effective cough are needed for normal airway clearance. Viscous secretions, the presence of a cuffed tracheal tube, dehydration, hypoxemia, immobility, and poor humidification of gases impede mucociliary clearance, causing secretion retention. Neurologic conditions and pharmacologically induced paralysis affecting the innervation of the glottis or intercostal and abdominal muscles may diminish airflow, resulting in an ineffective cough. Patients in the ICU usually have one or more of these conditions. The treatment techniques used in the ICU are similar to those advocated by Thoren more than 40 years ago. Postural drainage, percussion, vibration, coughing, suctioning, breathing exercises, patient mobilization, and sometimes manual lung inflation are the usual treatments used to remove secretions. The effectiveness of positioning alone to remove retained secretions is unknown. Most patients in the ICU cannot tolerate strenuous exercise programs. However, turning, suctioning, transfer training, and ambulation (with an MRB, if necessary) are integral parts of the chest physical therapy assessment and treatment and may minimize the need for postural drainage using manual techniques.

**Positioning**

The benefits of positioning versus postural drainage is often difficult to discern. Changes in ventilation-perfusion relationships with positional changes have been documented. Side-to-side turning decreases postoperative fever and improves oxygenation. Improvements in arterial oxygenation after patient positioning, including in patients with adult respiratory distress syndrome (ARDS), have been shown. Positioning patients for chest physical therapy with the "good lung down" is associated with improved ventilation-perfusion ratios and oxygenation. Patients with pathology in the superior, and frequently the atelectatic posterior, segments of the lower lobes may have better oxygenation with prone positioning than with supine positioning.

**Postural Drainage**

Postural drainage refers to placing the body in a position that allows gravity to assist drainage of mucus from the lung periphery to the segmental bronchus and upper airway. Eleven positions are commonly used to drain 14 lung segments. A detailed description of positioning the patient in the ICU is published elsewhere. Postural drainage enhances peripheral lung clearance, increases functional residual capacity, and accelerates mucus clearance. Postural drainage in conjunction with mechanical ventilation and PEEP is thought to increase transpulmonary pressure, improve ventilation-perfusion ratios, increase lung/thorax compliance of the non-dependent hemithorax, and reduce collateral airway resistance. Atelectasis may resolve more quickly when the patient is turned with the affected lung uppermost. Obese patients placed in the 15-degree Trendelenburg position after abdominal surgery for postural drainage of the lower lobes rarely demonstrate clinically significant oxygen desaturation. Transient decreases in oxygen saturation measured by pulse oximetry (Spo2) that occur with postural drainage positioning return to baseline within a few minutes. Therefore, most spontaneously breathing and mechanically ventilated patients tolerate positional changes necessary for segmental postural drainage. Infrequently, an increase in metabolic demand or worsening ventilation-perfusion ratios result in a decrease in oxygenation, insufficient gas flow, or low lung volumes. Increasing the patient's Fio2 or additional ventilator adjustments are therefore required prior to or during therapy. Positioning for postural drainage is usually continued once the patient has responded favorably to changes in ventilator settings. The duration of postural drainage may range from 15 to 60 minutes, depending on the patient's tolerance to changes in position and the amount of sputum production.

Cooperative, spontaneously breathing patients who can cough effectively may not need postural drainage. Johnson et al. found no difference in the resolution of atelectasis when postural drainage and percussion were added to deep breathing exercises in patients with acute lobar atelectasis, although the diagnoses and mobility level of the patients studied were not addressed.

**Patient Example #1**

The following example demonstrates improvement in both atelectasis and oxygenation after prone positioning and chest physical therapy. The patient was discharged 8 days after treatment was initiated. Although it was initially felt that this patient would require extracorporeal lung assistance to sustain life, after positioning and chest physical therapy this was not necessary.
A 33-year-old white man was admitted to a trauma center following a near-drowning accident. He had been submerged for approximately 20 minutes and had hypothermic cardiac arrest with 30 minutes of cardiac asystole. His admitting Glasgow Coma Scale was 3. The patient had a core temperature of 80°F. On admission to the hospital, he was rewarmed with gastric peritoneal lavage. During the initial hospitalization, the patient developed progressive respiratory failure requiring pressure-control ventilation with 36 cm of water pressure, 18 cm of water pressure of PEEP, and 100% of Fio₂. Due to severe ARDS and increasing airway pressures, the patient was transferred to a trauma center with expertise in extracorporeal lung assistance. Five days following the accident, the patient was transferred to the second trauma center. At this trauma center, computerized tomography and chest radiography demonstrated bilateral lower-lobe atelectasis and consolidation, with right pleural effusion without evidence of ARDS (Figs. 1, 2A).

To optimize ventilation and treat the bilateral lower-lobe consolidation, the patient was placed on a turning frame for prone positioning and chest physical therapy. Twenty-four hours following admission to the second trauma center, the patient was evaluated for chest physical therapy while pharmacologically paralyzed with metaxine and mechanically ventilated via an endotracheal tube. Coarse rales were noted over the posterior lung zones. The initial treatment consisted of postural drainage and percussion to the posterior basal segments of both lower lobes for 45 minutes with the patient in the prone head-down position. Less than 10 cc of sputum was obtained with suctioning. Following treatment, improved air entry was noted by auscultation.

After 5 days of treatment, the patient was placed on a regular bed due to the marked improvement in his respiratory status. Chest physical therapy was administered for 7 days and consisted of postural drainage, percussion, and vibration to the lower lobes (Tab. 2). Sputum production increased, with a gradual improvement in breath sounds and chest radiograph findings and marked improvement shown in computerized tomography scan (Fig. 3). The patient was extubated on day 8. Following extubation, the patient ambulated with assistance and had a good productive cough. Within 24 hours, the patient was discharged back to the original hospital, alert and oriented while following three-step commands.

Chest physical therapy and prone positioning were most likely responsible for reexpansion of this patient's collapsed lower lobes and for improved oxygenation, which in turn led to successful weaning from mechanical ventilation. The physicians and physical therapists involved with this patient did not know which intervention was primarily responsible for the patient's improvement. However, when faced with a patient with increasing airway pressures and secretion retention who is difficult to ventilate on 100% of Fio₂, simultaneous treatment using gravity to maximize ventilation-perfusion ratios and postural drainage with manual techniques to mobilize retained secretions appear to be indicated until further research demonstrates that positioning alone can be equally effective.

**Percussion and Vibration**

Percussion and vibration are the techniques most frequently recommended for the patient who is intubated and mechanically ventilated and for patients with impaired cognition or poor coughing ability. Percussion and vibration are used to enhance mucociliary clearance from both central and peripheral airways. The exact mechanism of action of chest percussion is unknown, but there is some evidence from animal models that physical stimulation alters airflow and is associated with the release of pulmonary chemical mediators, mediators that may improve ciliary transport speed by as much as 340%. Mucociliary flow is dependent on the viscoelastic property of mucus, the geometry of the airway, and the speed of airflow. Alterations in airway diameter and airflow may decrease the viscosity of mucus, making percussion more effective in mobilizing secretions that are adherent to the bronchial walls. Percussion with postural drainage has been used to remove mucus and aspirated teeth from patients who are medically too unstable to undergo bronchoscopy. This suggests that manual techniques can assist in clearing secretions from both the central and peripheral airways. Because of differences in aerosol deposition in the airways and no standardization of manual versus mechanical technique, controversy exists as to whether the radionuclide clearance noted with percussion and vibration indicates peripheral or central airway clearance. Manual percussion and vibration, when performed
with postural drainage, are thought to expedite drainage of secretions from the central and peripheral airways, which may reduce treatment time.\textsuperscript{65,66} This is particularly important for patients in the ICU who have periods of hemodynamic instability and require multiple diagnostic and therapeutic procedures. Both techniques are used with postural drainage.

Manual techniques should be applied only over the lung that approximates the chest wall with full inspiration.\textsuperscript{65} Commonly accepted anatomic landmarks for percussion and vibration include the level of the 10th thoracic vertebra posteriorly and the xiphoid process anteriorly with normal respiration. Posteriorly, the lower borders of the lung descend to T-12 with deep inspiration and rise to T-9 with forced expiration.\textsuperscript{65}

The lower lung borders may be two to three levels higher in patients with abdominal distention and in patients with liver or kidney disease. Lower lung borders can be assessed with auscultation and mediate percussion (percussion as part of the physical examination to determine the density of underlying structures). One lung segment, the medial segment of the right lower lobe, is not accessible to manual techniques because of its anatomic location. Percussion and vibration should be applied directly over the skin to allow the therapist to observe anatomic landmarks, skin redness, or petechiae, as well as chest tube and line insertion sites, and to detect undiagnosed rib and sternal fractures or the presence of subcutaneous emphysema (air in the subcutaneous tissue). The presence of, and any increases in, subcutaneous emphysema may be associated with a life-threatening pneumothorax. This condition should therefore be monitored closely, and the physician or nurse should be notified when airway pressures are increasing. The physician or nurse should also be notified when subcutaneous emphysema is increasing, as noted with palpation.

Redness or petechiae are usually a result of improper technique. For patients with thoracic abrasions or burns needing manual techniques, a sterile drape should be placed over the chest wall. When treating a patient with spinal injuries who is stabilized in either a halo vest or thoracic corset, the therapist opens the vest after the patient is placed in the appropriate postural drainage position. Opening the vest in this manner allows access to the thorax without disrupting spinal stabilization. For the patient with severe brain injury requiring intracranial pressure (ICP) monitoring, manual techniques are not contraindicated because they do not increase ICP.\textsuperscript{66,67} The force and frequency of manual percussion and vibration vary depending on the therapist's experience; whether a one- or two-handed technique is used; and the patient's pain tolerance, especially when rib fractures are present.

Percussion. Percussion is used during both the inspiratory and expiratory phases of respiration. The therapist's hand should create an air cushion, and the energy wave created by that hand is transmitted through the chest wall and is thought to dislodge secretions from the bronchial walls.\textsuperscript{65,66} Bronchospasm is the most frequently discussed adverse effect of percussion in patients with chronic bronchi\textsuperscript{69,70} Gallon\textsuperscript{71} noted that bronchospasm can be prevented when a forced-expiration technique or the active cycle of breathing is incorporated into chest physical therapy. Bronchospasm is rare in patients in the ICU who have undergone trauma or surgery. More often, particularly in patients with quadriplegia, wheezes are noted as secretions are mobilized from the lung periphery.\textsuperscript{72} Once the secretions are removed by coughing or suctioning, breath sounds improve.\textsuperscript{72} Patients with reactive airway disease may require inhaled bronchodilators prior to or following treatment.\textsuperscript{73} When bronchospasm persists as a result of

\begin{figure}[h]
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\caption{Computerized tomography scans showing (A) bilateral lower-lobe atelectasis and right pleural effusion and (B) improvement in bilateral lower-lobe atelectasis.}
\end{figure}
percussion, appropriate intervention should be implemented.

The optimal frequency and force of chest percussion are not known. Frequencies of 100 to 480 cycles per minute, producing 2 to 4 ft-lb (2.7–5.4 N·m) and 58 to 65 N of force on the chest wall have been reported. There is some evidence that both fast and slow percussion increase sputum production in patients with bronchiectasis and alveolar proteinosis. Gallon and Hammon (WE Hammon, PT, Chief of Rehabilitative Services, Oklahoma Memorial Hospital, Oklahoma City, Okla; personal communication) report that fast percussion (240 cycles per minute) demonstrated the greatest sputum production, although slow percussion (6–12 cycles per minute) was more effective than no percussion. Hammon reported that when large amounts of proteinaceous material are present in the alveoli, percussion is more effective than vibration (WE Hammon, personal communication). In patients in the ICU, the quantity of sputum produced has not been shown to correlate with improvements in pulmonary function. Differences in technique may account for discrepancies in therapy advocated in different parts of the United States.68,74

The use of percussion over rib fractures remains controversial. Extrapleural pathology, pneumothorax, and hemothorax that develop as a result of the initial injury should not be considered a contraindication to percussion. In a retrospective study of 252 patients with rib fractures who received chest physical therapy (including manual percussion), 24 patients developed extrapleural pathology. Ten of these patients developed extrapleural pathology before chest physical therapy was started, and 14 patients developed extrapleural pathology after chest physical therapy was started. There was no difference in the development of extrapleural hematomas between the patients who received manual percussion and those who did not receive manual percussion. Following treatment of more than 500 patients with rib fractures, physical therapists at the R Adams Cowley Shock Trauma Center (Baltimore, Md) have noted that patients who are intubated and who are being mechanically ventilated usually tolerate percussion in conjunction with analgesics and sedation. Greater alterations in intrathoracic pressure occur with coughing than with properly performed percussion. For patients with rib and sternal fractures, controlled mechanical ventilation may even stabilize the fracture site by minimizing negative intrathoracic pressures. The force and frequency of percussion can be modified to patient tolerance. Percussion is not indicated for the spontaneously breathing patient with rib fractures who is responding to breathing exercises and assistive coughing techniques.
adult patients in the ICU, use of these devices increases cost, does not reduce staffing requirements, and introduces the risk of cross-infection, without documented benefit over manual techniques. Although Radford and colleagues\(^7\) advocate mechanical percussion at 25 to 35 Hz, their research using an animal model has not been extended to human subjects. Mechanical devices, used with patients who have chronic pulmonary disease, offer no benefit over forced-expiration techniques combined with postural drainage.\(^78-80\) In patients with pulmonary alveolar proteinosis, manual percussion (180–270 cycles per minute) was almost twice as effective as mechanical percussion (36 Hz) in removing proteinaceous material from the alveoli.\(^81\) Recently, Hammon and McCaffree\(^82\) studied the effects of manual percussion, saline alone, and a commercially available pneumatic percussor on the removal of alveolar material in three patients with pulmonary alveolar proteinosis. Measurements of optical density were better with manual percussion than with saline alone or the pneumatic percussor.\(^82\) Although these results cannot be extrapolated directly to non-saline-filled lungs, they suggest that manual percussion is capable of removing secretions from the most distal airways and alveoli and is more effective than mechanical percussors, vibrators, or saline alone.

High-frequency chest compression (HFCC) has recently gained popularity as a means of enhancing mucus clearance in patients with cystic fibrosis.\(^60\) The patient wears an inflatable vest that covers any lung lobes affected with pathology. Frequencies are adjusted to optimize expiratory airflow and to maximize mucus clearance. Whitman and colleagues,\(^83\) however, found no increase in mucus clearance over traditional techniques in six patients who had been mechanically ventilated for 90 to 1,203 days. Percussion was applied for 2 minutes to five lung regions with postural drainage. No indications for treatment were stated other than that the patients were mechanically ventilated. The practicality of using HFCC with mechanical ventilation in the ICU is questionable when patients are at high risk for cross-contamination and access to the thorax is required for cardiovascular monitoring. Further study is needed to determine whether HFCC and use of a flutter valve facilitate mucus clearance from central and peripheral airways for patients who are critically ill and immobile.

**Vibration.** Vibration is a more forceful technique than percussion. At 12 to 20 Hz, vibration is similar to the normal beat frequencies of human cilia.\(^76\) The rib cage is "shaken" during the expiratory phase of respiration. Some clinicians define vigorous vibration as "rib shaking" or "rib springing."\(^17\) Vibration is used with both patients who are spontaneously breathing and patients who are mechanically ventilated. Secretions move into the upper airways when vibration is performed during bronchoscopy.\(^74\) Forceful vibration is not recommended over rib fractures, which may perforate the pleura and cause a pneumothorax, intrapleural bleeding, or an extrapleural hematoma. Some clinicians use a mild vibration of light, fast oscillations over rib fractures and report no adverse effects. Vibration in patients with thoracic spinal fractures should be mild and performed by clinicians trained in chest physical therapy techniques. Spontaneously breathing patients who are difficult to arouse (such as those with acute brain injury) may benefit from vibration to encourage deep inspiration and stimulate a cough. In my clinical experience, dysrhythmias are more likely to occur as a result of hemodynamic instability associated with positional change than as a result of the actual manual technique. Percussion and vibration adjacent to a cardiac electrode may produce artifacts. After consultation with nurses and physicians, electrodes can usually be repositioned or, in rare cases, temporarily disconnected. The therapist should then closely monitor the clinical status of the patient and any alterations in blood pressure or heart rate.

**Mechanical devices.** Mechanical percussors and vibrators were introduced in the late 1960s to permit patients with cystic fibrosis more independence with therapy. For
and the amount of pressure generated. This technique, often referred to as the “bag-squeezing method,” was introduced in the 1960s to prevent pulmonary segmental collapse, reexpand collapsed alveoli, minimize the risk of hypoxemia, and stimulate a cough in the patient who is intubated. Vibration is sometimes performed during the expiratory phase to enhance mobilization of secretions from the central airways. The additional tidal volume delivered, however, most likely reaches the most compliant lung zones and therefore expands normal rather than collapsed alveoli. Because the patient is removed from the ventilator, lung volumes, PEEP, flow rates, and FiO2 are not controlled. Novak and colleagues studied 16 patients with hypoxemic respiratory failure in a surgical ICU and were unable to demonstrate any improvement (<5 minutes) in gas exchange or pulmonary compliance with hyperinflations of 40 cm H2O of pressure for 15 to 30 seconds. Flow rates were not documented. Although Jones and colleagues found an increase in lung compliance for up to 2 hours in patients without pulmonary disease with bagging and percussion, the same results have been demonstrated with postural drainage, percussion, and vibration in patients with pulmonary pathology.

Hyperinflation may be hazardous in patients with severe ARDS, because high airway pressures and overdistension of normal alveoli may damage normal lung parenchyma and increase the quantity of lung tissue contributing to the respiratory distress syndrome. The effect of hyperinflation on cerebral perfusion pressure in patients with brain injury who are not medically paralyzed is unknown. Garrard and Bullock used ICP monitoring to study 20 patients with brain injuries. Prolonged manual hyperinflation with a 2-L rebreathing bag caused a 5-mm Hg increase in ICP in patients who were medically paralyzed and in patients who were not paralyzed. Because cerebral perfusion pressures were not reported, the clinical significance is unknown. Hyperinflation, with a plateau pressure of 80 cm H2O of pressure for 2 to 3 seconds, of 13 patients with severe brain injuries who were paralyzed and well-sedated did not decrease cerebral perfusion pressure. For patients who are mechanically ventilated, lung hyperinflation with vibration is associated with large fluctuations in cardiothoracic pressure, and the physiologic benefit is therefore questionable.

Coughing
Coughing removes secretions from the trachea, mainstem bronchi, and up to the fourth generation of segmental bronchi. Many patients spontaneously breathing in the ICU are unable to cough effectively because of respiratory muscle weakness, pain, or a decreased level of consciousness. Therapists working in the ICU, therefore, should be familiar with cough stimulating and assistance techniques. Compressing the trachea just above the sternal notch or huffing (after a maximal inspiration, the patient exhales several times quickly) is indicated when the patient has sufficient neuromuscular function of the respiratory and abdominal muscles. While huffing, the glottis remains open and intrathoracic pressure is lower than with coughing. When incisional pain is the limiting factor, support of thoracic and abdominal incisions and huffing are indicated. Upright positioning also improves cough pressures. Coughing is also enhanced by early tracheostomy removal, placing an airtight dressing over the tracheostomy stoma, and supporting the stoma site during expiration.

Loss of innervation of the intercostal and abdominal muscles decreases airflow in individuals with quadriplegia. Support and compression of the upper abdomen during expiration facilitates an effective, productive cough. Abdominal support and pressure during exhalation are necessary with injuries or diseases that result in abdominal muscle weakness that prohibits effective coughing.

Tracheal Suctioning
Tracheal suctioning is an integral component of chest physical therapy for the patient who is intubated. Deep suctioning is necessary for patients who cannot mobilize secretions to the proximal portion of the tracheal tube by coughing or huffing. Withholding suctioning may result in airway occlusion and hypoxemia. Because upper-airway secretions are most prevalent before and after a change in patient position and during or following chest physical therapy, the suctioning procedure should be timed with these interventions, particularly in patients who have difficulty tolerating the procedure.

Suctioning is a sterile procedure. Occupational Safety and Health Administration guidelines for exposure to blood and body fluids, therefore, must be followed. Eye protection, a mask for protection from bloody or mucus secretions, and sterile gloves should be worn. As part of the initial assessment, the therapist should evaluate the patient’s need for and response to suctioning. Airway suctioning frequently improves breath sounds and may lower airway pressures. When no segmental or lobar pathology is present, suctioning may be adequate and postural drainage with manual techniques may not be indicated. Patients who are intubated and who have a poor cough usually require tracheal suctioning. As with all physical therapy in the ICU, the patient’s vital signs should be assessed before, during, and after the procedure. Table 3 lists the most frequently cited complications associated with tracheal suctioning and the recommended interventions to minimize side effects.
Precautions and contraindications. Suctioning through an artificial airway of a patient with adequate oxygenation and stable vital signs has relatively few contraindications. Prior to suctioning the patient with unstable vital signs or a low SpO₂, the benefit of suctioning versus the risk of causing additional arrhythmias or desaturation should be weighed in consultation with medical and nursing staff. When coughing results from mechanical stimulation of the trachea caused by heavy ventilator tubing or a malpositioned tracheal tube, suctioning is not indicated. Appropriate treatment is to remove the stimulus triggering the coughing. For patients who have retained secretions, are unable to cough effectively, and have difficulty tolerating suctioning, suctioning should be timed with chest physical therapy to minimize the risk of hypoxemia.

Nasotracheal suctioning (suctioning through the nose into the trachea without an artificial airway in place) is contraindicated in the presence of stridor because of the increased risk of mechanical trauma to an edematous airway.64 Because the catheter may enter the brain, nasotracheal suctioning with basilar skull fracture, facial fractures, and known or suspected cerebrospinal fluid leaks is also contraindicated.64 Nasotracheal suctioning may result in apnea, laryngospasm, bronchospasn, and severe cardiac arrhythmias.67 Nasotracheal suctioning is recommended only when vigorous chest physical therapy, including prolonged postural drainage, cough stimulation techniques, and suctioning of the oropharynx, is ineffective and the medical team does not plan to intubate the patient.

Systems. Suctioning can be performed using either an open or closed system. When using an open system, the patient is disconnected from the mechanical ventilator and suctioned using a conventional catheter. The patient remains on the mechanical ventilator for closed-system suctioning. Closed-system suctioning is accomplished by using either a "port adapter" or the more recently introduced in-line suctioning.99,100 The recommended features of suction catheters are listed in Table 4.

Prior to suctioning a patient who is mechanically ventilated, the therapist should be aware of the washout time (the time necessary for the gas volume in the ventilator circuit to be replaced with gases at the higher FIO₂) of the ventilator in use.101 With current technology, the washout time may be as little as three to five breaths for ventilators such as the SERVO 900C.102
adapter may minimize the need for preoxygenation, therefore eliminating the potential hazards of exposure to 100% oxygen. A port adapter is recommended for patients who are mechanically ventilated patients and require a PEEP of >10 cm H2O and for patients who are at high risk for suction-induced arrhythmias and hypoxemia.99,105

Proponents of in-line suctioning report less oxygen desaturation than with an open system; however, the same results have been achieved by using a port adapter.99,106,104,106 Clinical impressions of in-line suctioning that need to be substantiated with further research include the following: (1) The catheter is more difficult to maneuver, (2) the additional weight of the catheter may increase tracheal damage, (3) higher inspiratory flow rates may be required, and (4) airway pressure may drop as a result with suctioning and intermittent mandatory ventilation (IMV).100,104,106

Preoxygenation is the most commonly used method for preventing oxygen desaturation.107,108 The mechanical ventilator or an MRB is used to inflate the lungs and increase the inspired oxygen concentration prior to suctioning. For patients who are mechanically ventilated, the ventilator is preferred over the MRB. Minute ventilation, PEEP, and FIO2 are all controlled, and there are no variations in lung volume, flow rates, and pressure based on the clinician's bagging technique.109,110 When using the ventilator, the second clinician who may be required when using an MRB is not needed. When using an MRB, the FIO2 varies from 33% to 100%, depending on flow rate, minute ventilation, and whether the bag has a reservoir.111,112

The majority of studies evaluating tracheal suctioning have compared the effects in patients who had cardiac surgery.107,108,111,112 Although hyperoxygenation is common practice, it may not be necessary for all patients. Based on my clinical experience, I believe that suction-induced hypoxemia may not be as significant in patients such as young patients with traumatic injuries but without cardiac disease. A suctioning protocol that encourages clinical judgment is recommended.114 When patients are hyperoxygenated prior to or during chest physical therapy, the effect of chest physical therapy on SAO2, SpO2, or partial pressure of arterial oxygen (PAO2) may be masked.

The most important indicators as to whether a patient will desaturate with suctioning are the resting SpO2 and the resting PAO2. Depending on the patient being suctioned, hyperoxygenation is recommended when the SpO2 is less than 90% (95% for high-risk patients). Hyperoxygenation also is recommended when the SpO2 drops below 85% during suctioning and does not return to baseline within 10 to 15 seconds and when the resting PAO2 is below 85 mm Hg.

Saline installation. Saline instillation is commonly used before and during trachael suctioning to "loosen" secretions.115 Saline instilled through a tracheal or endotracheal tube is not likely to reach the peripheral airways, where secretions are most prevalent.115 To be effective, the saline must pass through several generations of segmental bronchi and reach the terminal bronchioles and alveoli. Patients should, however, receive adequate systemic hydration and airway humidification rather than saline instillation.115,116 Patients with copious purulent secretions (eg, bronchiectasis) may require saline instillation to remove viscous secretions from the upper airways and tracheal tube.

Breathing Exercises

Once extubated, alert, and cooperative, the patient in the ICU may benefit from breathing exercises to increase tidal volume, improve thoracic-cage mobility, increase inspiratory capacity, enhance cough efficacy, and assist in removal of secretions.84 Breathing exercises are indicated in the ICU setting for patients with neuromuscular disease or injury affecting the respiratory muscles. Breathing exercises also are used when thoracic excursion is decreased as a result of retained secretions or pain or when a patient is immobile following surgery. Breathing exercises are not indicated during mechanical ventilation but may be used during weaning from mechanical ventilation.

There are several types of breathing exercises. Diaphragmatic breathing and lateral costal and segmental costal expansion exercises are used most often postoperatively.51 Use of a flutter valve, the forced-expiration technique—more recently referred to as the active cycle of breathing (huffing at various lung volumes interspersed with diaphragmatic breathing)—and autogenic drainage (using a sequence of breathing maneuvers at various lung volumes to optimize airflow within multiple generations of bronchi) are beneficial in patients with cystic fibrosis, although the efficacy of these procedures after surgery has not been determined.88,117 Inspiratory muscle training and resistive diaphragmatic breathing exercises may be beneficial while weaning the patient with quadriplegia or chronic obstructive pulmonary disease from the ventilator.118-120 Incentive spirometry is commonly used postoperatively, although it is no more advantageous or cost-effective than instruction in deep breathing and coughing.121 Following coronary artery bypass or gall-bladder surgery, breathing exercises offer no advantage over early patient mobilization.18-21
Patient Mobilization

Mobilizing the patient in the ICU is important, but the patient’s medical condition usually prohibits independent ambulation and vigorous activity. The severity of injury or disease and life-sustaining paraphernalia also usually limit mobilization of patients who are mechanically ventilated to dependent or stand-pivot transfers and active- and passive-range-of-motion exercises. Upright positioning of patients is encouraged to improve coughing and lung volumes, including functional residual capacity, and lung compliance. Patients who are difficult to wean from the ventilator frequently benefit from patient mobilization. Rehabilitative techniques are used while monitoring vital signs to note any alterations from baseline. The details of mobilizing the patient in the ICU are beyond the scope of this article but are described elsewhere.16,122

Chest Physical Therapy Versus Therapeutic Bronchoscopy

Several investigators62,123–126 have compared the efficacy of chest physical therapy versus therapeutic bronchoscopy for treatment of atelectasis and foreign-body aspiration. Both treatments are indicated for aspiration of blood, gastric contents, and foreign bodies. Lung congestion, lung abscess, smoke inhalation, and pneumonia also are indications for chest physical therapy or bronchoscopy. In the surgical ICU, chest physical therapy is recommended because it is less costly and less invasive for treatment of an atelectasis or infiltrate for 24 to 48 hours before therapeutic bronchoscopy or starting antibiotics (M Joshi, personal communication). Chest physical therapy can be performed regardless of tracheal tube size, as long as the appropriate-size suction catheter is used, and does not require physician participation. Chest physical therapy is directed to the area of peripheral lung pathology; during bronchoscopy, secretion removal is limited to the level of the segmental bronchus. Cardiac arrhythmias are reported with both procedures, although fatal dysrhythmias were noted only with bronchoscopy.126,127 The major fall in PaO₂ associated with bronchoscopy has not been seen with chest physical therapy.127,128

Several case studies129–131 have demonstrated a favorable response to chest physical therapy for lobar collapse when bronchoscopy was either too high-risk or unsuccessful. Raghu and Pierson132 reported successful removal, with chest physical therapy, of a tooth aspirated during intubation. Due to the patient’s life-threatening myocardial infarction, bronchoscopy was considered too invasive. There are two reports of the effectiveness of selective lung insufflation through a balloon-tipped catheter in expansion of collapsed lobes in patients with atelectasis who were unresponsive to chest physical therapy, but the treatment regimen was not described.132,133 Haenel and colleagues133 advocate use of a kinetic (rotating) bed that in itself prohibits postural drainage of the most frequently affected lower-lobe segments (posterior, superior, and lateral) and of the posterior segments of both upper lobes.

### Table 5

<table>
<thead>
<tr>
<th>Day/Time</th>
<th>Positioning/Chest Physical Therapy</th>
<th>Chest Radiograph Results</th>
<th>SaO₂</th>
<th>PaO₂/FIO₂ Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admission</td>
<td>Positioned supine on turning frame</td>
<td>Clear</td>
<td>99%</td>
<td>190/100</td>
</tr>
<tr>
<td>Days 1–2</td>
<td>Positioned prone four times and suctioned for copious secretions</td>
<td>Clear</td>
<td>99%</td>
<td></td>
</tr>
<tr>
<td>Day 3</td>
<td>Positioned prone 7½ hours, supine 9½ hours, suctioned for</td>
<td>5:20 PM, LLL atelectasis</td>
<td>96%</td>
<td>96/90</td>
</tr>
<tr>
<td></td>
<td>copious secretions prior to chest radiograph</td>
<td></td>
<td></td>
<td>106</td>
</tr>
<tr>
<td>Day 4, 12:15 PM</td>
<td>Turned into the right side-lying head-down position for</td>
<td>Left lung collapse</td>
<td>87%</td>
<td>53/100</td>
</tr>
<tr>
<td></td>
<td>segmental postural drainage of the posterior and lateral segments of the</td>
<td>(see Fig. 4)</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>LLL; percussion and vibration over appropriate segments while in the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>drainage position; copious viscid bloodtinged secretions suctioned; follow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ing a 45-minute treatment, auscultation revealed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>improved air entry over the LLL and lingula with expiratory wheezes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 4, 2:00 PM</td>
<td>Repeat chest radiograph</td>
<td>Left lung reexpanded</td>
<td>99%</td>
<td>420/100</td>
</tr>
<tr>
<td></td>
<td>(see Fig. 5)</td>
<td></td>
<td></td>
<td>420</td>
</tr>
</tbody>
</table>

SaO₂ = oxygen saturation measured by pulse oximetry; PaO₂ = partial pressure of oxygen, arterial; FIO₂ = fraction of inspired oxygen concentration; LLL = left lower lobe.
Patient Example #2
The following example demonstrates the development of a left lung collapse (Fig. 4) despite prone positioning and tracheal suctioning. Chest physical therapy that included postural drainage with percussion and vibration was necessary to reexpand the patient’s left lung. Chest physical therapy eliminated the need for therapeutic bronchoscopy, a more costly procedure with risks of hypoxemia and life-threatening cardiac arrhythmias.

A 22-year-old white man was admitted to the trauma center following a diving injury with a C-4 teardrop compression fracture. Neurological examination following American Spinal Injury Association Standards revealed incomplete sensory deficit (impaired sensation at C-6, C-7, T-3 to T-5, L-3, and all sacral segments). Motor level was C-4. The patient required mechanical ventilation for respiratory support. Table 5 describes the sequence of therapeutic positioning, airway suctioning, and the need for chest physical therapy due to an increasing left-lung atelectasis.

Following chest physical therapy, the patient’s Sao₂ increased from 87% to 99% and his PaO₂/FIO₂ ratio increased from 53 to 420. The patient’s FIO₂ was lowered from 100% to 40% within 24 hours of treatment. In addition, the left-lung atelectasis resolved immediately following 45 minutes of chest physical therapy, as noted in Figure 5. Prone positioning and suctioning did not prevent the secretion retention that resulted in collapse of the patient’s left lung.

Special Conditions
Table 6 summarizes the medical conditions commonly found in patients in the ICU, indications for chest physical therapy, and treatment guidelines.

Summary
This article provides a discussion of the literature relating to chest physical therapy, indications for treatment, and the rationale for its use in the ICU. Comparisons are made with therapeutic bronchoscopy and therapeutic positioning. The complications of tracheal suctioning are discussed as well as methods for minimizing hypoxemia, and the necessary features of suction catheters are described. Although patient mobilization and deep-breathing exercises with coughing can often replace postural drainage, percussion, and vibration, many patients in the ICU cannot be mobilized sufficiently to eliminate the sequelae of secretion retention due to the severity of injury or illness and the paraphernalia necessary to sustain life.

I believe that when a clear indication for chest physical therapy is present, it can be performed safely and effectively by clinicians who have received training in the ICU. I contend that the recommended treatment of lobar and segmental atelectasis is postural drainage with percussion and vibration in conjunction with airway suctioning for patients who are intubated. Further research is needed to assess the efficacy of manual hyperinflation in patients who are mechanically ventilated and the efficacy of therapeutic positioning without postural drainage and manual techniques.
Table 6. Chest Physical Therapy With Special Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased intracranial pressure</td>
<td>Maintain cerebral perfusion pressure &gt;50 mm Hg and ICP &lt;25 mm Hg in the head-down position; routine head-down positioning is limited to 15 min; head-down positioning should be restricted when it exacerbates an increase in a cerebrospinal fluid leak.</td>
</tr>
<tr>
<td>Coagulopathy</td>
<td>Determine cause; when copious bleeding occurs in the tracheobronchial tree, risk/benefit must be weighed; treatment is coordinated with other nursing interventions; suction carefully.</td>
</tr>
<tr>
<td>Bronchopleural fistula</td>
<td>Chest physical therapy is continued to decrease incidence of infection and enhance healing; avoid prolonged periods of time with affected lung uppermost with positive-pressure ventilation and PEEP, which may increase leakage through the fistula.</td>
</tr>
<tr>
<td>Spinal fracture</td>
<td>Vest may be opened after patient positioning; after stabilization, use head-down positioning as indicated by the patient's clinical condition.</td>
</tr>
<tr>
<td>Rib fractures</td>
<td>Avoid vigorous vibration.</td>
</tr>
<tr>
<td>Pulmonary embolus</td>
<td>Therapy is withheld until medical intervention.</td>
</tr>
<tr>
<td>Continuous arterial-venous hemodialysis</td>
<td>Avoid line occlusion; bed may need to be elevated to maximize flow.</td>
</tr>
<tr>
<td>Continuous venenous hemodialysis</td>
<td>Avoid line occlusion.</td>
</tr>
<tr>
<td>Peritoneal dialysis</td>
<td>Treatment is given while the dialysate is draining from the abdomen to minimize intra-abdominal pressure.</td>
</tr>
<tr>
<td>Extracorporeal lung assistance</td>
<td>Avoid line occlusion; ensure that flow is within preset guidelines.</td>
</tr>
<tr>
<td>Adult respiratory distress syndrome (ARDS)</td>
<td>Prone positioning may optimize oxygenation; may require evaluative treatment to determine whether the patient is productive of secretions or whether lung volumes and ( \text{SpO}_2 ) improve with manual techniques and postural drainage.</td>
</tr>
<tr>
<td>Extrapleural hematoma</td>
<td>Therapy may be restricted when the hematoma is expanding or the patient has a coagulopathy.</td>
</tr>
<tr>
<td>Pneumothorax, hemothorax</td>
<td>Treatment is initiated after chest tube placement has been confirmed radiologically.</td>
</tr>
<tr>
<td>Lung abscess, lung contusion</td>
<td>Follow treatment of involved lung lobe or segment with treatment of dependent area to minimize transbronchial aspiration.</td>
</tr>
</tbody>
</table>

*ICP=intracranial pressure; PEEP=positive end-expiratory pressure; \( \text{SpO}_2 \)=oxygen saturation measured by pulse oximetry.*

**Acknowledgments**

I acknowledge Bill Hammon, PT, Alex Sciaky, PT, CCS, and Susan Ludwig-Mihans, PT, for their critical review of the manuscript as it pertains to patients in the ICU. I thank Marianne Mars, PT, Jill Kuramoto, PT, and Faith Kousalis, PT, for their critique of the manuscript and for providing data for the case studies.

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