Published in final edited form as:

Am J Crit Care. 2009 July ; 18(4): 299–309. doi:10.4037/ajcc2009724.

Not-So-Trivial Pursuit: Mechanical Ventilation Risk Reduction

Mary Jo Grap, RN, PhD, ACNP

Abstract

As many as half of critically ill patients require mechanical ventilation. In this article, a program of research focused on reduction of risk associated with mechanical ventilation is reviewed. Airway management practices can have profound effects on outcomes in these patients. How patients are suctioned, types of processes used, effects of suctioning in patients with lung injury, and open versus closed suctioning systems all have been examined to determine best practices. Pneumonia is a common complication of mechanical ventilation (ventilator-associated pneumonia), and use of higher backrest elevations reduces risk of pneumonia, although compliance with such recommendations varies. The studies reviewed here describe backrest elevation practices, factors that affect backrest elevation, and the effect of backrest elevation on ventilator-associated pneumonia.

Oral care strategies also have been investigated to determine their effect on ventilator-associated pneumonia. Oral care practices are reported to hold a low care priority, vary widely across care providers, and differ in intubated versus nonintubated patients. However, in several studies, oral applications of chlorhexidine have reduced the occurrence of ventilator-associated pneumonia.

Although ventilator patients require sedation, sedation is associated with significant risks. The overall goals of sedation are to provide physiological stability, to maintain ventilator synchrony, and to ensure patients' comfort—although methods to evaluate achievement of these goals are limited. Reducing risks associated with mechanical ventilation in critically ill patients is a complex and interdisciplinary process. Our understanding of the risks associated with mechanical ventilation is constantly changing, but care of these patients must be based on the best evidence.

Approximately one-fourth to one-half of critically ill patients will require mechanical ventilation. Although mechanical ventilation saves lives, it can present a variety of significant risks to patients. This article provides a review of a program of research focused on reduction of risk associated with mechanical ventilation, specifically risks related to airway management practices, prevention of ventilator-associated pneumonia (VAP, particularly via positioning and oral care interventions), and sedation issues.

Airway Management Practices

Airway management practices can have profound effects on outcomes in patients who receive mechanical ventilation and may present significant risks. How patients are

---

© 2009 American Association of Critical-Care Nurses

Corresponding author: Corresponding author: Mary Jo Grap, RN, PhD, ACNP, FAAN, School of Nursing, Virginia Commonwealth University, P O Box 980567, 1100 East Leigh St, Richmond, VA 23219, mjgrap@vcu.edu.

Mary Jo Grap is a professor in the school of nursing at Virginia Commonwealth University in Richmond, an acute care nurse practitioner, and associate editor of the *American Journal of Critical Care*.

Financial Disclosures: None reported.

To purchase electronic or print reprints, contact The InnoVision Group, 101 Columbia, Aliso Viejo, CA 92656. Phone, (800) 899-1712 or (949) 362-2050 (ext 532); fax, (949) 362-2049; reprints@aacn.org.

Presented May 18, 2009, at the AACN National Teaching Institute, New Orleans, Louisiana.

suctioned, types of processes used, and duration and number of suction catheter passes have all been examined to determine best practices. In our early work, we also asked questions about nurses' suctioning practices. At that time, we documented processes that used a manual resuscitation bag during suctioning. Although in the United States, the majority (60%-80%) of endotracheal tube suctioning now occurs by using closed suctioning systems,¹ worldwide, open suctioning systems, that is, systems that use a manual resuscitation bag, are still common.^{2,3}

Endotracheal tube narrowing is significant, increases over time and the entire tube is affected.

Early guidelines for prevention of hypoxemia during endotracheal tube suctioning with manual resuscitation bags recommended hyperoxygenation by using 100% oxygen and hyperinflation to 1.5 times the ventilated tidal volume.⁴⁻⁷ However, in a study⁸ of 100 nurses, we found that the mean fraction of inspired oxygen delivered was 0.70, that it varied widely (from 0.24 to 0.97), and that it was determined by the liters of oxygen flow and by nurses' delivered minute ventilation. Although the nurses achieved only 57% of the volume standard for hyperinflation, patients' heart rate, mean arterial pressure, and oxygen saturation were not adversely affected. Because we found that oxygen delivery to the manual resuscitation bag was an important factor in oxygen delivery to the patient, we tested oxygen delivery via a manual resuscitation bag in the clinical setting and found that although oxygen flow to the manual resuscitation bag should be set at 15 L/min, it actually varied from 6 L/min to 15 L/min.⁹ As a result, compressions of the manual resuscitation bag at these levels delivered oxygen flow that ranged from 23% to 97% oxygen, which significantly affected oxygen flow to the patient.

Endotracheal suctioning in patients with lung injury presents unique challenges to maintaining airway clearance while also ensuring adequate oxygenation and ventilation. Patients with lung injury are therefore particularly at risk for development of complications from suctioning because of their poor oxygenation status. Using standard suctioning practices with a manual resuscitation bag, we determined the effect of level of lung injury on patients' outcomes (heart rate, mean arterial pressure, oxygen saturation) during endotracheal tube suctioning. We found that level of lung injury did not correlate significantly with changes from baseline in heart rate, oxygen saturation, or mean arterial pressure.¹⁰ However, heart rate and mean arterial pressure increased significantly but returned to baseline 5 minutes after suctioning. Patients' oxygen saturation did not change significantly during the procedure or up to 15 minutes afterwards. In that study,¹⁰ patients with lung injury were able to be suctioned safely while maintaining adequate oxygenation.

As mechanical ventilators were developed to include the ability to hyperoxygenate through the ventilator circuit by using closed suctioning systems, questions arose about the comparability of the manual resuscitation bag versus the ventilator for hyper-oxygenation during endotracheal tube suctioning. We conducted a comparison study¹¹ by using common clinical practice methods. We found that PaO₂ was significantly higher when the ventilator method was used and that peak inspiratory pressures during hyperoxygenation were significantly higher with the manual resuscitation bag. Significant increases in mean arterial pressure were observed during and after suctioning, with both delivery methods, but no difference was found between methods. Maximal increases in PaO₂ and oxygen saturation occurred 30 seconds after hyperoxygenation, decreasing to baseline values at 3 minutes for both methods. Results of that study¹¹ supported the use of the mechanical ventilator for effective hyperoxygenation during suctioning.

As with all innovations, unexpected consequences may arise. With increasing use of closed suctioning systems, clinical concerns emerged about the potential buildup of secretions

within the endotracheal tube. In an examination of endotracheal tubes used as part of a closed suctioning system, we described the extent, prevalence, and distribution of narrowing of endotracheal tubes. We found mean overall depth of debris was 0.64 mm, with greatest depth of 2.0 mm (range, 0-5 mm).¹² Interestingly, the entire tube was affected, with the greatest depth of debris at the 6- to 9-cm and 13- to 14-cm markings. Duration of intubation, but not endotracheal tube size or amount of secretions, was associated with the degree of narrowing. Results of this study¹² indicated that significant narrowing of the endotracheal tube occurs and increases over time; however, the study results do not provide answers about whether such narrowing occurs with open and closed suctioning systems. Clinicians frequently have concerns about the efficacy of suctioning systems, and this study provided a beginning step in that line of clinical inquiry.

Risk Factors for Ventilator-Associated Pneumonia

Backrest Position

Pneumonia is a common complication of mechanical ventilation (ie, VAP) that occurs in 25% of patients who receive mechanical ventilation¹³⁻¹⁵ and is responsible for 90% of nosocomial infections in ventilator patients.^{16,17} VAP is the leading cause of death from nosocomial infections¹⁸ and the second most common nosocomial infection in the United States,¹⁴ greatly adding to cost,^{19,20} mechanical ventilation time,²¹⁻²³ length of stay in the intensive care unit (ICU),^{22,24} length of stay in the hospital,^{25,26} and mortality.^{19,27} The position of the patient is a key risk factor in the development of VAP.

Describing Positioning Practice—Backrest elevation, generally defined as elevations of 30° to 45°, reduces the occurrence of aspiration and VAP. Because aspiration is common²⁸ and can occur even around an inflated endotracheal tube cuff,^{29,30} use of backrest elevation may reduce these risks.³¹⁻³³ Even though early guidelines from the Centers for Disease Control and Prevention¹⁴ recommended use of higher backrest positioning (30°–45°) for critically ill patients, doing so is not always a common nursing practice. ICU mortality rate is greater for flat supine patients (30.2%) than for semirecumbent patients (8.9%),³² but studies have shown common use of the recumbent position for patients,³⁴ often with no clear indication for that position.³²

To describe practice related to patients' position more fully, we evaluated backrest elevation in a 12-bed medical respiratory ICU for 2 months, collecting 347 measurements from 52 patients.³⁵ Mean backrest elevation was 22.9°, and 86% of patients were supine. Backrest position differed significantly among nursing shifts (days, evenings, nights). In an attempt to identify the rationale for low backrest positions, we evaluated hemodynamic and nutritional status at the time of backrest measurements and found that lower backrest positions were not related to blood pressure or presence of enteral feedings, either continuous or bolus. Use of higher levels of backrest elevation (30°) was minimal and was not related to presence of enteral feeding or unstable hemodynamic status.

In the United States, most endotracheal tube suctioning is done with closed systems, but worldwide, open systems are common.

In a more comprehensive follow-up study³⁶ in 3 ICUs (medical, surgical, and neuroscience), we noted backrest elevations randomly during a 6-week period, making 506 observations on 170 patients. Results showed mean backrest elevation of 19.2° and that 70% of subjects were supine, although backrest elevations used did not differ among units. Unlike in our first study,³⁵ we found significant correlations between backrest elevation and systolic blood pressure ($r = 0.15$, $P = .006$) and between backrest elevation and diastolic blood pressure ($r = 0.13$, $P = .02$). Similarly to the first study,³⁵ we found no differences in backrest elevation between patients who were being fed and patients who were not being fed. When these

studies were done, strategies to meet published recommendations for backrest elevation were a priority. However, compliance with backrest elevation for VAP reduction is now a national health care focus.³⁷

Backrest Position and VAP—Although the use of higher backrest elevation reduces aspiration, empirical evidence of the effect of backrest positions on the incidence of VAP, especially during extended periods of mechanical ventilation, is more limited. Kollef³² reported that supine head positioning during the first 24 hours of mechanical ventilation was one of 4 risk factors for VAP (which also included organ system failure, age >60 years, and prior antibiotic use). Drakulovic et al³³ randomly assigned patients receiving mechanical ventilation to either semirecumbent ($n = 39$) or supine ($n = 47$) body position and found that the pneumonia rate was significantly less in the semirecumbent group than in the supine group. In a descriptive study of 360 ICU adults, Metheny et al³⁸ demonstrated that low backrest elevation was a risk factor for both aspiration ($P = .02$) and pneumonia ($P = .02$).

We continuously documented backrest elevation in a longitudinal study to describe the relationship between backrest elevation and development of VAP in up to 7 days of mechanical ventilation in 66 subjects (276 patient days). The Clinical Pulmonary Infection Score (CPIS) was used to determine VAP, and backrest elevation was measured continuously with a transducer system developed by our research team.³⁹ Mean backrest elevation for the entire study period was 21.7° . Backrest elevations were less than 30° 72% of the time and less than 10° 39% of the time. The mean CPIS increased from baseline but not significantly, and backrest elevation had no direct effect on mean scores. However, a model for predicting the CPIS at day 4 that included baseline CPIS, percentage of time spent at a backrest elevation less than 30° on study day 1, and score on the Acute Physiology and Chronic Health Evaluation (APACHE) II explained 81% of the variability ($F = 7.31$, $P = .003$). That study showed that subjects spent most of their time at backrest elevations less than 30° .

Early, low backrest elevation and greater severity of illness increases ventilator-associated pneumonia.

Importantly, the combination of early, low backrest elevation and greater severity of illness increased the incidence of VAP. These findings are clinically significant because the greatest effect of lower backrest positions on VAP outcome occurred in the first ICU day and in the sickest patients. Unfortunately, these are the patients and that is the time period when supine positions are most likely to be used, namely, during the first day of ICU admission, when patients are in unstable condition and multiple procedures are underway that require long periods of recumbent positioning. However, this period may be the most critical time to use higher backrest positions whenever possible.

The National Quality Forum³⁷ currently recommends the use of a “ventilator bundle,” a group of interventions to reduce VAP, that includes backrest elevation of 30° to 45° . Quality improvement projects have illustrated that implementation of higher backrest positions, often in combination with other VAP prevention strategies (eg, ventilator bundle), reduces the incidence of VAP.⁴⁰⁻⁴² In many critical care areas, including our academic medical center, backrest elevation is continually monitored to ensure compliance with the recommendations for elevation of 30° to 45° in patients receiving mechanical ventilation. The American Association of Critical-Care Nurses has developed a practice alert related to reducing the occurrence of VAP.⁴³ The practice alert includes a procedure for auditing backrest elevation, suggestions for audit frequency, backrest elevation contraindications to consider, and a data collection tool. This procedure provides an ideal method of monitoring backrest elevation, promoting discussions of positioning with regard to specific patients, and providing consistent feedback to staff on performance improvement.

Oral Health

Oral health status has a profound effect on general health. Oral health is influenced by the microbial flora of the person, and the surgeon general's report, *Oral Health in America*,⁴⁴ identifies a "silent epidemic" of dental and oral disease. Colonization of the oropharynx is another critical risk factor for the development of VAP.^{45,46} Potentially pathogenic bacteria in dental plaque provide a nidus of infection for microorganisms responsible for the development of VAP.^{45,47} Most organisms that are associated with VAP (including *Staphylococcus aureus*, *Streptococcus pneumoniae*, *Acinetobacter baumannii*, *Haemophilus influenzae*, and *Pseudomonas aeruginosa*) colonize the oropharynx of critically ill patients before the VAP diagnosis⁴⁸ and are most likely transferred from the oropharynx to the trachea during intubation.^{49,50} After intubation, the endotracheal tube provides a pathway for direct entry of bacteria from the oropharynx through an open glottis to the lower respiratory tract. Therefore, reducing the number of microorganisms in the mouth reduces the pool of organisms available for translocation to and colonization of the lung. However, oral care is often viewed as an intervention aimed primarily at patients' comfort rather than at reduction of infection, and as a result may become a lower priority.

Describing Oral Care Practice—Although the importance of oral care in critically ill patients has begun to gain greater attention,^{47,51} no data have been collected to describe the products, methods, and frequency of oral care needed to reduce dental plaque, oral colonization, and ventilator-associated pneumonia in critically ill patients. We therefore surveyed nursing staff members about their oral care practices in both intubated and nonintubated patients and about their documentation of oral care.⁵² Most respondents (75%) reported providing oral care 2 or 3 times daily for nonintubated patients, and 72% reported providing oral care 5 times daily or more for intubated patients. However, oral care was documented on the unit's flow sheet a mean of 1.2 times per patient. Reported use of toothpaste and a toothbrush was significantly greater in nonintubated than intubated patients ($P < .001$), and use of a sponge toothette was significantly more frequent in intubated than nonintubated patients ($P < .001$). We asked nurses to rate the priority of oral care on a 100-point scale, and found that the mean priority was 53.9. Results also showed that despite evidence that they are ineffective for plaque removal, sponge toothettes remained the primary tool for oral care, especially in intubated patients in ICUs. In addition, nurses reported frequent oral care interventions, but few are documented.⁵²

In a recent follow-up study, Hanneman and Gusick⁵³ evaluated the generalizability of our findings in 9 ICUs in their setting and reported results comparable to the results of our original study. Frequency of oral care and use of oral care products differed between nonintubated and intubated patients ($P < .001$), and nurses reported more frequent oral care than is documented. More recently, oral care protocols have been introduced widely in critical care settings, but the evidence base for these protocols, including care frequency, products, and methods of oral care, remains limited.

Effect of Oral Health on VAP—Although bacterial colonization of the oropharynx with potential VAP pathogens has been associated with the incidence of VAP, the relationship between oral health status and development of VAP had not been extensively studied over time in patients receiving mechanical ventilation. Dental plaque scores are increased in critically ill patients,⁴⁷ increase over time in the ICU setting,⁴⁵ and are worse at ICU admission in patients who are subsequently colonized with respiratory pathogens.⁵⁴

We examined the trajectory of oral health in a sample of 66 critically ill patients receiving mechanical ventilation.⁵⁵ Subjects were enrolled within 24 hours of intubation and were followed up for up to 7 days. Data on oral health and VAP (CPIS) were collected at

baseline, on day 4, and on day 7. Similar to others, we found that dental plaque and the number and type of oral organisms increased over time. Potential VAP pathogens were identified in oral cultures for 6 patients before or at the same time as the appearance of the organisms in tracheal aspirates. Our data support a link between increases in dental plaque and the development of VAP.⁵⁵ However, the relationship was not straightforward and was influenced by interactions among dental plaque, baseline severity of illness, and baseline pulmonary infection status. The effect of increased plaque was most predictive of pneumonia in patients with greater severity of illness and lower baseline CPIS. This finding suggests that oral care interventions may have the greatest effect on patients who are the most severely ill but do not yet have signs of pulmonary infection.

Oral Care Interventions to Reduce VAP—Because of my long history of military service, military oral health and its effect on VAP in combat casualties became an area of interest. The Tri-Service Comprehensive Oral Health Survey, a 30-site study of the oral health of almost 16 000 active duty personnel and recruits in the US Army, Navy, Marine Corps, and Air Force, documented that military recruits had a higher proportion of decayed teeth and a lower annual rate of use of dental care than did their civilian cohorts. Nearly all (99.3%) recruits needed some type of dental care. Combat casualty care includes treatment of blunt and penetrating trauma, burns, and blast injuries, which often require airway stabilization with endotracheal intubation.⁵⁶⁻⁵⁸ Trauma victims, including combat casualties, who may require endotracheal intubation in the field and prolonged mechanical ventilation due to traumatic injury, are particularly at risk for increases in oral colonization by microbial flora and therefore VAP. A single oral care intervention at the time of intubation may reduce this risk and is also practical, economical, and easy to administer in a combat field setting or en route to a health care facility.

Oral care may have the greatest effect on the most severely ill who do not yet have signs of pulmonary infection.

To evaluate the effect of a single, early oral care intervention in trauma victims, we first conducted a 2-phase pilot study to determine the feasibility of administration and the effectiveness of the intervention (chlorhexidine gluconate) on known VAP pathogens. At the time of this study, little was known about the effects of an oral care intervention soon (<24 hours) after intubation in critically ill patients. Evidence-based protocols for oral care of patients receiving mechanical ventilation after intubation were not available,⁵⁹ and use of an oral intervention soon after intubation had not been tested. During the first 24 to 48 hours of critical illness, trauma and surgical patients are generally in very unstable condition and nursing care is appropriately focused on achieving physiological stability. As a result, oral care is not a high priority. Because oral flora change in the first 48 hours of critical illness from the usual predominance of viridans streptococci and associated colonizers to more potentially pathogenic microbes responsible for pneumonia,⁴⁷⁻⁵⁰ a single oral intervention soon after intubation may reduce the growth of potential oral pathogens for 24 to 48 hours, until the patient's condition stabilizes and routine oral care can be instituted.

Chlorhexidine gluconate, a broad-spectrum antibacterial agent, reduces respiratory tract infection rates before and after elective cardiac surgery when compared with usual care.^{60,61} However, the duration of action of a single application of chlorhexidine gluconate had not been described in critically ill patients. In addition, the best method of administration of chlorhexidine gluconate to critically ill patients (ie, spray or swab) had not been identified. Therefore, in this pilot study, we sought to describe (1) the effect of a single oral application of chlorhexidine gluconate (by spray and by swab) soon after intubation on oral microbial flora and (2) the effect of a single oral application of chlorhexidine gluconate (by spray and by swab) on VAP.⁶² Thirty-four intubated patients were randomly assigned either to an experimental group that received chlorhexidine gluconate by spray or swab or to a control

group. Oral cultures were done at study admission and 12, 24, 48, and 72 hours after admission, and CPIS was documented at study admission and 48 and 72 hours after admission. Reductions in oral culture scores (less growth) were found only in the treatment groups (swab and spray); no reduction was found in the control group. A trend for fewer positive cultures in the combined treatment groups was noted. The mean CPIS for the control group increased from 4.7 to a level indicating pneumonia (6.6), whereas the CPIS for the treatment group increased only slightly (from 5.17 to 5.57). Trends in the data suggested that use of chlorhexidine gluconate in the early postintubation period may mitigate or delay the development of VAP.

A single, early dose of chlorhexidine reduces ventilator-associated pneumonia.

In comparing data on the use of chlorhexidine gluconate applied by spray versus swab, we found that none of the subjects receiving chlorhexidine gluconate by swab had evidence of oral colonization by 12 hours after admission or beyond, even though 1 patient had an oral culture that showed growth of *S pneumoniae* on admission to the study. Thus, a single swabbing with chlorhexidine gluconate may be the best method of reducing potential pathogens in oral flora.

After this pilot study, we conducted a randomized, controlled clinical trial in civilian trauma victims to further test the early (within 12 hours of intubation) application of chlorhexidine by swab versus control (no swab) on oral microbial flora and VAP. One hundred forty-five trauma patients requiring endotracheal intubation were randomly assigned to either the intervention group (5 mL chlorhexidine) or the control group. Oral microbial flora from semiquantitative oral cultures and VAP (CPIS) were obtained on study admission and at 24 (oral culture data only), 48, and 72 hours after intubation. Trauma-injury and severity score, illness severity (APACHE III) score, and frequency of usual oral care also were recorded. A repeated-measure proportional odds model was tested for differences in the oral cultures between the groups, and a repeated-measures random effects model was tested for differences in CPIS, with CPIS greater than 6 indicating VAP.

Of the 145 randomized patients, 71 were randomized to the intervention group and 74 to the control group. Seventy percent of the patients were male and 60% were white. Mean age was 42.4 years (SD, 18.2 years); mean APACHE III score was 66 (SD, 29.8). The 2 groups did not differ significantly at study admission for any clinical characteristic except CPIS scores (intervention group: mean, 5.05; SD, 0.28 vs control group: mean, 3.98; SD, 0.27; $P < .01$) and greater levels of positive oral cultures (18.3% intervention group vs 5.6% control group, $P < .01$). No significant treatment effect ($P = .33$) on oral cultures was found. However, a significant treatment effect ($P = .02$) on CPIS both from admission to 48 hours after admission and from admission to 72 hours after admission was found.⁶³

Because VAP had developed in 41.7% of the control patients with a baseline CPIS less than 6 (no VAP) by 48 or 72 hours after admission vs only 19.4% of the intervention patients, this study showed that the use of a single dose of chlorhexidine early in the intubation period is effective in reducing early VAP, especially in trauma patients without pneumonia at intubation.

Others^{60,61,64} have found chlorhexidine to be effective in reducing nosocomial respiratory tract infections, although some used it preoperatively in elective cardiac surgery patients^{60,61} or used broad definitions of pulmonary infection^{60,61,64} rather than focusing specifically on ICU interventions for VAP. Most recently, Munro et al,⁶⁵ in a randomized controlled clinical trial, tested the effects of chlorhexidine and toothbrushing, administered up to 7 days, on reducing VAP in 249 critically ill adults receiving mechanical ventilation. We found that chlorhexidine significantly reduced the incidence of pneumonia among subjects

who did not have pneumonia at baseline ($P = .02$), but that toothbrushing had no effect on CPIS. Chlorhexidine oral swabbing was therefore effective in reducing early VAP in patients without pneumonia at baseline. Chlorhexidine should be considered in the development of oral care protocols, but may not completely eradicate all occurrences of VAP.

Sedation in Mechanical Ventilation

Patients receiving mechanical ventilation require sedation to help attenuate the anxiety, pain, and agitation associated with this intervention,⁶⁶⁻⁶⁸ and although 85% of ICU patients receive intravenous sedation, risks associated with sedation in ventilator patients are significant. The overall goal of sedation in critical care settings is to provide physiological stability, ventilator synchrony, and comfort for patients.⁶⁷⁻⁷⁰ Inappropriately high or low levels of sedation in critically ill adults are associated with significant risks. Inappropriately high levels of sedation lead to alterations of respiratory drive, inability to maintain and protect the airway, and cardiovascular instability,⁷¹ as well as prolonged duration of mechanical ventilation and VAP.⁷² Conversely, inadequate levels of sedation may result in agitation, which places the intubated patient at risk for self-extubation, hemodynamic instability, and physical harm or injury.⁷³ Therefore, identifying appropriate strategies to optimize sedation is an important goal, not only to reduce sedation-associated risks, but to reduce the duration of and enhance weaning from mechanical ventilation.

Weaning From Mechanical Ventilation

Mechanical ventilation is often associated with prolonged weaning processes, with 41% of mechanical ventilation time spent weaning patients.⁷⁴ The use of multidisciplinary weaning protocols significantly reduces the duration of mechanical ventilation.⁷⁵⁻⁷⁹ The key to successful weaning may be simply that a protocol is used, rather than specifically how the protocol is constructed or what method of weaning is used.⁸⁰

Several important issues related to ventilator weaning have been identified.⁸¹ First, the evidence suggests that independent clinical judgment or experience about readiness to wean is a relatively poor predictor of weaning success. Second, clinical assessments (respiratory pattern, cardiovascular response, comfort/anxiety, oxygenation) are better predictors of success than are more complex weaning parameters. Third, daily spontaneous breathing trials are superior to gradual ventilator-reduction strategies (ie, gradual reduction in synchronized mandatory ventilation or pressure support ventilation). Finally it is clear that nurses and respiratory therapists can achieve weaning goals effectively by using protocols. Importantly, implementation of weaning protocols requires a consistent team effort that may be difficult to sustain in the complex critical care environment.

With these issues in mind, our medical respiratory ICU initiated a systematic approach to the weaning process by developing, implementing, and evaluating a protocol for weaning patients from mechanical ventilation. The weaning protocol used was a modification of protocols developed by others,⁸²⁻⁸⁴ including a more aggressive approach in proceeding to the spontaneous breathing trial, inclusion of the Richmond Agitation-Sedation Scale, and documentation of the production of secretions. Implementation of the protocol significantly reduced the duration of mechanical ventilation as measured by 8-hour shifts and ventilator days. Although length of stay in the ICU was not significantly reduced ($P = .29$), a continuing downward trend occurred, from a mean of 8.6 days before the protocol was implemented to 7.9 days during the last 6 months of data collection ($P = .07$). The need to provide efficient care requires the collaboration of all disciplines involved in providing patients' care. The weaning protocol introduced in this study demonstrated the benefits of

using a collaborative team to identify best practices and implement them in a practice setting.

Present sedation evaluation may not adequately assess all domains of sedation efficacy.

Actigraphy, Agitation, and Sedation

The best method for measuring sedation and agitation, especially in patients receiving mechanical ventilation, has gained much attention recently and is a clinically important issue.^{68,85-90} In a comprehensive review of sedation-agitation scoring systems, DeJonghe et al⁹¹ found that although sedation-agitation tools have been used to measure sedation effectiveness in ICU patients, few such tools exhibit satisfactory clinimetric properties. Only a few sedation scales also include multiple levels of excessive activity and/or agitated behavior.⁹²⁻⁹⁴ Tools currently in use include direct observations and intermittent structured assessments by nurses and other care providers, but these tools do not provide a continuous measure of activity and/or agitation. Available continuous measures such as blood pressure or heart rate may reflect a patient's status, for example, higher blood pressure or heart rate often accompanies increased activity or agitation. However, these measures are very nonspecific and include a variety of reasons for change. Because agitation is associated with excessive restlessness and physical activity, the ability to identify increased activity, especially continuously, may be an important first step in assessment of agitation.

The actigraph, a continuous measure of activity, was initially developed to measure sleep activity. It is a small electronic device that can be strapped to the wrist or ankle and can continuously sense and record minimal movements or activity (eg, accelerations, linear displacements) during predetermined epochs for as long as several days. Actigraphy data are expressions of the acceleration movement in numerical form. Actigraphy is easy to use and has proven reliable across other noncritical populations. Although wrist actigraphy has not been widely tested as a measure of agitation or sedation in critically ill patients, its use as a continuous activity monitor may assist in the objective measure of agitation by providing a numerical record of limb movement resulting in early detection of excessive nonpurposeful movement that characterizes agitation.

We evaluated the use of actigraphy as a continuous measurement of limb movement by using wrist and ankle actigraphy in critically ill patients and comparing the actigraphy measurements with observed patient activity, scores on subjective sedation-agitation scales (Richmond Agitation Sedation Scale [RASS] and Comfort Scale⁹⁵), and heart rate and blood pressure. The RASS was developed at our institution by members of the research team.⁹⁴ In a prospective, descriptive, correlational study,⁹⁶ all activity of 20 adult patients in medical and coronary care units in a university medical center was observed for 2 hours and documented. Wrist and ankle actigraphy, heart rate, and systolic and diastolic blood pressure data were collected every minute. The Comfort Scale and the RASS were completed at the beginning of the observation period and 1 and 2 hours later. Wrist actigraphy data correlated with scores on the RASS ($r = 0.58$) and the Comfort Scale ($r = 0.62$) and with observed stimulation and activity events of patients ($r = 0.45$). Correlations with systolic, diastolic, and mean arterial pressures were weaker. Wrist and ankle actigraphy data were significantly correlated ($r = 0.69$; $P < .001$); however, their mean values (wrist, 418; ankle, 147) were significantly different ($t = 5.77$; $P < .001$). Actigraphy measurements correlate well with patients' observed activity and with subjective scores on agitation and sedation scales and may become particularly important as a continuous measurement of activity for use in behavioral research and potentially enhancing early recognition and management of the excessive activity that characterizes agitation.

Meeting the Goals of Sedation

The overall goals of sedation in critical care settings are to provide physiological stability, maintain ventilator synchrony, and ensure comfort for patients.⁶⁷⁻⁷⁰ Although sedation scales are used to assess sedation level, the extent to which various levels of sedation actually achieve sedation goals is unknown. We examined the effect of sedation level on the sedation outcomes of physiological stability and comfort. Twenty-four subjects in the medical respiratory ICU were continuously monitored and data were recorded every 15 seconds (326 patient hours). Sedation level was measured with the Patient State Index (PSI; processed electroencephalogram), physiological stability was documented by using heart rate and respiratory rate, comfort was evaluated by using arm and leg actigraphy and the percentage of time outside the normal range for heart rate, respiratory rate, and actigraphy was evaluated. Sedation level was categorized as deep (PSI, <60), mild/moderate (PSI, 60-80), or awake/alert (PSI, >80).⁹⁷

Subjects were predominantly female (73%), with a mean age of 55 years, and the majority had been admitted for acute respiratory failure. Subjects were identified as physiologically unstable (either heart rate or respiratory rate outside of normal limits) 65% of the time during deep sedation, 62% of the time during mild/moderate sedation, and 60% of the time when alert. The percentage of time that the patient was moving, which may indicate discomfort, was 2% during deep sedation, 10% during mild/moderate sedation, and 13% while alert. Although patients' movement increases as expected with less sedation, physiological stability was not achieved more than half the time, even with deep levels of sedation. The present methods of evaluating sedation may not be adequate to assess all domains of sedation efficacy, and efforts to achieve the goals of sedation should remain a priority.

Summary

Reducing risks associated with mechanical ventilation in critically ill patients is a vast, complex, and interdisciplinary process. Although our understanding of the uses, complications, and outcomes associated with mechanical ventilation changes almost every day, the importance of this understanding for bedside clinicians is paramount. Reducing risks associated with airway management, backrest position, oral health, and sedation in patients receiving mechanical ventilation has provided the foundation for a program of research that has attempted to answer clinical questions while providing evidence on which to base practice decisions.

Acknowledgments

A program of research is never the product of a single individual's work. It can be successful only through the combined talents, dedication, and enthusiasm of the research team. I have been blessed to work with just such an extraordinary team. The support of the Virginia Commonwealth University (VCU) Medical Center's critical care areas, particularly the medical respiratory ICU, has been unparalleled. The VCU School of Nursing has consistently provided "whatever I needed" in my research endeavors, and without my "right-hand," project director Anne Hamilton, many of these studies would simply never have been completed. To the best collaborators ever—I cannot begin to describe what your friendship and contributions have meant to me and this work. In particular, Drs Cindy Munro and Curtis Sessler, your guidance and support have been the constant throughout and are the solid foundation of this program of research. Thank you all so much!

References

1. Sole ML, Byers JF, Ludy JE, Zhang Y, Banta CM, Brummel K. A multisite survey of suctioning techniques and airway management practices. *Am J Crit Care*. 2003; 12:220–230. [PubMed: 12751396]

2. Bourgault AM, Brown CA, Hains SM, Parlow JL. Effects of endotracheal tube suctioning on arterial oxygen tension and heart rate variability. *Biol Res Nurs*. 2006; 7:268–278. [PubMed: 16581897]
3. Kelleher S, Andrews T. An observational study on the open-system endotracheal suctioning practices of critical care nurses. *J Clin Nurs*. 2008; 17:360–369. [PubMed: 18205692]
4. Chulay M. Arterial blood gas changes with a hyperinflation and hyperoxygenation suctioning intervention in critically ill patients. *Heart Lung*. 1988; 17:654–661. [PubMed: 3192411]
5. Chulay M. Hyperinflation/hyperoxygenation to prevent endotracheal suctioning complications. *Crit Care Nurs*. 1987; 7:100–102.
6. Baun MM. Physiological determinants of a clinically successful method of endotracheal suction. *West J Nurs Res*. 1984; 6:213–228. [PubMed: 6567436]
7. Powaser MM, Converse AL. The relative roles of hyperinflation and oxygen in raising arterial oxygen tension after pre-oxygenation prior to endotracheal suctioning. *Am Rev Respir Dis*. 1980; 121(suppl):216.
8. Glass C, Grap MJ, Corley MC, Wallace D. Nurses' ability to achieve hyperinflation and hyperoxygenation with a manual resuscitation bag during endotracheal suctioning. *Heart Lung*. 1993; 22:158–165. [PubMed: 8449760]
9. Corley M, Ledwidge MK, Glass C, Grap MJ. The myth of 100% oxygen delivery through manual resuscitation bags. *J Emerg Nurs*. 1993; 19(1):45–49. [PubMed: 8437402]
10. Grap MJ, Glass C, Corley M, Creekmore S, Mellott K, Howard C. Effect of level of lung injury on HR, MAP and SaO₂ changes during suctioning. *Intensive Crit Care Nurs*. 1994; 10:171–178. [PubMed: 7803966]
11. Grap MJ, Glass C, Corley M, Parks T. Endotracheal suctioning: ventilator vs manual delivery of hyperoxygenation breaths. *Am J Crit Care*. 1996; 5:192–197. [PubMed: 8722922]
12. Glass C, Grap MJ, Sessler CN. Endotracheal tube narrowing after closed-system suctioning: prevalence and risk factors. *Am J Crit Care*. 1999; 8:93–100. [PubMed: 10071699]
13. Fagon JY, Chastre J, Hance AJ, Montravers P, Novara A, Gibert C. Nosocomial pneumonia in ventilated patients: a cohort study evaluating attributable mortality and hospital stay. *Am J Med*. 1993; 94:281–288. [PubMed: 8452152]
14. Tablan OC, Anderson LJ, Arden NH, Breiman RF, Butler JC, McNeil MM. Guideline for prevention of nosocomial pneumonia. The Hospital Infection Control Practices Advisory Committee. *Am J Infect Control*. 1994; 22:247–292. [PubMed: 7985826]
15. Dreyfuss D, Djedaini K, Gros I, et al. Mechanical ventilation with heated humidifiers or heat and moisture exchangers: effects on patient colonization and incidence of nosocomial pneumonia. *Am J Res Crit Care Med*. 1995; 151:986–992.
16. Chevret S, Hemmer M, Carlet J, Langer M. Incidence and risk factors of pneumonia acquired in intensive care units: results from a multicenter prospective study on 996 patients. European Cooperative Group on Nosocomial Pneumonia 49. *Intensive Care Med*. 1993; 19:256–264. [PubMed: 8408934]
17. Alvarez-Lerma F, Palomar M, Martinez-Pellus AE, et al. Etiology and diagnostic techniques in intensive care-acquired pneumonia: a Spanish multi-center study. *Clin Intensive Care*. 1997; 8:164–170.
18. Craven DE, Steger KA, Barber TW. Preventing nosocomial pneumonia: state of the art and perspectives for the 1990s. *Am J Med*. 1991; 91:44S–53S. [PubMed: 1928191]
19. Leu HS, Kaiser DL, Mori M, Woolson RF, Wenzel RP. Hospital-acquired pneumonia: attributable mortality and morbidity. *Am J Epidemiol*. 1989; 129:1258–1267. [PubMed: 2729261]
20. Haley RW, Schaberg DR, Crossley K, Von Allmen SD, McGowan JE Jr. Extra charges and prolongation of stay attributable to nosocomial infections: a prospective interhospital comparison. *Am J Med*. 1981; 70:51–58. [PubMed: 7457491]
21. Kollef MH, Wragge T, Pasque C. Determinants of mortality and multiorgan dysfunction in cardiac surgery patients requiring prolonged mechanical ventilation. *J Hosp Infect*. 1995; 107:1395–1401.
22. Rodriguez JL, Gibbons KJ, Bitzer LG, Dechert RE, Steinberg SM, Flint LM. Pneumonia: incidence, risk factors, and outcome in injured patients. *J Trauma*. 1991; 31:907–912. [PubMed: 2072428]

23. Jimenez P, Torres A, Rodriguez-Roisin R, et al. Incidence and etiology of pneumonia acquired during mechanical ventilation. *Crit Care Med*. 1989; 17:882–885. [PubMed: 2766759]
24. Berg DE, Hershov RC, Ramirez CA, Weinstein RA. Control of nosocomial infections in an intensive care unit in Guatemala City. *Clin Infect Dis*. 1995; 21:588–593. [PubMed: 8527548]
25. Craven DE, Barber TW, Steger KA, Montecalvo MA. Nosocomial pneumonia in the 1990s: update of epidemiology and risk factors. *Semin Respir Infect*. 1990; 5:157–172. [PubMed: 2255802]
26. Craven DE, Steger KA. Nosocomial pneumonia in mechanically ventilated adult patients: epidemiology and prevention in 1996. *Semin Respir Infect*. 1996; 11:32–53. [PubMed: 8885061]
27. Kappstein I, Schulgen G, Beyer U, Geiger K, Schumacher M, Daschner FD. Prolongation of hospital stay and extra costs due to ventilator-associated pneumonia in an intensive care unit. *Eur J Clin Microbiol Infect Dis*. 1992; 11:504–508. [PubMed: 1526233]
28. Huxley EJ, Viroslav J, Gray WR, Pierce AK. Pharyngeal aspiration in normal adults and patients with depressed consciousness. *Am J Med*. 1978; 64:564–568. [PubMed: 645722]
29. Valles J, Artigas A, Rello J, et al. Continuous aspiration of subglottic secretions in preventing ventilator-associated pneumonia. *Ann Intern Med*. 1995; 122:179–186. [PubMed: 7810935]
30. Ibanez J, Penafiel A, Raurich JM, Marse P, Jorda R, Mata F. Gastroesophageal reflux in intubated patients receiving enteral nutrition: effect of supine and semirecumbent positions. *JPEN J Parenter Enteral Nutr*. 1992; 16:419–422. [PubMed: 1433774]
31. Torres A, Serra-Batlles J, Ros E, et al. Pulmonary aspiration of gastric contents in patients receiving mechanical ventilation: the effect of body position. *Ann Intern Med*. 1992; 116:540–543. [PubMed: 1543307]
32. Kollef MH. Ventilator-associated pneumonia: a multivariate analysis. *JAMA*. 1993; 270:1965–1970. [PubMed: 8411554]
33. Drakulovic MB, Torres A, Bauer TT, Nicolas JM, Nogue S, Ferrer M. Supine body position as a risk factor for nosocomial pneumonia in mechanically ventilated patients: a randomised trial. *Lancet*. 1999; 354:1851–1858. [PubMed: 10584721]
34. Evans D. The use of position during critical illness: current practice and review of the literature. *Aust Crit Care*. 1994; 7:16–21. [PubMed: 7727906]
35. Grap MJ, Cantley M, Munro C, Corley M. Use of backrest elevation in critical care: a pilot study. *Am J Crit Care*. 1999; 8:475–480. [PubMed: 9987545]
36. Grap MJ, Munro CL, Bryant S, Ashtiani B. Predictors of backrest elevation in critical care. *Intensive Crit Care Nurs*. 2003; 19:68–74. [PubMed: 12706732]
37. Roadmap for safety: National Quality Forum officially releases 30 safe practices for better healthcare. *Qual Lett Healthc Lead*. 2003; 15:12–14. 1.
38. Metheny NA, Clouse RE, Chang YH, Stewart BJ, Oliver DA, Kollef MH. Tracheobronchial aspiration of gastric contents in critically ill tube-fed patients: frequency, outcomes, and risk factors. *Crit Care Med*. 2006; 34:1007–1015. [PubMed: 16484901]
39. Hummel R, Grap MJ, Sessler CN, Munro CL, Corley M. Continuous measurement of backrest elevation in critical care: a research strategy. *Crit Care Med*. 2000; 28:2621–2625. [PubMed: 10921605]
40. Helman DL Jr, Sherner JH III, Fitzpatrick TM, Callender ME, Shorr AF. Effect of standardized orders and provider education on head-of-bed positioning in mechanically ventilated patients. *Crit Care Med*. 2003; 31:2285–2290. [PubMed: 14501958]
41. Joiner GA, Salisbury D, Bollin GE. Utilizing quality assurance as a tool for reducing the risk of nosocomial ventilator-associated pneumonia. *Am J Med Qual*. 1996; 11:100–103. [PubMed: 8704496]
42. Zack JE, Garrison T, Trovillion E, et al. Effect of an education program aimed at reducing the occurrence of ventilator-associated pneumonia. *Crit Care Med*. 2002; 30:2407–2412. [PubMed: 12441746]
43. American Association of Critical Care Nurses. [Accessed April 27, 2009] VAP Practice Alert. http://www.aacn.org/WD/Practice/Content/practicealerts.pcms?menu=Practice&lastmenu=divHeader_Evidence-Based_Resources. Issued January 1, 2008

44. US Department of Health and Human Services. Oral Health in America: A Report of the Surgeon General-Executive Summary. Rockville, MD: US Department of Health and Human Services; 2000.
45. Fourrier F, Duvivier B, Boutigny H, Rourel-Delvallez M, Chopin C. Colonization of dental plaque: a source of nosocomial infections in intensive care unit patients. *Crit Care Med*. 1998; 26:301–308. [PubMed: 9468169]
46. Garrouste OM, Chevret S, Arlet G, et al. Oropharyngeal or gastric colonization and nosocomial pneumonia in adult intensive care unit patients: a prospective study based on genomic DNA analysis. *Am J Respir Crit Care Med*. 1997; 156:1647–1655. [PubMed: 9372689]
47. Scannapieco FA, Stewart EM, Mylotte JM. Colonization of dental plaque by respiratory pathogens in medical intensive care patients. *Crit Care Med*. 1992; 20:740–745. [PubMed: 1597025]
48. Cardenosa Cendrero JA, Sole-Violan J, Bordes BA, et al. Role of different routes of tracheal colonization in the development of pneumonia in patients receiving mechanical ventilation. *Am J Respir Crit Care Med*. 1999; 116:462–470.
49. Schwartz SN, Dowling JN, Benkovic C, DeQuittner-Buchanan M, Prostko T, Yee RB. Sources of gram-negative bacilli colonizing the tracheae of intubated patients. *J Infect Dis*. 1978; 138:227–231. [PubMed: 355582]
50. Rubenstein JS, Kabat K, Shulman ST, Yogev R. Bacterial and fungal colonization of endotracheal tubes in children: a prospective study. *Crit Care Med*. 1992; 20:1544–1549. [PubMed: 1424697]
51. Jenkins DA. Oral care in the ICU: an important nursing role. *Nurs Stand*. 1989; 4:24–29. [PubMed: 2513508]
52. Grap MJ, Munro CL, Ashtiani B, Bryant S. Oral care interventions in critical care: frequency and documentation. *Am J Crit Care*. 2003; 12:113–118. [PubMed: 12625169]
53. Hanneman SK, Gusick GM. Frequency of oral care and positioning of patients in critical care: a replication study. *Am J Crit Care*. 2005; 14:378–386. [PubMed: 16120889]
54. El-Solh AA, Pietrantonio C, Bhat A, et al. Colonization of dental plaques: a reservoir of respiratory pathogens for hospital-acquired pneumonia in institutionalized elders. *Am J Respir Crit Care Med*. 2004; 126:1575–1582.
55. Munro CL, Grap MJ, Elswick RK Jr, McKinney J, Sessler CN, Hummel RS III. Oral health status and development of ventilator-associated pneumonia: a descriptive study. *Am J Crit Care*. 2006; 15:453–460. [PubMed: 16926366]
56. Behbehani A, Abu-Zidan F, Hasaniya N, Merei J. War injuries during the Gulf War: experience of a teaching hospital in Kuwait. *Ann R Coll Surg Engl*. 1994; 76:407–411. [PubMed: 7702326]
57. Brundage JF, Kohlhasse KF, Rubertone MV. Hospitalizations for all causes of U.S. military service members in relation to participation in Operations Joint Endeavor and Joint Guard, Bosnia-Herzegovina, January 1995 to December 1997. *Mil Med*. 2000; 165:505–511. [PubMed: 10920647]
58. Blood CG, Gauker ED, Jolly R, Pugh WM. Comparisons of casualty presentation and admission rates during various combat operations. *Mil Med*. 1994; 159:457–461. [PubMed: 7984306]
59. Anderson J, Lester J. Can a patient who has an endotracheal tube and is on mechanical ventilation be given ice chips? *Critical Care Nurse*. 1999; 19(1):95–96. [PubMed: 10401296]
60. Houston S, Hougland P, Anderson JJ, LaRocco M, Kennedy V, Gentry LO. Effectiveness of 0.12% chlorhexidine gluconate oral rinse in reducing prevalence of nosocomial pneumonia in patients undergoing heart surgery. *Am J Crit Care*. 2002; 11:567–570. [PubMed: 12425407]
61. DeRiso AJ, Ladowski JS, Dillon TA, Justice JW, Peterson AC. Chlorhexidine gluconate 0.12% oral rinse reduces the incidence of total nosocomial respiratory infection and nonprophylactic systemic antibiotic use in patients undergoing heart surgery. *Am J Respir Crit Care Med*. 1996; 109:1556–1561.
62. Grap MJ, Munro CL, Elswick RK Jr, Sessler CN, Ward KR. Duration of action of a single, early oral application of chlorhexidine on oral microbial flora in mechanically ventilated patients: a pilot study. *Heart Lung*. 2004; 33:83–91. [PubMed: 15024373]
63. Grap MJ, Munro CL, Elswick RK, Sessler CN, Ward KR, Higgins SM. Early, single chlorhexidine application to reduce oral flora and ventilator-associated pneumonia in trauma victims [abstract]. *Am J Crit Care*. 2009; 18(3):200. [PubMed: 19411580]

64. Segers P, Speekenbrink RG, Ubbink DT, van Ogtrop ML, de Mol BA. Prevention of nosocomial infection in cardiac surgery by decontamination of the nasopharynx and oropharynx with chlorhexidine gluconate: a randomized controlled trial. *JAMA*. 2006; 296:2460–2466. [PubMed: 17119142]
65. Munro CL, Grap MJ, McClish D, Sessler CN. Chlorhexidine reduces ventilator associated pneumonia (VAP) in mechanically ventilated ICU adults. *Crit Care Med*. 2006; 34(12, suppl):A1. [PubMed: 17265562]
66. Sessler CN, Grap MJ, Brophy GM. Multidisciplinary management of sedation and analgesia in critical care. *Semin Respir Crit Care Med*. 2001; 22:211–225. [PubMed: 16088675]
67. Sessler CN. Comfort and distress in the ICU: scope of the problem. *Semin Respir Crit Care Med*. 2001; 22:111–113. [PubMed: 16088666]
68. Jacobi J, Fraser GL, Coursin DB, et al. Clinical practice guidelines for the sustained use of sedatives and analgesics in the critically ill adult. *Crit Care Med*. 2002; 30:119–141. [PubMed: 11902253]
69. Blanchard AR. Sedation and analgesia in intensive care: medications attenuate stress response in critical illness. *Postgrad Med*. 2002; 111(2):59–64. 67–70. [PubMed: 11868314]
70. Tufano R. Analgesia and sedation in intensive care: a progress report. *Minerva Anesthesiol*. 2003; 69:735–737. [PubMed: 14673395]
71. Barr J, Donner A. Optimal intravenous dosing strategies for sedatives and analgesics in the intensive care unit. *Crit Care Clin*. 1995; 11:827–847. [PubMed: 8535981]
72. Rello J, Diaz E, Roque M, Valles J. Risk factors for developing pneumonia within 48 hours of intubation. *Am J Respir Crit Care Med*. 1999; 159:1742–1746. [PubMed: 10351912]
73. Boulain T. Unplanned extubations in the adult intensive care unit: a prospective multicenter study. Association des Reanimateurs du Centre-Ouest. *Am J Respir Crit Care Med*. 1998; 157:1131–1137. [PubMed: 9563730]
74. Esteban A, Alia I, Ibanez J, Benito S, Tobin MJ. Modes of mechanical ventilation and weaning: a national survey of Spanish hospitals. The Spanish Lung Failure Collaborative Group. *Am J Respir Crit Care Med*. 1994; 106:1188–1193.
75. Kollef MH, Shapiro SD, Silver P, et al. A randomized, controlled trial of protocol-directed versus physician-directed weaning from mechanical ventilation [see comments]. *Crit Care Med*. 1997; 25:567–574. [PubMed: 9142019]
76. Ibrahim EH, Kollef MH. Using protocols to improve the outcomes of mechanically ventilated patients: focus on weaning and sedation. *Crit Care Clin*. 2001; 17:989–1001. [PubMed: 11762271]
77. Ely EW, Baker AM, Dunagan DP, et al. Effect on the duration of mechanical ventilation of identifying patients capable of breathing spontaneously. *N Engl J Med*. 1996; 335:1864–1869. [PubMed: 8948561]
78. Cohen IL, Bari N, Strosberg MA, et al. Reduction of duration and cost of mechanical ventilation in an intensive care unit by use of a ventilatory management team. *Crit Care Med*. 1991; 19:1278–1284. [PubMed: 1914485]
79. Henneman E, Dracup K, Ganz T, Molayeme O, Cooper C. Effect of a collaborative weaning plan on patient outcome in the critical care setting. *Crit Care Med*. 2001; 29:297–303. [PubMed: 11246309]
80. Kollef MH, Horst HM, Prang L, Brock WA. Reducing the duration of mechanical ventilation: three examples of change in the intensive care unit. *New Horiz*. 1998; 6:52–60. [PubMed: 9508258]
81. MacIntyre NR, Cook DJ, Ely EW Jr, et al. Evidence-based guidelines for weaning and discontinuing ventilatory support: a collective task force facilitated by the American College of Chest Physicians; the American Association for Respiratory Care; and the American College of Critical Care Medicine. *Am J Respir Crit Care Med*. 2001; 120:375S–395S.
82. Esteban A, Alia I. Clinical management of weaning from mechanical ventilation. *Intensive Care Med*. 1998; 24:999–1008. [PubMed: 9840232]
83. Ely EW, Bennett PA, Bowton DL, Murphy SM, Florance AM, Haponik EF. Large scale implementation of a respiratory therapist-driven protocol for ventilator weaning. *Am J Respir Crit Care Med*. 1999; 159:439–446. [PubMed: 9927355]

84. Ely EW, Baker AM, Evans GW, Haponik EF. The prognostic significance of passing a daily screen of weaning parameters. *Intensive Care Med.* 1999; 25:581–587. [PubMed: 10416909]
85. Riker RR, Fraser GL. Sedation in the intensive care unit: refining the models and defining the questions. *Crit Care Med.* 2002; 30:1661–1663. [PubMed: 12131001]
86. Nasraway SA Jr, Jacobi J, Murray MJ, Lumb PD. Sedation, analgesia, and neuromuscular blockade of the critically ill adult: revised clinical practice guidelines for 2002. *Crit Care Med.* 2002; 30:117–118. [PubMed: 11902252]
87. McGaffigan PA. Advancing sedation assessment to promote patient comfort. *Crit Care Nurse.* 2002; (suppl):29–36. [PubMed: 11852493]
88. Avramov MN, White PF. Methods for monitoring the level of sedation. *Crit Care Clin.* 1995; 11:803–826. [PubMed: 8535980]
89. Magarey JM. Sedation of adult critically ill ventilated patients in intensive care units: a national survey. *Aust Crit Care.* 1997; 10:90–93. [PubMed: 9362609]
90. Murray K. The need for assessment of sedation in the critically ill. *Nurs Crit Care.* 1997; 2:297–302. [PubMed: 9887767]
91. De Jonghe B, Cook D, Appere-De-Vecchi C, Guyatt G, Meade M, Outin H. Using and understanding sedation scoring systems: a systematic review. *Intensive Care Med.* 2000; 26:275–285. [PubMed: 10823383]
92. Riker RR, Picard JT, Fraser GL. Prospective evaluation of the Sedation-Agitation Scale for adult critically ill patients. *Crit Care Med.* 1999; 27:1325–1329. [PubMed: 10446827]
93. Devlin JW, Boleski G, Mlynarek M, et al. Motor Activity Assessment Scale: a valid and reliable sedation scale for use with mechanically ventilated patients in an adult surgical intensive care unit. *Crit Care Med.* 1999; 27:1271–1275. [PubMed: 10446819]
94. Sessler CN, Gosnell M, Grap MJ, et al. The Richmond Agitation-Sedation Scale: validity and reliability in adult intensive care unit patients. *Am J Respir Crit Care Med.* 2002; 166:1338–1344. [PubMed: 12421743]
95. Ambuel B, Hamlett KW, Marx CM, Blumer JL. Assessing distress in pediatric intensive care environments: the COMFORT scale. *J Pediatr Psychol.* 1992; 17:95–109. [PubMed: 1545324]
96. Grap MJ, Borchers CT, Munro CL, Elswick RK, Sessler CN. Actigraphy in the critically ill: correlation with agitation and sedation. *Am J Crit Care.* 2005; 14(1):52–60. [PubMed: 15608109]
97. Grap, MJ.; Munro, CL.; Sessler, CN.; Wetzel, PA.; Best, AM. The relationships among ICU environment light and sound, hemodynamic stability, agitation and sedation. *Proceedings of the 20th Anniversary Conference of the Southern Nursing Research Society: Remembering the Past and Celebrating the Future 2006*; Wheat Ridge, CO. Southern Nursing Research Society; 2006.