

# Secretion Management in the Mechanically Ventilated Patient

Richard D Branson MSc RRT FAARC

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### **Summary**

Secretion management in the mechanically ventilated patient includes routine methods for maintaining mucociliary function, as well as techniques for secretion removal. Humidification, mobilization of the patient, and airway suctioning are all routine procedures for managing secretions in the ventilated patient. Early ambulation of the post-surgical patient and routine turning of the ventilated patient are common secretion-management techniques that have little supporting evidence of efficacy. Humidification is a standard of care and a requisite for secretion management. Both active and passive humidification can be used. The humidifier selected and the level of humidification required depend on the patient's condition and the expected duration of intubation. In patients with thick, copious secretions, heated humidification is superior to a heat and moisture exchanger. Airway suctioning is the most important secretion removal technique. Open-circuit and closed-circuit suctioning have similar efficacy. Instilling saline prior to suctioning, to thin the secretions or stimulate a cough, is not supported by the literature. Adequate humidification and as-needed suctioning are the foundation of secretion management in the mechanically ventilated

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Richard D Branson RRT FAARC is affiliated with the Department of Surgery, Division of Trauma/Critical Care, University of Cincinnati, Cincinnati, Ohio.

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Correspondence: Richard D Branson RRT FAARC, Department of Surgery, University of Cincinnati, 231 Albert Sabin Way, Cincinnati OH 45267-0558. E mail: richard.branson@uc.edu.

patient. Intermittent therapy for secretion removal includes techniques either to simulate a cough, to mechanically loosen secretions, or both. Patient positioning for secretion drainage is also widely used. Percussion and postural drainage have been widely employed for mechanically ventilated patients but have not been shown to reduce ventilator-associated pneumonia or atelectasis. Manual hyperinflation and insufflation-exsufflation, which attempt to improve secretion removal by simulating a cough, have been described in mechanically ventilated patients, but neither has been studied sufficiently to support routine use. Continuous lateral rotation with a specialized bed reduces atelectasis in some patients, but has not been shown to improve secretion removal. Intrapulmonary percussive ventilation combines percussion with hyperinflation and a simulated cough, but the evidence for intrapulmonary percussive ventilation in mechanically ventilated patients is insufficient to support routine use. Secretion management in the mechanically ventilated patient consists of appropriate humidification and as-needed airway suctioning. Intermittent techniques may play a role when secretion retention persists despite adequate humidification and suctioning. The technique selected should remedy the suspected etiology of the secretion retention (eg, insufflation-exsufflation for impaired cough). Further research into secretion management in the mechanically ventilated patient is needed. *Key words: secretion management, heated humidification, heat and moisture exchanger, percussion, postural drainage, insufflation, exsufflation, airway suctioning, closed-circuit suctioning, saline instillation, manual hyperinflation, silver coated endotracheal tube, Mucus Shaver, Mucus Slurper, intrapulmonary percussive ventilation.* [Respir Care 2007;52(10): 1328–1342. © 2007 Daedalus Enterprises]

## Introduction

Secretion management in the mechanically ventilated patient consists primarily of adequate humidification and airway suctioning. The role of mechanical aids to improve cough and mobilize secretions is poorly defined and lacks supporting evidence in the intensive care unit (ICU). Even commonly performed procedures such as percussion and postural drainage have little support from the literature. This paper will review the evidence for secretion-management techniques in the mechanically ventilated patient and introduce some new techniques that are early in development.

### Secretion Retention in the Ventilated Patient

Mechanically ventilated patients are at risk for retained secretions from a myriad of causes. Endotracheal intubation disrupts the mucociliary escalator and predisposes the patient to infection,<sup>1,2</sup> which increases the volume and tenacity of mucus.<sup>3</sup> Relative immobility of the mechanically ventilated patient confined to bed can lead to atelectasis, impaired cough, and retained secretions.<sup>4</sup> Upper-abdominal and thoracic surgery frequently lead to postoperative atelectasis, weak cough, and secretion retention.<sup>5</sup> Muscle weakness associated with prolonged ICU stay may also contribute to secretion retention.<sup>6</sup> Finally, fluid status, particularly fluid restriction in the mechanically ventilated patient, may contribute to thickened secretions. When any or all of these coexist, the problem is compounded.

## Secretion Clearance Techniques

Management of secretions in the mechanically ventilated patient includes routine standard of care therapies such as humidification, suctioning, and mobilization. When these routine methods fail, intermittent therapy is employed, with a variety of techniques, to simulate a cough, loosen secretions, drain secretions via positioning, or a combination of the three. Common respiratory therapy techniques for mechanical loosening of secretions include manual percussion and high-frequency chest wall compression, with or without postural drainage. These techniques can be combined with hyperinflation, as is the case with intrapulmonary percussive ventilation. A simulated cough maneuver, with either manual hyperinflation or insufflation-exsufflation, may aid in expelling secretions in the patient with secretion retention and neuromuscular weakness. These will be addressed separately.

### Routine Secretion Management in the Ventilated Patient

#### Mobilization

“Up and out of bed” is a common postoperative order aimed at preventing atelectasis, stimulating cough, and improving circulation.<sup>7</sup> This common sense approach is widely practiced and uniformly supported, but has little scientific evidence.<sup>8</sup> Recently, Browning and colleagues found that in the first 96 postoperative hours the duration and quality of “up time” was poor, averaging only 3 min

on postoperative day 1. They also showed no difference in pulmonary complications based on the duration of up time.<sup>9</sup> Interestingly, greater duration of up time was associated with shorter stay. It remains to be proven if this is a cause-and-effect phenomenon or a “true, true, and unrelated” phenomena. It may simply be that patients who are improving tolerate more up time than their sicker counterparts. Another study suggested that early mobilization is equivalent to postoperative coughing and deep breathing,<sup>10</sup> which raises the question of whether these treatments are equally effective or equally ineffective.<sup>11</sup> Clearly, investigation of early postoperative ambulation is warranted.

## Humidification

Heating and humidifying the inspired gas is an established standard of care during mechanical ventilation,<sup>12,13</sup> but the minimum requirements and optimum devices and settings for humidification are less clear. The ability of any device, regardless of operation, to prevent drying of secretions depends on delivered gas temperature and relative humidity.<sup>14,15</sup> Absolute humidity is the amount of water vapor present in a gas. Relative humidity is the ratio of the absolute humidity to the maximum absolute humidity. Relative humidity is perhaps most important, as any deficit must be provided by the tracheobronchial tree.

Assessing the adequacy of humidification is difficult. A number of potential surrogates for comparing humidification techniques have been suggested, including secretion volume and consistency, incidence of endotracheal tube (ETT) occlusion, changes in ETT effective diameter and/or resistance, suctioning frequency, and requirement for normal saline instillation.<sup>14,16–18</sup> Measurements of secretion volume are inherently flawed. Secretion volume may change with the number of suctioning attempts, patient position, use of aerosolized medications, and saline instillation. Excessive humidification may cause an increase in secretion volume, and insufficient humidification may result in a decrease in secretion volume because mucus becomes encrusted in the airways.<sup>16</sup> In my experience, secretion volume measurements are poorly reproducible and often reflect the individual practice of the clinician rather than the condition of the patient, so secretion volume is not reliable for comparing secretion-management techniques.

### Heated Humidification Versus Heat and Moisture Exchanger for Humidification and Secretion Management.

A comparison of the ability of heated humidifiers versus heat and moisture exchangers (HMEs) to optimize secretion management requires measurable and reproducible variables. Those most frequently described are ETT occlusion and changes in effective inner diameter of the ETT resulting from encrusted secretions. Narrowing of the ETT

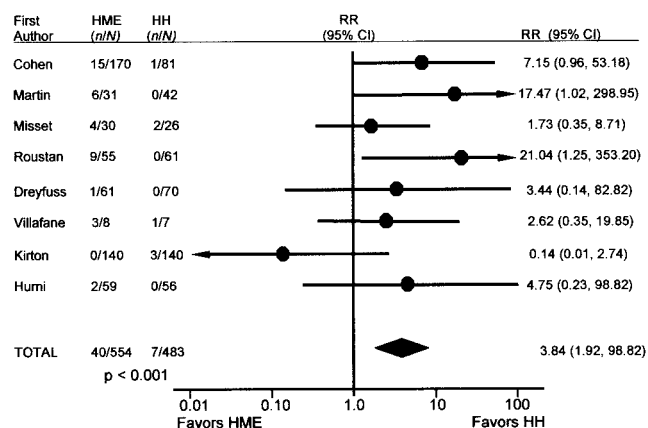


Fig. 1. Meta-analysis of risk of endotracheal tube occlusion with a heat and moisture exchanger (HME) versus with a heated humidifier (HH). RR = relative risk. (Adapted from Reference 33.)

and ETT occlusion have been described with both heated humidifiers<sup>19–21</sup> and HMEs.<sup>22–25</sup>

During use of a heated humidifier and heated-wire circuit, ETT occlusion is associated with an increase in gas temperature from the humidifier chamber to the patient. As gas temperature rises, relative humidity falls. Gas entering the ETT at a humidity deficit absorbs moisture from secretions in the ETT and large airways.<sup>19</sup> This problem can be avoided by maintaining a constant temperature from the chamber to the airway, and by using a connecting tube between the heated-wire circuit and the airway, which allows for cooling and a relative humidity of 100%. The problem of caregivers creating a large temperature difference between the chamber and the airway to reduce condensate in the heated-wire circuit, which increased the risk of ETT occlusion, undoubtedly led to introduction of heated humidifiers with no such clinician-set control.<sup>26</sup>

Occlusion of the ETT during HME use occurs secondary to poor HME performance, changes in ambient conditions, leaks, and patient conditions (eg, body temperature, minute ventilation, and fluid status).<sup>22–25,27,28</sup> HME performance plays a large role, and hygroscopic HMEs clearly outperform hydrophobic HMEs.<sup>29–31</sup> Even the most efficient HME allows a net loss of heat and moisture from the respiratory tract, so prolonged use is associated with a greater incidence of ETT occlusion. There is also evidence that HMEs are less effective in patients with chronic lung disease, although this is not well understood.<sup>32</sup>

Hess evaluated studies of HMEs and heated humidifiers with and without a heated-wire circuit, using a meta-analysis to determine the risk of ETT occlusion.<sup>33</sup> Figure 1 depicts the results of that analysis. The studies in that meta-analysis represent a cumulative total of over 1,000 patients and the analysis indicates that the risk of ETT occlusion is nearly 4 times greater with HME than with heated humidification. That finding argues against the use



Fig. 2. Heat and moisture exchanger nearly completely occluded by mucoid secretions.

of HMEs in patients with retained secretions, and for limiting HME use to < 5 days.

Another issue with HME use in patients with increased secretions is the possibility of occlusion of the HME. This has not been specifically studied, but frequent soiling of the HME has been reported as a trigger for switching to heated humidification.<sup>34</sup> In our experience, HMEs are most frequently occluded by blood or pulmonary edema fluid. However, in the presence of copious sputum production an HME can become completely or nearly completely occluded (Fig. 2).

A series of studies have compared the effects of humidification devices on in vivo and in vitro ETT resistance, inner diameter, and surface area.<sup>35–38</sup> In an early study, Villafane et al measured the effective inner diameter by measuring flow and pressure at the proximal ETT and threading a hollow catheter to the distal tip of the ETT. This allowed measurement of the pressure drop across the tube. They made these measurements in patients on a daily basis. Three groups of patients were studied: group 1 used a heated humidifier, group 2 used a hygroscopic HME, and group 3 used a hydrophobic HME. ETT resistance increased with duration of use in all 3 study groups, but the hydrophobic HME group had the highest resistance. Figure 3 shows these changes in 4 patients in that study.

Several authors have used acoustic reflectometry to evaluate changes in ETT inner diameter.<sup>36–38</sup> Boqué et al measured loss of effective inner diameter and found that within 48 hours > 60% of ETTs lost  $\geq 10\%$ . All patients used an HME.<sup>36</sup>

Shah and Kollef found similar losses of intraluminal surface area when they compared unused to used ETTs.<sup>37</sup> The most convincing evidence comes from Jaber et al, who used acoustic reflectometry to compare ETT volume and resistance over 10 days. Half the patients used heated humidifiers and half used HMEs. At day 5 there was no difference in the changes in ETT resistance. However, at day 10 the HME group had a  $19 \pm 18\%$  increase in resistance, compared to an  $8 \pm 12\%$  increase in the heated humidification group (Fig. 4). The authors concluded that ETT resistance increases with duration of use and that HMEs increase ETT resistance more than do heated humidifiers.<sup>38</sup>

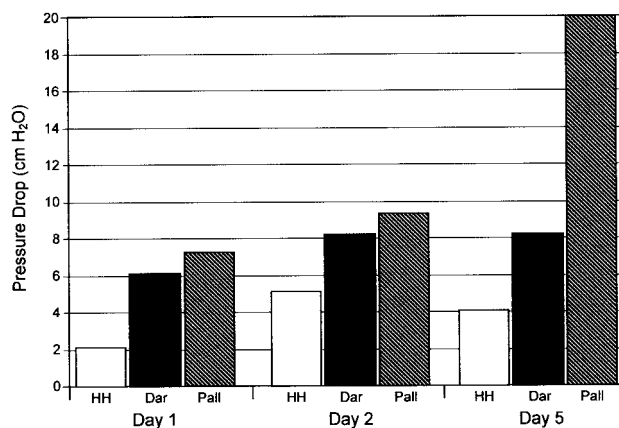


Fig. 3. Example of repeated pressure and flow measurements obtained from representative mechanically ventilated patients who received humidification via heated humidifier (HH) or one of 2 brands of heat and moisture exchanger (HME) (Dar Hygrobac 35254111, and Pall BB2215). (Data from Reference 35.)

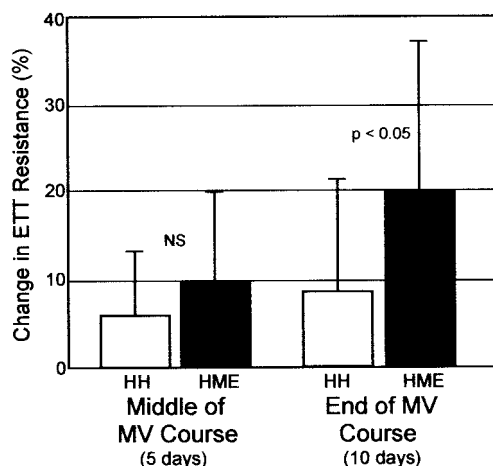


Fig. 4. Percent change in resistance of the endotracheal tube (ETT) at the middle and end of a 10-day course of mechanical ventilation (MV) with either a heated humidifier (HH) or a heat and moisture exchanger (HME). (Data from Reference 38.)

These findings are clinically important because several authors have described ETT resistance as a cause of weaning failure.<sup>39–41</sup> The findings also reinforce the concept that the selection of a humidification device should be based on the expected duration of use and the presence of thickened secretions.<sup>34</sup> In the mechanically ventilated patient with secretion-management issues (thick and/or copious sputum), heated humidification is preferred. When mechanical ventilation is expected to last more than 96 hours, a heated humidifier should be used from the outset.

#### Maintaining the Endotracheal Tube Lumen

Humidification maintains mucociliary function and assures that secretions remain hydrated so they can be ex-




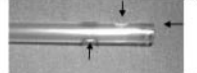

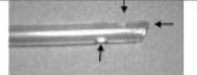

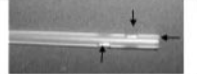

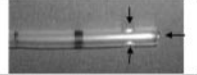

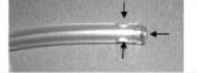
Catheter	Side hole diameter	Size	Whistle Design	Side Hole Design
Cardinal Tri-Flo	3 mm	14 Fr		
Kendall Regu-vac	4 mm, 6.35 mm apart	14 Fr		
Kendall Sensi-vac	5 mm, 9.52 mm apart	14 Fr		
Medline Delee	4 mm, 9.52 mm apart	14 Fr		
Medline Whistle Tip	4 mm	14 Fr		
Portex suction tray	4 mm	14 Fr		

Fig. 5. Comparison of catheters studied by Shah et al, showing the positions of the side holes and other design characteristics. (From Reference 45, with permission.)

pectorated. In the mechanically ventilated patient, the ETT cuff abruptly stops the mucociliary escalator. At this point the second most important secretion-management technique, suctioning, becomes required. The suctioning procedure may include pre-oxygenation and/or hyperinflation, depending on the technique. Suctioning methods include open-circuit suction, closed-circuit suction, and minimally invasive (or shallow) suctioning. One contentious issue in suctioning is instillation of normal saline either to loosen secretions or to stimulate a cough as an aid to secretion mobilization. Studies are also now being done on when to suction. These issues are reviewed below.

### Suctioning

Removal of tracheobronchial and upper-airway secretions to maintain airway patency and reduce the risk of silent aspiration is a standard of care.<sup>42,43</sup> Suction catheters differ greatly in design but have the same general characteristics. Most adult catheters are 48–56 cm in length, to allow the catheter to reach the mainstem bronchi. The distal tip of the catheter has several openings for secretion removal, and the proximal portion contains a thumb port that the practitioner occludes to activate the suction. The distal tip is blunt, to avoid trauma to the mucosa or perforation of the tracheobronchial tree. The side holes in the distal tip of the catheter also serve to minimize the risk of local tissue damage. If the catheter had only one opening at the distal end, the mucosa could be drawn into the catheter tip and torn during withdrawal of the catheter. Suction catheters should be transparent to allow visual inspection of secretions, rigid enough to pass through the ETT, yet pliable enough to traverse the airways without damaging the mucosa.

Few comparative evaluations of suction catheter designs have been accomplished.<sup>44,45</sup> Shah et al compared six 14 French suction catheters in a bench study that evaluated the characteristics (side-hole placement) that facilitated the removal of simulated mucus.<sup>45</sup> The viscosity of the simulated mucus was altered to represent thin and thick secretions. Shah et al found that the major factors that affect secretion removal are the position and size of the catheter side holes. Offset side holes were associated with better mucus clearance. The catheters they tested are depicted in Figure 5. These findings are important for future catheter designs.

**Open Versus Closed Suctioning.** Two decades ago the standard of care for suctioning was a single-use, disposable, open-circuit suction catheter. The patient was disconnected from the ventilator, hyperventilated, and hyperoxygenated with a self-inflating manual resuscitator. The patient was then disconnected from the manual resuscitator and the suction catheter was passed into the ETT to remove secretions. The manual resuscitator was also used to simulate a cough, by stacking breaths or giving large volumes. This procedure was also known to result in both hemodynamic instability and hypoxemia.

In the last decade, closed-circuit suction catheters have become popular for a number of reasons, including prevention of problems associated with disconnecting the patient from the ventilator, reduced cost, and reduced exposure of caregivers to infectious materials. Comparisons of closed-circuit and open-circuit suctioning techniques suggest that there is no difference in their ability to evacuate secretions.<sup>46,47</sup> Because the patient does not need to be disconnected from the ventilator during closed-circuit suctioning, the positive end-expiratory pressure (PEEP) is



maintained and hypoxemia and ventilator malfunction may be reduced. There is also evidence that the closed-circuit system reduces caregiver and environmental contamination, although the evidence regarding this is weak. Studies of prolonged use of closed-circuit suction catheters suggests that, compared to open-circuit suctioning, the incidence of ventilator-associated pneumonia is either lower or unchanged.<sup>48–64</sup> Interestingly, many clinicians have suggested that, by preventing disconnection of the circuit from the ETT, closed-circuit suctioning reduces the risk of ventilator-associated pneumonia. Although this is an attractive hypothesis, it has not been studied. When closed-circuit suctioning was introduced, it was my (RDB) opinion that closed-circuit suctioning removed less secretions than open-circuit suctioning, and that eliminating the manual resuscitator not only prevented the clinician from “feeling” the compliance, but removed the ability to create a cough to propel mucus cephalad. I (RDB) was often told that the sound of closed-circuit suctioning is different because the airway is closed. The satisfying sound of secretions being removed with open-circuit suctioning was also lost. However, if PEEP is preserved during closed-circuit suctioning, it means that while we are trying to suction secretions out, the ventilator is blowing them back into the patient. So closed-circuit suctioning, despite its advantages, may be an inferior secretion-removal device.

This hypothesis was recently tested by Lasocki and colleagues, who compared the effects of open and closed suctioning in patients with respiratory failure.<sup>65</sup> They found that closed suctioning prevented suction-related hypoxemia, but that secretion removal was reduced. They suggested that during open suctioning the disconnection from the ventilator and loss of PEEP simulates a cough and propels mucus upward. They also postulated that the disconnection from the ventilator during open-circuit suctioning increases the pressure differential, which enhances suctioning, whereas during closed-circuit suctioning the ventilator gas delivery that maintains the PEEP forces secretions away from the suction catheter. In that study, secretion volume was reduced with closed-circuit suctioning unless the suction pressure was increased to  $-400$  mm Hg, which restored secretion removal volume (Fig. 6). However, this greater negative pressure was not associated with hypoxemia. They suggested the use of a post-suctioning recruitment maneuver to restore alveolar recruitment.<sup>65</sup> Despite these findings, closed-circuit suctioning appears to have more advantages than disadvantages. In patients with retained secretions, increasing the vacuum pressure may be required to improve secretion removal, but gas exchange and ventilator performance should be monitored closely.

**Bronchial Suctioning.** During routine endotracheal suctioning, the suction catheter most likely enters the right

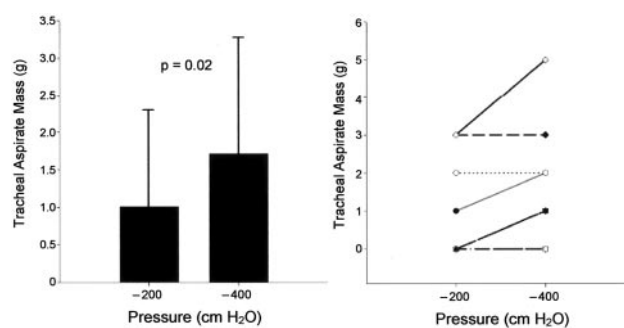


Fig. 6. Tracheal aspirate mass at 2 different vacuum pressures with closed-circuit suctioning in patients with acute respiratory distress syndrome. (Data from Reference 65.)

main bronchus if the catheter is advanced far enough, because the angle from the trachea into the left main bronchus is more acute than that into the right main bronchus. As such, the left lung is less likely to be suctioned. Attempts at suctioning the left mainstem have been described and have ranged from simple maneuvers to the use of special catheters.<sup>66–68</sup> One simple way of suctioning the left main bronchus is by turning the head to the right to increase the likelihood of the catheter entering the left mainstem. The same effect may be gained by placing the patient in the left lateral position and attempting to use gravity to guide the catheter to the left lung.

Specialized catheters that have a curved tip enter the left main bronchus in up to 90% of cases. The success of bronchial suctioning can be affected by tube position, patient body and head position, and type of tube (ETT vs tracheostomy tube). We have not found selective endobronchial suctioning to be a necessary routine technique. Frequent changes in patient body position facilitate movement of secretions to the carina, where they can be suctioned. In patients with infectious processes confined to the left lung, selective endobronchial suctioning may prove useful.

**Deep Versus Shallow Suctioning.** Prior to suctioning a neonate, the length of the suction catheter is often measured to prevent traversing the tip of the ETT and thus to prevent trauma to the neonatal tracheobronchial mucosa. Shallow (or minimally invasive) suctioning means passing the suction catheter tip to the end of the ETT, but no farther. Suctioning past the ETT tip is therefore called deep suctioning. In adults this issue is less frequently discussed. A recent meta-analysis of this topic found that the supporting literature is poor and that no definitive conclusions could be made.<sup>69</sup> Ahn and Hwang examined secretions from neonates following deep and shallow suctioning and found evidence of detached ciliated airway cells with deep suctioning, but no more secretions were removed than with shallow suctioning.<sup>70</sup> They suggested

that deep suctioning has no advantage, causes unnecessary trauma, and should be avoided.

In adults, van de Leur et al found that minimally invasive suctioning resulted in fewer recollections of suctioning by ventilated patients. However, this was not associated with less discomfort with the suctioning procedure.<sup>71</sup> In a large study of adult patients, they also found that minimally invasive suctioning resulted in fewer hemodynamic and gas-exchange adverse effects but had no effect on duration of ventilation and other outcomes.<sup>72</sup> In the latter study the traditional suction catheter was 49 cm long, compared to 29 cm for the minimally invasive catheter.

This issue essentially pits deep suctioning (to remove the most secretions) against shallow suctioning (just keeping the ETT clear of secretions). The limited evidence seems to suggest that minimally invasive suctioning is as effective at secretion removal, but has fewer adverse effects, so the “first, do no harm” principle suggests that minimally invasive suctioning should be preferred, but further study is necessary.

**Saline Instillation.** During the suctioning procedure it is common for some practitioners to instill 5–10 mL of normal saline in an attempt to thin the tracheobronchial secretions. This practice remains a point of contention, and studies have failed to show any advantage from saline instillation. Our studies of humidification techniques revealed that the only correlation between saline instillation and patient care is practitioner preference.<sup>34</sup> That is, our research failed to show that saline instillation is used uniformly or has any benefit in terms of liquefying secretions. Saline instillation frequently does cause the patient to cough violently, which may aid in the secretion-removal process. From a conceptual standpoint, instilling saline to stimulate a cough makes sense, but the current literature does not support the routine use of saline instillation. From a mucus rheology perspective, the properties of mucus are unlikely to change with the addition of water unless some physical means of mixing the two is accomplished. As well, severe coughing episodes and bronchospasm occasionally may result from saline instillation.

There is also some concern that the use of saline may dislodge bacteria-laden biofilm from the ETT and into the small airways. A host of recent studies found that saline instillation failed to produce any of the intended effects, while potentially causing more pulmonary infections.<sup>73–89</sup> Based on this evidence, saline instillation to thin secretions is, at best, unsupported and, at worst, dangerous.

**When to Suction.** Routine suctioning should be avoided. Instead, patient assessment, including auscultation and visual inspection, should be used to determine the need for suctioning. In recent years, ventilator graphics have been used to detect the need for endotracheal suctioning. Jubran

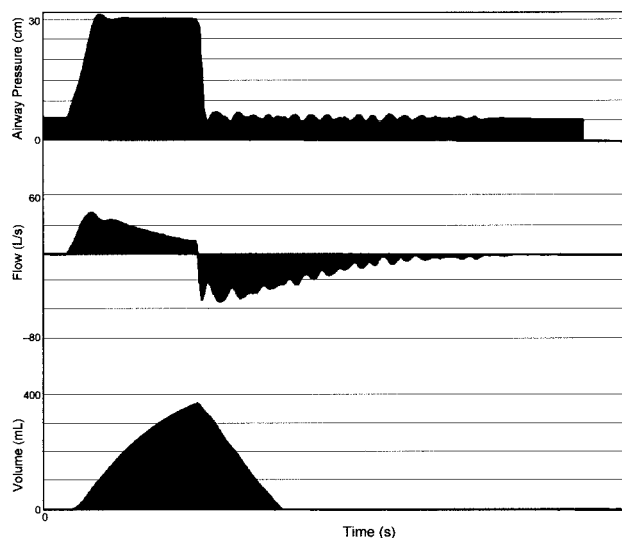


Fig. 7. Characteristic sawtooth pattern of the expiratory flow signal, which suggests the need for suctioning.

and Tobin,<sup>90</sup> Guglielminotti et al,<sup>91</sup> and Zamanian and Marini<sup>92</sup> all described alterations in the pressure and flow curves that might suggest the need for suctioning. Figure 7 depicts changes in the expiratory flow signal that suggest airway secretions. The most common finding is a sawtooth pattern in the expiratory flow signal, caused by secretions in the large airways. This finding is also seen with condensate in the expiratory limb of the ventilator circuit, so visual inspection of the circuit should be included in the evaluation.

Visaria and Westenskow demonstrated the ability to detect ETT occlusion using an automated evaluation of pressure and flow signals.<sup>93</sup> They were able to distinguish airway obstruction from bronchospasm and changes in chest wall compliance. Similar systems might be developed to determine when suctioning is required.

Endotracheal suctioning is associated with many complications, and should be undertaken only when necessary, keeping the potential complications in mind. Minimizing these complications by minimally invasive suctioning and suctioning only when necessary, based on reliable detection methods, may both be routine in the future.

### Novel Methods for Secretion Removal From the Endotracheal Tube

#### The Mucus Slurper

Intermittent closed-circuit suctioning is the current standard of care in mechanically ventilated patients. Kolobow and colleagues recently described a system (the “Mucus Slurper”) that provides automated, intermittent suctioning of the ETT lumen (Fig. 8).<sup>95</sup> The Mucus Slurper is a

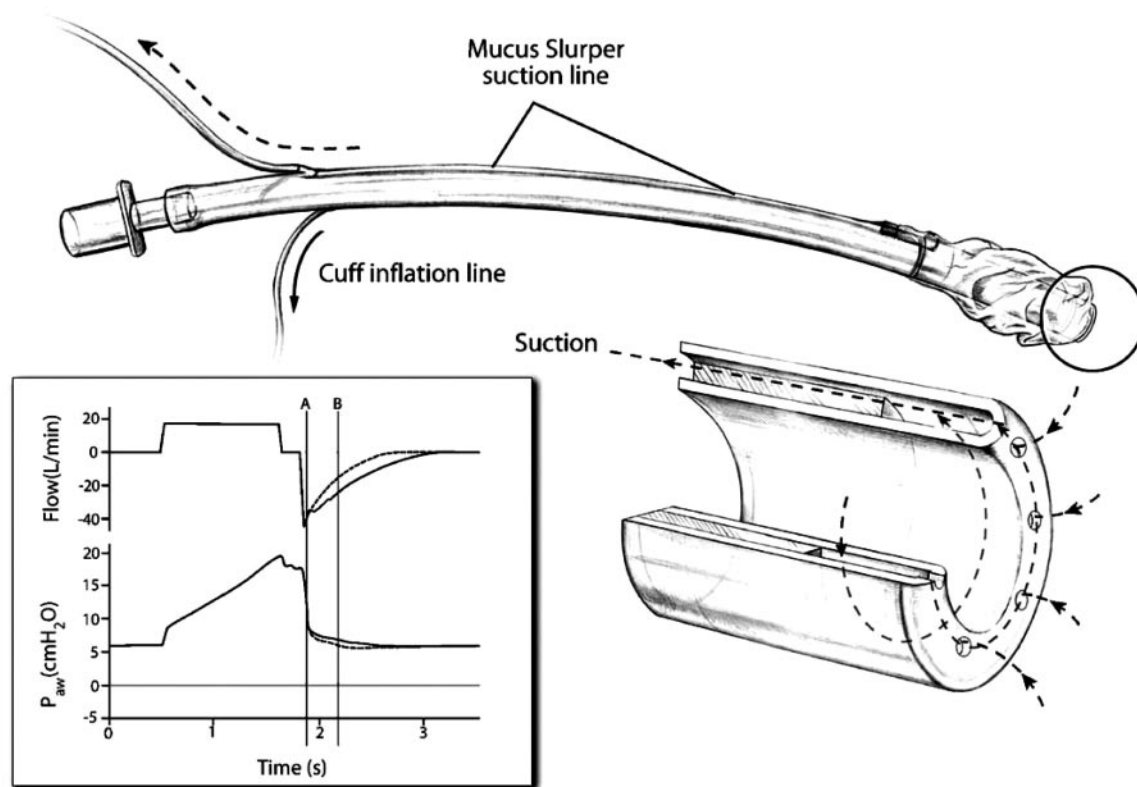


Fig. 8. The Mucus Slurper endotracheal tube, a modification of a CASS (continuous aspiration of subglottic secretions) endotracheal tube. The CASS suction line runs to the hollow, concentric, vinyl suction ring in the tip of the tube (magnified at lower right). Mucus is intermittently suctioned via the eight 1.3-mm holes in the perimeter of the tube's tip. The graph at lower left shows the expiratory airway pressure ( $P_{aw}$ ) and flow waveforms during one suctioning event by the Mucus Slurper (dashed line) and without aspiration (solid line). The Mucus Slurper activates within a few milliseconds of the start of exhalation (A), and aspirates 135 mL from the expiratory flow, with no decrease in the positive end-expiratory pressure. The aspiration lasts 0.3 s (B). (From Reference 94, with permission.)

modified continuous subglottic suctioning ETT. The end of the ETT is modified by cutting off the portion beyond the cuff, and attaching a plastic ring with eight 1.3-mm holes. The suction lumen is extended to apply suction to these 8 holes.

In Figure 8, the pressure and flow waveforms show the effects of activating suction to the 8 holes at the end of inspiration. The system draws 135 mL over 0.3 seconds. In this preliminary evaluation in an animal model, the system did not affect ventilator performance. There was some concern about auto-triggering, but most ventilators have a "lockout" period following completion of the inspiratory time, which is near the 0.3-second time frame. Figure 9 shows the system for control of suction pressure and timing.

This very preliminary evidence indicates that in an animal model without pulmonary disease, the ETT lumen remains clean. Presumably, as the secretions approach the ETT, they are removed through the 8 narrow lumens. Recently, the Mucus Slurper system was tested for 72 hours in an animal model that compared every-2-min activation with the mucus slurper to every-6-hour suctioning.<sup>95</sup> There

were no differences in airway colonization between the groups. However, inspection of the ETT showed less secretion accumulation in the Mucus Slurper group. Kolobow and colleagues measured protein content in the expiratory condensate as a marker of secretion movement up the ETT. The protein concentrations were lower in the Mucus Slurper group. How this system will perform in a patient with copious, tenacious secretions remains to be seen.

### The Mucus Shaver

Kolobow and colleagues also described the Mucus Shaver system for removing secretions from the inner wall of the ETT.<sup>96</sup> The Mucus Shaver is a manually operated system that scrapes the inside of the ETT to remove secretions (Fig. 10). The Mucus Shaver is placed inside the ETT, much like a stylet. The balloon is inflated and the shaving heads are forced against the inner wall; the device is then withdrawn over 3–5 seconds to remove secretions. The intention is to return the ETT resistance characteristics to their pre-use values. In an animal model with normal lungs, the Mucus Shaver maintained a clean internal



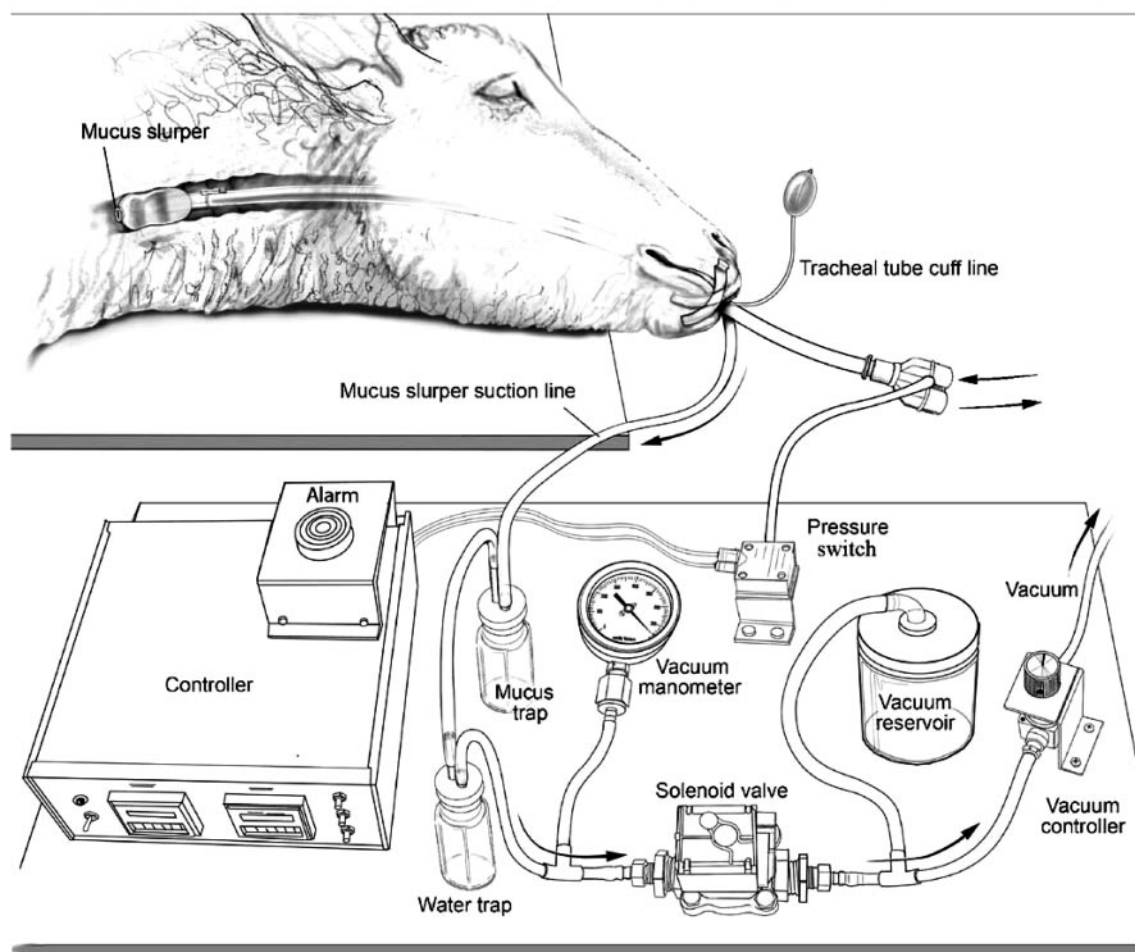


Fig. 9. Aspirated mucus is collected in a 25-mL mucus trap connected to the external suction line of the Mucus Slurper. A water trap prevents accumulation of water in the solenoid valve. The controller is connected via a pressure transducer to the respiratory circuit, and synchronizes the opening of the solenoid valve during the early expiratory phase. When the valve opens, the circuit is connected to a vacuum source (suction level is adjustable with a vacuum controller). The frequency of activation and the duration of suction are adjustable via an electronic controller. An alarm activates when no synchronized aspiration is detected. (From Reference 94. with permission.)

lumen and reduced biofilm accumulation. The clinical role for this device remains uncertain.

### Special Endotracheal Tubes

ETT's are designed for a number of special situations. There are wire-reinforced ETT's, ETT's for laser surgery, specially shaped ETT's to improve the operative field, and ETT's for high-frequency ventilation. Silver-coated and silver-impregnated ETT's are designed to reduce bacterial colonization and maintain a patent lumen.

Silver has long been appreciated for its bacteriostatic properties.<sup>97-99</sup> Older clinicians will remember the time when all tracheostomy tubes were silver or silver-plated stainless steel. Silver-coated and silver-impregnated urinary catheters and central venous catheters have been used for over a decade.<sup>100</sup> Silver has other medically useful

properties, including prevention of biofilm formation, reduction in bacterial burden, and reduction in inflammation. To test the potential bacterial burden reduction in the respiratory tract with silver-coated ETT's, Olson et al performed an experimental study in 11 ventilated dogs. The silver-coated ETT's reduced biofilm formation and there was a significant lumen-narrowing difference between the ETT's. Five of the 6 noncoated ETT's (83%) and none of the 5 coated tubes had a narrowing of  $> 50\%$ . The coated tubes not only reduced the bacterial burden, with a statistically minor risk of colonization, but also delayed the formation of luminal side colonization from  $1.8 \pm 0.4$  d to  $3.2 \pm 0.8$  d.<sup>101</sup>

A recent prospective randomized phase II pilot study tested silver-coated ETT's in ICU patients. The main objective was to determine whether a silver-coated ETT reduced the incidence and/or delayed the onset of coloniza-

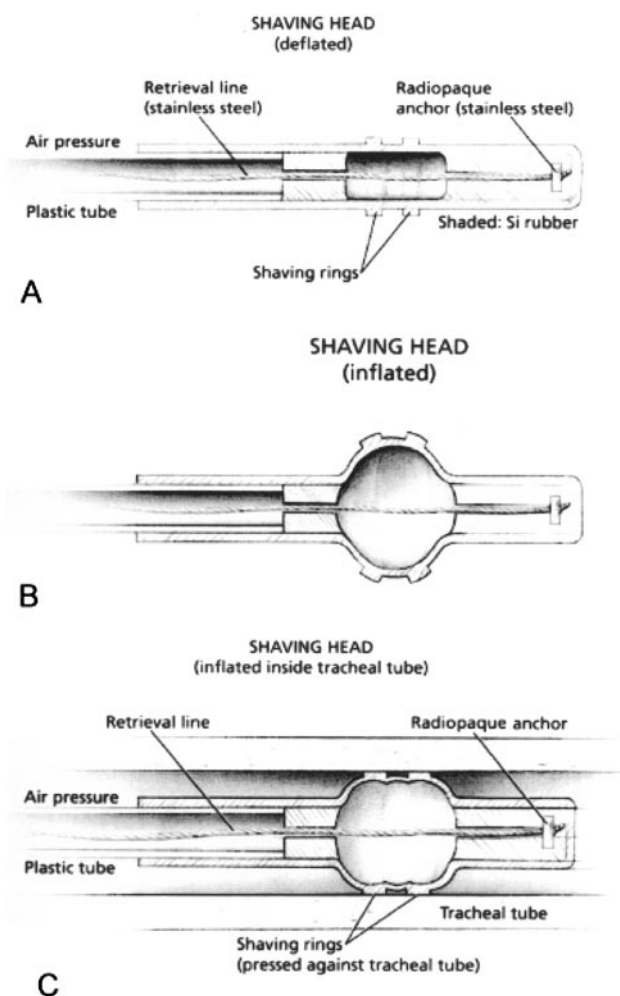


Fig. 10. A: Mucus Shaver. B: Mucus Shaver inflated. C: Mucus Shaver inflated inside an endotracheal tube. Shaded areas = silicone rubber. (From Reference 96, with permission.)

tion, compared to a noncoated ETT, in mechanically ventilated patients. There was a significant reduction in microbiologic burden with the silver-coated ETT.<sup>102</sup> The high bacterial concentration on the inner surface of a standard ETT can play a role in the development of late-onset ventilator-associated pneumonia when biofilm fragmentation occurs. This fragmentation can be facilitated by airway suctioning or installation of saline. The future role of silver-coated or silver-impregnated ETTs remains to be determined.

#### Intermittent Techniques to Enhance Secretion Removal

The term respiratory therapy often refers to “treatments” provided by the respiratory therapist to aid in lung expansion, prevent atelectasis, and mobilize retained secretions. Within the realm of respiratory therapy for secretion mo-

bilization are techniques that simulate a cough, that loosen mucus through external forces (chest clapping, vibration), and positioning. In many cases these methods combine two or three of these techniques. Each will be considered.

#### Techniques to Simulate a Cough

**Manual Hyperinflation.** Manual hyperinflation during suctioning was at one time a common procedure. By stacking small breaths or providing a large breath and holding it, the respiratory therapist could simulate and/or stimulate a cough. This is separate from the technique of manual hyperinflation aimed at lung recruitment.

Manual hyperinflation with a self-inflating bag for secretion removal is a popular practice in the United Kingdom and some former United Kingdom colonies in Asia.<sup>103–110</sup> Recent studies indicate that the mechanical ventilator can also be used to achieve hyperinflation, with similar results.<sup>111,112</sup>

As a separate technique, manual hyperinflation is not commonly used for secretion removal in the mechanically ventilated patient in the United States. Manual hyperinflation delivers a large-tidal-volume breath over a prolonged inspiratory time, followed by an inspiratory hold and rapid release of pressure. The goal is to simulate a cough and propel mucus cephalad. Most studies have suggested that as peak expiratory flow is increased, secretion removal is enhanced. The evidence for the efficacy of manual hyperinflation is scant. Several studies have shown improved compliance and oxygenation after manual hyperinflation, but the findings about changes in secretion volume have been inconsistent.<sup>111–114</sup>

Manual hyperinflation is not without risk. High airway pressure and large lung volumes produce adverse hemodynamic effects and can injure the lung via barotrauma and/or volutrauma.<sup>115,116</sup>

**Insufflation-Exsufflation.** Mechanical insufflation-exsufflation (in-exsufflation) is done with the CoughAssist In-Exsufflator (Respironics, Murrysville, Pennsylvania), which is a stand-alone device that insufflates a fairly large volume of gas into the lungs, and then rapidly reverses to a negative pressure that exsufflates the gas from the lungs, which simulates a cough and propels secretions cephalad.<sup>117,118</sup> The active expiratory portion of the CoughAssist In-Exsufflator’s operation separates it from manual hyperinflation.

To date, the CoughAssist In-Exsufflator has primarily been used in patients with neuromuscular weakness who are on noninvasive ventilation.<sup>119–121</sup> There are no clinical trials of the CoughAssist In-Exsufflator in mechanically ventilated patients in the ICU. In our experience, we have used the CoughAssist In-Exsufflator in the neurosurgical ICU, in patients with head and spinal cord injuries and

who retained secretions. These have primarily been tracheostomized patients who cannot cough because of muscle weakness or altered mental status. The intermittent use of the CoughAssist In-Exsufflator appears to assist in secretion removal. Studies of in-exsufflation in these patients are warranted.

### External Application of Force to Loosen Secretions

These techniques include percussion and postural drainage, high-frequency chest wall vibration, rib-cage compression, and chest physiotherapy. Each of these therapies uses patient positioning and postural drainage to facilitate secretion removal, so these will be considered together.

**Percussion and Postural Drainage.** Though percussion and postural drainage are widely used in patients with cystic fibrosis in the out-patient setting, use of percussion and postural drainage in mechanically ventilated patients is sporadic. Conceptually, the mechanisms are similar. In the mechanically ventilated patient with retained secretions, chest clapping is supposed to mechanically loosen secretions. It is interesting to note that percussion and postural drainage are often used to treat or prevent atelectasis in the absence of secretion retention. There is no known mechanism by which percussion and postural drainage can improve atelectasis, unless it is by removal of mucus plugs.

The literature on percussion and postural drainage in mechanically ventilated patients is poor. In fact, more papers have described complications from percussion and postural drainage (pain, anxiety, atelectasis, elevated oxygen consumption) than have found any positive effects.<sup>122–128</sup> At present, in mechanically ventilated patients the use of percussion and postural drainage, or chest physiotherapy, or other external vibration methods is unfounded.

**High-Frequency Chest Wall Compression.** This topic was covered by Chatburn in his contribution to this conference.<sup>129</sup> Suffice it to say that at present there is no evidence for the use of chest wall compression in the mechanically ventilated patient. One case report described removal of bronchial casts with high-frequency chest wall compression<sup>130</sup> but it has not been systematically tested in mechanically ventilated patients.

### Manual Rib-Cage Compression

Manual rib-cage compression (also known as “squeezing”) refers to manually applying external force to the rib cage to increase expiratory flow and thus facilitate secretion removal. The literature is confined to a couple of reports from Japan, which found no increase in secretion

removal with squeezing.<sup>131,132</sup> As with various other techniques, anecdotal reports of success predominate.

**Kinetic Therapy.** The literature is replete with descriptions of the use of rotating beds designed to prevent ventilator-associated pneumonia and treat atelectasis.<sup>133–139</sup> However, study of these beds’ effect on secretion clearance has been limited.<sup>140</sup> Davis et al compared secretion clearance, lung mechanics, and gas exchange in paralyzed patients with acute respiratory distress syndrome randomized to receive manual turning, manual turning with percussion and postural drainage, continuous lateral rotation, or continuous lateral rotation with percussion and postural drainage performed by the pneumatic cushions of the bed. Each of 20 patients received each treatment, in a randomized order, for 6 hours. The combination of continuous lateral rotation and percussion and postural drainage produced more secretions in this small group of paralyzed patients, but no other benefits were identified. As with most of the intermittent techniques discussed here, continuous lateral rotation seems to make common sense for secretion management, but there is no evidence to support its efficacy.

### Intrapulmonary Percussive Ventilation

Chatburn’s contribution to this conference<sup>129</sup> also discussed intrapulmonary percussive ventilation, which combines the secretion-loosening effects of mechanical percussion with hyperinflation to facilitate cough and propel mucus cephalad. Study of intrapulmonary percussive ventilation in mechanically ventilated patients has been limited to a few case reports.<sup>141–143</sup>

### Summary

Management of secretions in the mechanically ventilated patient requires adequate humidification and appropriate suctioning. The level of humidification required has been not well defined, but it is clear that in a patient with thick and copious secretions a heated humidifier is preferred to an HME. A heated humidifier should also be used for prolonged ventilation (> 5 d). Suctioning should be done when clinical signs (auscultation, visible secretions in the tube, graphic displays) suggest secretions in the large airways. Closed-circuit suctioning has some advantages over open-circuit suctioning with regard to preventing de-recruitment, but neither technique is superior for removing secretions. Some interesting new suctioning methods have been described, and future studies should determine if these have merit.

The use of intermittent secretion-removal techniques, including percussion and postural drainage, manual hyperinflation, insufflation-exsufflation, and intrapulmonary per-

cussive ventilation, have a dearth of supporting evidence and should be used cautiously. Routine use of these techniques is not supported by the literature.

#### REFERENCES

- Sackner MA, Hirsch J, Epstein S. Effect of cuffed endotracheal tubes on tracheal mucous velocity. *Chest* 1975;68(6):774-777.
- Safdar N, Crnich CJ, Maki DG. The pathogenesis of ventilator-associated pneumonia: its relevance to developing effective strategies for prevention. *Respir Care* 2005;50(6):725-739.
- Palmer LB, Smaldone GC, Simon SR, O'Riordan TG, Cuccia A. Aerosolized antibiotics in mechanically ventilated patients: delivery and response. *Crit Care Med* 1998;26(1):31-39.
- Ray JF 3rd, Yost L, Moallem S, Sanoudos GM, Villamena P, Paredes RM, Clauss RH. Immobility, hypoxemia, and pulmonary arteriovenous shunting. *Arch Surg* 1974;109(4):537-541.
- Qaseem A, Snow V, Fitterman N, Hornbake ER, Lawrence VA, Smetana GW, et al. Risk assessment for and strategies to reduce perioperative pulmonary complications for patients undergoing non-cardiothoracic surgery: a guideline from the American College of Physicians. *Ann Intern Med* 2006;144(8):575-580.
- Schweickert WD, Hall J. ICU-acquired weakness. *Chest* 2007;131(5):1541-1549.
- Scheidegger D, Bentz L, Piolino G, Pusterla C, Gigon JP. Influence of early mobilisation of pulmonary function in surgical patients. *Eur J Intensive Care Med* 1976;2(1):35-40.
- Latimer RG, Dickman M, Day WC, Gunn ML, Schmidt CD. Ventilatory patterns and pulmonary complications after upper abdominal surgery determined by preoperative and postoperative computerized spirometry and blood gas analysis. *Am J Surg* 1971;122(5):622-632.
- Browning L, Denehy L, Scholes RL. The quantity of early upright mobilisation performed following upper abdominal surgery is low: an observational study. *Aust J Physiother* 2007;53(1):47-52.
- Mackay MR, Ellis E, Johnston C. Randomised clinical trial of physiotherapy after open abdominal surgery in high risk patients. *Aust J Physiother* 2005;51(3):151-159.
- Lawrence VA, Cornell JE, Smetana GW. Strategies to reduce postoperative pulmonary complications after noncardiothoracic surgery: systematic review for the American College of Physicians. *Ann Intern Med* 2006;144(8):596-608.
- AARC Clinical Practice Guideline: Humidification during mechanical ventilation. *Respir Care* 1992;37(8):887-890.
- American Association for Respiratory Care: Consensus statement on the essentials of mechanical ventilators—1992. *Respir Care* 1992;37(9):1000-1008.
- Williams R, Rankin N, Smith T, Galler D, Seakins P. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. *Crit Care Med* 1996;24(11):1920-1929.
- Rankin N. What is optimum humidity? *Respir Care Clin N Am* 1998;4(2):321-328.
- Sottiaux TM. Consequences of under- and over-humidification. *Respir Care Clin N Am* 2006;12(2):233-252.
- Branson RD. The effects of inadequate humidity. *Respir Care Clin N Am* 1998;4(2):199-214.
- Suzukawa M, Usuda Y, Numata K. The effects of sputum characteristics of combining an unheated humidifier with a heat-moisture exchanging filter. *Respir Care* 1989;34(11):976-984.
- Miyao H, Hirokawa T, Miyasaka K, Kawazoe T. Relative humidity, not absolute humidity, is of great importance when using a humidifier with a heating wire. *Crit Care Med* 1992;20(5):674-679.
- Nishida T, Nishimura M, Fujino Y, Mashimo T. Performance of heated humidifiers with a heated wire according to ventilatory settings. *J Aerosol Med* 2001;14(1):43-51.
- Gilmour IJ, Boyle MJ, Rozenberg A, Palahniuk RJ. The effect of heated wire circuits on humidification of inspired gases. *Anesth Analg* 1994;79(1):160-164.
- Cohen IL, Weinberg PF, Fein IA, Rowinski GS. Endotracheal tube occlusion associated with the use of heat moisture exchangers in the intensive care unit. *Crit Care Med* 1988;16(3):277-279.
- Martin C, Perrin G, Gevaudan MJ, Saux P, Gouin F. Heat and moisture exchangers and vaporizing humidifiers in the intensive care unit. *Chest* 1990;97(1):144-149.
- Misset B, Escudier B, Rivara D, Leclercq B, Nitenberg G. Heat and moisture exchangers vs heated humidifier during long term mechanical ventilation. *Chest* 1991;100(1):160-163.
- Roustan JP, Kienlen J, Aubas P, Aubas S, du Cailar J. Comparison of hydrophobic heat and moisture exchangers with heated humidifiers during prolonged mechanical ventilation. *Intensive Care Med* 1992;18(2):97-100.
- Lellouche F, Taillé S, Maggiore SM, Qader S, L'her E, Deye N, Brochard L. Influence of ambient and ventilator output temperatures on performance of heated-wire humidifiers. *Am J Respir Crit Care Med* 2004;170(10):1073-1079.
- Beydon L, Tong D, Jackson N, Dreyfuss D. Correlation between simple clinical parameters and the in vitro humidification characteristics of filter heat and moisture exchangers. *Chest* 1997;112(3):739-744.
- Hess DR, Kallstrom TJ, Mottram CD, Myers TR, Sorenson HM, Vines DL. Care of the ventilator circuit and its relation to ventilator-associated pneumonia. *Respir Care* 2003;48(9):869-879.
- Branson RD, Davis K Jr. Evaluation of 21 passive humidifiers according to the ISO 9360 standard: moisture output, deadspace, and flow resistance. *Respir Care* 1996;41(9):736-743.
- Medical Devices Directorate Evaluation. Department of Health, Scottish Home and Health Department, Welsh Office and Department of Health and Social Services Northern Ireland, London, 1994.
- Unal N, Pompe JC, Holland WP, Gültuna I, Huygen PE, Jabaaij K, et al. An experimental set-up to test heat-moisture exchangers. *Intensive Care Med* 1995;21(2):142-148.
- Ricard JD, Le Mière E, Markowicz P, Lasry S, Saumon G, Djedaïni K, et al. Efficiency and safety of mechanical ventilation with a heat and moisture exchanger changed only once a week. *Am J Respir Crit Care Med* 2000;161(1):104-109.
- Hess DR. And now for the rest of the story (letter). *Respir Care* 2002;47(6):696-699.
- Branson RD, Davis K, Campbell RS, Porembka DT. Humidification in the intensive care unit: prospective study of a new protocol utilizing heated humidification and a hygroscopic condenser humidifier. *Chest* 1993;104(6):1800-1805.
- Villafane MC, Cinnella G, Lofaso F, Isabey D, Harf A, Lemaire F, Brochard L. Gradual reduction of endotracheal tube diameter during mechanical ventilation via different humidification devices. *Anesthesiology* 1996;85(6):1341-1349.
- Boqué MC, Gualis B, Sandiumenge A, Rello J. Endotracheal tube intraluminal diameter narrowing after mechanical ventilation: use of acoustic reflectometry. *Intensive Care Med* 2004;30(12):2204-2209.
- Shah C, Kollef MH. Endotracheal tube intraluminal volume loss among mechanically ventilated patients. *Crit Care Med* 2004;32(1):120-125.
- Jaber S, Pigeot J, Fodil R, Maggiore S, Harf A, Isabey D, et al. Long-term effects of different humidification systems on endotracheal tube patency: evaluation by the acoustic reflection method. *Anesthesiology* 2004;100(4):782-788.



39. Rumbak MJ, Walsh FW, Anderson WM, Rolfe MW, Solomon DA. Significant tracheal obstruction causing failure to wean in patients requiring prolonged mechanical ventilation: a forgotten complication of long-term mechanical ventilation. *Chest* 1999;115(4):1092–1095.
40. Kirton OC, Banner MJ, Axelrad A, Drugas G. Detection of unsuspected imposed work of breathing: case reports. *Crit Care Med* 1993;21(5):790–795.
41. Kirton OC, DeHaven CB, Morgan JP, Windosr J, Civetta JM. Elevated imposed work of breathing masquerading as ventilator weaning intolerance. *Chest* 1995;108(4):1021–1025.
42. Hess DR, Branson RD. Airway and suction equipment. In: Branson RD, Hess DR, Chatburn RL, eds. *Respiratory care equipment*. Philadelphia: Lippincott Williams and Wilkins; 1999, 157–186.
43. AARC Clinical Practice Guideline: Endotracheal suctioning of mechanically ventilated adults and children with artificial airways. *Respir Care* 1993;38(5):500–504.
44. Lomholt N. Design and function of tracheal suction catheters. *Acta Anaesthesiol Scand* 1982;26(1):1–3.
45. Shah S, Fung K, Brim S, Rubin BK. An in vitro evaluation of the effectiveness of endotracheal suction catheters. *Chest* 2005;128(5):3699–3704.
46. Witmer MT, Hess D, Simmons M. An evaluation of the effectiveness of secretion removal with the Ballard closed-circuit suction catheter. *Respir Care* 1991;36(8):844–848.
47. Carlon GC, Fox SJ, Ackerman NJ. Evaluation of a closed-tracheal suction system. *Crit Care Med* 1987;15(5):522–525.
48. Johnson KL, Kearney PA, Johnson SB, Niblett JB, MacMillan NL, McClain RE. Closed versus open tracheal suctioning: costs and physiologic consequences. *Crit Care Med* 1994;22(4):658–666.
49. Harshbarger SA, Hoffman LA, Zullo TG, Pinsky MR. Effects of a closed tracheal suction system on ventilatory and cardiovascular parameters. *Am J Crit Care* 1992;1(3):57–61.
50. Deppe SA, Kelly JW, Thoi LL, Chudy JH, Longfield RN, Ducey JP, et al. Incidence of colonization, nosocomial pneumonia, and mortality in critically ill patients using a Trach Care closed-suction system versus an open-suction system: prospective, randomized study. *Crit Care Med* 1990;18(12):1389–1393.
51. Cobleby M, Atkins M, Jones PL. Environmental contamination during tracheal suction. *Anaesthesia* 1991;46(11):957–961.
52. Ritz R, Scott LR, Coyle MB, Pierson DJ. Contamination of a multiple-use suction catheter in a closed-circuit system compared to contamination of a disposable, single-use suction catheter. *Respir Care* 1986;31(11):1086–1091.
53. Kollef MH, Prentice S, Shapiro SD, Fraser VJ, Silver P, Trovillion E, et al. Mechanical ventilation with or without daily changes of in-line suction catheters. *Am J Respir Crit Care Med* 1997;156(2 Pt 1):466–472.
54. Cereda M, Villa F, Colombo E, Greco G, Nacoti M, Pesenti A. Closed system endotracheal suctioning maintains lung volume during volume-controlled mechanical ventilation. *Intensive Care Med* 2001;27(4):648–654.
55. Maggiore SM, Lellouche F, Pigeot J, Taille S, Deye N, Durrmeyer X, et al. Prevention of endotracheal suctioning-induced alveolar derecruitment in acute lung injury. *Am J Respir Crit Care Med* 2003;167(9):1215–1224.
56. Freytag CC, Thies FL, Konig W, Welte T. Prolonged application of closed in-line suction catheters increases microbial colonization of the lower respiratory tract and bacterial growth on catheter surface. *Infection* 2003;31(1):31–37.
57. Combes P, Fauvage B, Oleyer C. Nosocomial pneumonia in mechanically ventilated patients, a prospective randomised evaluation of the Stericath closed suctioning system. *Intensive Care Med* 2000;26(7):878–882.
58. Darvas JA, Hawkins LG. The closed tracheal suction catheter: 24 hour or 48 hour change? *Aust Crit Care* 2003;16(3):86–92.
59. Stoller JK, Orens DK, Fatica C, Elliott M, Kester L, Woods J, et al. Weekly versus daily changes of in-line suction catheters: impact on rates of ventilator-associated pneumonia and associated costs. *Respir Care* 2003;48(5):494–499.
60. Zeitoun SS, de Barros AL, Diccini S. A prospective, randomized study of ventilator-associated pneumonia in patients using a closed vs. open suction system. *J Clin Nurs* 2003;12(4):484–489.
61. Maggiore SM, Iacobone E, Zito G, Conti C, Antonelli M, Proietti R. Closed versus open suctioning techniques. *Minerva Anestesiol* 2002;68(5):360–364.
62. El Masry A, Williams PF, Chipman DW, Kratochvil JP, Kacmarek RM. The impact of closed endotracheal suctioning systems on mechanical ventilator performance. *Respir Care* 2005;50(3):345–53.
63. Morrow BM. Closed-system suctioning: why is the debate still open? *Indian J Med Sci* 2007;61(4):177–178.
64. Caramez MP, Schettino G, Suchodolski K, Nishida T, Harris RS, Malhotra A, Kacmarek RM. The impact of endotracheal suctioning on gas exchange and hemodynamics during lung-protective ventilation in acute respiratory distress syndrome. *Respir Care* 2006;51(5):497–502.
65. Lasocki S, Lu Q, Sartorius A, Fouillat D, Remerand F, Rouby JJ. Open and closed-circuit endotracheal suctioning in acute lung injury: efficiency and effects on gas exchange. *Anesthesiology* 2006;104(1):39–47.
66. Anthony JS, Sieniewicz DJ. Suctioning of the left bronchial tree in critically ill patients. *Crit Care Med* 1977;5(3):161–162.
67. Panacek EA, Albertson TE, Rutherford WF, Fisher CJ, Foulke GE. Selective left endobronchial suctioning in the intubated patient. *Chest* 1989;95(4):885–887.
68. Haberman PB, Green JP, Archibald C, Dunn DL, Hurwitz SR, Ashburn WL, Moser KM. Determinants of successful selective tracheobronchial suctioning. *N Engl J Med* 1973;289(20):1060–1063.
69. Spence K, Gillies D, Waterworth L. Deep versus shallow suction of endotracheal tubes in ventilated neonates and young infants. *Cochrane Database Syst Rev* 2003;(3):CD003309.
70. Ahn Y, Hwang T. The effects of shallow versus deep endotracheal suctioning on the cytological components of respiratory aspirates in high risk infants. *Respiration* 2003;70(2):172–178.
71. van de Leur JP, Zwaveling JH, Loef BG, van der Schans CP. Patient recollection of airway suctioning in the ICU: routine versus a minimally invasive procedure. *Intensive Care Med* 2003;29(3):433–436.
72. Van de Leur JP, Zwaveling JH, Loef BG, van der Schans CP. Endotracheal suctioning versus minimally invasive airway suctioning in intubated patients: a prospective randomised controlled trial. *Intensive Care Med* 2003;29(3):426–432.
73. Celik SA, Kanan N. A current conflict: use of isotonic sodium chloride solution on endotracheal suctioning in critically ill patients. *Dimens Crit Care Nurs* 2006;25(1):11–14.
74. Ridling DA, Martin LD, Bratton SL. Endotracheal suctioning with or without instillation of isotonic sodium chloride solution in critically ill children. *Am J Crit Care* 2003;12(3):212–219.
75. Akgül S, Akyolcu N. Effects of normal saline on endotracheal suctioning. *J Clin Nurs* 2002;11(6):826–830.
76. Raymond SJ. Normal saline instillation before suctioning: helpful or harmful? A review of the literature. *Am J Crit Care* 1995;4(4):267–271.
77. Ji YR, Kim HS, Park JH. Instillation of normal saline before suctioning in patients with pneumonia. *Yonsei Med J* 2002;43(5):607–612.

78. Shorten DR, Byrne PJ, Jones RL. Infant responses to saline instillations and endotracheal suctioning. *J Obstet Gynecol Neonatal Nurs* 1991;20(6):464–469.
79. Blackwood B. Normal saline instillation with endotracheal suctioning: primum non nocere (first do no harm). *J Adv Nurs* 1999;29(4):928–934.
80. Ackerman MH, Ecklund MM, Abu-Jumah M. A review of normal saline instillation: implications for practice. *Dimens Crit Care Nurs* 1996;15(1):31–38.
81. Hagler DA, Traver GA. Endotracheal saline and suction catheters: sources of lower airway contamination. *Am J Crit Care* 1994;3(6):444–447.
82. Druding MC. Re-examining the practice of normal saline instillation prior to suctioning. *Medsurg Nurs* 1997;6(4):209–212.
83. Ackerman MH. The effect of saline lavage prior to suctioning. *Am J Crit Care* 1993;2(4):326–330.
84. Ninan A, O'Donnell M, Hamilton K, Tan L, Sankaran K. Physiologic changes induced by endotracheal instillation and suctioning in critically ill preterm infants with and without sedation. *Am J Perinatol* 1986;3(2):94–97.
85. Schwenker D, Ferrin M, Gift AG. A survey of endotracheal suctioning with instillation of normal saline. *Am J Crit Care* 1998;7(4):255–260.
86. Bostick J, Wendelgass ST. Normal saline instillation as part of the suctioning procedure: effects on  $P_{aO_2}$  and amount of secretions. *Heart Lung* 1987;16(5):532–537.
87. Ackerman MH, Mick DJ. Instillation of normal saline before suctioning in patients with pulmonary infections: a prospective randomized controlled trial. *Am J Crit Care* 1998;7(4):261–266.
88. Morrow BM, Futter MJ, Argent AC. Endotracheal suctioning: from principles to practice. *Intensive Care Med* 2004;30(6):1167–1174.
89. Gray JE, MacIntyre NR, Kronenberger WG. The effects of bolus normal-saline instillation in conjunction with endotracheal suctioning. *Respir Care* 1990;35(8):785–790.
90. Jubran A, Tobin MJ. Use of flow-volume curves in detecting secretions in ventilator-dependent patients. *Am J Respir Crit Care Med* 1994;150(3):766–769.
91. Guglielminotti J, Alzieu M, Maury E, Guidet B, Offenstadt G. Bedside detection of retained tracheobronchial secretions in patients receiving mechanical ventilation: is it time for tracheal suctioning? *Chest* 2000;118(4):1095–1099.
92. Zamanian M, Marini JJ. Pressure-flow signatures of central-airway mucus plugging. *Crit Care Med* 2006;34(1):223–226.
93. Visaria RK, Westenskow D. Model-based detection of partially obstructed endotracheal tube. *Crit Care Med* 2005;33(1):149–154.
94. Kolobow T, Li Bassi G, Curto F, Zanella A. The Mucus Slurper: a novel tracheal tube that requires no tracheal tube suctioning. A preliminary report. *Intensive Care Med* 2006;32(9):1414–1418.
95. Li Bassi G, Curto F, Zanella A, Stylianou M, Kolobow T. A 72-hour study to test the efficacy and safety of the “Mucus Slurper” in mechanically ventilated sheep. *Crit Care Med* 2007;35(3):906–911.
96. Kolobow T, Berra L, Li Bassi G, Curto F. Novel system for complete removal of secretions within the endotracheal tube: the Mucus Shaver. *Anesthesiology* 2005;102(5):1063–1065.
97. Balazs DJ, Triandafillu K, Wood P, Chevolut Y, van Delden C, Harms H, et al. Inhibition of bacterial adhesion on PVC endotracheal tubes by RF-oxygen glow discharge, sodium hydroxide and silver nitrate treatments. *Biomaterials* 2004;25(11):2139–2151.
98. Hollinger MA. Toxicological aspects of topical silver pharmaceuticals. *Crit Rev Toxicol* 1996;26(3):255–260.
99. Jansen B, Kohnen W. Prevention of biofilm formation by polymer modification. *J Ind Microbiol* 1995;15(4):391–396.
100. Kumon H, Hashimoto H, Nishimura M, Monden K, Ono N. Catheter-associated urinary tract infections: impact of catheter materials on their management. *Int J Antimicrob Agents* 2001;17(4):311–316.
101. Olson ME, Harmon BG, Kollef MH. Silver-coated endotracheal tubes associated with reduced bacterial burden in the lungs of mechanically ventilated dogs. *Chest* 2002;121(3):863–870.
102. Rello J, Kollef M, Diaz E, Sandiumenge A, del Castillo Y, Corbella X, Zschorn R. Reduced burden of bacterial airway colonization with a novel silver-coated endotracheal tube in a randomized multiple-center feasibility study. *Crit Care Med* 2006;34(11):2766–2772.
103. Denehy L. The use of manual hyperinflation in airway clearance. *Eur Respir J* 1999;14(4):958–965.
104. Maxwell LJ, Ellis ER. Pattern of ventilation during manual hyperinflation performed by physiotherapists. *Anaesthesia* 2007;62(1):27–33.
105. Maxwell LJ, Ellis ER. The effect of circuit type, volume delivered and “rapid release” on flow rates during manual hyperinflation. *Aust J Physiother* 2003;49(1):31–38.
106. Maxwell LJ, Ellis ER. The effect on expiratory flow rate of maintaining bag compression during manual hyperinflation. *Aust J Physiother* 2004;50(1):47–49.
107. Ntoumenopoulos G. Indications for manual lung hyperinflation (MHI) in the mechanically ventilated patient with chronic obstructive pulmonary disease. *Chron Respir Dis* 2005;2(4):199–207.
108. Patman S, Jenkins S, Smith K. Manual hyperinflation: consistency and modification of the technique by physiotherapists. *Physiother Res Int* 2001;6(2):106–117.
109. Savian C, Chan P, Paratz J. The effect of positive end-expiratory pressure level on peak expiratory flow during manual hyperinflation. *Anesth Analg* 2005;100(4):1112–1116.
110. Redfern J, Ellis E, Holmes W. The use of a pressure manometer enhances student physiotherapists’ performance during manual hyperinflation. *Aust J Physiother* 2001;47(2):121–131.
111. Savian C, Paratz J, Davies A. Comparison of the effectiveness of manual and ventilator hyperinflation at different levels of positive end-expiratory pressure in artificially ventilated and intubated intensive care patients. *Heart Lung* 2006;35(5):334–341.
112. Berney S, Denehy L. A comparison of the effects of manual and ventilator hyperinflation on static lung compliance and sputum production in intubated and ventilated intensive care patients. *Physiother Res Int* 2002;7(2):100–108.
113. Berney S, Denehy L, Pretto J. Head-down tilt and manual hyperinflation enhance sputum clearance in patients who are intubated and ventilated. *Aust J Physiother* 2004;50(1):9–14.
114. Choi JS, Jones AY. Effects of manual hyperinflation and suctioning in respiratory mechanics in mechanically ventilated patients with ventilator-associated pneumonia. *Aust J Physiother* 2005;51(1):25–30.
115. Singer M, Vermaat J, Hall G, Latter G, Patel M. Hemodynamic effects of manual hyperinflation in critically ill mechanically ventilated patients. *Chest* 1994;106(4):1182–1187.
116. Turki M, Young MP, Wagers SS, Bates JH. Peak pressures during manual ventilation. *Respir Care* 2005;50(3):340–344.
117. Barach AL, Beck GJ. Exsufflation with negative pressure: physiologic and clinical studies in poliomyelitis, bronchial asthma, pulmonary emphysema and bronchiectasis. *Arch Intern Med* 1954;93(6):825–841.
118. Cherniak RM, Hildes JA, Alcock AJW. The clinical use of the exsufflator attachment for tank respirators in poliomyelitis. *Ann Intern Med* 1954;40(3):540–548.
119. Bach JR. Mechanical insufflation-exsufflation: comparison of peak expiratory flows with manually assisted and unassisted coughing techniques. *Chest* 1993;104(5):1553–1562.
120. Bach JR. Update and perspective on noninvasive respiratory muscle aids: part 2. The expiratory aids. *Chest* 1994;105(5):1538–1544.

121. Bach JR. Continuous noninvasive ventilation for patients with neuromuscular disease and spinal cord injury. *Semin Respir Crit Care Med* 2002;23(3):283–292.
122. Ntoumenopoulos G, Presneill JJ, McElholum M, Cade JF. Chest physiotherapy for the prevention of ventilator-associated pneumonia. *Intensive Care Med* 2002;28(7):850–856.
123. Krause MF, Hoehn T. Chest physiotherapy in mechanically ventilated children: a review. *Crit Care Med* 2000;28(5):1648–1651.
124. Barker M, Adams S. An evaluation of a single chest physiotherapy treatment on mechanically ventilated patients with acute lung injury. *Physiother Res Int* 2002;7(3):157–169.
125. Weissman C, Kemper M, Harding J. Response of critically ill patients to increased oxygen demand: hemodynamic subsets. *Crit Care Med* 1994;22(11):1809–1816.
126. Weissman C, Kemper M. Stressing the critically ill patient: the cardiopulmonary and metabolic responses to an acute increase in oxygen consumption. *J Crit Care* 1993;8(2):100–108.
127. Weissman C, Kemper M. The oxygen uptake-oxygen delivery relationship during ICU interventions. *Chest* 1991;99(2):430–435.
128. Klein P, Kemper M, Weissman C, Rosenbaum SH, Askanazi J, Hyman AI. Attenuation of the hemodynamic responses to chest physical therapy. *Chest* 1988;93(1):38–42.
129. Chatburn RL. High-frequency assisted airway clearance. *Respir Care* 2007(52);9:1224–1235.
130. Koga T, Kawazu T, Iwashita K, Yahata R. Pulmonary hyperinflation and respiratory distress following solvent aspiration in a patient with asthma: expectoration of bronchial casts and clinical improvement with high-frequency chest wall oscillation. *Respir Care* 2004;49(11):1335–1338.
131. Unoki T, Kawasaki Y, Mizutani T, Fujino Y, Yanagisawa Y, Ishimatsu S, et al. Effects of expiratory rib-cage compression on oxygenation, ventilation, and airway-secretion removal in patients receiving mechanical ventilation. *Respir Care* 2005;50(11):1430–1437.
132. Unoki T, Mizutani T, Toyooka H. Effects of expiratory rib cage compression combined with endotracheal suctioning on gas exchange in mechanically ventilated rabbits with induced atelectasis. *Respir Care* 2004;49(8):896–901.
133. Fink MP, Helsmoortel CM, Stein KL, Lee PC, Cohn SM. The efficacy of an oscillating bed in the prevention of lower respiratory tract infection in critically ill victims of blunt trauma. A prospective study. *Chest* 1990;97(1):132–137.
134. deBoisblanc BP, Castro M, Everret B, Grender J, Walker CD, Summer WR. Effect of air-supported, continuous, postural oscillation on the risk of early ICU pneumonia in nontraumatic critical illness. *Chest* 1993;103(5):1543–1547.
135. Gentilello L, Thompson DA, Tonnesen AS, Hernandez D, Kapadia AS, Allen SJ, et al. Effect of a rotating bed on the incidence of pulmonary complications in critically ill patients. *Crit Care Med* 1988;16(8):783–786.
136. Demarest GB, Schmidt-Nowara WW, Vance LW, Altman AR. Use of the kinetic treatment table to prevent the pulmonary complications of multiple trauma. *West J Med* 1989;150(1):35–38.
137. Summer WR, Curry P, Haponik EF, Nelson S, Elston R. Continuous mechanical turning of intensive care unit patients shortens length of stay in some diagnostic-related groups. *J Crit Care* 1989;4:45–53.
138. Whiteman K, Nachtmann L, Kramer D, Sereika S, Bierman M. Effects of continuous lateral rotation therapy on pulmonary complications in liver transplant patients. *Am J Crit Care* 1995;4(2):133–139.
139. Traver GA, Tyler ML, Hudson LD, Sherrill DL, Quan SF. Continuous oscillation: outcome in critically ill patients. *J Crit Care* 1995;10(3):97–103.
140. Davis K, Johannigman JA, Campbell RS, Marraccini A, Luchette FA, Frame SB, Branson RD. The acute effects of body position strategies and respiratory therapy in paralyzed patients with acute lung injury. *Crit Care* 2001;5(2):81–87.
141. Deakins K, Chatburn RL. A comparison of intrapulmonary percussive ventilation and conventional chest physiotherapy for the treatment of atelectasis in the pediatric patient. *Respir Care* 2002;47(10):1162–1167.
142. Tsuruta R, Kasaoka S, Okabayashi K, Maekawa T. Efficacy and safety of intrapulmonary percussive ventilation superimposed on conventional ventilation in obese patients with compression atelectasis. *J Crit Care* 2006;21(4):328–332.
143. Wada N, Murayama K, Kaneko T, Kitazumi E. Effect of intrapulmonary percussive ventilation in a severely disabled patient with persistent pulmonary consolidation. *No To Hattatsu* 2005;37(4):332–336. (*article in Japanese*)

## Discussion

**MacIntyre:** That was terrific, as always. I have a bunch of questions, let me just start. There's been discussion about the ventilator as a mucus clearance tool, specifically the use of high-frequency ventilation, and Kolobow has been very keen on tracheal-gas-insufflation-type techniques.<sup>1</sup> What's your take on using HFO [high-frequency oscillation] or tracheal gas insufflation as a mucus clearance?

1. Trawöger R, Kolobow T, Cereda M, Giacomini M, Usuki J, Horiba K, Ferrans VJ. Clearance of mucus from endotracheal tubes during intratracheal pulmonary ven-

tilation. *Anesthesiology* 1997;86(6):1367–1374.

**Branson:** Well, I think they're separate. If you remember, when Miroslav Klain first came out using high-frequency jet ventilation,<sup>1</sup> one of the claims was you could ventilate the patient with the ETT cuff not inflated and it would prevent aspiration; and along with that there was the idea that if there was mucus in the airway you would propel it forward. I think either of those techniques, high-frequency or TGI [tracheal gas insufflation] to remove secretions, are really dependent on how well you humidify that gas. Because if you blow a high flow of

gas in tracheal gas insufflation into the ETT with the thought of propelling mucus forward, like with the reverse thrust catheter that Kolobow developed, and it's not adequately humidified, you will make secretion problems worse.

I don't know that high-frequency oscillation is any different than IPV [intrapulmonary percussive ventilation] or anything else that we do in terms of secretion clearance via "shaking"—the question is, does that shaking actually eliminate or loosen secretions? I have to tell you, when you do percussion postural drainage with the Hill-Rom bed, it can create a lot of pressure, and we actually had a pa-



tient in a study<sup>2</sup> who had a pulmonary artery catheter who could not tolerate the percussion, because whenever he got the percussion the catheter would whip against his heart and would cause him to go into runs of ventricular fibrillation. So it does actually create quite a bit of percussion into the airway. I don't know if that answers your first question or not.

1. Klain M, Keszler H, Stool S. Transtracheal high frequency jet ventilation prevents aspiration. *Crit Care Med* 1983;11(3):170-172.
2. Davis K, Johannigman JA, Campbell RS, Marraccini A, Luchette FA, Frame SB, Branson RD. The acute effects of body position strategies and respiratory therapy in paralyzed patients with acute lung injury. *Crit Care* 2001;5(2):81-87.

**MacIntyre:** I have just been intrigued with Ted Kolobow's ideas over the years, and he's come up with a lot of them. He has these ETTs with gills on them that don't really seal; and, as you say, he argues that you can ventilate people without cuffs, which he believes facilitates movement of the mucus out of the airway. It is an interesting area of research, but probably not ready for prime time yet.

1. Trawöger R, Kolobow T, Cereda M, Sparacino ME. Tracheal mucus velocity remains normal in healthy sheep intubated with a new endotracheal tube with a novel laryngeal seal. *Anesthesiology* 1997;86(5):1140-1144.

**Chatburn:** Rich, can you say anything about the relationship between the loss of effective ETT diameter and any kind of observable clinical effect on patients' work of breathing?

**Branson:** There are a couple of papers<sup>1,2</sup> that look at the changes in the work of breathing associated with these changes in ETT diameter. We had our lesson in physics yesterday, so anything that decreases the diameter is going to increase the work on the patient. There are a couple of papers, most of them from Orlando Kirton<sup>3-5</sup> that suggest that there are pa-

tients who fail spontaneous breathing trials because their ETTs have become narrowed by retained secretions, and that there is an iatrogenic reason for weaning failure.

1. Shah C, Kollef MH. Endotracheal tube intraluminal volume loss among mechanically ventilated patients. *Crit Care Med* 2004;32(1):120-125.
2. Jaber S, Pigeot J, Fodil R, Maggiore S, Harf A, Isabey D, et al. Long-term effects of different humidification systems on endotracheal tube patency: evaluation by the acoustic reflection method. *Anesthesiology* 2004;100(4):782-788.
3. Rumbak MJ, Walsh FW, Anderson WM, Rolfe MW, Solomon DA. Significant tracheal obstruction causing failure to wean in patients requiring prolonged mechanical ventilation: a forgotten complication of long-term mechanical ventilation. *Chest* 1999;115(4):1092-1095.
4. Kirton OC, Banner MJ, Axelrad A, Drugas G. Detection of unsuspected imposed work of breathing: case reports. *Crit Care Med* 1993;21(5):790-795.
5. Kirton OC, DeHaven CB, Morgan JP, Windsor J, Civetta JM. Elevated imposed work of breathing masquerading as ventilator weaning intolerance. *Chest* 1995;108(4):1021-1025.

**Rubin:** Rich, that was a brilliant summary. I would like to continue on a rant that you started, vilifying the addition of saline, not only in terms of the extra time. What interests me, and what I think should require severe corporal punishment is: if saline really is effective in loosening up secretions so they can be suctioned, I can't understand why so many people put down the saline and then bag the secretions and the saline way down deep in the lungs, well beyond the reach of any suction catheter. I've never been able to understand why people would follow saline instillation with bagging. Is this done at other people's institutions?

**Branson:** All the time. I think the normal way that is done is that somebody puts saline down, the patient starts to cough, they bag them real good, and then try to give them a big breath so that they kind of simulate a cough and then suction it out. I've actually talked to Dean [Hess] about this

before. I *know* that we don't want to lose PEEP in recruitment in the mechanically ventilated patient, but I think when we went to closed-circuit suctioning, we lost the *old way* where we bagged the patients and did a simulated cough that, I thought, seemed to help clear secretions. I realize there are other reasons, ventilator-induced lung injury, not to give big volumes, but I always thought that—in some patients even now I will take them off the ventilator and try to give them a simulated cough. But I agree with you; we probably ought to change the policy to be, put the saline in and as soon as the patient starts to cough, suction, and then if you want to do some other technique for hyperventilation or manual inflation, you should do it.

**Schechter:** Studies of neonates and children on mechanical ventilation failed to provide support for the routine use of airway-clearance therapies for the prevention of atelectasis.<sup>1,2</sup> However, there is some suggestion that it helps to promote resolution of atelectasis when it develops in these children.<sup>3</sup> Is there any adult literature on that?

1. Flenady VJ, Gray PH. Chest physiotherapy for preventing morbidity in babies being extubated from mechanical ventilation. *Cochrane Database Syst Rev* 2002(2):CD000283.
2. Argent AC, Morrow BM. What does chest physiotherapy do to sick infants and children? *Intensive Care Med* 2004;30(6):1014-1016.
3. Deakins K, Chatburn RL. A comparison of intrapulmonary percussive ventilation and conventional chest physiotherapy for the treatment of atelectasis in the pediatric patient. *Respir Care* 2002;47(10):1162-1167.

**Branson:** There are some review articles—one is in *Critical Care Medicine*<sup>1</sup>—that are written by physiotherapists that say that chest PT [physical therapy] is by far the most effective treatment for a lobar atelectasis. But I can find absolutely no evidence that that is true. It has never made any sense to me that somehow you can percuss the lung that has collapsed and



make it open. And I don't know, and not to put Dave [Pierson] on the spot, but Dave actually has a case report that's about 20-something years old now, where they did chest PT to remove a foreign body.<sup>2</sup> So there are things like that. I will ask the pulmonologists—I thought I would for sure get into the literature and find that a therapeutic bronchoscopy was a really good evidence-based technique for removing secretions; and it's not! There's not a single study that suggests that a clean-out procedure with bronchoscopy helps, and we do this all the time! Go in to do a bronchoscopy for a bronchoalveolar lavage for culture, and while we're in there we see that the lung is a mess, and so whoever the ICU person is spends the next 20 minutes cleaning and suctioning mucus; and we all feel better about that when we're done. But there is no evidence that *I* can find that that does anything.

1. Krause MF, Hoehn T. Chest physiotherapy in mechanically ventilated children: a review. *Crit Care Med* 2000;28(5):1648–1651.
2. Raghu G, Pierson DJ. Successful removal of an aspirated tooth by chest physiotherapy. *Respir Care* 1986;31(11):1099–1101.

**Pierson\*:** At Harborview we did a study in the late 1970s, when John Marini was a fellow,<sup>1</sup> in which we prospectively randomized patients with acute lobar atelectasis detected on a chest x-ray to receive vigorous chest PT, which included postural drainage, bronchodilator inhalation, and clapping—with and without immediate bronchoscopy to try to suck out the “mucus plug” and relieve the atelectasis. First of all we found that to do the study we had to take a chest x-ray after randomization and immediately before we did anything, because so often the atelectasis just went

away on its on, which obviously would have skewed the results. But in that relatively small and probably underpowered study, we were unable to detect any difference in the rate of resolution of the atelectasis when bronchoscopy was added to chest PT.

We embarked on a subsequent study in which we tried to do chest PT with and without the clapping, in exactly that same setting, and unfortunately that wound up getting abandoned about two thirds of the way through for poor recruitment of patients. And that's, I think, where the literature stands on this. You are certainly correct that bronchoscopy is very often performed in patients who have perceived secretions, perceived atelectasis, radiographic abnormalities that might be atelectasis, or fever or hypoxia that *could* be due to atelectasis, but that is not an evidence-based practice.

1. Marini JJ, Pierson DJ, Hudson LD. Acute lobar atelectasis: a prospective comparison of fiberoptic bronchoscopy and respiratory therapy. *Am Rev Respir Dis* 1979;119(6):971–978.

**Rogers:** What is the mechanism of action whereby silver inhibits bacterial biofilm in bacterial formation in the tubes?

**Branson:** I don't know if I can answer that fully. There are some good studies in the engineering and biomaterials literature<sup>1–3</sup> that silver prevents bacterial growth and adhesion to surfaces—to this day we use silver-coated Foley catheters for patients who have need to be chronically catheterized. We used silver-coated central venous catheters because the silver prevents infection—it's not bactericidal, it's bacteriostatic. Again, from the historical standpoint the interesting thing was that in the early part of our country's history, prostate problems were as common as they probably are today. Supposedly Ben Franklin had a silver straight catheter that he used on himself to empty his bladder and pre-

vent infection. So the idea that silver is somehow bacteriostatic has been around for 200 or more years.

1. Balazs DJ, Triandafillu K, Wood P, Chevolut Y, van Delden C, Harms H, et al. Inhibition of bacterial adhesion on PVC endotracheal tubes by RF-oxygen glow discharge, sodium hydroxide and silver nitrate treatments. *Biomaterials* 2004;25(11):2139–2151.
2. Donelli G, Francolini I. Efficacy of antiadhesive, antibiotic and antiseptic coatings in preventing catheter-related infections. *J Chemother* 2001;13(6):595–606.
3. Jansen B, Kohnen W. Prevention of biofilm formation by polymer modification. *J Ind Microbiol* 1995;15(4):391–396.

**Rogers:** When you say bacteriostatic, what does that mean compared with bactericidal?

**Branson:** A bactericidal actively kills bacteria, whereas a bacteriostatic prevents further growth. Like I said, there are some interesting studies in the literature about silver-coated tubes and preventing the adhesion to the surface of the ETT. Bruce, I don't know if you can understand that or explain that better from an engineering perspective?

**Rubin:** No, that was all absolutely correct. That is exactly it. Ionized silver apparently prevents the growth of bacteria in biofilms. It's not very good at killing them, but it doesn't allow new growth and development in planktonic forms floating off and doing more bad stuff. But that's exactly what it does. Just as you described.

**Branson:** All of you have been around as long or longer than I have, and when Dave was talking about that paper in the 1970s, I said, “Well I missed that, because I was in the 8th grade.” But when I first started in respiratory therapy, all the heated humidifiers for ventilators had copper wool in them. So it looked like a Brillo pad, only it was all copper, and the idea was that the copper would prevent the growth of any bacteria inside the humidifier. So these ideas that met-

\* David J Pierson MD FAARC, Division of Pulmonary and Critical Care Medicine, Harborview Medical Center, University of Washington, Seattle, Washington.

als somehow can be, I guess, helpful, aren't new. There are studies going on now looking at this very issue: does the silver-coated tube prevent this adherence of secretions to the ETT?

**Myers:** Maybe not as often as the saline debate comes up, but about every 3 times the saline debate comes up, comes up the debate about patients who have thick, tenacious secretions using a diluted sodium bicarbonate down there to break up those secretions. Is there anything in the literature that supports that, or not?

**Branson:** No, there's not. There are treatments described where they administer Mucomyst down a bronchoscope channel directly onto secretions, with the idea of breaking up the mucus. But I have to tell you, if you have ever seen Mucomyst applied directly to the bronchial mucosa, when done it's all irritated and red and inflamed and looks terrible. There's a group that used to do what's called BBS, "bicarbonate, bag, and suction," where they put sodium bicarbonate down the ETT. It's the same idea with hypertonic saline solution to try and somehow change the secretion volume, but there's no evidence that I know of that *any* of that works.

**Fink:** Just a comment Rich. I appreciate the mechanical concept that was shown by the Rouby study using the open or closed suction catheter,<sup>1</sup> but as our discussions went yesterday, the quantity of secretions isn't nearly as important in this case as whether or not the use of the different catheter affected the *frequency* for the requirement to suction. Obviously, if you have secretions in the airway, you want to clear them, but if you clear them and you have no greater time component difference or frequency difference, does size really matter?

1. Lasocki S, Lu Q, Sartorius A, Fouillat D, Remerand F, Rouby JJ. Open and closed-circuit endotracheal suctioning in acute lung injury: efficiency and effects on gas ex-

change. *Anesthesiology* 2006;104(1):39–47.

**Branson:** I will be careful. I think what the study shows is that if you have secretions that have moved themselves to within reach of the suction catheter, you'd like to remove them. Whether or not that makes some long-term difference, I don't have any idea, and I don't know that we could ever even study that.

**Fink:** The other question I had was the depth of suctioning. There's a difference between being at the predicted end of the ETT, and the method of extending the catheter till it stops, withdrawing about a centimeter, and then applying suction. Have those techniques been differentiated?

**Branson:** No comparisons. There are 3 or 4 studies in the literature; the Dutch study looked at adult patients, and compared the secretion volume that was eliminated.<sup>1</sup> And then they went in and did outcomes, too. How long did the patient stay on the ventilator? How many days of care? How much time in the ICU? All that other stuff—incidence of ventilator-associated pneumonia—no difference between just placing the suction catheter to the end of the ETT or further down than that; and potentially, obviously there is probably less damage, and I guess you could make the argument that poking the carina with the suction catheter probably is not a good thing and might actually damage the carina and lead to greater infection.

1. van de Leur JP, Zwaveling JH, Loef BG, van der Schans CP. Endotracheal suctioning versus minimally invasive airway suctioning in intubated patients: a prospective randomised controlled trial. *Intensive Care Med* 2003;29(3):426–432.

**Wojtczak:**\* Very nice presentation, Rich. I'm a pediatric pulmonologist, and one of the treatments that I've

\* Henry Wojtczak MD, Naval Medical Center, San Diego, California, representing Monaghan/Trudell Medical.

started using, in conjunction with my pediatric surgery colleagues, is prophylactically placing selected children, postoperatively on HFCWC [high-frequency chest-wall compression]. Specifically, children who have undergone posterior spinal fusion. In a medicine-based-evidence way, I plan to take a closer look to see how these children fare in the immediate post-operative period.

There is an abstract; it's a small study done by the group at Oakland Children's Hospital, that looked at using the HFCWC via the Vest, postoperatively in adolescents after posterior spinal fusion.<sup>1</sup> The authors reported that HFCWC with the Vest is a clinically safe and effective airway-clearance technique in ventilated or post-extubation patients who have undergone spinal fusion, and suggested that further studies should be performed. The other question I had was, Do you know of any studies that have looked at the use of HFCWC for nonventilated children with tracheostomy tubes?

1. Gomez A, Acker R, Buehler C, Newman V. Successful use of high frequency chest wall oscillation in pediatric post operative spinal fusion (abstract). *Respir Care* 2002; 47(9):1035.

**Branson:** Not that I'm aware of. It's almost always done in acutely ill patients with ETTs, but I would assume the same thing.

**Wojtczak:** So often we will have a child come in, acutely ill with a tracheostomy in and spend 10–14 days on a ventilator in the pediatric ICU. But that's not been studied as far as you know?

**Branson:** No, it has not.

**Wojtczak:** Thank you.

**McMahon:**\* It seems that, due to the depressed respiratory system and

\* Carolyn McMahon, Cardinal Health, Riverside, California.

all of the complications that occur with mechanical ventilation, that adult patients coming off the ventilator, either out of surgery or post-extubation would be great candidates for airway-clearance techniques, devices, probably a combination of positive airway pressure, aerosol, and oscillation. Are there any studies ongoing or prompted based off of this discussion to look at airway-clearance devices for earlier extubation, keeping the patient stable, just to support the patient post-surgery to be able to get them out of the ICU earlier, to extubate earlier—similar to getting them up out of the bed, studies based on how they fare overall?

**Branson:** I think the answer is no. In critical care what we do is look to people who fail extubation, and we look for ways to prevent them from being re-intubated. And that's being studied, noninvasive ventilation, mask CPAP [continuous positive airway pressure] to prevent those things from happening. But, clearly, once the patient gets extubated in the ICU, the respiratory care group mobilizes, essentially—to make a pun about this entire conference—to the bedside, and our therapists routinely will include aerosol therapy, PEP [positive expiratory pressure], and, if need be, nasotracheal suctioning in patients who are recently extubated, who have a secretion problem. My patient population—I have all of these surgery and trauma patients, and except for once in a while, like when we get a 76-year-old with a hundred pack years of smoking, in a car accident—I don't see very many people who *come in* with secretion problems. When you are perfectly normal until you get shot, stabbed, or hit by a car, you don't have a lot of respiratory mechanics issues, unless you develop pneumonia. I think it's different in the surgical ICU, in the medical ICU, and in the neurological ICU, where patients with spinal cord injury and head injury—that, to me, is an area that just

*really* needs investigation with all of these devices.

**Pierson:** Following on that, I agree that the circumstance you've identified is clearly one in which we desperately need more knowledge, and working in a surgery trauma unit like you do, Rich, one of the populations of patients who I think *most* needs to be studied and most needs help is the nonintubated elderly patient with a couple of rib fractures or other injuries who has either not been intubated deliberately from the beginning to try to avoid all of that, or has just been extubated but *now* has to contend with the effects of heavy sedation, recent trauma, impaired clearance mechanisms because of their rib fractures, their pain, or other things, with or without a history of previous lung disease or smoking.

**Branson:** This is a different issue, but in my experience the elderly trauma patients—"elderly" gets older all the time, right?—but to me, somebody who's more than 70, who's been in an automobile accident and requires mechanical ventilation, I would prefer that we trach [tracheostomize] all of those people, because I think it helps them get off the ventilator faster. I think it helps them get out of the ICU faster; that's just my clinical impression. It's really hard to go to families and say, "Hey, we're doing a study where there is a 50–50 chance we're going to trach Dad, and, no, we don't know that he needs it." It's just kind of hard to do, but I think there are retrospective reviews that suggest early tracheostomy in the *elderly* patient actually improves outcomes.<sup>1</sup> And secretion clearance becomes *infinitely* easier when you have a channel to suction through.

1. Arabi Y, Haddad S, Shirawi N, Al Shimemeri A. Early tracheostomy in intensive care trauma patients improves resource utilization: a cohort study and literature review. *Crit Care* 2004;8(5):347–352.

**Hess:** Rich, you talked about clearing secretions from below the ETT, but what about clearing them from *above* the ETT?

**Branson:** I didn't address the idea that you have to suction above the ETT because you have this collection of oropharyngeal secretions, which we believe are the reservoir for creating ventilator-associated pneumonia. Some of us have experience with the CASS [continuous aspiration of subglottic secretions] ETTs, the continuous subglottic suction where you have a little hole in the ETT just above the cuff, and it continuously suctions out the material there. Early studies<sup>1</sup> suggested that in patients who were recently intubated without infection, that reduces the incidence of *early* pneumonia, and the early pneumonias are probably due to aspiration. But it *doesn't* reduce the incidence of late pneumonia, which are usually nosocomial infections—*Pseudomonas*, MRSA [methicillin-resistant *Staphylococcus aureus*], *Acinetobacter*, or whatever, whichever one you have. And that's because those are probably spread through another mechanism, poor hand-washing by *us*, contamination of the environment, and things like that.

1. Safdar N, Crnich CJ, Maki DG. The pathogenesis of ventilator-associated pneumonia: its relevance to developing effective strategies for prevention. *Respir Care* 2005; 50(6):725–739.

**Restrepo:** I have a couple of comments. I don't know if you've noticed this, but once you read the Cochrane review published in 2004 on normal saline instillation and the use of deep endotracheal suction technique,<sup>1</sup> it just ends with a comment, that even though there is no study that could actually just be analyzed, or just summarized, they consider it to be unethical to use the deep suction technique in light of anecdotal data. Three years ago we conducted a survey, which of course carries the usual limitations of valid-

ity associated with questionnaires, at Children's Healthcare of Atlanta at Eggleston. We did survey 102 clinicians, 27 RTs [respiratory therapists] in this group. Back then, suctioning and saline instillation were considered to be the most common procedures performed in any ICU—and I believe they still are. It might have changed a little now that we performed SBTs [spontaneous breathing trials] on a daily basis and we keep RTs busier than what it was 3 years ago.

All we found—in the process of just writing the manuscript—was that there is a lot of variability on what the nurse's perception is in terms of the indications from normal saline instillation on endotracheal suction, and the frequency. What we could not believe was that, even among RTs, there were several unknowns in terms of the amount of negative pressure that needs to be applied, the amount of normal saline recommended according to age groups, and for how long these suction events should last. Some clinicians were confused about differences between deep and shallow suctioning.

Also, as a comment, it is amazing

that when you review literature, several publications that have evaluated the effects of normal saline instillation go back to the 1970s. It has been 30 years of documenting the adverse effects of both normal saline instillation and endotracheal suctioning, and we still haven't been that proactive in terms of just trying to create guidelines that are followed by everyone; as Richard said, there's a lot of variability. Some clinicians are going to be using normal saline no matter what. What is funny about this survey is that when you compare this response to the ones we got 5 years before, the current trend to respond, "No, we don't use normal saline," is quite different with the routine use a few years back. Of course, as you turn around, some clinicians will do the complete opposite to what their answer was: deep suction and normal saline instillation. Just a comment.

1. Spence K, Gillies D, Waterworth L. Deep versus shallow suction of endotracheal tubes in ventilated neonates and young infants. *Cochrane Database Syst Rev* 2003; (3):CD003309.

**Branson:** The people around the

room who do ICU and ventilator patients, how many of your therapists normally put saline down the ETT? Are you guys sure about that? I think you made some good points. Like I said; there are a couple of therapists who work at my place who have been there 25, 30 years, and they are going to put saline down every single time, and there's nothing you are going to do to change that practice. It's going to take more than explaining that when you put saline down the tube in a patient with a head injury and it increases their intracranial pressure when they cough. These isolated incidents showing that there is a difference. I think most people just have the impression that it *might* help, and it probably doesn't hurt, and that's why they continue to do it.

**Restrepo:** One final comment. So far—I've been very interested in this for years—the only real indication of a routine normal saline instillation was when we conducted studies on partial liquid ventilation.

**Branson:** Totally different idea.