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To estimate the percentage of adult asthmatics with occupational asthma in Michigan, a sample of 94 patients, aged 20 to 65 years, who were discharged from one of three Michigan hospitals in 1990 with the primary diagnosis of asthma were interviewed. The patients were classified using the National Institute for Occupational Safety and Health (NIOSH) criteria as having either probable occupational asthma, possible occupational asthma, or not having occupational asthma. Three percent of the adult asthmatics interviewed met the criteria for having probable occupational asthma. One patient from each hospital had probable occupational asthma. Fifteen of 60 patients (25%) from Hospital A, 3 of 25 patients (12%) from Hospital B, and 2 of the 9 patients (22%) from Hospital C had probable or possible occupational asthma. After adjusting for the difference in response rate among patients from the three hospitals, the percentage of adult asthmatics in Michigan whose asthma is caused by work exposure is estimated to be between 3% and 20.2%. In contrast, 25.5% of the patients stated their asthma was caused by bad working conditions. If these percentages were generalizable to the whole state, then according to our survey 330 to 2,222 or by self-reports of the patients, 2,800 of the 11,000 hospital discharges per year in Michigan for asthma among adults could be attributed to a work exposure.


Various human pulmonary diseases are characterized by an increased oxidant burden on the respiratory epithelial surface. As a step toward developing a therapy to augment the antioxidant defenses of respiratory epithelial lining fluid (ELF) of the human lung, we have evaluated the feasibility of aerosolizing a human protein antioxidant to the respiratory epithelial surface of an experimental animal sufficiently large to permit repetitive sampling of ELF. To accomplish this, recombinant human Cu+/Zn++ superoxide dismutase (sSOD) was aerosolized to sheep, and the levels of human superoxide dismutase (SOD) and anti-superoxide anion (O2-) capacity were quantified in ELF over time. In-vitro aerosolization did not alter the specific activity of sSOD (p > 0.5). In-vivo aerosolization of sSOD (100 mg) to sheep (n = 7) resulted in peak amounts of human Cu+/Zn++ SOD in ELF of 3.1 ± 0.6 μmol/L with a parallel increase in the anti-O2- capacity of ELF. For
the duration of the study (5 h), levels of SOD and anti-"O" in ELF remained elevated, with a value 50% of the peak at 5 h. Aerosolization of phosphate-buffered saline (n = 5) had no effect on SOD or anti-"O" levels in ELF. In animals receiving rSOD, there was no change in the specific activity of SOD recovered in ELF compared to the starting material (p > 0.4). We conclude that rSOD can be delivered by aerosol to the ELF of a large animal with preservation of specific activity and that a substantial increase in both the amount of SOD and the anti-"O" capacity can be achieved for a period of time applicable to human therapy, supporting the rationale for evaluation of rSOD aerosol as an antioxidant in human pulmonary disease.


Subjects with isolated complaints of chronic daytime sleepiness are usually classified as "idiopathic hypersomnias" and treated symptomatically. A group of these subjects was investigated during nocturnal sleep and daytime naps. In a subgroup of them, sleep was fragmented by very short alpha EEG arousals throughout the sleeping period. These short arousals are usually ignored in sleep analyses, but their impact is significant (in the 15 subjects identified with the syndrome, the mean sleep latency in multiple sleep-latency tests was 5.1 ± 1 min). These arousals are directly related to an abnormal increase in respiratory efforts during sleep (the mean peak inspiratory esophageal pressure measured in our subjects in the respiratory cycle just preceding a transient arousal was −33 ± 7 cm H2O). Typically, an arousal occurs within one to three breaths of flow limitation associated with abrupt but limited reduction in tidal volume (ie, abnormal increase in upper airway resistance during sleep). The arousal restores normal breathing. Snoring was noted in association with these transient arousals in 10 of the 15 subjects; however, snoring was neither sufficient nor necessary for the identification of the clinical syndrome. Both sexes were equally represented in the affected group. All studied subjects had upper airway anatomy that was mildly abnormal. Nasal continuous positive airway pressure, used as an experimental tool, eliminated the daytime sleepiness (multiple sleep latency mean score = 13.5 min), the transient arousals (mean alpha EEG arousal index decreased from 31.3 ± 12.4 to 8 ± 2 per hour of sleep), and the abnormal upper airway resistance. Chronic daytime sleepiness is a major cause of social, economic, and medical impairment. Recognition of this syndrome and its cause is important, as specific treatments can be developed to eliminate the problem.


BACKGROUND: Comparative studies of albuterol by wet nebulizer or metered dose inhaler have tested fixed doses of medications. We compared the dose-response relationship to albuterol by wet nebulization or metered dose inhaler in acute asthma. METHODS: Randomized, double-blind, placebo-controlled trial. Patients with acute asthma received either albuterol, 0.4 mg, by metered dose inhaler (and holding chamber) or albuterol, 2.5 mg, by wet nebulizer every 30 min until maximal bronchodilation. Forty patients (forced expiratory volume in 1 s [FEV1]; 1.15 ± 0.43 L; 36 ± 12% predicted) received metered dose inhaler and 40 others (FEV1; 1.08 ± 0.52 L; 35 ± 16% predicted) received wet nebulization. RESULTS: Twenty-six patients (65%) receiving metered dose inhaler and 30 (75%) receiving wet nebulization achieved maximal bronchodilation after two doses. Almost all reached maximal bronchodilation by four doses. The FEV1 improved by 0.72 ± 0.49 L for metered dose inhaler and 0.68 ± 0.61 L for wet nebulizer (p = 0.71). A significant linear relationship was seen in both groups (metered dose inhaler r = 0.94; wet nebulizer r = 0.98) between the log dose of albuterol and change in FEV1. About 1/6 the wet nebulizer dose of albuterol was needed to achieve similar response to the metered dose inhaler. CONCLUSIONS: Albuterol by metered dose inhaler provided similar bronchodilation to that achieved by wet nebulization in patients with acute asthma. The cumulative dose-response technique is applicable in the emergency department setting and is helpful in comparing the relative utility of various bronchodilator regimens.


To characterize the effectiveness of a local ordinance that restricts smoking in restaurants to one third of the seating area, this study made simultaneous measurements of two markers of environmental tobacco smoke, respirable suspended particles and nicotine, in the smoking and no-smoking sections of seven restaurants. The mean concentrations of respirable suspended particles and nicotine were 40% and 65% lower, respectively, in the no-smoking than in the smoking sections, indicating substantial but not complete protection against exposure.
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BACKGROUND: The relative efficacy of streptokinase and tissue plasminogen activator and the roles of intravenous as compared with subcutaneous heparin as adjunctive therapy in acute myocardial infarction are unresolved questions. The current trial was designed to compare new, aggressive thrombolytic strategies with standard thrombolytic regimens in the treatment of acute myocardial infarction. Our hypothesis was that newer thrombolytic strategies that produce earlier and sustained reperfusion would improve survival.

METHODS: In 15 countries and 1,081 hospitals, 41,021 patients with evolving myocardial infarction were randomly assigned to four different thrombolytic strategies, consisting of the use of streptokinase and subcutaneous heparin, streptokinase and intravenous heparin, accelerated tissue plasminogen activator (t-PA) and intravenous heparin, or a combination of streptokinase plus t-PA with intravenous heparin. (“Accelerated” refers to the administration of t-PA over a period of 1 1/2 hours—with two thirds of the dose given in the first 30 minutes—rather than the conventional period of 3 hours.) The primary end point was 30-day mortality.

RESULTS: The mortality rates in the four treatment groups were as follows: streptokinase and subcutaneous heparin, 7.2%; streptokinase and intravenous heparin, 7.4%; accelerated t-PA and intravenous heparin, 6.3%; and the combination of both thrombolytic agents with intravenous heparin, 7.0%. This represented a 14% reduction (95% confidence interval, 5.9 to 21.3%) in mortality for accelerated t-PA as compared with the two streptokinase-only strategies (p = 0.001). The rates of hemorrhagic stroke were 0.49%, 0.54%, 0.72%, and 0.94% in the four groups, respectively, which represented a significant excess of hemorrhagic strokes for accelerated t-PA (p = 0.03) and for the combination strategy (p < 0.001), as compared with streptokinase only. A combined end point of death or disabling stroke was significantly lower in the accelerated t-PA group than in the streptokinase-only groups (6.9% vs 7.8%, p = 0.006).

CONCLUSIONS: The findings of this large-scale trial indicate that accelerated t-
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ABSTRACTS


BACKGROUND: Patients receiving long-term anticoagulant therapy may be subject to unnecessary risks of bleeding or thromboembolism because of variability in the commercial thromboplastins used to determine prothrombin time and consequent uncertainty about the actual intensity of anticoagulation. METHODS: We explored the effect of this uncertainty on the benefits and risks of anticoagulation in patients with prosthetic heart valves, using models of thromboembolic and hemorrhagic complications as a function of the intensity of anticoagulation, with quality-adjusted life expectancy and average variable costs used to describe outcomes. RESULTS: Anticoagulation provides a striking benefit for patients whose treatment is conducted within the recommended range of the international normalized ratio (INR)—ie, 2.5 to 3.5—but if uncertainty about the laboratory results causes the intensity of anticoagulation to fall outside this range, the gain becomes smaller. Uncertainty about the true intensity of anticoagulation may reduce the potential gain in life expectancy, adjusted for quality of life, by more than half and may increase the ratio of costs to effectiveness to almost five times the optimal value. Variability in the intensity of anticoagulation is even greater if older recommendations advocating a higher level of anticoagulation are followed. CONCLUSIONS: Uncertainty about the sensitivities of the commercially available thromboplastins used in the United States can have important clinical and economic effects. This problem could be eliminated if clinical laboratories uniformly reported the intensity of anticoagulation as the INR, by adjusting prothrombin-time ratios for variability in thromboplastins.


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To assess the cardiorespiratory effects of pressure-controlled ventilation (PCV) and pressure-controlled inverse ratio ventilation (PC-IRV), we compared pressure-controlled ventilation with an inspiratory-to-expiratory time ratio (I/E) of 1/2 (PCV) and of 2/1 (PC-IRV) to volume-controlled ventilation (VCV) with an I/E of 1/2 in 10 patients suffering from the adult respiratory distress syndrome. In all modes, the inspiratory oxygen fraction, tidal volume, respiratory rate, and total positive end-expiratory pressure (PEEP = applied PEEP + intrinsic PEEP) were kept constant. Each ventilatory mode was applied for 1 h in a randomized order. No significant differences in PaO2 were observed among the three modes. The PaCO2 was lower (p < 0.05) in PC-IRV (39 ± 4 torr) than in PCV (43 ± 5 torr) and in VCV (45 ± 5 torr). The peak airway pressure was significantly lower in PC-IRV than in PCV (p < 0.05) and in PCV than in VCV (p < 0.05), but plateau pressure was not different in the 3 modes. The mean airway pressure (mPaw) was significantly higher (p < 0.05) in PC-IRV (21.4 ± 0.7 cm H2O) than in PCV (17.1 ± 0.7 cm H2O) and VCV (16.4 ± 0.5 cm H2O). As a consequence of this increased mPaw, PC-IRV induced a decrease in cardiac index (CI) (3.3 ± 0.2 vs 3.7 ± 0.2 L/min/m2 in VCV; p < 0.05) and hence in oxygen delivery (DO2) (424 ± 28 vs 469 ± 38 mL/min/m2 in VCV; p < 0.05). Our results suggest that neither PCV nor PC-IRV bring any benefit over VCV in terms of arterial oxygenation. Moreover, the increase in mPaw induced by PC-IRV may be deleterious to the CI and DO2.


BACKGROUND: Differences between Blacks and Whites have been reported in the incidence of several forms of cardiovascular disease, including hypertension and stroke. We examined racial differences in the incidence of cardiac arrest in a large urban population and in subsequent survival. METHODS: We collected data on all nontraumatic, out-of-hospital cardiac arrests in Chicago from January 1, 1987, through De-
ABSTRACTS

cember 31, 1988, and compared the incidence and survival rates for Blacks and Whites. We examined the association between survival and race and seven other known risk factors by logistic-regression analysis. We computed incidence rates by coupling our data with U.S. Census population data. RESULTS: Our study population comprised 6,451 patients: 3,207 Whites, 2,910 Blacks, and 334 persons of other races. The incidence of cardiac arrest was significantly higher for Blacks than for Whites in every age group. The survival rate after cardiac arrest was 2.6% in Whites, as compared with 0.8% in Blacks (p < 0.001). Blacks were significantly less likely to have a witnessed cardiac arrest, bystander-initiated cardiopulmonary resuscitation, or a "favorable" initial rhythm or to be admitted to the hospital. When they were admitted, Blacks were half as likely to survive. The association between race and survival persisted even when other recognized risk factors were taken into account. We did not find important differences between Blacks and Whites in the response times of the emergency medical services. CONCLUSIONS: The Black community in our study was at higher risk for cardiac arrest and subsequent death than the White community, even after we controlled for other variables.


The effect of large doses of salbutamol (S) and ipratropium bromide (IB) were studied for 8 h on 2 separate days. Pulmonary function tests (PFTs) included spirometry (FEV_{1}), lung volumes (FRC), and airway resistance (R_{aw}) measured by body plethysmography. Heart rate (HR) and oxygen saturation (S_{ao2}) were measured before each test. On 1 day patients received S 200 μg, S 400 μg, and IB 80 μg, by inhalation at 45-min interval (Sequence A). On the other day, the sequence was IB 80 μg, S 200 μg, and S 400 μg (Sequence B). The PFTs were obtained at baseline, 45 min after each inhalation, and 4 and 8 h after baseline measurements. Baseline PFTs (mean ± SE) were not significantly different on the 2 study days (FEV_{1}, 1.48 ± 0.1 vs 1.42 ± 0.1 L; FRC, 2.77 ± 0.6 vs 2.87 ± 0.6 L; R_{aw}, 4.04 ± 0.2 vs 4.00 ± 0.3 cm H2O/L/s). The FEV_{1} and R_{aw} improved from baseline after each inhalation, and at 4 and 8 h during both days (p < 0.05). Forty-five minutes after S 200 μg, plus S 400 μg, FEV_{1}, FRC, and R_{aw} were not significantly different compared with the values 45 min after IB 80 μg, plus S 200 μg (1.67 ± 0.1 vs 1.63 ± 0.1 L; 2.81 ± 0.6 vs 2.65 ± 0.5 L; and 2.98 ± 0.2 vs 2.66 ± 0.1 cm H2O/L/s, respectively). The PFTs were not significantly different after maximal doses of IB (80 μg) compared with S (600 μg). The HR and S_{ao2} were not significantly different from baseline throughout the study period. These results indicate that both single and sequential therapy have a similar acute bronchodilator effect provided that large doses are used. We speculate that adrenergic and muscarinic pathways are equally important in airflow obstruction in patients with CF.


The purpose of this study was to determine if sigh breaths delivered during pressure support ventilation (PSV) were beneficial in maintaining arterial oxygenation (P_{ao2}) and pulmonary mechanics. Ten patients being weaned from mechanical ventilation in the PSV mode were studied. All patients were ventilated for 4 h without sighs, 4 h with sighs, and again for 4 h without sighs. During each 4-h period, continuous measurements of ventilatory volumes and airway pressures were accomplished. At the end of each 4-h period, an arterial blood gas determination was obtained. There were no statistically significant differences in any of the measured variables during the different periods of ventilation. We conclude that the sigh breath is of no benefit during PSV.

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Decreasing the Work of Breathing: How Much of a Change Is Important?

The work of breathing (WOB) is by convention a complicated and, oftentimes, confusing topic. The clinical measurement is based on a series of assumptions and any number of extraneous variables can invalidate its accuracy. An excellent review of this topic by Mador et al. has recently been published and should be required reading for anyone involved with such measurements.

The units used to measure the WOB also lend to the confusion. To review, the standard units of measurement for work are kg \cdot m or joules (J). One joule of work is equivalent to 0.1 kg \cdot m. Typically work is normalized to volume or time allowing measurements in joules/L (kg \cdot m/L) or joules/min (kg \cdot m/min). The normal work of breathing is reported to be 0.4-0.7 J/L or 0.04-0.07 kg \cdot m/L.

Unfortunately, these units don’t allow one to conjure up a mental picture of what a change in the WOB looks like or how much of a change is important. Any such discussion brings to mind a memorable exchange between Mike Benson RRT and John Marini MD. After a typically masterful presentation on WOB by Marini, Benson whimsically asked, “Dr Marini, how many joules are in a dozen?” Of course, there was no answer and one wasn’t expected, but the question does underscore the problem of discussing the importance of a measurement when the units are elusive.

In this issue, Tobia and Fisher describe decreases in WOB associated with a prototype ventilator compared to the Puritan-Bennett 7200a.

The purported advantages of the prototype ventilator are based on the use of separate inspiratory and expiratory controllers to maintain a constant airway pressure during spontaneous breathing. The expected clinical result would be a decrease in WOB.

I believe that the use of separate controllers for inspiration and expiration may well represent an improvement in the control of airway pressure and that many ventilators will incorporate such systems in the future. According to Tobia and Fisher, the reduction in WOB with the prototype ventilator is 43-78%. I think this needs clarification.

The authors consider an “error” in the WOB to occur at two points in the pressure-volume curve. The first is the drop in airway pressure associated with triggering the demand valve. The second is related to the control of baseline pressure. They suggest that if airway pressure is below or above set baseline pressure, this represents an error in the WOB. It is the latter point that troubles me.

When airway pressure during a spontaneous breath on CPAP exceeds baseline pressure, the ventilator is providing a slight amount of positive pressure ventilation. And while this can be considered an error in control of airway pressure, it actually decreases WOB! Katz et al were the first to describe the concept of “reduced work.” They found that some ventilators overshot the CPAP level and provided a small amount of what we would now consider pressure support. In the Tobia-Fisher paper, this represents the majority of the “expiratory error” and accounts for the large reductions in the WOB. But, in the clinical situation this would result in an unloading of the respiratory muscles.

I think this can be shown nicely by comparing the work by Hirsch et al and Sassoon et al. Hirsch and colleagues found that the difference in WOB between the Puritan-Bennett 7200a in flow-triggering and pressure-triggering configurations was 0.01 J/L (0.032 vs 0.022 J/L). We could say that in this case, the WOB was reduced by 30% (or that the WOB fell by a third). But, if you consider the normal WOB is 0.5 J/L, then the improvement from 0.032 to 0.022 J/L represents about 2% of the patient’s total WOB.

Yet, in the study by Sassoon and colleagues, switching patients from pressure- to flow-triggering caused a reduction in the WOB from a mean of about 0.8 J/L to 0.5 J/L (a decrease of 32%). On the
surface, these studies might seem contradictory. Another concept has to be introduced to solve the discrepancy.

In my view, the only logical system for classification of ventilators has been proposed by Chatburn. Using what I like to call the TLC method, we can distinguish the difference between flow-triggering and pressure-triggering as performed by the 7200a. TLC refers to Trigger, Limit, and Cycle.

During pressure triggering the 7200a triggers into inspiration when the set sensitivity threshold is breached (airway pressure falls below the sensitivity setting minus the baseline pressure). The ventilator responds by increasing flow to maintain a pressure at the expiratory airway pressure transducer equal to the baseline pressure minus the sensitivity. This is the limit variable. For example if CPAP is 5 cm H2O and sensitivity is set at 2 cm H2O, the ventilator triggers on when airway pressure falls below 3.0 cm H2O and flow increases to maintain pressure at 3.0 cm H2O throughout inspiration. Inspiration is cycled off when measured pressure exceeds the CPAP setting by 1.0 cm H2O.

During flow-triggering the 7200a triggers on when the flow through the expiratory transducer falls below the flow sensitivity. The ventilator responds by increasing flow to maintain pressure (the limit variable) at 0.5 cm H2O above the baseline pressure. Cycling occurs when flow through the expiratory transducer is 2 L/min greater than the baseline flow (signaling expiration).

The TLC technique demonstrates that the limit variable for the two methods is different. In the example above, when the ventilator is set to flow-trigger, airway pressure will be 2.5 cm H2O greater throughout inspiration. The result is equivalent to adding that level of pressure support. So when the tiny improvements seen by Hirsch et al turn into the important improvements demonstrated by Sassoon et al, we can determine why and how.

Returning to the Tobia-Fisher paper then, the expiratory error may, in fact, represent a reduction in the work of breathing associated with a slight amount of pressure support. Looking at their results the situation with the lowest compliance and highest resistance shows an "inspiratory error" between the prototype and the 7200a of 21% (0.141 vs 0.112 J/L). Again, if we assume that the patient's work of breathing is 0.5 J/L, this change represents 0.03 J/L or about 6%.

One of the goals of mechanical ventilation is to reduce the work of breathing. How much it is reduced is quite another matter. I don’t have the answer for what a significant change is and certainly it depends on the situation. We should all be careful of falling into the traps of quoting a percent reduction in a seeming dimensionless value. However, I have observed that patients appear to be more comfortable using the 7200a with flow-triggering compared to pressure-triggering, and measurements made by Sassoon et al confirm this to be a clinically and statistically significant improvement. We have recently completed a study of four ventilators capable of flow-triggering and found that in the best-performing ventilator the imposed WOB is one tenth that of the ventilator placing last. The difference was 0.001 vs 0.01 J/L, which when compared to the normal WOB (0.5 J/L) represents an infinitesimal number that is not clinically important.

I appreciate the work of Tobia and Fisher and welcome a technical paper of this quality in the Journal. As I stated earlier, the use of separate controllers to maintain airway pressure throughout the respiratory cycle probably represents one of the designs of the future. We must be careful however, to judge the improvements based on clinical effects rather than speculation. My feeling is that the significant reductions in the WOB shown using the prototype ventilator on a lung model may dissipate when patients are studied.

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REFERENCES


Relative Agreement between Raman and Mass Spectrometry for Measuring End-Tidal Carbon Dioxide

John M Graybeal CRTT and Garfield B Russell MD

BACKGROUND: Several technologies can measure carbon dioxide in the exhaled breath and determine the end-tidal partial pressure of carbon dioxide (P_e\text{CO}_2). Commonly used methods employ an infra-red capnometer, mass spectrometer (MS), or Raman spectrometer (RS). We sought to determine the relative agreement of representative MS and RS devices as a function of respiratory frequency. MATERIALS & METHODS: A bench-top lung system was designed to simulate mechanical respiration. An airway connector with parallel gas sampling ports allowed simultaneous gas sampling. We attached sampling catheters from calibrated MS and RS and simultaneously determined P_e\text{CO}_2 by MS and RS, collecting data in triplicate at each of 5 frequencies. We analyzed data by paired t-test, linear regression, and ANOVA, with p < 0.05 considered significant. Bias and limits of agreement were calculated at each frequency from a total of 60 P_e\text{CO}_2 pairs. RESULTS: The RS measurement was consistently higher than MS. The bias (SD) and limits of agreement were 4.98 (2.7) and -0.4 to 10.4 torr for the full range of P_e\text{CO}_2. At a frequency of 10, the bias (SD), 2.0 (2.9), was significantly lower (p = 0.0007) than at any other frequency. CONCLUSIONS: A statistically significant bias exists between MS and RS measurements. At frequencies greater than 10, this bias is constant. These differences at different frequencies may be due to gas sampling rates, differences in algorithm for determining P_e\text{CO}_2, or differences in the basic measurement technology. The observed bias should not affect the use or clinical applicability of either of these devices in the clinical setting, although it may be desirable to use the same device for all measurements in a given patient. [Respir Care 1994;39(3):190-194.]

Background

Measurement of respiratory gases, especially carbon dioxide (CO\textsubscript{2}), has become a routine part of intraoperative monitoring for patient care, and use in intensive care units is increasing. Measurement of CO\textsubscript{2} in exhaled respiratory gas has been used for confirmation of correct endotracheal tube placement and for detection of acute pulmonary embolism, intravascular gas embolism, and sudden dramatic changes in cardiac output. Recently, the slope of the capnogram (in this case the expired CO\textsubscript{2} concentration plotted against the expired volume) has been shown to correlate with the severity of lung injury both in a rabbit model of ARDS and in patients with ARDS. The difference between the CO\textsubscript{2} tension at end expiration (P_e\text{CO}_2) and the arterial tension (P_a\text{CO}_2), termed the arterial-to-end-tidal gradient (P_a-e\text{CO}_2), has been shown to correlate with alveolar dead space and the dead-space-to-tidal-volume ratio.

Several technologies have been developed for the measurement of respiratory gases, including infrared gas analysis, mass spectrometry, and Raman.
spectrometry. Each of these use different physical principles to determine the CO₂ concentration; infra-red gas analyzers use light absorption properties, the mass spectrometer (MS) uses differences in ionic mass, and the Raman spectrometer (RS) uses the Raman light-scattering properties of gases. RS and MS both offer the advantage of simultaneously measuring several other respiratory and anesthetic gases. Differences exist, not only in the measurement technique but also in the analysis algorithm, that could cause either an over- or underestimation of the true PetCO₂. Both MS and RS withdraw gas for sampling, although each has a different predetermined gas withdrawal rate. Both the MS and RS measure CO₂ continuously but determine the "end-tidal" CO₂ they report using different algorithms. The MS reports the last CO₂ value prior to a sudden decrease in CO₂, whereas the RS reports the highest CO₂ during an exhalation as the end-tidal value.¹⁴ We sought to determine the effect of respiratory frequency on the relative agreement between these two devices.

Materials and Methods

We designed a bench-top system to simulate mechanical respiration, in which the exhaled CO₂ (varied from 23 to 85 torr), tidal volume (700 mL), and frequency (set at 10, 18, 28, 35, and 40 breaths/min) could be controlled. A piston pump respirator (Harvard Apparatus Dual-Phase Control Pump Respirator, Harvard Instruments, Cambridge MA) with variable stroke volume and cycle frequency acted as the lungs. Fresh gas from a tank of compressed air flowed past the ventilator connection, thereby reducing the risk of ‘rebreathing’ CO₂ from the exhaled gas during the next inspiration. During each inspiration, CO₂ was added to the mechanical lung by way of a valved inlet that opened during inspiration and closed during exhalation. We varied the exhaled CO₂ concentration by changing the inlet flowrate of CO₂ (Fig. 1). This produced a normal-appearing capnogram.

We designed and produced an airway connector with parallel gas sampling ports to allow simultaneous sampling of gases and attached it to the endotracheal tube. We attached sampling catheters from a calibrated MS (Perkin-Elmer MGA 1100, Marquette Electronics Inc, Milwaukee WI) and RS (Rascal II, Ohmeda, Madison WI) to two of these ports. Calibration of both the MS and RS was performed according to the manufacturers’ standards. The sampling flowrates were set at 60 mL/min for the MS and at 185 mL/min for the RS. The end-tidal carbon dioxide tension (PetCO₂) was adjusted to and then maintained at a specific level while we changed the frequencies. Frequencies of 10, 18, 28, 35, and 40 were chosen for this study. PetCO₂ values were collected simultaneously from MS and RS using a data acquisition system.

We collected data in triplicate at each of the 5 frequencies and analyzed data by paired t test, linear regression, and ANOVA with a Scheffe post-hoc analysis, as appropriate. A p < 0.05 was considered significant. The bias—average RS – MS value—(SD) was calculated at each frequency. The overall bias with 95% confidence interval (limits of agreement)¹⁵ was calculated using all data from all frequencies combined.

Results

We collected a total of 60 PetCO₂ pairs. Correlation between RS and MS was positive and significant (r = 0.982, slope = 1.087, and y intercept = 2.384. Fig. 2). PetCO₂ ranged from 18.1 to 75.5 torr for the MS and from 23.3 to 84.9 torr for the RS, with no significant difference in the range of PetCO₂ values at each of the preset frequencies. The RS PetCO₂ was consistently higher than that measured by the MS (p = 0.001). The bias (SD) was 4.98 (2.7)
torr for the full range of $P_{etCO_2}$. At a frequency of 10, the bias (SD), 2.0 (2.9), was significantly lower ($p = 0.0007$) than at any other frequency (Fig. 3) (ANOVA). Figure 4 provides the 95% confidence interval (limits of agreement) for the bias of this data set (average difference between RS and MS).

**Discussion**

Despite a highly significant correlation coefficient, a statistically significant bias exists between MS and RS for measurement of $P_{etCO_2}$. This bias increased with increasing $P_{CO_2}$ levels. The bias was smaller when frequency was 10 breaths/min than at any other frequency (Fig. 3). At frequencies greater than 10 the bias was constant.

Westenskow et al$^{16}$ evaluated the MS and a prototype RS in both a laboratory bench model and in patients in the operating room. In the laboratory, they used a precision gas mixer to deliver a gas with a CO$_2$ concentration ranging from 0-10%. Values from the RS and MS were compared to the setting of the precision gas mixer, and a bias and precision were calculated. They found good agreement comparing the RS [-0.03 (0.06) volumes %] and MS [0.04 (0.13) volumes %] with the gas mixer setting. In the operating room, they compared 205 samples of $P_{etCO_2}$ from both the RS and MS, with good agreement [-0.01 (0.35) volumes %]. The 95% confidence interval was -0.36 to 0.34 volumes % (-2.57 to 2.42 torr). The frequencies for the patients included in their study ranged from 8-12 breaths/min (personal communication, DR Westenskow, 1993). The bias for a frequency of 10 in our study is
not significantly different from that reported in Westenskow’s study.

The increase in bias that occurs with higher PCO₂ levels may be due to the different gas standards used for calibrating the RS and MS. Each device was calibrated according to factory recommended standards. The factory supplied standards for the RS have a minimum CO₂ value of 0% and maximum CO₂ value of 5.0%. The MS uses calibration gases with a minimum CO₂ value of 0% and maximum CO₂ value of 10.0%. A small difference in calibration when using a 5.0% CO₂ standard as the high value could explain larger biases at higher Pe₅CO₂ values. An error of 0.05% could be magnified to at least an error of 0.1% in the higher CO₂ ranges. Any degree of nonlinearity in the calibration or an error in the zero point standard would further magnify this problem. The issues related to calibration procedure could explain an increase in the bias, at higher Pe₅CO₂ values, similar to that found in our study. It does not, however, explain the difference in the bias noted at higher frequencies.

Two other differences exist between the RS and MS, which might contribute to the increased bias at higher frequencies. First, each device determines the Pe₅CO₂ in a different way. The RS measures counts of scattered light sensed by several different photodetectors, each at a different wavelength. These counts are compared with a scale (set during calibration) for each photodetector. The resulting reported value is a ratio of the measured counts to the standard counts. This is done for each gas measured, independent of the other gases present. It is possible then to have the reported concentrations of respiratory gases not sum to 100%, if an unmeasurable gas such as helium is present. The advantage of this is that a measurement error in one of the gases does not affect the reported values of the other gases present in the mix. However, the MS assumes the sum of all counts of ions detected to be 100%. It does not allow for the presence of an unmeasured gas. The effect of a measurement error in one gas of a mixture would directly influence the reported values of all gases in the mixture. It is unclear how this might account for the difference in the bias at higher frequencies.

Second, a difference exists in the algorithms by which these two machines determine end-tidal CO₂. The RS continuously measures CO₂ and reports the highest CO₂ value during exhalation as the Pe₅CO₂; the MS continuously measures CO₂ but reports the value at the end of the alveolar plateau as the Pe₅CO₂. This difference could account for an increased bias especially if any oscillation occurred during the alveolar plateau phase. The RS would report the highest CO₂ value detected while the MS would report the value detected at the end of the plateau. Although we could not visually detect any such oscillations on the recorded capnogram, such oscillations could explain our findings. The RS Pe₅CO₂ value was consistently higher than the MS Pe₅CO₂ value (by paired t test, p < 0.001). Why this bias would increase at higher frequencies is unclear.

Conclusions

Differences exist between the Pe₅CO₂ values reported using an RS and MS, measuring respiratory gases during ventilation of a bench-top model lung. These differences may be due to different calibration standards, different gas sampling rates, different algorithms for determining the Pe₅CO₂, and differences in the basic measurement technology. This consistent bias should not affect the use of either of these devices in the clinical setting. This bias should be considered when evaluating Pe₅CO₂ values from two different sources, especially in the case where a patient may have monitored with one device in the operating room and then with the other device in the intensive care setting. This bias may make it desirable to use the same device for all measurements in a given patient.

Further investigation is needed into the nature of the significant bias (between RS and MS), eg. the effect of changing sampling flowrates and measurement algorithms.

REFERENCES


A Comparison of the CPAP Performance Characteristics of the Puritan-Bennett 7200a and a Prototype Continuous Pressure-Regulating Ventilator

Ronald L Tobia MS PE and Russell J Fischer MS

BACKGROUND: A prototype demand-flow medical ventilator for intensive care unit (ICU) applications has been developed with the ability to maintain continuous pressure regulation of proximal airway pressure during both inspiratory and expiratory respiratory phases. The performance of this system was investigated in laboratory tests of continuous positive airway pressure (CPAP) mode, a ventilatory mode in which airway pressure regulation is strongly challenged. MATERIALS & METHODS: Comparative tests of the pressure-regulating ventilator (PRV) prototype and a Puritan-Bennett 7200a (PB7200a) ventilator were made in three performance categories: pressure-volume product error, peak pressure error during inspiration, and peak pressure error during expiration. Testing was performed on a Bio-Tek VT-2 test lung modified to simulate spontaneous breathing, at CPAP levels of 0, 10, and 20 cm H2O. Results were obtained at a lung compliance of 50 mL/cm H2O and at three parabolic airway resistance levels (Rp10, Rp20, and Rp50 cm H2O · L⁻² · s² per ANSI Z79.7-1976). RESULTS: The PRV prototype achieved reductions in pressure-volume product error of more than 0.111 joules (43%) for all test conditions, relative to the PB7200a. Peak pressure errors were reduced by at least 4.0 cm H2O (55%) during inspiration and 4.9 cm H2O (38%) during expiration. CONCLUSIONS: An ICU ventilator utilizing continuous regulation of proximal airway pressure has been shown to provide statistically significant improvements in CPAP performance relative to the PB7200a in laboratory tests. Further testing will be required to quantify the clinical significance of these results. [Respir Care 1994;39(3):195-203.]

Background

An important goal in the design of mechanical intensive-care unit (ICU) ventilators is to reduce or eliminate the work of breathing (WOB) of the spontaneously breathing patient that is added by the machine during delivery of continuous positive airway pressure (CPAP). Although the clinical use of mechanical ventilation includes various ventilator settings and modes to alter the WOB during the weaning phase, it is undesirable to have added WOB imposed on the patient due to inherent design deficiencies of the ventilator. Ventilator design is severely tested in CPAP mode by the need for fast and accurate gas delivery, regulated by the patient. Shortcomings in the design can increase the WOB and may even hinder weaning.

For a typical demand-flow ventilator, there are two main sources of added inspiratory WOB. One source is the work associated with triggering the ventilator. This can be understood from a graphic depiction of a breath on a pressure-volume (PV) plot. Figure 1 shows a typical spontaneous breath taken during CPAP from a demand-flow ventilator. In most demand-flow ventilator designs, the patient must lower airway pressure to a predetermined threshold to begin inspiration. Inspiratory work,
seen here as the area subtended by the PV curve, increases in direct proportion to this pressure drop. Excessive WOB at the onset of inspiration may also have added clinical significance by initiating a sustained respiratory effort from the patient that persists beyond the time needed to trigger. Inspiratory triggering thresholds are typically set low (0.5 or 1 cm H2O, i.e., at high sensitivity) to reduce this problem; however, a threshold set too low can increase the likelihood of false triggering (i.e., auto- or self-cycling).

The second source of added WOB is due to the variation (from the ideal) in the airway pressure (Paw) maintained by the ventilator as the patient takes a spontaneous breath. On the inspiratory limb of the PV loop, Paw drops below the prescribed CPAP level of 10 cm H2O because of pneumatic resistance in the ventilator circuit and demand-valve insufficiency. The effect of this pressure drop is to shift a certain amount of the work of breathing from the ventilator to the patient (often referred to as added work). This is shown on the PV graph (Fig. 1) as an increase in area circumscribed by the loop.

![Fig. 1. Typical Paw vs volume curve for a demand-flow ICU ventilator showing sources of pressure-volume product error (ie, deviation from ideal performance).](image)

Later in the inspiratory phase, the ventilator may even overshoot the desired CPAP level as the delivered gas overcomes pneumatic delays in the ventilatory circuit. Although this pressure overshoot tends to decrease inspiratory WOB (reduced work), added expiratory work will be required to counteract the pressure drift if it persists until the onset of expiration. Moreover, both types of pressure error (undershoot and overshoot) are indicative of a gas delivery system that responds too slowly to quick changes in Paw. We believe, consistent with control theory, that such a system, being unable even to maintain constant Paw during CPAP, would be inappropriate for inspiratory delivery with more complicated pressure profiles.

To characterize a ventilator’s ability to control Paw, we continuously measured the pressure and volume of gas delivery in CPAP mode, multiplied the values, then mathematically integrated to obtain the pressure-volume product (PVP). For an ideal machine delivering CPAP, the pressure of delivered gas never drifts from the set pressure, and thus produces a PVP value of zero. The PVP measured for a real ventilator during CPAP therefore quantifies the absolute amount of work variation (error) from the ideal due to its inability to accurately control Paw. The PVP error is thus useful for the design and comparison of ventilators and as a measure of how well gas delivery matches that specified by the clinician, but the magnitude of PVP error cannot be equated to typical WOB measurements because both added and reduced work increase the PVP error.

To improve PVP accuracy and reduce sources of added WOB, a ventilator prototype has been developed with the ability to maintain feedback control on Paw throughout the respiratory cycle. The continuous pressure-regulating ventilator (PRV) uses an accurate, calibrated flow-regulating valve for inspiratory flow and can easily assume standard volume ventilatory modes. With the addition of continuous feedback pressure control, accurate Paw is maintained for spontaneously breathing patients in CPAP, pressure support ventilation (PSV), and positive end-expiratory pressure (PEEP) modes, with improved PVP accuracy. The ability to maintain continuous pressure control in real-time also provides the means to create more elaborate ventilatory modes, incorporating fixed volume delivery and pressure control within a single breath.

The PRV is shown schematically in Figure 2. A pressure transducer at the Y-piece of a standard patient circuit supplies a feedback signal for the pressure control. The transducer signal is digitized and read by a TMS320C25 digital signal processor, which runs the real-time control algorithms (controllers). The algorithms (inspiratory and expira-
tory) use proportional-integral-differential control strategies to continuously match $P_{aw}$ to a desired level within a tight tolerance (response to a step change in pressure is typically within 63% of full-scale in less than 50 milliseconds).

The controllers effect changes in $P_{aw}$ via their respective pneumatic components. During inspiration, the inspiratory controller varies the current supplied to a flow-regulating solenoid valve to match the $P_{aw}$ to a desired pressure waveform. In CPAP mode, for example, the controller simply establishes a constant $P_{aw}$ throughout inspiration that is maintained within the pressure tolerance regardless of patient attempts to drop $P_{aw}$.

For expiration, the expiratory controller tracks a desired $P_{aw}$ waveform by commanding a pressure-regulating valve to maintain a specific back pressure on an expiratory diaphragm valve. As long as the back pressure on the valve is less than the patient’s $P_{aw}$, the expiratory valve is open and pressure control is possible. When the back pressure exceeds $P_{aw}$, the expiratory valve seals. The addition of a gas ejector to the vent port of the valve provides a slight negative pressure bias in order to improve the pressure-regulating capability at near-atmospheric pressure. This also allows the diaphragm valve to fail in an open position in the event of power loss.

The inspiratory and expiratory respiratory phases pose different dynamic problems for the PRV controller software and necessitate separate control strategies. During the inspiratory phase, the airway resistance and lung compliance of the patient affect control of gas delivery and must be estimated in some way for optimal control. Our mathematical simulations of respiratory dynamics revealed that estimation of the patient’s respiratory resistance is more critical than compliance; overestimates of resistance lead to slower system response, whereas underestimates produce an initial overshoot of the target pressure. For the testing presented here, the ventilator was manually set in one of three broad ‘patient resistance’ categories (low, medium, or high).

Switching between the inspiratory and expiratory controllers is the responsibility of a synchronization algorithm that allows continuous pressure control through both respiratory phases but prevents situations in which both controllers attempt to influence $P_{aw}$ simultaneously. Through continuous observation of the state of the inspiratory and expiratory controllers, the synchronization algorithm determines which controller is capable of providing the required pressure error correction. For example, at the onset of expiration $P_{aw}$ rises above the CPAP level. The inspiratory controller responds by attempting to reduce inspiratory valve output below zero (an impossibility), alerting the synchronization algorithm to invoke the expiratory controller to accomplish the required pressure correction. Conversely, the use of the inspiratory controller begins when $P_{aw}$ falls in response to inspiratory efforts. The expiratory controller attempts to raise $P_{aw}$ by increasing back pressure on the expiratory diaphragm valve; however, this has no effect on $P_{aw}$ and the synchronization algorithm invokes the inspiratory controller.
To maintain continuity of the controllers as inspiratory and expiratory control is alternated, the controllers track $P_{aw}$ at all times and can be invoked whenever necessary. During inspiration, this has the safety advantage of allowing the expiratory diaphragm valve to act as a variable-threshold 'pop-off' valve to prevent overpressures. The sealing pressure on the expiratory diaphragm valve is always maintained at a fixed pressure above $P_{aw}$ during inspiration. If an inadvertent overpressure occurs, it is simply vented out of the system through the diaphragm valve.

**Materials and Methods**

To evaluate the performance characteristics of the PRV, we devised a testing protocol to compare the PRV to the Puritan-Bennett 7200a (PB7200a). The PB7200a can operate as a demand-flow system or as a flow-by system to reduce inspiratory work. Flow-by is another approach to achieving ideal ventilator performance in which a continuous bias flow of gas is provided to the patient, and inspiratory delivery is triggered on flow instead of pressure. For our comparative tests, we chose to operate both ventilators as demand-flow systems. We selected three variables to characterize performance in CPAP mode: PVP error and inspiratory and expiratory peak pressure errors.

The equipment arrangement used for the comparative tests is diagrammed in Figure 3. A mechanical lung simulator externally actuated by a pneumatic air cylinder was used to simulate a spontaneously breathing patient. Gas flow metered into the air cylinder by a pneumatic flow valve generated the spontaneous inspirations. A signal generator controlled flow valve output, enabling respiratory cycle timing and amplitude to be specified.

The flow profiles for the simulated breaths produced by this system are shown in Figure 4. The repeatability of the breaths generated by this 'patient' allowed tests to be performed between the two ventilators in a more consistent manner than possible with human test subjects and allowed calibrated changes in lung resistance and compliance. The breathing circuit used for experimentation consisted of a standard 36-in long, 22-mm diameter corrugated dual-hose patient circuit with a humidifier having 0.42 L of compressible volume.

![Computer with a 12-bit A/D board](image)

**Fig. 3.** Equipment arrangement for the comparative ventilator tests.

To measure volumetric gas flow in the airway, an indirect measurement approach was used. Prior to ventilator testing, the pressure-flow calibration of the standard airway resistances was measured using a laminar flow pneumotachometer and a differential pressure transducer. During testing, the pressure drop across the resistances was continuously measured, allowing airway flowrate to be computed as a function of the pressure drop and the nonlinear resistance (parabolic) calibration value. This technique allowed continuous flow measurement without adding to the resistance already present in the airway. The nonlinear characteristics of the resistances causes the accuracy of this method to be flowrate dependent, worse for low flows through low airway resistances.

For tidal volume measurements, the flow signal was sampled at 333 Hz and digitally integrated. The error of this measurement over a full breath cycle was found to be less than 3% for the worst case (resistor $R_p$, 10). Airway pressure was measured with a differential transducer at the Y-piece of the patient circuit.

The performance of the ventilators was assessed in three tests: (1) pressure-volume product error, (2) inspiratory pressure error, and (3) expiratory pressure error.
The Pressure-Volume Product Error test quantifies the deviation in PVP from that of an ideal machine. In an ideal ventilator maintaining CPAP, a spontaneous breath is perfectly matched with gas delivery, and airway pressure never drifts from the prescribed level. However, for a spontaneous breath from an actual machine, there is an error in gas delivery that can be seen graphically on a PV loop as the difference in area between the PV loop of the actual machine and the ideal machine.

To calculate the PVP error, the products of the discrete pressure error and volume measurements are summed over a complete breath:

$$WOB_{\text{err}} = \sum_{i=1}^{n} (|P_{\text{act}} - P_{\text{CPAP}}| \cdot V_T)$$

where $n$ = the number of PV samples for a complete breath (typically > 1,600 samples per breath); $P_{\text{act}}$ = the current airway pressure value; $P_{\text{CPAP}}$ = the desired CPAP level; and $V_T$ = the change in tidal volume since the previous sample.

Note that the PVP error is increased by both added and reduced inspiratory work. Reduced inspiratory work is included in the measurement because it is not a prescribed delivery parameter, but rather an uncontrollable consequence of delivery system design. However, to the extent that inspiratory PVP error is dominated by added work, the inspiratory PVP error closely correlates to imposed work on the patient.

Inspiratory pressure error is the maximum negative excursion of the airway pressure from the CPAP level during inspiration.

Expiratory pressure error is the maximum positive excursion of the airway pressure from the CPAP level during expiration.

The ventilators were both fully calibrated for these tests. To optimize the response of the PB7200a, we used its highest sensitivity level (0.5 cm H$_2$O).

Five measurements were obtained for each test condition and used to calculate sample means and standard deviations. The results were then analyzed for significance using the Mann-Whitney test ($p = 0.05$). The Mann-Whitney test is a nonparametric method that does not require the assumptions of normal distribution or equal variance for group
CPAP PERFORMANCE CHARACTERISTICS

means. No limits for what would constitute a clinically important error were prospectively established.

Results

Typical time traces of airway pressure and flow acquired over a simulated respiratory cycle are shown in Figure 4 for the two ventilators in CPAP mode. These results represent performance under nominal test conditions—specifically 10 cm H2O CPAP, parabolic airway resistance of 17.6 cm H2O·L−2·s2 (R020), and 0.05 cm H2O/L lung compliance (C50)—and are typical of those evaluated during the study. Plotting the time integral of the flow profile synchronously against the airway pressure data yields the PV diagrams of Figure 5.

As described, the PVP error relative to an ideal machine is computed by integrating the area enclosed by the PV loops. A summary of the mean PVP error for each test condition is presented in Table 1. The PVP error was calculated for the total respiratory cycle and for the inspiratory and expiratory phases in order to evaluate the performance of the individual controllers. Percent difference in PVP error of the PRV relative to the Puritan-Bennett 7200a is also tabulated for the cases in which a significant difference (p < 0.05) was found.

Figure 4 also illustrates the peak inspiratory and expiratory pressure errors typically observed. These errors were measured at the maximum excursion from the desired CPAP level as indicated by P1 for inspiration and PE for expiration. Table 2 is a summary of the pressure errors for each test condition and the percent difference in error for the PRV relative to the PB7200a. A significant difference in peak pressure error was found in all cases.

Discussion

The PV diagrams of Figure 5 provide a number of insights into the performance differences between the Puritan-Bennett 7200a and the PRV. Upon initiation of a spontaneous inspiration, a sharp drop in airway pressure is observed in the PV profiles of both systems. The PB7200a, despite its high sensitivity setting, consistently allowed greater inspiratory peak pressure errors. In Figure 4 this error is 7 cm H2O relative to 3 cm H2O for the PRV. For the complete set of test conditions this error varied from 6.5 to 8.3 cm H2O for the PB7200a versus a 2.2 to 3.6 cm H2O range for the PRV. The results are indicative of the improved Paw accuracy achieved by the feedback pressure control of the PRV; inspiratory flow is continuously regulated to maintain the CPAP level without the need for a conventional inspiratory trigger.

This study did not determine whether the difference in inspiratory peak pressure error observed in the laboratory for the two devices would be maintained in a clinical setting. A reduction of these errors in clinical use may have an added significance beyond the reduction in inspiratory work it would provide, however. Katz et al. made the observation that the short period of time between the initiation of inspiration and flow delivery may cause energy utilization by the inspiratory muscles that would not be measured as work because of the negligible amount of flow. The situation is analogous to making an inspiratory effort against an occluded airway:
CPAP PERFORMANCE CHARACTERISTICS

Table 1. A Comparison of Pressure-Volume Product Error in Prototype Pressure-Regulating Ventilator and Puritan-Bennett 7200a during CPAP*

<table>
<thead>
<tr>
<th>CPAP cm H2O</th>
<th>Test Lung Resistance† cm H2O · L⁻² · s²</th>
<th>PB joules</th>
<th>PRV joules</th>
<th>PVP Error joules (% reduction)</th>
<th>PB joules</th>
<th>PRV joules</th>
<th>PVP Error joules (% reduction)</th>
<th>PB joules</th>
<th>PRV joules</th>
<th>PVP Error joules (% reduction)</th>
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<tr>
<td>0</td>
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<td>0.564</td>
<td>0.229</td>
<td>0.335 (59)</td>
<td>0.055</td>
<td>0.056</td>
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<td>0.509</td>
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<td>0.315 (78)</td>
<td>0.091</td>
<td>0.053</td>
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<td>0.038</td>
<td>0.278 (88)</td>
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<td>0.052</td>
<td>0.038 (42)</td>
<td>0.227</td>
<td>0.068</td>
<td>0.159 (70)</td>
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<tr>
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<td>10</td>
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<td>0.108</td>
<td>0.328 (75)</td>
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<td>0.078 (63)</td>
<td>0.312</td>
<td>0.062</td>
<td>0.250 (80)</td>
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<tr>
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<td>0.150</td>
<td>0.111 (43)</td>
<td>0.141</td>
<td>0.112</td>
<td>0.029 (21)</td>
<td>0.121</td>
<td>0.038</td>
<td>0.083 (69)</td>
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</table>

*Pressure-volume product error = deviation from pressure-volume product of ideal ventilator. Reductions are significant at p < 0.05 except where noted by †. PB = Puritan-Bennett 7200a; PRV = prototype pressure-regulating ventilator.

†Compliance at test lung setting C50, or 0.05 L/cm H2O.

Airway pressure drops without a volume change. To the extent that the peak inspiratory pressure errors can be reduced, this type of energy utilization is minimized.

After the initial negative pressure error, the systems respond with inspiratory flow and the initial drop in airway pressure is arrested and reversed. The airway pressure maintained by the PB7200a returns to 2 cm H2O below the target value after delivery of approximately 7% of the tidal volume. From this point, pressure error slowly decreases and actually becomes slightly positive after 75% of the tidal volume has been delivered. Typically this pressure overshoot segment accounted for less than 5% of the total inspiratory PVP error. In comparison, the PRV returns airway pressure to a value 1.5 cm H2O below the CPAP level upon delivery of 5% of the tidal volume, reducing the error to essentially zero after 75% of the tidal volume delivery.

We attribute the pressure response differences of the ventilators to the efficacy of their respective control algorithms in matching inspiratory flow to that demanded by the patient, with improved controller performance translating into reductions in inspiratory PVP error. Our evaluations showed that the PRV produced substantially lower inspiratory PVP errors under most operating conditions. The only exception occurred at the 0 cm H2O CPAP level, at which the Puritan-Bennett achieved its lowest PVP error, essentially identical to the inspiratory performance of the PRV.

Upon initiation of expiration, sharp rises in airway pressure are observed in both systems. The PRV’s ability to quickly attenuate this pressure rise...

Table 2. A Comparison of Peak Pressure Error in Prototype Pressure-Regulating Ventilator and Puritan-Bennett 7200a during CPAP*

<table>
<thead>
<tr>
<th>CPAP Level cm H2O</th>
<th>Test Lung Resistance† cm H2O · L⁻² · s²</th>
<th>PB cm H2O</th>
<th>PRV cm H2O</th>
<th>Reduction cm H2O (% reduction)</th>
<th>PB cm H2O</th>
<th>PRV cm H2O</th>
<th>Reduction cm H2O (% reduction)</th>
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<tr>
<td>0</td>
<td>20</td>
<td>6.5</td>
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<td>3.2</td>
<td>4.0 (55)</td>
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<tr>
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<td>20</td>
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<td>3.4</td>
<td>4.3 (56)</td>
<td>14.5</td>
<td>8.61</td>
<td>5.9 (41)</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>8.0</td>
<td>3.6</td>
<td>4.4 (55)</td>
<td>14.3</td>
<td>7.49</td>
<td>6.8 (48)</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>8.2</td>
<td>3.0</td>
<td>5.2 (63)</td>
<td>10.7</td>
<td>5.58</td>
<td>5.1 (48)</td>
</tr>
</tbody>
</table>

*Peak pressure error = deviation from ideal ventilator; p < 0.05 for all pressure reductions. PB = Puritan-Bennett 7200a; PRV = prototype pressure-regulating ventilator.

†Compliance at test lung setting C50, or 0.05 L/cm H2O.
enabled it to reduce expiratory pressure peaks relative to the PB7200a. These reductions were on the order of 40% (> 4.9 cm H₂O) with the most pronounced improvement, 60% (10.0 cm H₂O), occurring at a 0 cm H₂O end-expiratory pressure (EEP) setting. The large improvement at this level reflects the low resistance of the PRV's expiratory valve system.

As expiration progresses, the PB7200a exhibits positive pressure error greater than 10 cm H₂O for nearly 20% of the tidal volume release. This error decays exponentially, returning to zero only after 85% of the tidal volume has been expended. In contrast, the PRV maintains active pressure control throughout expiration, holding airway pressure at the EEP level after approximately 15% of tidal volume release. Reductions in the expiratory PVP error from 66% to 88% over all test conditions reflect this performance difference.

Although expiration under normal conditions is thought to be a passive event, studies have described measurable patient work imposed by the resistance of expiratory valves and PEEP devices common to ICU breathing circuits. By performing feedback control of airway pressure during expiration, the PRV compensates for the effects of these added resistances. In effect, this capability enables the ventilator to control EEP in the manner of an ideal threshold resistor as described by Banner et al. The elimination of undesirable resistance from within the expiratory pathway may be clinically important for patients supported by mechanical ventilation during hyperpneic or weaning phases of their illness.

Conclusions

Our evaluations indicate that the PRV provides a significant reduction in CPAP pressure-volume product and peak pressure error relative to the Puritan-Bennett 7200a. These reductions reflect the PRV's ability to provide continuous feedback pressure control throughout both the inspiratory and expiratory phases of the respiratory cycle. Although previous studies have shown correlation between increased WOB and reduced tolerance for weaning, clinical testing of the PRV will be required to establish whether the laboratory performance corresponds to clinical reductions in WOB and improvement in patient respiratory care.

PRODUCT SOURCES

Pressure Transducers:
Omega PX 163-120BD 5V (feedback transducer for PRV ventilator), Omega PX 163-120BD 5V (to monitor airway pressure for PV loops), and Omega PX 143-2.5BD 5V (differential transducer for airway flow monitoring), Omega Engineering, Stamford CT

Pneumatic Valves:
Flow regulating solenoid valve, p.n. 10021105 (inspiratory flow valve in PRV ventilator); flow regulating solenoid valve, p.n. 10021105 (drives pneumatic air cylinder to create spontaneous inspirations with lung simulator); pressure-regulating solenoid valve, p.n. 10021110 (pilots expiratory diaphragm valve in PRV ventilator), South Bend Controls, South Bend IN

Expiratory Valve in PRV Ventilator:
Advent expiratory valve, Ohmeda Inc, Madison WI

Lung Simulator:
VT-2, Bio-Tek, Winooski VT

Pneumatic Air Cylinder:
IB8-550, Goodyear, Akron OH

Signal Generator:
FG2A, Beckman Instruments Inc, San Diego CA

Humidifier:
MR 500, Fisher & Paykel, Auckland, New Zealand

Laminar Flow Pneumotachometer:
Ohmeda Inc, Madison WI

Data Acquisition:
DT2801, Data Translations, Marlboro MA

Digital Signal Processor (in PRV Ventilator):
TMS320C25, Texas Instruments, Dallas TX

REFERENCES

4. Samodelov LF, Falke KJ. Total inspiratory work with modern demand valve devices compared to continuous flow CPAP. Intensive Care Med 1988;14:632-638.
5. Gherini S, Peters RM, Virgilio RW. Mechanical work on the lungs and work of breathing with positive end-expiratory pressure and continuous positive airway pressure. Chest 1979;76(3):251-256.


Evaluation of an Educational Program for Asthmatic Children Ages 4-8 and Their Parents

Daniel A Detwiler PhD, Linda Murphy Boston MA RRT, and Steven J Verhulst PhD

BACKGROUND: Evaluation of a number of asthma education programs for children 8-13 has shown improved self-management behaviors and decreased use of healthcare services. However, nearly 80% of children with asthma develop symptoms by age 5. MATERIALS & METHODS: We evaluated a program (Huff and Puff®: The Children’s Asthma Program) that addresses the developmental learning needs of children ages 4-8. This multicenter study employed a pre- and post-test design to evaluate the impact of the Program on cognitive, behavioral, and affective learning and medical care utilization. We report here data on 128 of the 130 children who completed the program and on the 125 households on which we have nonduplicated data. RESULTS: Statistically significant changes were observed in all categories of learning in those who completed the Program. Medical care utilization (including hospitalizations, days of hospitalization, emergency room visits and sick visits to the physician for “out-of-control” asthma) demonstrated statistically significant decreases. CONCLUSION: The Program was shown to be an effective educational intervention for children 4-8 years of age and their parents in this cohort (nonrandomized, noncontrolled study of volunteers). Future research should also explore ways to utilize and adapt the program for specific populations such as inner-city children and parents and non-English speaking groups. [Respir Care 1994;39(3):204-212.]

Background

Patient education is one of four major components of asthma management recognized in The Guidelines for the Diagnosis and Management of Asthma, published by the National Heart, Lung and Blood Institute. Evaluation of a number of asthma education programs has shown improved self-management behaviors and decreased use of healthcare services, including emergency room visits and hospitalizations. The majority of these programs have been used with children ages 8-13, cover generally similar content areas, and stress the need for shared partnership among physician, parent, and child. They are grounded in self-management psychology and derived from behavioral, cognitive, and social learning theories. These programs also seek to develop self-efficacy, which means that they foster confidence in the abilities of parents and children to control asthma. Furthermore, they employ a number of interactive learning strategies, easily understood paradigms, games, simulations, and modeling.

Unfortunately, most children with asthma develop signs and symptoms before the age of 8 years and the majority before the age of 5 years. A review of the literature indicates the need for asthma programs for this younger population and their par-
Programs for younger children should be sensitive to their developmental learning needs and should use powerful instructional techniques. Children ages 4-8 move from the preoperational to the concrete operational stage of cognitive development. As children progress, they develop a command of language and can reflect, to some degree, upon their experiences. We have observed that despite advancing sophistication with language, they retain attachments to fantasy and only gradually give up the ‘real’ qualities of their make-believe experiences. Children may use their imagination to enhance memory, understand novel ideas, and design and rehearse action plans. We believe children learn best by doing and want to see, touch, and interact with objects of learning. As their social interaction develops, they model the behaviors of their peers, which provides the basis for social learning. Furthermore, they have a strong desire for personal competence and mastery, often expressed through participation in group games.

The purpose of the study was to evaluate the impact of Huff and Puff®: The Children’s Asthma Program on medical care utilization and on cognitive, behavioral, and affective learning in children ages 4-8 and their parents.

Materials and Methods

Description of Program

The Program was developed specifically to address the developmental learning needs of children with asthma who are between the ages of 4 and 8 years. The Program provides information about the nature of asthma and its treatment; affords the opportunity to learn and practice self-management skills aimed at preventing and controlling symptoms; and seeks to develop self-efficacy.

The Program uses puppets to draw upon the child’s imagination. Initially, children may identify with Huff, who ignores early signals, forgets what to do, and often wheezes. Children observe the negative consequences of Huff’s behavior but also observe Puff, a credible role model who knows how to prevent and control asthma signals. After learning about asthma management, children practice self-management skills as they teach Huff how to control signals.

The program promotes children’s active participation and sensory involvement. In addition to the puppets, program materials include the companion workbook, Huff and Puff and Me®, which supplements instruction and provides individualization of learning; Huff and Puff Music Stuff®, an audiocassette with four songs designed to reinforce cooperative management and teach breathing and relaxation skills; Puff’s Path®, a felt board that children use to build the parts of the breathing path and learn what happens during asthma; and the Big D® board game, which children play as they learn how to make good decisions about asthma (Fig. 1). This 5-session program encourages cooperative care among physician, parents, and child. Because parents assume primary responsibility for the day-to-day management of their child’s asthma, the first two 2-hour sessions address parental learning needs. Children and parents attend the other three 1 1/2 hour sessions. Sessions are scheduled at 1-week intervals.

Fig. 1. Materials used in the Huff and Puff® program to help young children ages 4-8 learn about asthma.

The parents’ portion of the program uses a facilitator-led, participant-centered approach. In Session 1, parents learn about the respiratory system and how asthma affects the airways, how to monitor asthma signals, and how to identify the factors that trigger their child’s signals. They also learn about asthma medications, proper use and maintenance of inhaled medicines, and the importance of medication compliance. Colored slides and workbook exercises provide reinforcement for the teaching-learning process.
In Session 2, parents learn the importance of having individualized action plans to prevent and control their child's signals. They are taught how to use peak flow meters and discuss prevention strategies and management plans. Parents are encouraged to complete their plans after talking with their physician. Through group discussion, parents identify and talk through concerns related to normal childhood development.

In Session 3, children use a felt board to learn about breathing and how asthma affects their airways (Fig. 2). Through dialogue with Huff and Puff and workbook exercises, children identify their early warning signals and asthma attack signals. After Huff ignores early warning signals and has trouble breathing, children learn the importance of identifying early signals and taking action.

During Session 4, children learn how to use the Five-Step Plan to control asthma signals: I tell someone; I breathe slowly; I relax; I drink liquids; I take medicine. Children practice these skills as they teach Huff how to use the Five-Step Plan. Through dialogue with Huff and Puff and workbook exercises, children identify possible triggers for their asthma attacks.

In Session 5, Huff and Puff share some unpleasant feelings about asthma, and the children are encouraged to express their feelings. Huff and Puff and the children explore ways of coping with feelings. Children learn the meaning of prevention and specific ways to prevent their signals. By playing the game Big D, children make decisions about asthma and learn that their behaviors have consequences.

Subjects & Test Sites

The Program was conducted at 19 sites in Illinois between January 1 and July 31, 1991. Of the 148 children who voluntarily enrolled in the program, 130 (88%) completed all 5 sessions. Some siblings were among those enrolled, and in most cases both parents were enrolled. Demographic and test information is complete for 128 children and 125 households. A stipulation of enrollment was that the subject participate in all 5 sessions. The 18 children who were dropped from the study either because of illness or schedule conflicts. No data from those dropped are included. Descriptive measures (including age of children, gender, ethnic identification, and level of parental education and income) are presented in Table 1.

Facilitator & Puppeteer Selection & Training

Program facilitators were required to be either registered nurses (7/19) or registered or certified respiratory care practitioners (12/19). The puppeteers were all volunteers; although many had medical backgrounds, this was not a requirement because they followed the prepared scripts.

Prior to conducting programs, all facilitators attended a 1 1/2 day training seminar that had been accepted for continuing education credit. They learned how to conduct the Program using the standardized scripts. They also learned how to administer pre- and post-tests and to collect and report medical care utilization data.

Testing of Parents & Children

Program facilitators administered a pretest to the children and parents prior to the first session and a post-test after the completion of Session 5. The tests were designed to evaluate cognitive, behavioral, and affective learning in children and parents. The children's knowledge of asthma was assessed with a series of seven items designed to evaluate whether they could identify parts of the respiratory system.
name their medication, identify their asthma signals, indicate up to two prevention strategies, and list up to five self-management behaviors. Children colored the appropriate body parts, and parents were allowed to assist the child if writing an answer became too difficult. Parents were evaluated on knowledge of asthma with six items designed to address much of the same information, including physiology, signals, prevention, medications, and monitoring their child’s symptoms.

Children’s self-management behaviors were evaluated with five questions that addressed how often children used strategies that could help manage their asthma and symptoms. These questions represented the Five-Step Plan. Children responded by using a 5-point scale: never, part of the time, half of the time, most of the time, and always. In addition, each response heading used a picture of a glass filled with a corresponding amount of liquid. For example, “part of the time” was represented by a glass that was about one fourth full. Parents were instructed to facilitate but not determine the use of this scale by their child. The parents’ self-management behaviors were more extensively evaluated by using an 11-item series that addressed the same issues presented to the children and also included items designed specifically for parents. The same 5-point scale was employed without the use of graphics.

Children’s attitudes about asthma were evaluated with four items that addressed feelings of embarrassment, sadness, worry, and confidence. The same 5-point scale was used. Parents’ attitudes about asthma were similarly evaluated using a series of eight questions.

### Other Data Collection

Medical care utilization data (including number of emergency room visits, hospitalizations, days of hospitalization, sick visits to physicians for “out-of-control” asthma, and phone calls to physicians regarding asthma management) were collected on 106 of the children. These data were collected retrospectively by chart review for 1 year and prospectively for the 1 year following completion of the program.

### Severity of Asthma

This study began before the current criteria for asthma severity were published. A revision of a previously reported categorization of asthma severity by medication regimen (type and duration) was used in this research. Children classified as having mild asthma received medications (oral or inhaled) only as needed (prn). Subjects considered moderate were those who used daily medications, oral or in-

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**Table 1. Demographic Information for Children and Parents Involved in Asthma Program Evaluation**

<table>
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<th>Variable</th>
<th>Frequency*</th>
<th>Percent</th>
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<table>
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<th>Information on Parents†</th>
<th>Variable</th>
<th>Frequency*</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational level (n = 125 households)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father</td>
<td>Some high school</td>
<td>7</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>High school graduate</td>
<td>28</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>Some college</td>
<td>29</td>
<td>23.4</td>
</tr>
<tr>
<td></td>
<td>College graduate</td>
<td>38</td>
<td>30.6</td>
</tr>
<tr>
<td></td>
<td>Advanced degree</td>
<td>22</td>
<td>17.7</td>
</tr>
<tr>
<td>Mother</td>
<td>High school graduate</td>
<td>26</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>Some college</td>
<td>49</td>
<td>39.2</td>
</tr>
<tr>
<td></td>
<td>College graduate</td>
<td>39</td>
<td>31.2</td>
</tr>
<tr>
<td></td>
<td>Advanced degree</td>
<td>11</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Annual Family Income (n = 98 households)*

<table>
<thead>
<tr>
<th>Mean (SD) income</th>
<th>$45,503 (25,078)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median income</td>
<td>$40,000</td>
</tr>
<tr>
<td>Range</td>
<td>$8,000-170,000</td>
</tr>
</tbody>
</table>

---

*130 children completed the Program. Data are incomplete in some categories.
† Does not include duplicated data.
haled, for more than 50% of the time during the 6 months prior to enrollment. Periodic steroid use during that time did not disqualify subjects from this category. Those subjects who were steroid dependent, defined as using oral steroids for more than 50% of the time in the 6 months prior to enrollment, were classified as having severe asthma.

Although the Program is applicable to asthmatic children of all severity levels, the intent was to limit recruitment to subjects who had mild or moderate asthma as defined; however, 4 children with severe asthma were recruited. Of the 126 children for whom severity information was available, 33 subjects (26.2%) had mild asthma, 89 subjects (70.6%) had moderate asthma, and 4 subjects (3.2%) had severe asthma.

**Study Design and Data Analysis**

This study utilized a one-group pre- and post-test design,20 with comparison of performance on questionnaire items before and after Program participation. For those items on a 5-point scale (1 = never, 5 = always), pre- and postintervention means were compared using paired t tests. For those items for which response options were categorical (incorrect/correct), proportions responding correct pre- and postintervention were compared by McNemar’s test for correlated proportions.21 Similar analyses were employed for the medical care utilization data. Overall, statistical significance was set at the 5% level and a topic-adjusted error rate was used to control for multiple testing (that is, 0.05 was divided by the number of items per topic to determine the final significance level for the items). Occasionally, some data were missing. Therefore, descriptive measures were calculated and presented on all available data as noted.

**Results**

Results and comparisons of testing of children and parents before and after Program participation are provided in Tables 2-4.

**Discussion**

**Knowledge**

Table 2 reveals statistically significant increases in all seven knowledge items measured in the children participating. We believe that the marked increase in knowledge of self-management behaviors clearly reflects their learning of the Five-Step Plan.

Our direct observations of the children as they participated in the Program suggest that the children learn from interaction with the puppets, Huff and Puff, the Program facilitator, and one another. They may also learn from interaction with their parents as they jointly complete workbook exercises and from ‘doing’ as they build the breathing pathway using Puff’s Path. In this activity, children develop language concepts needed to understand asthma and its effect on their bodies.

Parents learn about asthma from didactic instruction from the program facilitator and the use of a participant-centered approach. They may also learn from group interaction and workbook exercises. Again, direct observation and parental feedback seem to suggest that parents’ learning is further enhanced as they watch and participate in the children’s sessions.

**Self-Management Behavior**

Children’s self-management behavior showed statistically significant increases (Table 2) in four of the five areas measured. Children were more likely to “stop and rest,” “breathe slowly,” “relax,” and “drink fluids,” after completing the Program. Children’s ability to “tell someone” did not show a comparable statistical increase because children were “telling someone” prior to the Program.

It appears that using imagination helped children improve their self-management abilities. Our direct observation suggests that they develop an affectionate relationship with Huff and Puff, whom they regard, to some extent, as ‘real.’ This may provide an emotional link that enhances their learning. In addition, the peer support and modeling provided by Huff and Puff may further enhance this behavior change. Because Huff is a slow learner, children rehearse the Five-Step Plan repeatedly.

Playing the Big D® game allows children to practice making decisions about asthma and may help them learn to make those decisions more often in their lives. Use of the audiocassette provides ongoing reinforcement and may enhance self-management behavior change.

Similar to that observed in children, 10 of the 11 items examining parents’ self-management ability
Table 2. Comparison of Children’s Pre- and Post-Test Results*

<table>
<thead>
<tr>
<th></th>
<th>Pretest No. Correct (%)</th>
<th>Post-Test No. Correct (%)</th>
<th>p†</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE (p_a = 0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location of</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windpipe</td>
<td>87 (67)</td>
<td>123 (97)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>25 (19)</td>
<td>120 (94)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Bronchial tubes</td>
<td>44 (34)</td>
<td>114 (90)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Name of medicine</td>
<td>47 (36)</td>
<td>103 (81)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Identification of signals</td>
<td>50 (39)</td>
<td>113 (89)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KNOWLEDGE (p_a = 0.025)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevention strategies (0-2 possible)</td>
<td>0.81</td>
<td>1.38</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Management behaviors (0-5 possible)</td>
<td>1.10</td>
<td>3.93</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>SELF-MANAGEMENT (p_a = 0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stop and rest</td>
<td>3.05</td>
<td>3.67</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Tell someone</td>
<td>3.70</td>
<td>3.79</td>
<td>0.598</td>
</tr>
<tr>
<td>Breathe slowly</td>
<td>2.45</td>
<td>3.26</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Relax muscles</td>
<td>2.63</td>
<td>3.19</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Drink fluids</td>
<td>3.34</td>
<td>3.98</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ATTITUDE (p_a = 0.0125)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feel embarrassed</td>
<td>2.22</td>
<td>2.00</td>
<td>0.170</td>
</tr>
<tr>
<td>Feel sad</td>
<td>2.74</td>
<td>2.44</td>
<td>0.048</td>
</tr>
<tr>
<td>Worry</td>
<td>2.74</td>
<td>2.48</td>
<td>0.076</td>
</tr>
<tr>
<td>Feel confident</td>
<td>3.20</td>
<td>3.81</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

*130 children completed the Program, but test results were complete on only 129.
†Analysis by McNemar’s Chi-Square.
‡Means are based on all available data.
§Analysis by paired t tests.
¶5-point scale: 1 = never, 2 = part of the time, 3 = half of the time, 4 = most of the time, 5 = always.

showed a statistically significant increase (Table 3). The only item not showing a significant change following the program was the parent’s ability to “communicate to a caregiver.” Parents were notifying caregivers nearly “all of the time” before the program. Even though the parents were already involved in the management of their child’s asthma, the Program was able to refine and improve their self-management abilities.

Parents appear to learn self-management strategies from the program facilitator and through interaction with one another, with behavioral changes reinforced by watching and participating in their child’s learning activities. In addition, both children and parents learn new vocabulary that may help them more effectively communicate with each other and their physician.

Attitude

Measurement of children’s attitudes demonstrated statistically significant increases in confidence in their ability to improve their asthma. This seems to indicate a greater sense of self-efficacy. It appears that the children’s sense of self-efficacy is further enhanced as they experience Huff’s improvement.
using the techniques they taught Huff. Feelings of embarrassment, sadness, and worry decreased after completing the program but these were not statistically significant changes.

Parents’ attitudes about asthma showed statistically significant changes on five of the eight items. Specifically, parents felt less worried about their child’s asthma, less concerned that asthma was interfering with their child’s normal development, and less sorry for their child because of asthma. In addition, they felt more confident in their ability to manage their child’s asthma and in their child’s ability to cooperatively manage asthma. The latter is similar to the attitudinal change reported by children. These changes suggest that parents felt a greater belief in their own self-efficacy and that of their children.

**Medical Care Utilization**

Children required less medical care in the year following participation in the program. Specifically, children’s medical care utilization data revealed sta-

---

<table>
<thead>
<tr>
<th>KNOWLEDGE (p_a = 0.0125)</th>
<th>Pretest No. Correct (%)</th>
<th>Post-Test No. Correct (%)</th>
<th>p†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early warning signals (2 possible)</td>
<td>67/125 (54)</td>
<td>119/123 (97)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Asthma signals (3 possible)</td>
<td>87/124 (70)</td>
<td>120/123 (98)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Medications (5 possible)</td>
<td>91/125 (73)</td>
<td>118/123 (96)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Monitoring symptoms (6 possible)</td>
<td>97/125 (77)</td>
<td>112/123 (91)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KNOWLEDGE (p_a = 0.025)</th>
<th>Pretest Mean (SD):‡</th>
<th>Post-Test Mean (SD):‡</th>
<th>p§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asthma physiology (scale 0-3)</td>
<td>1.62 (0.87)</td>
<td>2.46 (0.62)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Prevention strategies (scale 0-3)</td>
<td>1.39 (0.90)</td>
<td>2.32 (0.74)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SELF-MANAGEMENT (p_a = 0.0045)</th>
<th>Pretest Mean (SD):‡</th>
<th>Post-Test Mean (SD):‡</th>
<th>p§</th>
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</thead>
<tbody>
<tr>
<td>Elimination</td>
<td>3.86 (1.07)</td>
<td>4.20 (0.73)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Avoidance</td>
<td>3.68 (0.92)</td>
<td>4.02 (0.59)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Preventive medicine</td>
<td>4.05 (1.20)</td>
<td>4.44 (0.75)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Caregiver communication</td>
<td>4.51 (0.94)</td>
<td>4.71 (0.63)</td>
<td>0.007</td>
</tr>
<tr>
<td>Breathing exercises</td>
<td>2.09 (1.44)</td>
<td>4.10 (1.10)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Relaxation</td>
<td>2.34 (1.51)</td>
<td>4.04 (1.10)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Fluids</td>
<td>2.16 (1.47)</td>
<td>4.15 (1.01)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Monitor severity</td>
<td>3.60 (1.03)</td>
<td>4.16 (0.68)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Medication management</td>
<td>4.03 (0.91)</td>
<td>4.47 (0.56)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Call physician</td>
<td>4.15 (0.93)</td>
<td>4.54 (0.59)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Stay calm</td>
<td>4.02 (0.92)</td>
<td>4.31 (0.71)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ATTITUDES (p_a = 0.006)</th>
<th>Pretest Mean (SD):‡</th>
<th>Post-Test Mean (SD):‡</th>
<th>p§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worry</td>
<td>3.59 (1.14)</td>
<td>3.08 (1.17)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Concern for development</td>
<td>2.65 (1.17)</td>
<td>2.13 (1.04)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Angry</td>
<td>2.00 (1.07)</td>
<td>1.77 (0.92)</td>
<td>0.004</td>
</tr>
<tr>
<td>Sorry</td>
<td>2.91 (1.30)</td>
<td>2.32 (1.07)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Afraid</td>
<td>2.20 (0.98)</td>
<td>2.11 (0.82)</td>
<td>0.251</td>
</tr>
<tr>
<td>Health perception</td>
<td>1.68 (0.87)</td>
<td>1.53 (0.73)</td>
<td>0.010</td>
</tr>
<tr>
<td>Self-confidence</td>
<td>3.70 (0.92)</td>
<td>4.08 (0.64)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Confidence in child</td>
<td>2.94 (1.20)</td>
<td>3.50 (0.95)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

*10 children completed the Program; however, numbers reflect removal of duplicated results (from parents with more than one child participating) and missing data.
†Analysis by McNemar’s Chi-Square.
‡Mean± are based on all available data.
§Analysis by paired t test, p < 0.001.
Table 4. Medical Care Utilization before and after Participation in Asthma Program*

<table>
<thead>
<tr>
<th>Number of</th>
<th>12 Months preceeding Program Mean (SD)</th>
<th>12 Months after Program Mean (SD)</th>
<th>p †</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone calls to doctor</td>
<td>4.46 (3.49)</td>
<td>3.98 (4.24)</td>
<td>0.344</td>
</tr>
<tr>
<td>Physician visits</td>
<td>4.26 (3.24)</td>
<td>2.43 (2.97)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Emergency room visits</td>
<td>0.97 (2.00)</td>
<td>0.42 (1.16)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Hospital admissions</td>
<td>0.42 (0.73)</td>
<td>0.10 (0.33)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Days in hospital</td>
<td>1.50 (2.68)</td>
<td>0.30 (1.14)</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

*Data are complete on 106/130 children who participated in the Program.
†Analysis by paired t test; p<sub>A</sub> = 0.010.

Statistically significant decreases in 4 of the 5 items measured (Table 4): number of emergency room visits, number of hospitalizations, days of hospitalization, and sick visits to physicians for “out-of-control” asthma. The remaining item, phone calls to physicians, declined, but not at a rate that was statistically significant.

This observed reduction in medical care utilization by children may have resulted from changes in knowledge, self-management behaviors, and attitudes, that enhance the capacity of children and parents to better manage asthma. It is also possible that the workbook and audiocassettes provide ongoing reinforcement, which impacts the way in which parents and children cooperatively manage asthma. However, one cannot rule out the effects of increasing age as a contributing factor in this decline.

Limitations of the Study

Several factors limit our ability to generalize the results of this study. The first is the voluntary nature of the participation of subjects. Voluntary participation suggests a high degree of motivation and established involvement on the part of the parents and, thus, a desire to obtain all possible benefit from participation. The second factor is the lack of a control group. Results from a randomly assigned control group might have helped to quantitate the effects of advancing age on the need to utilize medical care.

Conclusion

The results of this study indicate that Huff and Puff®: The Children’s Asthma Program is an effective health education tool for children ages 4-8 and their parents. Furthermore, its educational design fosters cognitive, behavioral, and affective learning in both children and parents and decreases medical care utilization.

Based on the results of this study, further investigation using random assignment to experimental and control groups is needed to allow generalization of the findings. Future research should also explore ways to utilize and adapt the program for specific populations such as inner-city children and parents and non-English speaking groups.

ACKNOWLEDGMENTS

We thank the 19 Program facilitators, their puppeteers, and sponsoring institutions for participating in this study. We also thank Sharon Tengler for her excellent secretarial assistance with the manuscript.

REFERENCES

Mobilization of Secretions in ICU Patients

Marc A Judson MD and Steven A Sahn MD

I. Introduction

The clearance of pulmonary secretions is a complex process that requires the integration of mucus production, ciliary movement, and cough.1 Excess pulmonary secretions can cause acute respiratory failure (ARF) or make the management of ARF more difficult. Patients in ARF require mechanical ventilation through endotracheal or tracheostomy tubes, and these artificial airways render coughs ineffective by preventing glottic closure. In addition, mucus transport presumably ends at the tube cuff.2 As a result, patients receiving mechanical ventilation frequently have a tendency to retain secretions, resulting in episodes of hypoxemia,3 atelectasis,4 pneumonia, and eventual fibrosis.5

Techniques to enhance clearance of secretions in intubated patients include tracheobronchial suctioning, postural drainage, chest physiotherapy, pharmacotherapy, and special ICU beds. Despite routine use of these therapies in the care of ICU patients, few studies have evaluated their efficacy, indications, contraindications, and cost.

II. Mechanisms of Clearance

The clearance of airway secretions occurs by mucociliary action and coughing, the latter being essentially a reserve mechanism.6 Mucociliary clear-

III. Impairment of Clearance in Intubated ICU Patients

A. The Endotracheal/Tracheostomy Tube
B. Tracheobronchial Suction
C. Temperature & Humidity of Inspired Air
D. High Concentrations of Inspired Oxygen
E. Drugs
F. Underlying Pulmonary Disease

IV. Methods To Improve Secretion Clearance in Intubated ICU Patients

A. Tracheobronchial Suctioning
B. Pharmacotherapy
C. Chest Physiotherapy
D. Continuous Lateral Rotation Therapy (CLRT)
E. Airway Pressure & Ventilator Management

V. Summary

Dr Judson is Medical Director, Lung Transplantation, and Dr Sahn is Professor of Medicine and Director, Division of Pulmonary and Critical Care Medicine—Medical University of South Carolina, Charleston, South Carolina.

The authors have no financial interest in any of the products mentioned in this paper.

A version of this paper was presented by Dr Judson during the Lifecare New Horizons Symposium “Cost-Effectiveness of Respiratory Care in the ICU” at the 1993 Annual Meeting of the AARC in Nashville, Tennessee.

Reprints: Marc A Judson MD, Medical Director, Lung Transplantation, Medical University of South Carolina, 171 Ashley Avenue, Charleston SC 29425-2220.
SECRETION MOBILIZATION IN ICU PATIENTS

ance is operative in most of the tracheobronchial tree from the larynx proximally to the sixteenth-order bronchi distally. Airway mucus originates primarily from goblet cells, which line the respiratory epithelium; submucosal glands, located chiefly in the cartilaginous airways, Clara cells, and tissue fluid transudate also contribute to airway secretions. The major bronchi are lined by pseudostratified columnar epithelial cells whose cilia project toward the airway lumen. The cilia of adjacent cells beat one after another in a coordinated fashion to generate a wave of ciliary motion.

According to the hypothesis of Lucas and Douglas, respiratory mucus is composed of two layers. The cilia appear to beat in a watery (sol) layer on which floats a viscous mucus (gel) layer. The tips of the cilia interact with the gel layer. Coordinated waves of ciliary motion propel mucus toward larger airways. Both the rate of ciliary beat and the proportion of ciliated cells in the epithelium increase from the smaller to the larger airways so that the rate and efficiency of propulsion increases as mucus ascends the mucociliary escalator.

A cough starts with a rapid inspiration followed by glottic closure for 200 milliseconds (ms), a rise in pleural pressure to 50-100 torr by expiratory muscle contraction, then subsequent glottic opening by the explosive cough. Expiratory flow may exceed 12 L/s. This high linear airflow interacts with secretions to create two-phase gas-liquid flow in which energy is transferred from the air to the liquid, shearing and moving the liquid and finally leading to expectoration of sputum.

Cough has been demonstrated not to contribute to tracheobronchial clearance in individuals who cannot produce sputum, although a recent study suggested that cough can enhance mucus clearance in normal individuals by stimulation of the mucociliary apparatus. Cough clearance is affected by the peak expiratory flow that is generated. It is also affected by the thickness and rheologic properties of the mucus, which include viscosity, elasticity, spinnability, and adhesivity. The forced expiration technique (FET) consists of one or two forced expirations (without glottic closure and the compressive phase of a cough) starting from mid-lung volume, followed by a period of relaxation and diaphragmatic breathing (a huff). Although glottic closure enhances the initial acceleration component of coughing, it is not absolutely necessary because FET is effective in removing airway secretions. However, FET requires that the subject generate high expiratory airflow that may not be attainable in intubated patients with respiratory failure. This technique has not been studied in intubated patients. Devices such as the mechanical exsufflator (discussed below) may generate an adequate expiratory flowrate in these patients.

Impairment of Clearance in Intubated ICU Patients

An intubated ICU patient has several impediments to airway clearance (Table 1), the most important of which is the endotracheal or tracheostomy tube. However, factors related to ventilator management, drug therapy, and the patient’s underlying disease may also adversely affect the clearance of airway secretions.

<table>
<thead>
<tr>
<th>Endotracheal or tracheostomy tube</th>
<th>Tracheobronchial suction</th>
<th>Inadequate humidification</th>
<th>High F[O]2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drugs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General anesthetics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opiates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narcotics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underlying pulmonary disease</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Endotracheal/Tracheostomy Tube

Mucus transport presumably ends at the tube cuff where the mucociliary escalator is mechanically blocked. As a result, secretions accumulate in the trachea and must be suctioned regularly. Cough is rendered ineffective by the presence of an artificial airway, which further limits airway secretion clearance. Erosions caused by movement of the cuff or tip of the tube against the trachea can also reduce mucus transport velocity.

Tracheal intubation per se may provoke reflex mucus secretion. The disruption of the mucociliary escalator by the artificial airway may lead to pooling and stagnation of secretions, thereby promoting bacterial colonization and pneumonia. Even routine endotracheal suctioning cannot completely eliminate secretion pooling.
Tracheobronchial Suction

Although tracheobronchial suctioning is essential to prevent atelectasis in intubated patients with excessive secretions, it causes mucosal hemorrhage and erosions in the tracheobronchial tree. These lesions slow mucociliary transport, presumably by directly damaging ciliated and mucus-secreting airway cells. Improved suction catheters whose suction ports do not directly contact the mucosa have been shown to decrease airway erosion and to increase mucociliary transport.

Temperature & Humidity of Inspired Air

Humidification and warming of inspired air are essential for proper functioning of the respiratory mucociliary system. When the nasopharynx and upper airway are bypassed by an endotracheal tube, a continuous loss of moisture and heat can lead to destruction of cilia, tissue inflammation, and necrosis. Inadequate humidification can further lead to desiccation of airway secretions, resulting in narrowing and even life-threatening obstruction of artificial airways. The use of high-frequency ventilation further compounds the problem because of difficulties in achieving adequate humidification, resulting in severe airway damage or lethal tracheobronchitis.

A heat and moisture exchanger (HME), also referred to as an artificial nose, works by trapping endogenous moisture and heat from exhaled gas and returning them to the inhaled gas delivery system. The advantages of an HME over a conventional heated humidifier include convenience, size, avoidance of airway burns, high bacterial filtering capacity, and cost. Branson and Hurst concluded from their study of 7 HMEs that these devices may be adequate for short-term use (24 to 48 hours) provided patients have normal body temperature, are well-hydrated, and do not have thick inspissated secretions. Cohen and co-workers found HMEs to be less effective for airway humidification than conventional humidifiers, with an increased incidence of endotracheal tube occlusions that was associated with pneumonia and atelectasis. In some patients, dramatic cement-like casts were seen to line the entire inner portion of the lumen when endotracheal tubes were removed. Misset and co-workers found an increased viscosity of airway secretions with HMEs compared to conventional humidifiers. Nevertheless, they advocated routine use of HMEs under cautious surveillance because of their advantages in cost and decreased nursing time. Branson and Chatburn describe an algorithm used to select patients for whom the use of HMEs is appropriate. Difficulty in suctioning or an increase in the peak inspiratory pressure suggests that the endotracheal tube should be examined and the HME replaced with a conventional humidification system.

High Concentrations of Inspired Oxygen

Patients with acute respiratory failure often have severe abnormalities in pulmonary gas exchange that require high concentrations of inspired oxygen that may produce an acute tracheobronchitis. Because acute tracheobronchitis produces a loss of ciliated epithelium and the retention of secretions, depression of mucus transport occurs. Sackner and co-workers found that tracheal mucus velocity was depressed as early as 3 hours after normal volunteers inspired 90-95% oxygen, and bronchoscopic evidence of tracheal injury was present by 6 hours. In an animal study, Sackner’s group demonstrated that even inspiration of 50% oxygen impaired mucus transport, although histologic evidence of acute tracheobronchitis could only be established in animals receiving 75 and 100% oxygen.

Drugs

A number of pharmacologic agents commonly used in the ICU (including several general anesthetics, morphine, and other narcotics) have been demonstrated to depress mucociliary transport. Konrad et al recently reported that bronchial mucus transport velocity was not affected by general anesthesia with midazolam, fentanyl, pancuronium, and nitrous oxide in 14 patients undergoing major abdominal surgery. The effect on mucociliary clearance of other common sedating or paralyzing drugs commonly used in the ICU (such as atracurium, lorazepam, and propofol) has not been studied.

Underlying Pulmonary Disease

Many patients with acute respiratory failure have a disease involving the airways that impairs mu-
ciliary clearance. For example, patients with asthma and chronic bronchitis usually have decreased mucociliary clearance. Mechanisms proposed to explain impaired mucociliary transport in these diseases include damage to ciliated cells, changes in the rheologic properties of mucus, and changes in airway diameter and structure.

Methods To Improve Secretion Clearance in Intubated ICU Patients

Although numerous techniques are used to enhance clearance of airway secretions in intubated ICU patients (Table 2), few studies have assessed their efficacy. Even if such techniques are shown to be effective, the clinical value (such as decreased morbidity, mortality, length of hospital stay, or hospital costs) would need to be demonstrated before they could be recommended for routine ICU care; few studies have directly addressed these issues. Therefore, it should be emphasized that our conclusions and recommendations are based on little objective data.

Table 2. Methods To Improve Secretion Clearance in Intubated Patients

<table>
<thead>
<tr>
<th>Method</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheobronchial suctioning*</td>
<td></td>
</tr>
<tr>
<td>Pharmacotherapy</td>
<td>Benefit unknown</td>
</tr>
<tr>
<td>β-agonist aerosols†</td>
<td></td>
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<tr>
<td>Mucolytic aerosols†</td>
<td></td>
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<tr>
<td>Continuous lateral rotational therapy‡</td>
<td></td>
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<tr>
<td>Airway-ventilator techniques</td>
<td></td>
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<tr>
<td>Mechanical exsufflator devices§</td>
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</table>

*Clearly beneficial.  †Benefit unknown.  ‡Beneficial in selected patients.  §Possibly beneficial.

The American Association for Respiratory Care has sponsored the development of Clinical Practice Guidelines. Several of these pertain to the topics that follow—cough, suctioning, chest physiotherapy and postural drainage, airway humidification during mechanical ventilation, and pressure-assisted bronchial hygiene. Therapy aimed at enhancing mucociliary clearance in intubated ICU patients must be individualized with these general guidelines kept in mind.

It is likely that the benefit of improving airway clearance varies among the different causes of acute respiratory failure. Several studies in nonintubated patients suggest that chest physiotherapy is not useful in acute lung diseases that are not characterized by excessive respiratory secretions (such as pneumonia and most exacerbations of chronic bronchitis). However, it is problematic to extrapolate these data to intubated patients who have additional problems in clearing secretions.

Enhancement of mucociliary clearance may have a negligible impact on the clinical course or outcome of severely ill ICU patients whose underlying medical conditions are likely to be the major determinants of complications and mortality. Techniques to improve mobilization of secretions are more likely to be of benefit prophylactically to prevent atelectasis and pneumonia in less critically ill intubated ICU patients.

Mucociliary clearance rates have been determined by sputum volume, sputum weight, inhalation of radioactive particles, deposition of a small-volume bolus of radioactive microspheres, and visual detection of teflon disc movement through a bronchoscope (fiberoptic cinebronchoscopy). Although these techniques have been performed in stable postoperative intubated patients, they have rarely been utilized in patients with acute respiratory failure. Some of these techniques are difficult to perform with patients in ARF because the requirement for frequent suctioning makes clearance rates difficult to determine, and the disconnection of positive end-expiratory pressure, which is required to perform several of these techniques, is potentially dangerous. In addition, deposition of aerosols is affected by lung disease and, therefore, differences in aerosol clearance rates may relate to aerosol deposition rather than to mucociliary clearance in patients with acute respiratory failure.

Tracheobronchial Suctioning

Because mucus transport presumably ends at the tube cuff, tracheobronchial suctioning is essential to prevent atelectasis in intubated patients with excessive secretions. Furthermore, any other maneuvers performed to enhance secretion clearance in intubated patients may be of limited value without adequate suctioning.
Tracheobronchial suctioning causes airway erosions, bronchospasm, hypoxemia, and increased intracranial pressure. Sackner and co-workers have stated that airway lesions were more readily induced when the negative suction pressure was increased from -40 mm Hg to -200 mm Hg; however, no specific data were provided. These authors observed that catheters designed to prevent the suction tip or side holes from coming in contact with the tracheobronchial mucosa decreased suction-induced airway damage. In contrast, Jung and Gottlieb believed that tracheal mucosal injury was related more closely to the repetition, vigor, and magnitude of negative pressure than to the type of catheter, although they only performed one pass with each catheter. Czarnick et al performed endotracheal suction in dogs with a negative pressure of 200 mm Hg and a suction flowrate of 16 L/min. The animals were randomized to receive 10 seconds of continuous or intermittent suction (2 seconds with, then 1 second without, for a total of 10 seconds). Tracheal damage was found in both groups, including ulceration and necrosis. They observed no difference in the severity of tracheal damage between the continuous and intermittent suction groups.

Although even careful intermittent suction may cause tracheal damage, the benefits of suctioning outweigh its risks in intubated patients who have copious sputum. It has been suggested that the frequency of suctioning should be guided by the amount of secretions produced by the intubated patient. Whether routine suctioning should be performed in intubated patients is more controversial and has not been studied. Czarnick et al concluded from their animal study that routine hourly suctioning should be avoided and the number of passes should be kept to a minimum to avoid unnecessary tracheal damage. In contrast, Bishop and Ritz have stated that routine suctioning is warranted, even in the absence of copious secretions, to ensure that the tube remains patent.

Although normal saline is commonly instilled into the endotracheal tube prior to suctioning, few studies have documented its efficacy. Bostick and Wendelglass compared the instillation of 0, 5, and 10 mL of normal saline in 45 patients who had undergone open heart surgery. Patients receiving saline had a statistically significant increase in the amount of sputum recovered. Gray et al also found a statistically significant increase in the amount of sputum recovered when 5 mL of normal saline was instilled (compared to withholding saline) in 15 critically ill intubated patients with pulmonary disease. Arterial blood gases, hemodynamic parameters, and level of discomfort were similar between the two groups. It was the investigators’ impression in both studies that normal saline instillation might enhance secretion clearance by stimulating the cough reflex rather than by increasing aspiration into a specimen trap. The differences in sputum obtained in these studies cannot be attributed to the instilled saline because less than 20% of it is recovered by suctioning. Recently, Isea and co-workers found that a continuous irrigation catheter suctioned statistically significantly more bronchial secretions in less time than conventional suctioning techniques in 20 mechanically ventilated patients. They believe that the constant irrigation system facilitates the removal of secretions by creating an interface that allows a film containing secretions to be in constant contact with the suction port.

Since the early 1980s, closed suction systems have been developed that allow suctioning without discontinuation of mechanical ventilation. Deppe et al showed that such a system increased the incidence of airway colonization but not the incidence of nosocomial pneumonia. Although closed systems limit suction-associated hypoxemia, prooxygenation with 100% oxygen is recommended.

Because cannulation of the left main-stem bronchus is more difficult than the right, suctioning of secretions from the left lung is problematic. Kirimli and co-workers demonstrated that a straight suction catheter traveled into the right main-stem bronchus more than 90% of the time, including when head turning procedures were employed. Even a properly directed curved-tip catheter was successfully placed in the left main-stem bronchus less than 50% of the time. Haberman et al concurred with the difficulty of entering the left main-stem bronchus. Use of angled-tip catheters increased the rate of successful left main-stem placement from 37 to 53%, and head positioning tended to improve left main-stem cannulation. They also showed that it was difficult to cannulate the left mainstem through a nasotracheal tube. Panacek et
al\textsuperscript{75} reported a 65% success rate of left endobronchial suctioning when the endotracheal tube was more than 2 cm above the carina and the head was turned to the left; they reported a 100% success rate (n = 15) through tracheostomy tubes. Kubota and co-workers\textsuperscript{76} described a method of assessing proper suction catheter placement by placing a sound generator on the proximal end of the suction catheter and auscultating with a stethoscope. They stated that the location of the catheter was determined by chest radiograph and sound signal over 1,000 times, but they did not provide specific data. Using the sound generator, they reported a 97.1% success rate of left main-stem catheter placement with a curved-tip catheter when the endotracheal tube was at least 3 cm above the carina.\textsuperscript{77}

Although suctioning through a bronchoscope can be directed into specific segmental bronchi, Marini and co-workers\textsuperscript{5} found bronchoscope-directed suction to be no more efficacious than standard respiratory therapy in 31 patients (half were intubated) with acute lobar atelectasis. The patients were randomized to receive fiberoptic bronchoscopy with saline lavage and suctioning or respiratory therapy that consisted of deep breathing (or large volume inflations with an anesthesia bag in intubated patients), chest percussion, postural drainage, $\beta$-agonist aerosols, and cough (or tracheal suction in intubated patients). They found no difference in the rate of resolution of volume loss between the groups. The presence of an air bronchogram on chest radiograph predicted delayed resolution for both groups. They advocate fiberoptic bronchoscopy in such patients when effective respiratory therapy cannot be accomplished or respiratory therapy is not successful.

Recently, two additional bronchoscopic techniques involving insufflation of air have been effective in resolving acute lobar collapse. Haenel and co-workers\textsuperscript{78} reported on 17 surgical ICU patients with acute lobar collapse who were treated by wedging a bronchoscope into the bronchus of the collapsed lung segment and, using a manual resuscitator, insufflating the segment with oxygen-enriched gas. This procedure was successful in reversing the atelectasis in 84% of patients. More than half of these patients had failed to respond to aggressive respiratory care. Susini et al\textsuperscript{79} injected air through a small-caliber balloon-tipped catheter in 18 patients (2 of whom were intubated) with postoperative atelectasis. Fifteen patients had complete resolution of atelectasis, and the remaining three had partial re-expansion.

Conclusion: Although endotracheal suctioning is essential for clearing secretions in intubated patients, there is a paucity of objective data concerning the optimal suction frequency, duration, negative pressure, flow rate, or catheter type. Limited data suggest that normal saline instillation prior to suctioning is beneficial. Even careful intermittent suctioning can cause mucosal damage. Suctioning frequency is dependent on the presence of secretions. The utility of routine suctioning is presently debated. Suctioning secretions from the left lung is difficult and remains a significant limitation of tracheobronchial suctioning. Special suction catheters and techniques are required to clear secretions from the left lung, but their effect on clinical outcome has never been evaluated.

Pharmacotherapy

Aerosolized $\beta$ agonists are routinely administered to intubated patients. In general, the delivery of aerosolized medications to intubated patients is not very efficient, and the major barrier to efficient delivery is the endotracheal tube.\textsuperscript{80}

Aerosolized $\beta$ agonists can be administered to intubated patients through a small-volume nebulizer (SVN) or metered-dose inhaler (MDI). Aerosol delivery by MDI has potential advantage over SVN because it reduces the time that a therapist's presence is required at the bedside and therefore reduces cost.\textsuperscript{81} Using the time saved by the use of MDI, the therapist is free to pursue other revenue-producing activities, reducing overall cost even further.\textsuperscript{80,82} In addition, continuous aerosol nebulization has been shown to damage expiratory flow transducers,\textsuperscript{80} can cause difficulty for some patients in triggering breaths if they are receiving pressure support ventilation,\textsuperscript{83} and can be a source of airway contamination.\textsuperscript{84}

Several factors affect aerosol delivery from SVNs and MDIs in intubated patients. O'Riordan and co-workers\textsuperscript{85} showed that aerosol delivery with SVNs during mechanical ventilation is influenced by the type of nebulizer, treatment duration, duty cycle, fill volume of the nebulizer, and presence of a
humidification device. Crogan and Bishop found that with an MDI, β-agonist delivery through an endotracheal tube was increased when the tube diameter was enlarged and the MDI was activated into a flowing airstream. Recently Taylor et al demonstrated that MDI delivery of β-agonist aerosols through endotracheal tubes could be improved over 30-fold by actuating the MDI through a 19-gauge catheter that extends the entire length of the endotracheal tube.

Although β agonists have been shown to increase mucociliary clearance, tracheal mucus velocity, and sputum yield in normal subjects and those with lung disease, few data are available concerning the utility of β agonists in enhancing mucociliary clearance in intubated ICU patients. Several studies have demonstrated that in intubated ICU patients, aerosolized bronchodilators cause significant bronchodilation when administered by MDI or SVN. Airway dilatation may also enhance mucociliary clearance, but this has not been substantiated.

The ability of mucolytic agents to enhance clearance of secretions in intubated patients has not been examined. Zandstra et al did show that nebulization of a mucolytic agent resulted in an increase in airway resistance in 10 intubated postoperative patients, but this effect could be blocked by the addition of a β agonist to the aerosol. Although theophylline and ipratropium bromide have been shown to be effective bronchodilators in intubated COPD patients, their effects on secretion clearance in intubated patients are unknown.

Conclusion: Beta agonists and other drugs that enhance secretion clearance are routinely given to intubated ICU patients. Most of these drugs are bronchodilators. Although the efficacy of their bronchodilating effect has been demonstrated, we have virtually no information concerning their efficacy or clinical importance in mobilizing airway secretions. Delivery of β agonists by MDI is more cost-effective than by SVN.

Chest Physiotherapy

Chest physiotherapy (CPT) consists of physical maneuvers such as cough, forced expiration, chest-wall percussion and vibration, and postural drainage to improve respiratory function, atelectasis, and pneumonia. It is assumed that the external mechanical maneuvers (chest-wall percussion and vibration, postural drainage) move secretions to the central airways where cough and forced expirations become effective in propelling secretions. Because the presence of an airway tube impairs effective cough and blocks mucus transport proximal to the tube cuff, adequate tracheal suctioning needs to be coupled with chest physiotherapy in intubated patients. CPT is thought to be of no value in patients who produce little sputum. It has been suggested that when the physician is uncertain whether the patient is producing enough sputum to benefit from CPT, a short trial of CPT should be given and should be continued only if an appreciable volume (> 30 mL) of sputum is produced.

A few studies have examined the various aspects of CPT in intubated patients. Because these studies involved several components of CPT, it is difficult to draw conclusions about each specific component. Laws and McIntyre studied the effects of CPT in 6 intubated patients with respiratory failure who did not have excessive secretions. Chest physiotherapy included postural drainage, shaking or vibrating the chest during expiration, clapping chest percussion, and assisted coughs produced by synchronizing powerful chest compression and vibration with expiration following a series of large breaths (20-25 mL/kg). These assisted coughs were performed in the supine and both lateral positions. CPT did not affect gas exchange in these patients, and changes in cardiac output were highly variable and probably related to the large swings in airway pressure from the CPT techniques. Assisted coughs may be more effectively delivered with a mechanical exsufflator (discussed in an upcoming section). Gormezano and Branthwaite examined changes in arterial blood gas tensions after CPT in 42 patients receiving mechanical ventilation. Treatment consisted of hyperinflation to achieve a maximal inflation pressure 20 cm H₂O above the peak inspiratory pressure of ventilated breaths, manual compression of the chest, and endotracheal suction. Statistically significant changes in arterial blood gases after CPT were largely confined to the patients with cardiovascular disease. Connors and co-workers performed chest percussion and postural drainage in 22 acutely ill hospitalized patients, 7 of whom were intubated. Patients who produced little or no sputum experienced a mean drop in PₕO₂ of 16.8 torr. These investigators suggested that the use of chest percussion
and postural drainage is not indicated and is potentially dangerous in such patients. Weissman and Kemper examined oxygen delivery and consumption in 16 mechanically ventilated patients who received CPT. Although oxygen delivery increased slightly after CPT, greater increases were observed in oxygen consumption and oxygen-extraction ratio, suggesting that CPT is energy costly in these patients and may cause significant hypoxemia. Kigin has recommended that 100% oxygen be administered when CPT is performed in mechanically ventilated patients.

CPT has been demonstrated to be of benefit in patients with atelectasis or lobar collapse. As previously mentioned, Marin et al showed that CPT led to radiographic improvement in patients with acute lobar atelectasis. Mackenzie and co-workers studied 47 patients who received CPT during mechanical ventilation. These patients all had excessive secretions and most had atelectasis or pneumonia. CPT consisted of postural drainage, external chest compression by percussion or vibration, encouragement to cough, and tracheobronchial suctioning. Although CPT did not improve gas exchange, chest radiographic improvement was seen in 68%. Stiller et al recently showed that the addition of positioning and chest vibrations to a CPT regimen of hyperinflation and suction resulted in a statistically significant improvement in the resolution of acute lobar atelectasis in 14 patients (11 were receiving mechanical ventilation). Holody and Goldberg showed mechanical chest vibration was effective in improving oxygenation in 10 acutely ill patients with atelectasis or pneumonia (8 were intubated).

Although patients with an intubated airway are unable to cough normally, the use of the forced expiration technique in conjunction with postural drainage was found to increase sputum yield in non-intubated patients with chronic bronchitis. FET in intubated patients could possibly be enhanced by mechanically inflating the lungs prior to performance of the procedure, which is similar to the assisted cough. This has been shown to be effective in increasing cough-induced expiratory flowrates in non-intubated postpoliomyelitis patients.

**Conclusion:** CPT is effective in the treatment of atelectasis and acute lung collapse in intubated patients. No long-term studies of CPT have been performed in the ICU setting, thus the value of CPT in preventing pulmonary complications in intubated patients is unknown. In short-term studies involving short CPT trials, CPT has been shown to be of little benefit and potentially dangerous in acutely ill intubated patients who are producing little or no sputum. Similarly, the value of CPT has not been demonstrated in intubated patients producing large amounts of sputum without localized radiographic abnormalities. It is not known which components of CPT are most useful in patients with acute lung collapse. FET may be of value in intubated patients, but it has not been studied.

**Continuous Lateral Rotation Therapy**

In 1967, Keane devised the first form of rotational therapy for immobile patients. He hypothesized that frequent automatic turning could prevent pulmonary complications by promoting improved mobilization of secretions. Major benefits include not only mobilization of secretions but also reduction in venostasis, prevention of skin and subcutaneous tissue breakdown, and effects of gravity on ventilation and pulmonary blood flow. Hess et al have provided an excellent review of the various methods available for positioning patients: we exclusively discuss the merits of continuous lateral rotational therapy (CLRT).

Several prospective, randomized studies have been published evaluating the utility of CLRT in intubated patients (Table 3). Gentilello and co-workers compared the effects of CLRT to management in a conventional bed in 65 critically ill surgical ICU patients immobilized because of head injury or traction. Many of the patients were intubated. Major pulmonary complications (including atelectasis and pneumonia) were decreased in those receiving CLRT. Ventilator days, need for FIO2 greater than 0.50, and incidence of adult respiratory distress syndrome were not significantly different but tended to be higher in the conventional bed group. There was no difference in length of ICU stay or mortality. Summer and co-workers compared CLRT to conventional beds in 86 patients admitted to a medical ICU. There was no difference in overall ICU mortality, length of stay, ventilator days, or incidence of nosocomial pneumonia between the two groups.
Table 3. Continuous Lateral Rotation Therapy: Clinical Trials in ICU Patients

<table>
<thead>
<tr>
<th>Study</th>
<th>Patients (n, type)</th>
<th>Results</th>
<th>Length of Stay</th>
<th>Mortality</th>
<th>Cost-Effective?</th>
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<tbody>
<tr>
<td>Gentillelo et al</td>
<td>65, head injury</td>
<td>↓* pulmonary complications</td>
<td>No change</td>
<td>No change</td>
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<td>Summer et al</td>
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<td>Shorter ICU stay</td>
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<td>—</td>
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<tr>
<td>Fink et al</td>
<td>106, blunt trauma</td>
<td>↓ pneumonia</td>
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<tr>
<td>deBoisblanc et al</td>
<td>124, MICU</td>
<td>↓ early pneumonia</td>
<td>No change</td>
<td>No change</td>
<td>Yes</td>
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<tr>
<td>Clemmer et al</td>
<td>49, head injury</td>
<td>No benefit</td>
<td>No change</td>
<td>No change</td>
<td>No</td>
</tr>
</tbody>
</table>

*↓ = lower incidence.

They found patients with sepsis and pneumonia receiving CLRT had a 3.5 day shorter ICU stay than those on conventional beds. Patients with chronic obstructive pulmonary disease receiving CLRT had an almost 7 day shorter ICU stay, and 4.5 fewer ventilator days. These investigators believed that CLRT was tolerated best by obtunded patients, particularly if they were intubated. They also suggested that patients who were less ill were most likely to be helped by CLRT because any benefits of turning severely ill patients would have less impact on outcome. Fink et al118 compared management in an oscillating bed versus a conventional bed in 106 blunt trauma victims admitted to a surgical ICU. They showed that continuous postural oscillation decreased the incidence of pneumonia and shortened hospital stay. DeBoisblanc and co-workers119 also compared the effects of an oscillating bed to a conventional bed in 124 critically ill patients in a medical ICU. The incidence of pneumonia during the first 5 ICU days was significantly reduced in patients managed with an oscillating bed. The treatment effect was greatest in patients with sepsis. No difference was found in ventilator days, length of ICU stay, length of hospital stay, or mortality while in hospital. Although CLRT beds are expensive,119 two of the above studies118,119 suggested that CLRT is cost-effective because ICU and hospital stays may be shortened.

Although most studies have shown benefits from CLRT in ICU patients, a prospective, randomized study by Clemmer and associates120 of severely head-injured patients admitted to an ICU failed to show a difference in mortality, length of ICU or hospital stay, or pulmonary improvement between CLRT and conventional beds. Sputum volume was increased in the CLRT group, although it is unclear whether this difference was statistically significant.

Absolute contraindications to CLRT include unstable spinal cord injuries and traction of arm abductors.121 Relative contraindications include marked agitation, severe diarrhea, a rise in intracranial pressure, a greater than 10% fall in blood pressure, and worsening dyspnea, hypoxia, and cardiac arrhythmias.122

**Conclusion:** CLRT appears to offer benefit to comatose or otherwise immobile intubated patients by decreasing the incidence of lower respiratory tract infection and pneumonia. Patients with less severe illnesses are more likely to benefit from CLRT because prevention of pulmonary complications will have a greater impact on outcome. The mechanisms of this benefit have not been clearly determined but may relate to the prevention of pulmonary complications by increasing secretion clearance.

**Airway Pressure and Ventilator Management**

There are several adjustments in airway pressure and mode of mechanical ventilation that theoretically could enhance secretion clearance, but few have been specifically studied. When excessive bronchial secretions are produced, the mucus layer accumulates and sets the stage for two-phase gas-liquid interaction. This phenomenon occurs when gas flow-
ing across a liquid imparts motion to the liquid. This interaction is successful in moving mucus when the surface airflow velocity exceeds 60 cm/s, and large amounts of mucus can be moved when the airflow rate exceeds 2,500 cm/s as occurs with cough.\textsuperscript{12,13} The peak expiratory flow generated is a major determinant of mucus clearance by gas-liquid interaction.\textsuperscript{17} Peak cough expiratory flows reach 6 to 12 L/s in normal subjects.\textsuperscript{12}

Peak expiratory flow rates necessary to generate significant mucus clearance by the above mechanism have been obtained with mechanical exsufflators.\textsuperscript{123-126} These devices create a negative airway pressure quickly to generate a peak expiratory flow that can exceed peak flow rates normally generated during a cough.\textsuperscript{123} Exsufflators were not used extensively and were abandoned altogether in the mid-1960s with the increasing popularity of tracheostomy for ventilatory support with tracheobronchial suctioning.\textsuperscript{126} Recently, Bach\textsuperscript{126} demonstrated a mechanical insufflation-exsufflation device that generated a peak cough expiratory flow in the normal range (mean 7.5 L/s) in 46 neuromuscular ventilator users. Several of these patients received mechanical exsufflation through a tracheostomy tube. This flow rate far exceeded that generated by patient huffing after intentional overinflation and abdominal compression. No significant complications were noted from use of the device over an average of 17 patient-years. The utility of exsufflators has not been examined in critically ill patients.

King et al\textsuperscript{127} found that clearance of tracheal mucus was increased in anesthetized, intubated dogs by high frequency chest-wall compression. They determined that the presence of airflow was required for this beneficial effect because diversion of airflow via a tracheostomy abolished the oscillation-dependent increase in mucus transport. Airflow rates produced by the chest oscillations were sufficient to produce a gas-liquid interaction; therefore, they suggested that this process could explain their results. Mucus probably moved cephalad because peak expiratory flows (generated by active compression) exceeded peak inspiratory flows (due to passive relaxation); and peak rather than average flows may determine the net direction of mucus movement from gas-liquid interaction.\textsuperscript{128}

Positive end-expiratory pressure (PEEP) and certain modes of mechanical ventilation may increase mean airway pressure, reverse atelectasis,\textsuperscript{128} and ablate intrinsic PEEP by opening up flow-limiting airway segments.\textsuperscript{129} Although these maneuvers may increase mucociliary clearance by opening previously obstructed airways, this mechanism has not been studied.

**Conclusion:** Airway and ventilator adjustments that generate peak expiratory flows that exceed peak inspiratory flows could theoretically increase secretion clearance in mechanically ventilated patients. The efficacy of such techniques has not been studied in critically ill patients, although data from studies with mechanical exsufflators suggest such techniques may be useful in intubated ICU patients.

**Summary**

Pulmonary secretions are normally cleared from proximal human airways by mucociliary action and cough. Both of these mechanisms are impaired by the presence of the artificial airways required for mechanical ventilation. Mucociliary transport is further impaired in intubated patients by tracheobronchial suctioning, lack of adequate humidification of inspired air, hyperoxia, and certain drugs commonly administered to patients in the ICU.

Few of the current methods employed to improve pulmonary secretion clearance in intubated patients have been extensively studied. Tracheobronchial suctioning is essential but the optimal technique, frequency of suctioning, and type of catheter have not been determined. Aerosolized B agonists improve mucociliary clearance, but the clinical importance of this therapy is unknown. Chest physiotherapy is clearly effective in intubated patients with acute lobar collapse; however, the routine use of chest physiotherapy in intubated patients has not been shown to be of value and cannot be recommended. Continuous lateral rotation therapy has been shown to decrease the incidence of lower respiratory tract infection and pneumonia in intubated, comatose patients and appears cost-effective, although larger studies will be required to confirm efficacy. Mechanical exsufflator devices may be beneficial but have not been studied in critically ill patients. Much research is needed before optimal techniques and procedures for secretion clearance in ICU patients can emerge.
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SECRESSION MOBILIZATION IN ICU PATIENTS


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Managing the Patient-Ventilator System: System Checks and Circuit Changes

Robert S Campbell RRT

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   B. Description
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IV. IN SUMMARY

INTRODUCTION

Management of the patient on a mechanical ventilator requires a team approach independent of the setting. Respiratory care practitioners (RCPs) are arguably the most valuable and useful member of the management team who cares for patients receiving mechanical ventilation. As our role continues to evolve in today’s healthcare delivery system, we must continually strive to solidify our position at the patient’s bedside and to scrutinize scientifically our routine practices to justify and document the need for the services we provide.

Caring for mechanically ventilated patients is one of the most important services that RCPs provide. This includes the initiation, maintenance, monitoring, and weaning and discontinuation of the mechanical ventilator. Although guidelines and recommendations have been published regarding the management of mechanically ventilated patients,\textsuperscript{1,3} regional and institutional differences persist as to the composition and frequency of ventilator checks and ventilator-circuit changes.

In this paper, I discuss the issues concerning the rationale for and the efficiency and frequency of checking the patient-ventilator system. I also review...
the literature relevant to the rationale for changing the ventilator circuit, the factors affecting the condition of the circuit, and the impact of circuit-change frequency on the incidence of nosocomial pneumonia and hospital costs.

PATIENT-VENTILATOR SYSTEM CHECKS

A patient-ventilator (PV) system check involves the assessment of the patient’s response to mechanical ventilation, the current ventilator settings, the presence and function of necessary equipment at the bedside, and the documentation of the findings in the patient’s chart. The committee, charged by the AARC to develop the clinical practice guideline for mechanical ventilation, introduced the term patient-ventilator system check. I prefer to use this term rather than the simpler and more common “ventilator check” because it implies that the patient is an integral part of the assessment. Emphasis should always be placed on the assessment of the patient on the mechanical ventilator rather than simply checking the function of the ventilator and documenting the settings.

Rationale

Patients who require life-support measures must be assessed frequently to assure their safety and comfort and their continued need for and response to that support. The mechanical ventilator affects the patient’s life on a breath-by-breath basis. Few matters could be considered more important. Yet it would be unrealistic to suppose that we should monitor and document each breath delivered from the ventilator—primarily because today’s mechanical ventilator is reliable, is equipped with comprehensive alarm packages, and, therefore, is able to monitor itself and the patient to some extent. Even with today’s technologic advancements in medicine, adverse events and complications continue to occur, many of which are associated with increased mortality. This risk of adverse events emphasizes the need for properly trained RCPs, not only to set up and intermittently check the ventilator but to be available to respond to any situation that may develop as a result of its use.

The main reason to perform a PV system check is to evaluate the patient’s response to his or her current level of mechanical ventilatory support and to assure that the ventilator is functioning properly. Assurance of ventilator function includes activation of the appropriate alarms, proper conditioning of the inspired gases, and verification that the current settings are in compliance with the most current physician’s order.

Description

To evaluate the patient on a mechanical ventilator, the PV system check must include appropriate clinical observations to indicate the patient’s tolerance. Much information can be attained prior to reaching the patient’s bedside by what Dr. George Burton refers to as “the view from the door” (personal communication, 1985). He points out that some of the most important information can be obtained by simply observing the patient. The patient’s color, respiratory rate and breathing pattern, level of consciousness, chest movement, status of the airway, and work of breathing and synchrony with the ventilator, plus information from the patient monitors (eg, heart rate, blood pressure, pulse oximetry saturation, and temperature) may all be assessed from a distance while viewing the patient in steady state. Once at the bedside, the patient’s lungs should be assessed through what may be the ‘lost’ art of auscultation. Assessment of the patient’s breath sounds can be helpful in detecting air leaks, fluid overload, atelectasis, and bronchospasm and for evaluating endotracheal tube position and airway secretions. In addition to detecting abnormalities, auscultation may be used to assess a patient’s response to therapeutic interventions such as bronchodilator and diuretic administration and suctioning. Patients’ cognitive status can be assessed by attempting to communicate with them. It is important to establish a rapport with the patient—introduce yourself and discuss his surroundings and his condition with him. Offer an explanation of your role in his care and of any procedures that are to be performed.

Clinical observations that reflect the patient’s oxygenation and ventilation status are essential to ensure the adequacy of mechanical ventilatory support. Arterial blood gas (ABG) analysis to determine pH, P$aCO_2$, P$aO_2$, and $S_02$ is considered the gold standard for assessment of ventilation and oxy-
genation and, yet, ABGs are expensive and provide only a 'snapshot' of the patient's status. Pulse oximetry is a popular method for the assessment of adequate oxygenation because it is continuous, noninvasive, relatively inexpensive, and easy to use. Therefore, it has become a standard of care in the operating room and in the postanesthesia care unit and is a de facto standard in the ICU. In critically ill patients, the use of an oximetric pulmonary artery catheter to assess mixed-venous oxygen saturation may be helpful in determining the hemodynamic effects of positive pressure ventilation and maintaining adequate oxygen delivery to the tissues. The use of a transcutaneous oxygen monitor may help to avoid hyperoxemia in mechanically ventilated neonates, but the benefits of this monitoring technique have yet to be shown in adults. Adequacy of ventilation may be monitored and a trend established by capnometry or with a transcutaneous CO2 monitor. Acute changes in the patient's respiratory rate, tidal volume (VT), and minute volume (VE) should prompt the practitioner to make a thorough assessment of the patient's ventilatory status.

Monitoring of the mechanical and spontaneous variables measured during mechanical ventilation assists the RCP in the evaluation of the appropriateness of the ventilator settings and the verification of proper ventilator function. Ventilatory variables that require monitoring include respiratory rate, various airway pressures, VT, and flow (V).

Modern ventilators have intricate timing mechanisms that are usually quite accurate (+5%) but the actual delivered rate should be verified by counting from time to time. When evaluating the ventilator's delivered pressure, volume, and flow, it is essential for RCPs to understand not only where each parameter is measured but also how it is measured. Readers are referred to a review by Tobin of how pressure, volume, and flow are monitored by different mechanical ventilators.

Monitoring Airway Pressure

Peak Inspiratory Pressure. Peak inspiratory pressure (PIP) is the pressure required to inflate the patient's lungs with a given VT at a given V, and is determined by airway resistance and by lung-thorax compliance. Elevations in PIP may result from increased resistance (eg, due to retained pulmonary secretions), decreased compliance, or patient ventilator dysynchrony ("bucking the ventilator"). Elevated PIPs are worrisome and may be associated with an increased risk of pulmonary barotrauma.

Plateau Pressure. Plateau pressure (Pplat) is measured by adding an end-inspiratory hold that is long enough to result in a brief period of zero flow. Measurement of Pplat is necessary to estimate static compliance (Cst) and is thought to be the best estimate of end-inspiratory alveolar pressure. Accurate measurement of Cst requires correction of the VT for the compressible volume of the breathing circuit and the subtraction of PEEP from Pplat. The difference between the PIP and Pplat may distinguish changes in airway resistance from changes in compliance. An increase in PIP without a concurrent increase in Pplat indicates an increase in airway resistance. An increase in both the PIP and the Pplat may indicate reduced lung-thorax compliance.

Baseline Airway Pressure. Monitoring of baseline airway pressure (PEEP and CPAP) is important for assessing the triggering sensitivity of the ventilator demand valve and to assure that the flowrate setting on the ventilator is adequate to meet the patient's demand. In general, pressure should not drop more than 2 cm H2O during a mechanical inspiration or fluctuate more than ±2 cm H2O during an unassisted spontaneous breath.

Mean Airway Pressure. It may be useful to monitor mean airway pressure (Paw) because both beneficial and adverse effects of positive pressure ventilation are related to this variable. Mean airway pressure is affected by peak and baseline airway pressures, inspiratory time, and the mandatory breathing rate set on the ventilator. The mode of ventilation and the inspiratory flow profile may also influence Paw. Because Paw affects both lung volume and cardiac output, it has a direct effect on blood and tissue oxygenation and is thus a variable that warrants monitoring.

Intrinsic Positive End-Expiratory Pressure. It is important to check routinely for the presence of intrinsic positive end-expiratory pressure (PEEP), which is the difference between alveolar pressure and baseline pressure at end-exhalation. PEEP may result from insufficient expiratory time or from dynamic airway closure during exhalation. The pres-
ence of PEEP, may contribute to hemodynamic instability, barotrauma, increased patient work of breathing, and miscalculation of dynamic and static compliance. Methods of measuring PEEP include expiratory port occlusion (expiratory hold technique) and the zero-flow technique. PEEP may be present in as many as 40% of mechanically ventilated patients. Risk factors for the development of PEEP include high minute ventilation (>10 L/min), small endotracheal tubes (<7.0-mm ID), age (>60 years), COPD, and intubation and ventilation primarily for respiratory complications.

The sensing site is an important factor affecting the measurement of airway pressure. Most ventilators measure pressure inside the ventilator. Measurement of pressure on the inspiratory side may cause overestimation due to the resistance of the breathing circuit, humidifier, and endotracheal tube. Measurement of pressure on the expiratory limb is affected by the resistance of the endotracheal tube but may cause underestimation because the sensor is distal to the breathing circuit and humidifying device. Measurement of pressure at the patient connection eliminates the effects of the humidifying device and breathing circuit on the measurement and thus is more desirable.

Measurement of pressure distal to the endotracheal tube is optimal, but this method is uncommon because it is technically difficult to provide accurate and reliable measurements for prolonged periods.

**Monitoring Volume & Flow**

Measurement of volume and flow are interrelated on today’s microprocessor ventilators because they actually measure flow and mathematically integrate the flow signal to display delivered and exhaled volume. Volume monitoring during ventilation with an older-generation mechanical ventilator may require the use of a hand-held spirometer or a bellows device. Accurate measurements of volume and flow are essential for monitoring the respiratory mechanics of mechanically ventilated patients. These variables may also be combined with others to provide information such as weaning ability and tolerance, response to therapeutic interventions, and appropriateness of ventilator settings.

Each monitored variable can be divided into four distinct types: mandatory, spontaneous, inspiratory, and expiratory. The most commonly measured volumes are VT and VE. The mandatory VT is generally set at 10-13 mL/kg during mechanical ventilation. The clinician may use pressure-volume loops to assist in determining the most appropriate VT for each patient. In patients with reduced lung compliance it may be beneficial to reduce the mandatory VT in an attempt to reduce PIP and the potential for barotrauma. Comparison of the inspiratory and expiratory VT may be useful in assessing the presence and magnitude of any leaks around the cuff of the endotracheal tube, in the breathing circuit, or across the chest wall (bronchopleural fistula). Measurement of spontaneous VT is helpful in the assessment of the patient’s respiratory drive, effort, and ability. Spontaneous VT is normally 4-6 mL/kg and may be used as an end point for titration of pressure support ventilation—the level of pressure support necessary to increase spontaneous VT to 10-12 mL/kg (PSVmax). VE is normally about 6 L/min in resting subjects. VE may be used to evaluate the patient’s respiratory drive, respiratory muscle function, and dead-space ventilation, but is probably less reliable as a predictor of weaning outcome. Minute ventilation may be partitioned into the components of frequency (f) and VT to provide a more reliable weaning predictor, the f/VT ratio (f/VT). The f/VT has recently been shown to be superior to conventional predictors of weaning outcome.

Many factors may affect the accuracy of the flow and volume measurement made during mechanical ventilation, and it is imperative that the clinician be familiar with the techniques and limitations of each measurement made by the ventilators used in his institution. The compressible volume of the breathing circuit is the major factor affecting the amount of the set volume that actually reaches the patient’s lungs. During inspiration, the breathing circuit expands and elongates while the gas within the circuit compresses relative to the positive pressure. During exhalation, the gas that was compressed within the circuit exits through the exhalation valve along with the gas from the patient’s lungs. This causes the ventilator monitor to underestimate the VT delivered to the patient’s lungs. Some ventilators attempt to correct for the compressible volume by using an algorithm to increase the delivered VT based on the measured or clinician-selected circuit-compliance value. Other ventilators compensate for this effect.
by measuring V_T between the endotracheal tube and the circuit. The effect of circuit compliance is most important when airway pressures are high and low V_Ts are used.\textsuperscript{13,16}

It is important for clinicians to understand the measurement techniques and the variables measured by mechanical ventilators, but understanding and interpretation of data may be influenced by the way that the ventilator displays the monitored ventilatory data. Ventilators may display information using gauges, digital readout, waveforms/graphics, and trends. Gauges and digital displays are adequate for breath-by-breath display of volume, flow, breathing rate, and airway pressures. The use of wave-forms and graphics may aid the clinician in rapidly assessing the patient-ventilator interaction and the appropriateness of ventilator settings. Waveforms and graphics allow the clinician actually to 'shape' the patient's breaths while making ventilator manipulations. The use of trending information aids in decision making and monitoring patient response to changes made when the clinician is away from the patient's bedside.

In addition to evaluating the patient's response to and appropriateness of mechanical ventilation, the PV system check should include verification that alarm limits have been set properly, that the inspired gas is properly heated and humidified, that the ventilator settings are in compliance with the current physician's order, and that all necessary equipment is present and functioning properly.

Two types of alarms are necessary during mechanical ventilation. First, the ventilator should have alarms to alert the clinician in the event that the ventilator malfunctions or fails. Microprocessor ventilators continuously monitor themselves and warn the clinician if power is lost, gas supply is insufficient, or an electronic/pneumatic malfunction has occurred. Second, the ventilator should have alarms designed to alert the clinician of a change in the patient's clinical status. These alarms may or may not be clinician-selectable or adjustable. The ventilator should at least be able to detect a patient disconnection. This usually is accomplished with a pressure monitor that alerts if a preset pressure is not attained within the circuit during a prescribed time period. In addition to disconnection, the clinician should be alerted to an acute change in the patient's respiratory status. A high respiratory rate and minute volume alarm may indicate respiratory distress, whereas low respiratory rate, tidal volume, and minute ventilation alarms suggest hypoventilation. An alarm for high airway pressure is generally set 10-15 cm H_2O above PIP and may indicate patient-ventilator dysynchrony, retained secretions, or a change in lung compliance. In order to minimize nuisance alarms that may contribute to complacency in the event of a true life-threatening condition, clinicians are warned against 'over alarming' the ventilator.

It is essential to condition the inspired gas delivered to patients with bypassed upper airways. This includes heating, humidifying, and filtering the gas delivered from the ventilator. With each PV system check, the humidification system should be assessed for proper function and operation. When a heated humidifier is in use, the chamber water level and proximal airway temperature should be checked, and any condensation should be removed from the breathing circuit. It is technically very difficult to measure humidity levels continuously within the ventilator circuits, thus the adequacy of delivered humidity is assessed by the amount and consistency of the patient's sputum. When a heat and moisture exchanger, or 'artificial nose,' is in use, it should be inspected for accumulation of secretions on the medium, and signs of increased resistance should be assessed.\textsuperscript{35}

Universal Precautions should be observed during the PV system check.\textsuperscript{36} Condensation from the ventilator circuit should be considered infectious waste and disposed of according to hospital policy.

**Frequency of System Checks**

The frequency of PV system checks depends on many factors including the setting (eg, operating room, ICU, transport, ward, or home), the patient's clinical condition, frequency of ventilator changes, and the equipment being used. The currently accepted guidelines and recommendations call for PV system checks at regularly scheduled intervals.\textsuperscript{1} Patients requiring mechanical ventilation in the operating room or during transport must be continuously monitored by properly trained personnel. Ventilated patients in the ICU are generally more stable than those in the OR and are assessed intermittently, usually every 2 to 4 hours.\textsuperscript{37} In my expe-
perience, ICU ventilators are more sophisticated and reliable than their counterparts used in the operating room, and are more heavily alarmed to eliminate the need for continuous bedside assessment. There are also additional staff responsible and available for the care of the patient in the ICU, enhancing patient safety and care. Patients receiving mechanical ventilation in extended care facilities or in the home are generally stable on their current ventilator settings, and their ventilator care may be assumed by a properly trained family member. These patients should continue to be assessed regularly by healthcare professionals, but the frequency of these assessments may vary from once per day to once per week or less. A trained healthcare provider should be available to any patient on a mechanical ventilator on a continuous on-call basis.

A PV system check should also be performed before obtaining an ABG, hemodynamic data, or bedside pulmonary function test to verify and document the patient’s respiratory status at the time of the measurement. A complete PV system check should be performed following a change in any ventilator setting to assess the patient’s response to that change. Any time the patient experiences an acute change in clinical condition (which may or may not result in activation of a ventilator alarm) or if the function of the ventilator is in doubt, a complete PV system check should be performed.

**Documentation of System Checks**

Documentation of the PV system check provides a record for legal purposes of the function, settings, and response to the mechanical ventilator and communicates the current settings and patient response to other members of the healthcare team. Documentation of the PV system check involves the ventilator flowsheet, the variables to be documented, the frequency of documentation, and the qualifications of the personnel who perform this documentation. The ventilator flowsheet generally varies by institution but minimally should include patient information (ie, name, medical record number, and diagnosis), current ventilator settings (eg, pressures, volumes, and rate), current alarm settings (eg, high-low pressure and volume), and appropriate monitored variables such as spontaneous respiratory rate, \( V_T \), \( S_pO_2 \), \( V_e \), peak inspiratory pressure, \( P_{aw} \), and heart rate. The flowsheet should have space for a brief narrative that describes the patient’s response to the ventilator settings and common bedside interventions like suctioning, repositioning, and efforts to wean the patient. Everything that takes place during the RCP’s interaction with the patient, the ventilator system, or monitors for any purpose should be documented on the flowsheet. I believe it is imperative that each respiratory care practitioner do a complete PV system check that includes full documentation of every setting on the mechanical ventilator and all monitored variables and observations (breath sounds, tube size and position, and sputum characteristics) at the beginning of the shift. From this initial assessment through the ensuing hours, only the settings that have been changed or manipulated and all of the appropriate monitored variables should be documented on the flowsheet. This serves to emphasize assessment of the patient’s response to the ventilator rather than the setup and maintenance of the equipment. The frequency of PV system checks should be determined by the severity and instability of the patient’s condition similar to the algorithm by which nurses determine the monitoring frequency of the patient’s vital signs. Patients in the ICU who are unstable or actively weaning may require very frequent (q 15-30 min) if not constant surveillance by a respiratory care practitioner. More stable patients will require less frequent assessment and intervention that may approach checking every 4 hours. The PV system check should only be performed by credentialed (eg, MD, RRT, CRTT, RN) individuals who have been properly trained to use each particular ventilator and who have knowledge of the pathophysiology of the respiratory system and patient-ventilator interaction.

**VENTILATOR CIRCUIT CHANGES**

An essential part of caring for a patient on a mechanical ventilator is maintaining the system—ventilator and the ancillary equipment—necessary to provide uninterrupted ventilatory support. The components of this system are the humidifying device, breathing circuit, suctioning apparatus, manual resuscitator, and monitors. The decision as to the type of equipment to use is institution-based and often application-specific. One of the factors to be considered in this decision is the maintenance that the var-
ious components of this system require. The breathing circuit is obviously an essential component of the patient-ventilator system. The type of breathing circuit used and the maintenance of the circuit is based largely on manufacturer recommendations, personnel beliefs, and/or fear, habit, regional/institutional practice, history, and, to a lesser degree, rational scientifically proven reasoning. The type of breathing circuit used and the policies that dictate circuit-change frequency should be based on rationale that has been scientifically developed and scrutinized for effectiveness and cost.

Several decisions must be made by the respiratory care department manager regarding breathing circuit types. The first decision is whether to use disposable or reusable circuits. Other options in ventilator circuits depend on both the type of ventilator and the humidification technique used. The humidification systems in common use are the heated bath humidifier (wick-type, bubbler, passover), heated wire systems, and heat and moisture exchangers (artificial noses).

Rationale for Circuit Changes

The reasons for changing the ventilator circuit are to protect the patient, to protect the caregiver, to preserve or improve the function of the mechanical ventilator, or because the circuit is soiled or ineffective. In this discussion, I concentrate on the protection of patients and caregivers because it should be obvious that damaged or dirty circuits should be changed.

Much of the rationale supporting the routine changing of breathing circuits has been carried over from the days when only reusable circuits were available, nebulizers were commonly used for humidification of inspired gas, and cleaning and sterilization procedures were suspect. The humidifiers and reservoir nebulizers that were used in the 1960s and early 70s were known to create aerosols that could transmit bacteria from contaminated reservoirs or condensate to the lower respiratory tract. These early studies proved that frequent changing and disinfection of the respiratory care equipment could reduce the risk of patient contamination and provided the basis for the recommendation that breathing circuits and humidifiers be changed every 24 hours. Today, most respiratory care department policies regarding ventilator circuit changes result from the synthesis of outdated regulations, sparse available research, circuit manufacturers’ recommendations, and habit, and often represent regional or community practice and/or the personal bias of respiratory care department managers. The available literature that suggests and supports ventilator-circuit changes every 24 or 48 hours was published more than a decade ago. More recent research has suggested that the frequency of ventilator circuit changes has little impact on the incidence of nosocomial pneumonia and may actually increase the risk of infection.

There are three routes by which bacteria may be transmitted to the lower respiratory tract: (1) aspiration of contaminated oropharyngeal secretions, (2) inhalation of contaminated aerosols, or (3) blood-borne pathogens from a distant site of infection. Aspiration of oropharyngeal secretions is the most common cause of bacterial pneumonia whether hospital or community acquired. Factors that may affect the transmission of bacteria from the stomach to the lung include the presence of a nasogastric tube, use of medications that block or neutralize gastric acids, and patient position. Elevating the head of the patient’s bed may prevent reflux and aspiration of gastric contents.

It was originally thought that contamination of the condensation within the ventilator circuit was a major cause of nosocomial pneumonia. Manufacturers developed heated-wire circuits in an attempt to minimize condensation, and many hospitals were quick to lengthen circuit change intervals due to the perceived reduction in patient risk. The use of artificial noses has become a popular humidification method to some extent because it eliminates condensation from the ventilator circuit. It was originally thought that the addition of filter media to the artificial nose was important to guard against bacterial migration into the breathing circuit. In a recently published study by Branson et al. no positive cultures were obtained from the proximal breathing circuit while using an artificial nose without a filter. Because this device traps heat and moisture from the patient’s exhaled gas, the resultant cold and dry breathing circuit creates an environment that is hostile to bacterial survival. More recent studies investigating the role of circuit condensation on the incidence of nosocomial pneumo-
nia have concluded that circuit change interval does not appear to affect rates of nosocomial pneumonia independent of the breathing circuit or humidification technique used. This is not surprising when the results of Craven and co-workers’ study of contamination of condensation is considered. They report that a ventilator circuit becomes contaminated quickly (within 8 hours), that the contaminating bacteria most often originates from the patient’s own secretions, and that high levels of bacteria are present in the proximal circuit. It can be assumed that if the proximal circuit is contaminated by the patient’s secretions that the endotracheal tube is also contaminated. Therefore, it is not intuitively sensible to connect a new ventilator circuit to a contaminated device.

The humidifying technique may influence the incidence of contamination in the breathing circuit. It has been suggested that heated humidifiers attain chamber temperatures that actually kill bacteria. This would eliminate the need to routinely change the humidifier chamber even if aerosol generation by the humidification device was suspected.

**Frequency and Cost of Circuit Changes**

Based on the available research, it would appear unwise and costly in terms of money, time, and materials to change the ventilator circuit routinely. Although few of the published studies extend the circuit-change interval beyond 7 days, the fact that in many cases the incidence of pneumonia and circuit colonization was increased with more frequent changing of the circuit supports the use of each ventilator circuit as a "single patient use" item that is changed only when it malfunctions or is dirty. With the exception of circuits that include artificial noses as the humidification method, there will be some condensation in the ventilator circuit. I believe it is sensible to apply our resources (time and money) in ventilator-circuit maintenance (removing condensate) rather than replacing it.

The choice of circuit type and the circuit-change policy influence the cost of mechanical ventilation and vary with the individual patient’s needs. For example, the cost of each type of ventilator circuit varies based on length of use. Initial costs for the three common circuit types based on circuit-change frequency are shown in Table 1. Respiratory care department managers are encouraged to develop circuit-use and changing policies and protocols that reflect the needs of the patients and staff that are based on sound judgment and monitored for safety and cost considerations.

**IN SUMMARY**

Checking and maintaining mechanical ventilators traditionally have been the responsibility of the respiratory care practitioner and among the many reasons that the need for the profession of respiratory care persists. The increasing complexity of the mechanical ventilator itself and the appropriate application and monitoring of the various modes available in a single device are such reasons. In addition, we must continually strive to be knowledgeable and skilled in the assessment and appropriate treatment of patients with respiratory diseases.

The practice of respiratory care focuses on patient care, education and research. The perception of an institution’s need for trained respiratory care specialists is affected by both the quality and quantity of service that each individual RCP offers to the care of patients. Our skills and performance should be patient-centered not device-centered so that our assessment and monitoring of patients includes more than just "writing down the numbers." Finally, respiratory care research must continue to subject the old dogma to rigorous scrutiny while searching

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**Table 1. Circuit Component Costs for 1, 8, and 30 Days of Mechanical Ventilation When Circuits Are Replaced Every 48 Hours, Weekly, or Not at All**

<table>
<thead>
<tr>
<th>Component</th>
<th>-48 Hours</th>
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<tbody>
<tr>
<td>Heated-wire circuit</td>
<td></td>
<td>1 Day</td>
<td>8 Days</td>
</tr>
<tr>
<td></td>
<td>22.50</td>
<td>96.00</td>
<td>360.00</td>
</tr>
<tr>
<td>Heated humidifier</td>
<td>18.50</td>
<td>84.00</td>
<td>315.00</td>
</tr>
<tr>
<td>Heat &amp; moisture exchanger</td>
<td>5.00</td>
<td>32.00</td>
<td>135.00</td>
</tr>
</tbody>
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for new and innovative ways to care for our patients.

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What Makes the Sky Blue?

Charles E. Wilson, a former president of General Motors, President Eisenhower’s Secretary of Defense from 1953 to 1957, and a determined opponent of basic research, will long be remembered by scientists for his classic phrase, “I don’t care what makes the grass green.” Wilson might as well have said, “I don’t care what makes the sky blue.” John Tyndall, the British physicist, did care what made the sky blue and this look into the Retrospectroscope shows how blue sky, of all things, paid off for biomedical research.

Born in 1820, Tyndall became professor of natural philosophy in the Royal Institution in 1853; in 1867, when Michael Faraday died, Tyndall succeeded him as Superintendent of the Institution. Tyndall made notable scientific contributions to the fields of diamagnetism, light, sound, and radiant heat. In addition, he was a gifted lecturer and writer and probably did more than any person of his time to make the great scientific discoveries of the nineteenth century intelligible and even fascinating to the general public. This special talent brought him an invitation to lecture in America in 1872-73; his book, Six Lectures on Light, that grew out of these went through 5 editions by 1895 and earned for Tyndall £6,000-7,000 (quite a sum in those days), all of which he used as a fund to encourage original research in the United States.

But back to blue sky. The idea that the color of the sky is due to the action of finely divided matter that creates a turbid atmosphere, through which we on earth look toward the darkness of space, dates back to Leonardo da Vinci. Newton, Goethe, Clausius, Stokes, and others also studied this phenomenon. But the cause of the blue color of the sky was, in the 1860s, still one of the enigmas of meteorology. Tyndall in 1869 conducted experiments with a glass tube about 36 inches long and 3 inches in diameter into which he introduced vapors. When he illuminated them with a strong condensed beam from an electric lamp, they “decomposed” and he now had a tube filled with fine particles. Sometimes these were so fine that their “diameters constitute but a very small fraction of the length of a wave of violet light.” When he plunged the room into darkness and focused his powerful beam of light on the tube, a sky-blue cloud now filled the tube.

With this dramatic, easily repeatable evidence in hand, he could now extrapolate from the glass tube in his laboratory to the blue sky and say:

Suppose our atmosphere surrounded by an envelope impervious to light, but with an aperture on the sunward side through which a parallel beam of solar light could enter and traverse the atmosphere. Surrounded on all sides by air not directly illuminated, the track of such a beam through the air would resemble that of the parallel beam of the electric lamp through an incipient cloud. The sunbeam would be blue, and it would discharge laterally light in precisely the same condition as that discharged by the incipient cloud. In fact the azure revealed by such a beam would be to all intents and purposes that which I have called a “blue cloud.”

As one would expect of the Superintendent of the Royal Institution, Tyndall performed controls using particle-free air and made the fascinating observation that air containing only pure gases and no particles acted like a vacuum, in that in a dark room it remained pitch black when “illuminated” by a powerful electric beam. It immediately became obvious to Tyndall that we perceive light only when light waves strike particles in their path (as when the beam from a powerful projector becomes visible in a dark theatre only because it hits its myriads of dancing particles of dust).

Tyndall soon put his discovery to work. Louis Pasteur in 1862 had announced a revolutionary new concept. Pasteur insisted that there was no such thing as spontaneous generation; germs (no matter how small) came from other germs. His experimental proof convinced many scientists, but the new doctrine shattered beliefs that were centuries old and aroused much vigorous opposition. Some of Pasteur’s opponents insisted that bacteria did in fact generate spontaneously because bacteria appeared where the most powerful microscopes could not detect a pre-existing generation. Tyndall came to Pasteur’s aid with a test for optically pure, uncontaminated air—a certain to be free of both inorganic dust and organic germs because it could not scatter light.3

Numerous experiments showed optically pure air to be incapable of developing bacterial life. In properly protected vessels, previously boiled infusions of fish, flesh, and vegetable, freely exposed to air that had been proved to be optically pure by the invisible passage of a powerful electric beam, remained permanently pure and unaltered, whereas the identical liquids, exposed afterwards to ordinary dust-laden air, soon swarmed with bacteria. Tyndall wrote:

"Why is the sky blue?" thus paid off handsomely for the new science of bacteriology.

"Why is the sky blue?" also paid off for pulmonary medicine. Lord Lister had pointed out that air that had passed through the lungs had lost its power of causing putrefaction, and, as a strong proponent of the germ theory of disease, he attributed the purification of air to the filtering action of the lungs. Tyndall provided experimental proof by showing that air from the upper airways scattered light but air from the deepest parts of the lung did not. He darkened a room containing dusty air and focused a powerful beam of light on the end of a glass tube through which the subject breathed (Figure 1). When the subject inspired the dusty room air, the inhaled particles scattered the intense beam of light as the air entered the glass tube en route to the airways and alveoli. When the subject expired, Tyndall observed at first a diminution in scattered light. But toward end-expiration, a perfectly black gap broke the white track of the light beam owing to the total absence from the end-expired air of any matter that could scatter light (the glass tube had been warmed to prevent condensation of water vapor). This was the first experimental demonstration of the defense mechanisms of the airways—of the ability of the airways (by mechanisms then unknown) to remove particles from inspired air before they reached alveolar gas. I believe it was also the first "single-breath test" used to demonstrate or evaluate a function of the lung. Light-scattering methods have, since Tyndall, played an important role in quantifying particles responsible for air pollution and for estimating the clearance of various-sized particles by pulmonary defense mechanisms.

Tyndall then became interested in one particular type of the particles known to float in air—atmospheric germs:

I wished . . . to obtain clearer and more definite insight as to the diffusion of atmospheric germs. Supposing a large tray to be filled with a suitable organic infusion and exposed to air, into it the germs would drop and, could the resulting organisms be confined to the locality where the germs fell, we should have the floating life of the atmosphere mapped, so to speak, in the infusion.
In 1877, he set up trays with 10 rows of 10 tubes in each and soon had his catch—both bacteria and molds. One of the molds was Penicillium. Tyndall appears to have accomplished by experiment in 1877 what Fleming happened upon in 1929, and Tyndall was probably the first to comment on antagonism between molds and bacteria. He wrote:

The Penicillium was exquisitely beautiful. In every case where the mould was thick and coherent, the Bacteria died, or became dormant, and fell to the bottom as a sediment. The growth of mould and its effect on the Bacteria are very capricious. Of two tubes placed beside each other, one will be taken possession of by Bacteria, which successfully fight the mould and keep the surface perfectly clean; while another will allow the mould a footing, the apparent destruction of the Bacteria being the consequence.

Score another for "Why is the sky blue?"

Tyndall made still another contribution to pulmonary medicine. Quite unknowingly, he was the father of the flexible bronchoscope and other techniques (such as intravascular spectrophotometry) that require a curved path of light. In 1854, he constructed a small box with one glass side and a glass tube (3/4" wide and 5" long) fitted into the opposite side. He then arranged to condense electric light so that it passed first through the pane of glass, then through the air-filled box and out the glass tube at the opposite side; the light formed a white disc on a screen held against the end of the tube. The top of the box was connected to a water tank on the roof; when Tyndall turned a tap, water filled the box and spouted out the glass tube in a downward curve. Now the path of the light beam was no longer straight but followed the curve. Tyndall noted that where the water flowed out of the glass tube, "the light on reaching the limiting surface of air and water was totally reflected and seemed to be washed downward by the descending liquid, the latter being thereby caused to present a beautiful illuminated surface."

This was a singular demonstration, under special circumstances, that light could follow a curved path. At first the path was a curved "water tube," then a glass thread, and, more recently, flexible glass fibers. Tyndall's 1854 demonstration was not put to medical use until 37 years after his death when, in 1939, Lamm advocated using glass fibers in a flexible gastroscope; the flexible bronchoscope of Ikeda came into use in 1968.

Out of a blue sky came (1) the final blow to the theory of spontaneous generation, (2) proof of the defense mechanisms of the airways against inhaled particles, (3) quantitative tests of air pollution and of clearance of particles from inspired air, and (4) the first observations of the antibacterial action of Penicillium. And the "blue-sky man" also provided the theoretic basis for the flexible bronchoscope.

Now Mr. Wilson, wouldn't you really like to know what makes the grass green?

JULIUS H. COMROE, JR.

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Hemoptysis and Dyspnea in a Young Woman

Paul Lange MD, Kevin McCarthy RCPT, James K Stoller MD, and Daniel Laskowski RPFT

A 36-year-old, nonsmoking and otherwise healthy Caucasian woman presented following two episodes of hemoptysis and dyspnea. She denied orthopnea, paroxysmal nocturnal dyspnea, palpitations, or dizziness. She had no lower extremity edema and no angina. Her physical examination disclosed a widely fixed splitting of S2 heart sounds with a normal P2 component and a grade II systolic murmur at the left lower sternal edge radiating to the left upper sternal edge. The remainder of the physical examination was normal. Chest radiographs were taken (Figs. 1 A & B).

How would you answer these questions?

What radiographic abnormality is apparent in Figure 1?

What should be included in the differential diagnosis?

What further diagnostic or therapeutic procedures are indicated?

Answers and Discussion on Page 244

Dr Lange is a Fellow, Mr McCarthy is Chief Technologist, Pulmonary Function Laboratory, Dr Stoller is Head, Section of Respiratory Therapy, and Mr Laskowski is Pulmonary Function Technologist—Department of Pulmonary and Critical Care Medicine, Cleveland Clinic Foundation, Cleveland, Ohio.

A paper based on the case reported here has been previously published (Gossman DE, Moodie DS, Gill CC, Sterba R, Cleve Clin J Med 1987;54:510-512). However, the focus of the paper was completely different.

Reprints: Dr Paul Lange/Mr Daniel Laskowski, Department of Pulmonary Disease and Critical Care Medicine, Desk A-90, Cleveland Clinic Foundation, One Clinic Center, Cleveland OH 44195.
Fig. 1. Anteroposterior (A) and lateral (B) chest radiographs of a 36-year-old woman complaining of two episodes of hemoptysis and dyspnea.
Answers

Radiographic Abnormality: Figure 1 shows a crescent-shaped shadow running parallel to the right heart border and into the right lower lung. An azygous fissure is also present as an incidental finding.

Differential Diagnosis: The differential diagnosis includes partial or total anomalous venous return (scimitar malformation), meandering pulmonary vein, dextrocardia, hypoplastic lung, and Swyer-James syndrome (unilateral hyperlucent lung).

Additional Diagnostic Procedures: Because of the likelihood of associated cardiac and pulmonary defects affecting function, further testing should include spirometry, electrocardiography, echocardiography, and cardiac catheterization. Bronchoscopy is indicated to find the source of the hemoptysis.

Test Results: Spirometry was normal with a FVC of 2.79 L (89% of predicted), an FEV\textsubscript{1} of 2.34 L (84% of predicted), an FEV\textsubscript{1}/FVC of 84%, and FEF\textsubscript{25-75} of 3.3 L/s. The electrocardiogram was normal and showed no evidence of right ventricular hypertrophy. Bronchoscopy revealed no obvious etiology for the hemoptysis, and the bronchial segmentation pattern was unremarkable. The echocardiogram was normal.

Catheterization of the right heart demonstrated an oxygenation step-up, with saturation rising from 72 to 84% from the low inferior vena cava (IVC) to the junction of the IVC and the right atrium. There was no further step-up within the right atrial or ventricular chambers. Measured hemodynamic variables are shown in Table 1. There was no atrial septal defect or ventricular septal defect. A resting digital-subtraction angiogram demonstrated a large anomalous pulmonary venous drainage from the right-middle and right-lower lobes to the IVC below the level of the diaphragm. The pulmonary arteries were not hypoplastic.

In summary, this patient demonstrated partial anomalous pulmonary venous return to the right lung to the IVC below the diaphragm (scimitar syndrome). Other frequently associated abnormalities were not present. She underwent ligation of the anomalous pulmonary vein to the IVC, and a conduit was sewn between the anomalous vein and the left atrium. A large common vein, which passed through the diaphragm and into the IVC, was found to drain the lower portion of the right lung.

Table 1. Hemodynamic Variables and Systemic Vascular Resistance Recorded during Right-Heart Catheterization

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<thead>
<tr>
<th>Variable</th>
<th>Measured Value</th>
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<tr>
<td>Right atrial pressure</td>
<td>6 mm Hg</td>
<td>2-8</td>
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<tr>
<td>Right ventricular pressure (systolic)</td>
<td>24 mm Hg</td>
<td>15-30</td>
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<tr>
<td>Pulmonary artery pressure</td>
<td>24/11 mm Hg</td>
<td>16-24/5-12</td>
</tr>
<tr>
<td>Pulmonary artery occlusion pressure</td>
<td>10 mm Hg</td>
<td>6-12</td>
</tr>
<tr>
<td>Cardiac index</td>
<td>4.4 L · min\textsuperscript{-1} · m\textsuperscript{2}</td>
<td>2.5-4.0</td>
</tr>
<tr>
<td>Pulmonary vascular resistance</td>
<td>45 dynes · s · cm\textsuperscript{-5}</td>
<td>20-130</td>
</tr>
<tr>
<td>Q\textsubscript{p}/Q\textsubscript{s} (pulmonary-to-systemic cardiac output ratio)</td>
<td>1.5:1</td>
<td>1.0:1.0</td>
</tr>
<tr>
<td>Systemic vascular resistance</td>
<td>1120 dynes · s · cm\textsuperscript{-5}</td>
<td>700-1600</td>
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Discussion

The Scimitar Malformation

The scimitar malformation is a rare congenital anomaly characterized by partial or total anomalous pulmonary venous return of the right lung veins to the IVC just above or below the diaphragm.\textsuperscript{2} The malformation is part of a syndrome consisting of (1) anomalous pulmonary venous connection and drainage of part or all of the right lung into the IVC, (2) hypoplasia of the right lung, (3) hypoplasia of the right pulmonary artery, (4) dextroversion of the heart (displacement of the heart to the right side of the chest), and (5) anomalous subdiaphragmatic systemic arterial supply to the right lung from the aorta or its branches. Synonyms for the condition include hypogenetic lung syndrome, pulmonary venolobar syndrome, mirror-image lung syndrome, epibranchial right pulmonary artery syndrome, vena cava bronchovascular syndrome, and dysomorphic right lung. Neill et al\textsuperscript{3} coined the term “scimitar syndrome,” based on the characteristic shape of the large anomalous vein that resembles a scimitar, a Turkish curved sword (Fig. 2).
Background

This rare malformation was first described independently by Cooper and Chassinat in 1836. Although the true prevalence is unknown, estimates suggest a frequency of 1 to 3 per 100,000 live births. Many cases are probably overlooked because most patients are asymptomatic, and many physicians are unfamiliar with the syndrome. Diagnosis is made most commonly in the third decade of life. There is a slight female predominance (1.4:1.0), and familial occurrences have been reported. Three forms of the syndrome have been described: (1) an adult form without pulmonary hypertension, (2) an infantile form with severe pulmonary hypertension, and (3) scimitar abnormality associated with other complex cardiac malformations. The pathogenesis of the scimitar syndrome is unknown, but it likely represents a basic developmental derangement of the entire lung bud early in embryogenesis.

Although the syndrome is variable, the defining feature is a single anomalous venous channel that drains the entire right lung resulting in a left-to-right shunt. Most cases involve anomalous venous drainage on the right, although left-side anomalous drainage has been described in two instances. Hypoplasia of lung elements is also a frequent but variable feature. For example, hypoplasia of the right pulmonary artery occurs in 60% of cases, and arterial supply to the right lung may arise from the pulmonary arteries, bronchial arteries, or from vessels originating from the thoracic aorta or from systemic arteries on or below the diaphragm. Hypoplasia of the right lung often causes rightward displacement of mediastinal structures obscuring the anomalous right pulmonary vein. Hypoplastic airway changes may include hyposegmentation of the bronchial tree and diverticular or cystic changes of the bronchi (21% of cases in a series by Kiely et al). The pulmonary vein may insert into the IVC either above or below the diaphragm.

Fig. 2. Anteroposterior chest radiograph with a superimposed image of a scimitar overlying the congenital anomalous venous return from the right lung veins to the inferior vena cava, which has been named for its resemblance to the scimitar shape.
Clinical Manifestations

Clinical manifestations are usually subtle in this syndrome, although the spectrum of clinical presentation ranges from severely ill infants to asymptomatic adults. When symptoms do occur they include recurrent respiratory infections including pneumonia, dyspnea on exertion, palpitations, cough, wheezing, and hemoptysis. Mardini et al. observed recurrent respiratory infections in 25% of patients. Extracardiac malformations are common and include vertebral malformations, scoliosis, thoracic deformations, and rib malformations.

Physical signs are often inconspicuous. Results of physical examination were normal in 64/122 patients in the series by Dupuis et al. Kiely et al. found displacement of the heart to the right to be the most common finding; a systolic murmur with fixed splitting of the second heart sound was observed in 20% of patients.

The electrocardiogram is usually normal. If abnormalities are present, they include right axis deviation with right ventricular hypertrophy, and incomplete right bundle branch block.

Chest radiography reveals the scimitar vein in 50-100% of cases depending upon the series. Dupuis et al. observed that the scimitar vein was present in 70% of cases. The anomalous vein characteristically shows a vertical course along the right heart border toward the right cardiophrenic angle, although it may be easily overlooked, as was noted in 45/85 cases (51%) in one series. Displacement of the heart to the right or an enlarged left atrium may obscure the scimitar sign. Although the presence of a scimitar vein is highly suggestive, the definitive diagnosis requires more sophisticated imaging than the plain radiograph alone. Specifically, many false-positive scimitar signs (ie, pseudoscimitars) have been reported on plain chest radiographs. A patient's radiograph may have the characteristic appearance of a scimitar vein, when only trivial drainage into the IVC is present or the vein drains exclusively into the left atrium. Other radiographic findings include dextrocardia, hypoplasia of the right lung, and hypervascularity of the left lung.

Portions of the right lung, especially the right upper lobe, may drain normally into the left atrium. This occurred in 8/28 cases reported by Kiely et al. These cases represent variants of the syndrome. Finally, "horse shoe lung," in which the isthmus of the pulmonary parenchyma extends from the right lung base across the midline, has also been associated with the scimitar syndrome.

Diaphragmatic anomalies were associated with the scimitar syndrome in 21% of cases in Kiely’s series. Abnormalities included elevated right hemidiaphragm due to volume loss, persistence of the foramen of Bochdalek, and diaphragmatic herniation of the liver.

The prevalence of associated congenital heart defects is 24% among all ages, 36% within the pediatric age group, and 75% among those diagnosed as neonates. Atrial septal defect of the secundum type, patent ductus arteriosus, coarctation of the aorta, tetralogy of Fallot, and ventricular septal defects are the most commonly associated malformations.

Fig. 3. Diagram depicting features of scimitar syndrome, including hypoplastic right lung with the pulmonary veins of the lower lobe draining into the inferior vena cava (IVC). The vessel can join the IVC at its junction with the right atrium or descend to join the infradiaphragmatic portion of the IVC. (Reprinted from Reference 12, with permission.)
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**Diagnosis & Evaluation**

All patients should undergo a cardiac catheterization and angiography to demonstrate the pulmonary venous drainage of each lung and to determine and quantify the degree of left-to-right shunt. Right heart catheterization is helpful in detecting congenital cardiovascular abnormalities, measuring oxygen saturation step-up between the superior vena cava and pulmonary artery and for determining pulmonary and systemic pressures. Elevated pulmonary artery pressures were documented in 28/122 (23%) by Dupuis et al.² The size of the left-to-right shunt usually is less than 50%, although larger shunts are observed in patients with atrial septal defects. Angiography defines the vascularity of the right lung, the degree of hypoplasia of the right pulmonary artery, and the degree of anomalous pulmonary venous drainage (complete or incomplete). In the Dupuis et al² series, venous return was complete in 99/122 (81%) and incomplete in 29/122 (24%).²

Aortography is essential to demonstrate the aberrant arterial supply arising from the abdominal aorta, thoracic aorta, or even the right subclavian artery.²

Although bronchoscopy is usually normal¹⁵ and may be unnecessary, bronchiectasis was observed in 3/122 (2%) cases.² Other bronchoscopic findings may include hypoplasia and anomalies of the segmentation of the right bronchial tree. Bronchoscopy can detect anomalies of segmentation and hypoplasia of the right bronchial tree as well, but, in our experience, bronchoscopy is not routinely performed.

Echocardiography can delineate the point of insertion of the pulmonary vein into the IVC and can detect associated anomalies.²⁶²⁷ Computerized tomography (CT) noninvasively delineates the anomalous venous drainage with greater precision and may show bronchiectasis (if present) when fine cut scans are performed.²⁸–³¹ Other modalities—including digital subtraction angiography (DSA),¹³² abdominal ultrasound,³³,³⁴ and MRT³⁵—have been useful occasionally.

**Treatment & Prognosis**

No clear consensus on treatment has been reached. In the past, surgery has been recommended for suppression of shunt or when the finding is associated with congenital heart disease.³⁶ However, Dupuis et al² compared prognosis in 122 patients with adult scimitar abnormality and observed that the nonsurgical group had fewer complications and fewer deaths. Lung resection has been proposed for patients with recurrent infections, hemoptysis, clotted interatrial shunts, or marked hypoplastic right lung.¹⁰¹³ Embolization of the systemic arterial supply to the right lung has also been performed, but too few data are available to establish its role.³⁵

In general, the prognosis is good as witnessed by the fact that patients are usually asymptomatic and live normal lives. Patients with severe pulmonary parenchymal hypoplasia with recurrent pulmonary infections and those with associated cardiac malformations tend to have a poorer prognosis.

**REFERENCES**


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The title, Critical Care, is general and implies that all the information required for one to function in the critical care setting is presented therein—Drs. Civetta, Taylor, and Kirby, experts in the field of critical care medicine, have done just that—and brilliantly. (Dr. Civetta is Professor of Surgery, Anesthesiology, Medicine, and Pathology and Director of Surgical Intensive Care at the University of Miami School of Medicine, Miami, Florida. Dr. Taylor is Director of the Critical Care Training Program at St. John's Mercy Medical Center, St. Louis, Missouri. Dr. Kirby is Professor of Anesthesiology at the University of Florida College of Medicine, Gainesville, Florida.) Complementing their expertise are 131 contributors who are physicians, respiratory therapists, nurses, pharmacologists, physician assistants, medical technologists, and research assistants.

As the editors explained in the preface to the first edition, "The book was organized in structure and content for the reader's first experience in the intensive care unit, perhaps at the beginning of a clinical rotation or fellowship." Their mission remains unchanged. The second edition contains 40 chapters that are either new or revised by new authors and 22 rewritten chapters. The rest of the chapters have been updated.

Critical Care is divided into 4 parts: Part I: General Principles, Part II: Systemic Problems, Part III: Disorders of the Organ Systems, and Part IV: Selected Topics. The opening chapters deal with the ICU environment and ICU personnel—physicians, nurses, patients, allied health personnel. These first chapters give perspectives for care and identifies the many factors influencing medical care in the ICU. These first chapters are valuable reading for everyone—with or without ICU experience. The middle portion of the book deals with diagnostic measures and therapeutic procedures. The last portion of the book deals with societal concerns, including medical care for society in general.

The editors suggest that this book is useful in two types of situations: (1) when a new or unfamiliar condition presents itself with urgency and (2) when the condition becomes stable and there is time to read in greater depth and detail. The chapters for the most part are written in this format. The most relevant and immediate concerns are presented first, followed by more detailed information. This format makes reading easy and enjoyable, whetting one's interest for more on the subject. With so many contributors, one would think that the writing style would change from chapter to chapter. Not so with Critical Care. Credit the editors for maintaining consistency throughout the book.

Of particular interest to respiratory therapists is Part III: Disorders of the Organ Systems, which is divided into 9 sections—2 of particular interest to respiratory therapists. Section I, cardiovascular concerns, presents common cardiovascular topics such as physiology, acute myocardial infarction, cardiogenic shock, heart failure, valvular heart disease, cardiac dysrhythmias, infective endocarditis, the pericardium, and hypertensive emergencies and urgencies.

Section 2, respiratory concerns, teaches the essentials of pulmonary physiology, ARDS, pneumonia, aspiration syndromes, drowning and near-drowning, acute deep venous thrombosis, pulmonary embolism, other embolic syndromes, acute respiratory failure in COPD, life-threatening bronchospasm in the asthmatic, inhalation injury, hemoptysis, and pleural effusions. The last few chapters in this section discuss procedural and technical topics such as fiberoptic bronchoscopy, oxygen therapy, airway pressure support, mechanical ventilation, airway management, and pulmonary barotrauma.

Like other chapters in the book, each of the chapters in Sections 1 and 2 begins with essential information and concerns related to the subject matter. For the most part, each chapter opens with a section entitled, "Immediate Concerns." The chapter then quickly unfolds more specific and clinically important material under heads such as "Clinical Management," "Diagnosis," "Management," "Special Considerations," and "Prognosis." In the chapters dealing with technical information, equipment and procedures are discussed in light of the diseases presented in that particular section.

In general, each chapter is concise, well referenced, easy to read, and provides the most critically important information with regard to the topic presented. However, I was somewhat disappointed in the Mechanical Ventilation chapter. I believe that some of the subtopics under "Microprocessor-Controlled Ventilators" (Data Manipulation & Logic and Digital & Analog Signals) are too lengthy. A brief presentation of this information is enough—3 pages is too much. I believe that this chapter could be improved with the use of case studies of ventilator patients in order to bridge the gap between theory and clinical practice.

Throughout this book, the text is complemented with tables, graphs, drawings, scanning photomicrogra-

This is an outstanding textbook for any healthcare professional interested in the pulmonary healthcare of the elderly, the segment of our population that is rapidly growing and utilizing a large portion of our healthcare dollar. Expanding our knowledge of how geriatric patients may present and how they respond differently should improve our ability to prevent some diseases and effectively treat others.

The 14 chapters discuss topics that are pertinent and clinically oriented toward the elderly. If additional information is desired by the reader, the reference list at the end of each chapter serves as a good resource and also support the statements of the author. The text begins with an interesting update on the aging lung. Included is a discussion of the physiologic and anatomic changes of the aging lung and the influence of these on pulmonary function tests. Two chapters are “Sleep-Disordered Breathing and Aging” and “Nutrition in the Elderly.” Certainly, as the human subject ages, changes in sleep and nutrition greatly influence the overall ability to function. These chapters give insight into what and how this occurs.

The chapter entitled “Noninvasive Monitoring of Respiration” reviews methods of obtaining valuable data that can be used to identify and avoid disastrous events. The use of reliable, simple, cost-effective tools allows providers to intervene quickly and provide appropriate therapy. I found the chapters covering dyspnea and wheeze and cough to be as good as those in any pulmonary text. In each of these well-written chapters, a discussion of the mechanisms involved with dyspnea, wheeze, and cough is followed appropriately by the assessment/evaluation, and lastly by helpful discussion of treatments. The chapter on smoking cessation is interesting and adds information on how professionals can approach this health problem in the elderly population. For the long-time smoker, the recognition of certain factors can assist healthcare providers in recommending and offering more effective support and therapy; factors such as cost, transportation, motivation, and social support impact the older individual’s success in smoking cessation in a different way than in the younger person. The chapter on COPD is a well-organized, well-referenced review of the disorder, including the epidemiology, course and prognosis, pathophysiology, diagnosis, and treatment. The chapter on pulmonary rehabilitation provides a good overview of what this type of rehabilitation includes—patient selection, program content—and a quick but inclusive review of the results of this type of therapy. The remaining chapters discuss the major diseases of this population: lung cancer, pneumonia, tuberculosis, interstitial lung disease, and thromboembolism. The epidemiology, presentation, diagnosis, and treatment of each is discussed in an organized, easy-to-understand style. The information is current, and pertinent studies and articles are identified in the references.

The authors of the chapters are well known in their field. The excellent presentations are easy to read, and the references add to the value of this book as a resource for specific questions. This text will be a valuable addition to the library of respiratory care professionals and provides a resource for further information concerning the elderly population.

Robert Harwood MSA RRT
Assistant Professor
Department of
Cardiopulmonary Care Sciences
Georgia State University
Atlanta, Georgia

Shirley M Pfister MS RN RRT
VA Medical Center
Denver, Colorado

This pocket-sized volume was written for clinicians who must think on their feet—house officers, fellows, and, yes, respiratory care practitioners. Each of the 55 chapters can be read in less than 10 minutes because only 2 or 3 are longer than 12 pages. The information contained therein is complemented by tables and graphs and a brief bibliography. The editors state that the authors (mostly fellows and junior faculty) were instructed to "...draw heavily on the 3-volume tome 'Pulmonary Diseases and Disorders' and the more recent 'Update',..." which is the first entry in each bibliography. This 3-volume set was recently re-viewed for this Journal by C Laura González-Lawless MD of Salem, Virginia (February 1994).

Most of the chapters include sections on pathophysiology, epidemiology, diagnosis, treatment, and prognosis. The chapter entitled "Nosocomial Pneumonia" includes a table listing the causes of this disorder; respiratory therapy equipment is not on the list.

This small compendium of pulmonary medicine will fit in the pocket of a lab jacket and, even though the pages are a little thin and the print small, page for page and dollar for dollar, the Pulmonary Diseases and Disorders, 2nd edition, Companion Handbook, is quite a value.

Kaye Weber MS RRT
Associate Editor
Respiratory Care
Dallas, Texas

Daedalus Enterprises has appointed Williams & Wilkins as the contact for your classified recruitment ads.

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Contact Jim Burke at (800) 528-1843. AARC Times and Respiratory Care, 428 E. Preston Street, Baltimore, MD 21202.
An Accurate Assessment of Peak Flow?

We have read with interest the article by Simmons, Wynegar, and Hess entitled “Evaluation of the Agreement between Portable Peak Flow Meters and a Calibrated Pneumotachometer.” Although we commend the authors for their venture into this subject area, we must question some of their methods and challenge some of their conclusions.

The pneumotachometer used in the study was unheated. Question 1: Were the results from the testing corrected to BTPS as they should have been?

The authors do not provide their methodology for calibration of the pneumotachometer. Accuracy of results from a pneumotachometer hinge on how well the calibration is performed. Question 2: Was the pneumotachometer calibrated at different flow levels? Question 3: Was the pneumotachometer calibrated for each type of device (to account for back pressure)? Question 4: Was the calibration done for each brand of meter individually to account for meter-to-meter variations in back pressure?

Question 5: Was the pneumotachometer calibrated with the resistors in place? The authors do not mention how peak flow was calculated. The peak flow derived from a pneumotachometer is highly dependent on computation. Question 6: What was the sampling rate? Question 7: Was there some kind of averaging or smoothing technique (as recommended in the ATS spirometry standards)? Question 8: Did the researchers report the highest instantaneous sample generated? It is difficult to make comparisons without this information.

Resistive devices were placed into the flow path of the two subjects to generate the full range of peak flows. This method of altering flow changes the character of the waveform and is likely to result in a waveform quite different from one generated in human subjects. This is likely to affect the outcome of the readings. Question 9: Was this compensated for and how?

As presented, it seems as though each subject was instructed to perform 200 peak flow maneuvers on each of 4 meters—a total of 800 peak flow maneuvers in 1 week or approximately 115/day! This seems high to us. Question 10: Did the subjects have any difficulty in performing this number of tests? Question 11: If effort was not consistent, was any effort made to randomize the delivery of peak flow maneuvers to each of the 4 different meters?

Because of the concerns expressed, we must question the conclusions reached by the authors. In order to accurately assess performance of peak flow meters via a pneumotachometer, it is necessary to account for the many factors that might influence accuracy. These details seem particularly important when, as the authors point out, different groups report different results with supposedly similar methodologies.

Lauren Ziegler
Manager
Research & Development

Shelley Fried
Manager
New Product Development

HealthScan Products Inc
Cedar Grove, New Jersey

REFERENCE


Mr Simmons responds:

Let me respond, for myself and my co-authors, to each of the concerns raised by Ms Ziegler and Mr Fried.

Answer 1: The Fleisch Pneumotachometer (pneumotach, Cybermedic, Louisville CO) used in our study was part of a computerized pulmonary function system and conformed to ATS standards. Although it was unheated, the values from the pneumotach were corrected for actual ambient conditions and reported at BTPS.

Answers 2-4: The pneumotach was calibrated as suggested by the manufacturer at different flow levels using a 3-L calibration syringe. It was calibrated with each of the different brands of peak flow meter (PFM) attached prior to testing of each brand. We did this to account for any back pressure that may have been present in the system. Two of the PFMs (Pocket and Mini-Wright) had to be disconnected during the inspiratory phase of the calibration; due to their construction, these brands do not allow inspiration to take place through them. To make sure this did not affect our results, we contacted a product specialist at Cybermedic to discuss the calibration procedure. Although both the expiratory and inspiratory phases are calibrated on newer pneumotachometers, the two phases calibrate independently and do not affect each other. Because we used only the expiratory phase in our testing of PFMs, our results are accurate.

Answer 5: The resistors used in our study were placed at the mouthpiece. They were used only to help in achieving more consistent low flow rates while still allowing the researcher to use a moderate effort to produce the peak flow. They were not in-line during the calibration procedure. Because they were placed at the prox-
imal end of the tube, the resistors would not have contributed to back pressure in the system; they only impeded the flow exiting the researcher's airway.

**Answers 6-8:** According to the manufacturer, the sampling frequency of the pneumotach is 128 Hz (128 samples/second). The peak flow readings were taken directly from the readout of each test as they presented on the screen.

**Answer 9:** We need to disagree with the challengers on this point. Following the manufacturer's suggested method of utilization, the pneumotach was connected to the distal end of a large-bore tube 38 inches long with an internal diameter of 1.75 inches. Each waveform was observed as the data were collected. Although small expiratory flow curves were generated at the low flowrates, none of the waveforms appeared abnormal compared to those that human subjects generate. Our goal was to generate a peak flow, not to complete the exhalation of a forced vital capacity during these maneuvers. The waveform with and without the resistors was normal.

**Answer 10:** We could have been more precise in our explanation of this part of the study. Sixteen different PFMs were used in the study and were distributed to many subjects. No study participant would have had more than two. Some PFMs were used only by adults and some by children and adults. We did not keep track of the actual peak flow rates generated on any of the meters, only the number of times the PFMs were used (200 each). Regardless, this accounted for much huffing and puffing.

Our conclusions were as follows: (1) The peak flow meters that we evaluated were in good agreement with a calibrated pneumotachometer, but we suggested that methods to improve their performance should continue to be investigated. (2) A statistically significant difference in bias was observed between flow meter brands. Based on this, we recommended that the same peak flow meter be used for serial peak flow measurements. (3) A significant change in bias was observed after 200 uses for some devices, but we believe that this change is not clinically important. We also recommended further research. We believe that our research methods were sound. Based on our research results and their similarity to those of others, we believe that our conclusions and recommendations are valid.

**Mark Simmons MSEd RPFT RRT**

Program Director
School of Respiratory Therapy
York Hospital & York College
York, Pennsylvania

**Therapist-Driven Protocols—A Different View?**

We read with interest the article by Stoller et al regarding their experience with therapist-driven protocols at the Cleveland Clinic. At our institution, Lutheran Medical Center, we have had therapist-driven protocols in place for many years and have found them to be effective at reducing costs and inappropriate therapy.²²

Our fear is that respiratory care departments contemplating the institution of therapist-driven protocols might be dissuaded from pursuing this after reading the Stoller et al paper. The authors found that patients had received more services, demonstrated a trend towards longer stay, and incurred significantly higher charges for respiratory services.

Fundamental differences between our two protocols may help to explain this disparity. In the system described by Stoller et al, a triage score is used to decide frequency of treatment and also frequency of re-evaluation by therapist evaluators. In some cases, this re-evaluation was done every third day. In contrast, our therapists evaluate the need for therapy on a treatment-by-treatment basis, possibly allowing earlier adjustment or discontinuation of therapy. Secondly, Stoller’s group reports on a highly selected series, with patients of much greater severity of illness on average than our more random and mixed population. Reduction in cost is far more apparent when inappropriate therapy is discontinued or never started. Because the patients in Stoller et al’s series were chosen by the physicians, it is possible they only placed their sicker patients on the protocol system to begin with, thereby trending results towards higher utilization of services. His patient population is sicker, smokes more, and was older than our average because we include all patients and are able to limit therapy for those who do not require it. In comparing our algorithms, it is also apparent that Stoller’s group offers more varieties of therapy than we do (eg, bland aerosol and IPPB), which may increase cost. A further difference may arise from our intensive ongoing training of our nursing staff who assume many responsibilities for postoperative prophylaxis, thereby allowing our therapists to reduce time with patients.

We remain convinced that therapist-driven protocols are cost-effective and improve quality when used comprehensively in a structured program such as ours.

**Judy Tietsort RRT**
Director
Respiratory Care Services

**Dennis Clifford MD**
Chairman
Critical Care Committee

Lutheran Medical Center
Wheat Ridge, Colorado
REFERENCES


Dr Stoller responds:

We appreciate Ms Tietzsort and Dr Clifford’s comments regarding our study and share their sentiment that our results should not be miscon- strued to discourage therapist-driven protocols.

Their concern appears to relate to the greater expense of respiratory care services provided to Consult pa- tients in our study and their worry that the greater expense might dampen enthusiasm to adopt therapist- driven protocols, or programs like our Respiratory Therapy Consult Service.1

As we discussed in the paper,2 critical examination of the study de- sign should allay this concern. This study was an observational cohort study, in which patients were selected by their physicians to either have the Respiratory Therapy Consult Service (RTCS) direct their respiratory care or to receive physician-directed respiratory care. To the extent that physi- cians seek consultative help for more complex and/or sick patients but self-manage more straightforward patients, it is not surprising that the RTCS patient group in our study appeared sicker (based on our Triage Score) and had both more respiratory care services and greater respiratory care charges. To our view, the critical issue is not whether more or fewer total dollars were spent by one service or another, but rather whether care was more appropriately allocated and whether fewer dollars were wasted. As discussed in the paper, appropriateness of care was not assessed in this preliminary report, but appropriateness has been examined in a larger, prospective observational study of 98 patients. The preliminary version (n = 48 patients) was presented at the recent AARC OPEN FORUM.3 In this larger observational study, we have shown that despite the greater severity of illness and longer length of stay of Respiratory Therapy Consult Service (RTCS) patients, the frequency of inappropriate respiratory care orders for RTCS patients was 2.7-fold lower than with physician-directed respiratory care (16% vs 43%, p < 0.05) and that respiratory care charges for these sicker RTCS patients were not higher. Indeed, a trend towards lower respiratory care charges was seen for RTCS patients. This analysis goes beyond a considera- tion of costs alone and suggests that sicker patients can be managed more appropriately and at no greater respiratory expense. This is the type of fuller analysis of therapist-driven protocols that is necessary to truly assess their efficacy and that we believe the respiratory care community seeks.

Even better than the observational studies we have conducted to date would be a randomized clinical trial of therapist-driven protocols vs physi- cian-directed respiratory care, in which successful randomization would assure similarity of the compared patient groups, so that differences in appropriateness of respira- tory care orders and costs can be reli- ably ascribed to the different respiratory care strategies (i.e., therapist-driven protocols vs physician-di- rected respiratory care). We are cur- rently designing such a trial to further critically assess the Respiratory Therapist Consult Service at the Cleveland Clinic Foundation.

However, until such a definitive study has been completed and care- fully analyzed, we caution against premature judgment about the efficacy of therapist-driven protocols— either premature rejection or over- simplified endorsement.

Although we are encouraged by the observations from our studies and others’ and strongly share Ms Tietzsort and Dr Clifford’s enthusiasm for the concept of therapist-driven protocols as a critical step to improve the delivery of respiratory care services, we encourage an attitude of dispassionate, scientific judgment that de- mands ‘hard-nosed’ analysis of data before wholehearted endorsement is possible.

James K Stoller MD
Head
Section of Respiratory Therapy
Pulmonary and
Critical Care Medicine
The Cleveland Clinic Foundation
Cleveland, Ohio

REFERENCES

1. Stoller JK. Misallocation of respira- tory care services: time for a change (editorial). Respir Care 1993;38(5):263-266.


The American Respiratory Care Foundation Awards for 1994

Allen & Hanbury Literary Awards

$2,000 for the best original paper (study, evaluation, or case report) accepted for publication from December 1993 through October 1994. This award is not limited to papers based on OPEN FORUM presentations.

Four awards of $1,000 each for papers accepted for publication from November 1993 through October 1994 based on any OPEN FORUM presentation (not limited to 1993 OPEN FORUM).

Five awards of $500 each for the best papers submitted (not necessarily published) by 1994 OPEN FORUM participants who have ‘never published’ in the Journal. The never-published first author must present the abstract at the Annual Meeting and must submit a paper based on the abstract before the 1994 Annual Meeting (received in the Editorial Office by November 1, 1994). Co-authors may have previously published in RESPIRATORY CARE.

Dr Allen DeVilbiss Literary Award

$2,000 cash plus travel expenses to the AARC Annual Meeting to receive the award—for the best paper published from November 1993 through October 1994 that addresses new technology or a new application of current technology in respiratory care.

Radiometer America Literary Awards

Three awards of $333 each are to be awarded to the authors of the three best features from Test Your Radiologic Skill, Blood Gas Corner, Kittredge’s Corner, and PFT Corner accepted for publication from November 1993 through October 1994. All three (or none) of the features may be chosen from a specific category (eg, all three may be chosen from Blood Gas Corner).

OPEN FORUM 1994

It’s time to submit your abstracts for possible presentation at the OPEN FORUM during the AARC Annual Meeting in Las Vegas, Nevada, December 10-13, 1994. An early deadline (March 15) allows opportunity for revision following review, with re-submission by the final deadline (May 28). For more information on changes to the rules/instructions, see Page 259 of this issue.

Annual Meeting Registration Reimbursement

As in the past, any 1994 OPEN FORUM presenter (or co-author designee) will receive complimentary registration for an adequately prepared paper based on his 1994 OPEN FORUM abstract, submitted prior to or at the 1994 Annual Meeting.

All awards will be made at the 1994 Annual Meeting. Papers are judged automatically. No application is necessary.

THE NATIONAL BOARD FOR RESPIRATORY CARE—1994 Examination and Fee Schedule

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AARC & AFFILIATES

March 29 AARC Videoconference. The AARC, in conjunction with VHA Satellite Network, presents the second of a 6-part videoconference series titled “Professor’s Rounds in Respiratory Care.” The second presentation is entitled “Therapist-Driven Protocols: Implementation” (1 CRCE credit). For information, call (214) 830-0061.

March 29-31 in Nashville, Tennessee. The TSRC announces its annual convention and exhibition to be held at the Loews Vanderbilt Plaza Hotel in Nashville. This year’s theme is “RC Odyssey 2001.” Contact Colleen Schabacker at (615) 384-1731.

April 11-13 in Philadelphia, Pennsylvania. The PSRC presents its 29th annual conference and exhibition at the Adam’s Mark Hotel. This year’s theme is “Winds of Change.” State Sputum Bowl finals are featured. Contact Betsy Schneck (215) 829-3578.

April 16 in Long Beach, California. The CSRC Chapter IV presents a Saturday conference titled “Health Care in California: How Changes Will Affect Respiratory Care” in the Britannia Salon of the Queen Mary. Call (213) 727-CSRC.

May 3-6 in Grand Rapids, Michigan. The MSRC holds its 1994 Scientific Symposium at the Amway Grand Plaza Hotel. Contact MSRC, PO Box 950, East Lansing MI 48826-0950, or call Caroline Kimmel (517) 336-7605.

May 11 AARC Videoconference. The AARC, in conjunction with VHA Satellite Network, presents the third of a 6-part videoconference series titled “Professor’s Rounds in Respiratory Care.” The third presentation is entitled “New Strategies for Asthma Management” (1 CRCE credit). For information call (214) 830-0061.

May 31-June 3 in Myrtle Beach, South Carolina. The Georgia/South Carolina Region VI Committee presents its annual conference and assembly at the Landmark Hotel. Topics include Hospital Restructuring, Health Care Reform, Nitric Oxide, and Artificial Hemoglobin. Contact Lynda Thomas-Gooldfellow at (404) 651-1498, or write to Region VI Committee, 275L Harbison Blvd, Suite #2, Columbia SC 29212.

June 8-10 in Checotah, Oklahoma. The OSRC presents its 29th Annual State Seminar and Exhibition at Fountainhead Resort and Convention Center on Lake Eufaula. This year’s theme, “The Times—They Are a Changing,” addresses anticipated changes in the healthcare delivery system and critical issues for respiratory care. Other activities include a Manager’s Mixer and the traditional golf tournament. For information on the seminar or exhibits, contact Karen Hart RRT at (405) 273-6442.

OTHER MEETINGS

March 15-16 in Durham, North Carolina. Eighth Annual Cardiopulmonary Technology Seminar is sponsored by Duke University Medical Center, Durham Regional Hospital, Durham Technical Community College, and University of North Carolina Hospitals Respiratory Care Departments. Featured speakers are Michael Newhouse MD on Aerosol Delivery Systems for Pulmonary Medications, Neil Maclntyre MD on Intrapulmonary Pressure Graphic Analysis and Weaning, James Donohue MD on Advances in Respiratory Pharmacology, and Kathryn Ellis MSN on Manpower Changes in an Era of Health Care Reform. The seminar also features a comprehensive exhibit hall, where the latest advances in medical scientific equipment and services are displayed. Registration for both days is $70.00 including lunch on Day 1. Contact Susan Rinaldo-Gallo RRT at (919) 681-2720 or Chuck Alford at (919) 470-5366.

March 17-19 in Destin, Florida. Tulane School of Medicine in New Orleans, Louisiana, The University of Alabama at Birmingham, and the University of Florida presents “Practical Issues in Pediatric Home Care: An Interdisciplinary Approach” at the Sandestin Beach Hilton, Destin FL. The purpose of this conference is to provide information and resources to healthcare professionals working in the hospital and community setting with chronically ill and technology-dependent children. The care of children with pulmonary disease is discussed specifically from an interdisciplinary perspective. Approved for 13 CRCE credits. Fee: $125/ $75 for employees of Title V Affiliated Agencies. Contact Pamela Rogers MSW or Anna Chiappetta RRT RCP, Pediatric Pulmonary Center, Tulane School of Medicine, Box SL 37, 1430 Tulane Ave, New Orleans LA 70112. (504) 588-5601.

April 15-17 Miami to Nassau. Sunset Seminars is happy to announce another Weekend Getaway “Floating Seminar” on a 2-night cruise aboard the SS Britannia with George Burton MD discussing “Therapist-Driven Protocols.” 6 CE credits are awarded. Contact Sunset Seminars/ Robbins & Associates, 19800 SW 180 Ave #127, Miami FL 33187. Call (305) 232-1908.
1994 Call for Abstracts

RESPIRATORY CARE • OPEN FORUM

The American Association for Respiratory Care and its science journal, Respiratory Care, invite submission of brief abstracts related to any aspect of cardiorespiratory care. The abstracts will be reviewed, and selected authors will be invited to present papers at the OPEN FORUM during the AARC Annual Meeting in Las Vegas, Nevada, December 10-13, 1994. Accepted abstracts will be published in the November 1994 issue of Respiratory Care. Membership in the AARC is not necessary for participation.

SPECIFICATIONS—READ CAREFULLY!

An abstract may report (1) an original study, (2) the evaluation of a method or device, or (3) a case or case series. Topics may be aspects of adult acute care, continuing care rehabilitation, perinatology/pediatrics, cardiopulmonary technology, health occupations education, or management of personnel and health-care delivery. The abstract may have been presented previously at a local or regional—but not national—meeting and should not have been published previously in a national journal. The abstract will be the only evidence by which the reviewers can decide whether the author should be invited to present a paper at the OPEN FORUM. Therefore, the abstract must provide all important data, findings, and conclusions. Give specific information. Do not write such general statements as “Results will be presented” or “Significance will be discussed.”

Essential Content Elements

An original study abstract must include (1) Introduction: statement of research problem, question, or hypothesis; (2) Method: description of research design and conduct in sufficient detail to permit judgment of validity; (3) Results: statement of research findings with quantitative data and statistical analysis; (4) Conclusions: interpretation of the meaning of the results. A method/device evaluation abstract must include (1) Introduction: identification of the method or device and its intended function; (2) Method: description of the evaluation in sufficient detail to permit judgment of its objectivity and validity; (3) Results: findings of the evaluation; (4) Experience: summary of the author’s practical experience or a notation of lack of experience; (5) Conclusions: interpretation of the evaluation and experience. Cost comparisons should be included where possible and appropriate. A case report abstract must report a case that is uncommon or of exceptional teaching/learning value and must include: (1) patient data case summary and (2) significance of case. Content should reflect results of literature review. The author(s) should have been actively involved in the case and a case-managing physician must be a co-author or must approve the report.

Abstract Format and Typing Instructions

Accepted abstracts will be photographed. First line of abstract should be the title in all capital letters. Title should explain content. Follow title with names of all authors (including credentials), institution(s), and location. Underline presenter’s name. Type or electronically print the abstract single spaced in the space provided on the abstract blank. Insert only one letter space between sentences. Text submission on diskette is encouraged but must be accompanied by a hard copy. Identifiers will be masked (blinded) for review. Make the abstract all one paragraph. Data may be submitted in table form and simple figures may be included provided they fit within the space allotted. No figures, illustrations, or tables are to be attached to the abstract form. Provide all author information requested in right column of abstract form. A clear photocopy of the abstract form may be used. Standard abbreviations may be employed without explanation. A new or infrequently used abbreviation should be preceded by the spelled-out term the first time it is used. Any recurring phrase or expression may be abbreviated if it is first explained. Check the abstract for (1) errors in spelling, grammar, facts, and figures; (2) clarity of language; (3) conformance to these specifications. An abstract not prepared as requested may not be reviewed. Questions about abstract preparation may be telephoned to the editorial staff of Respiratory Care at (214) 243-2272.

Deadlines

Deadline Allowing Revision

Authors may choose to submit abstracts early. Abstracts received by March 15 will be reviewed and the authors notified by April 22. Rejected abstracts will be accompanied by a written critique that should in many cases enable authors to revise their abstracts and resubmit them by the final deadline (May 28).

Final Deadline

The mandatory Final Deadline is May 28 (postmark). Authors will be notified of acceptance or rejection by letter only—to be mailed by August 15.

Mailing Instructions

Mail (Do not fax!) 2 clear copies of the completed abstract form and a stamped, self-addressed postcard (for notice of receipt) to:

RESPIRATORY CARE OPEN FORUM
11030 Ables Lane
Dallas TX 75229-4593
1994 Respiratory Care Open Forum

Abstract Form

1. Title must be in all upper case (capital) letters, authors' full names and text in upper and lower case.
2. Follow title with all authors' names including credentials (underline presenter's name), institution, and location.
3. Do not justify (ie, leave 'ragged' right margin).
4. Do not use type size less than 9 points.
5. All text, tables, and figures must fit into the rectangle shown.
6. Submit 2 clean copies. This form may be photocopied if multiple abstracts are to be submitted.

Presenter’s Name & Credentials

Presenter’s Mailing Address

Presenter’s Voice Phone & Fax

Corresponding Author’s Name & Credentials

Corresponding Author’s Mailing Address

Corresponding Author’s Voice Phone & Fax

Mail original & 1 photocopy (along with postage-paid postcard) to:

Respiratory Care Open Forum
11030 Ables Lane
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Early deadline is March 15, 1994 (abstract received)
Final deadline is May 28, 1994 (abstract postmarked)
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UNION TEE FITTING. Colder Products Company introduces the new Softube union tee fitting for 1/2-inch plastic tubing such as PVC, vinyl, Tygon, Norprene, or Viton. These fittings use a unique sliding sleeve to seal and hold soft-walled plastic tubing. After sliding the tubing over the fitting stem, the locking sleeve is pulled over the tubing to make a leak-free 360° seal. There are 24 fittings in 5 configurations available. Contact Colder Products Company, Dept RC, 1001 Westgate Drive, St Paul MN 55114, or call (612) 645-0091. Don’t forget to mention RESPIRATORY CARE when you call.

PET-ALLERGY RELIEF. Faraham Pet Products announces the rollout of Allerpet, a non-prescription, easy-to-use grooming emollient that cleanses a pet’s coat of its dander, saliva, and urine antigens—irritants that contribute to allergic reactions in humans. The manufacturer reports that their consumer testing revealed that 85% of the respondents who used Allerpet experienced quick relief. Allerpet is available in three formulas—for dogs, cats, and birds. The product is simply applied to the animal’s coat and does not harm the pet or leave residue on furniture or clothing. For more information about Allerpet call (800) 825-2555. Don’t forget to mention RESPIRATORY CARE when you call.

VIDEO TARGETS MYTHS. “Don’t let it hold you back.” That’s the message of a newly released patient education videotape about asthma from the Allen & Hanbury’s Respiratory Institute (AHRI) and Glaxo Inc. The video entitled “Essence of Life,” portrays asthma patients who are coping effectively with their condition and emphasizes how, with proper medical treatment, the 10 to 12 million individuals diagnosed with asthma can live normal, active lives. The 20-minute tape features frank discussion between asthma sufferers and leading asthma and allergy physicians addressing the myths that surround this chronic lung disease. Glaxo representatives state that their purpose in producing this public service program was “…to help family practitioners and respiratory health professionals teach asthma patients and their families the facts about asthma and successful ways to control the disease.” “Essence of Life” is available from any Allen & Hanbury’s or Glaxo sales representative or can be obtained by calling Glaxo’s Video Library toll-free at (800) 824-2896.

NEW HEPA FILTER. Gibeck-Dryden introduces a HEPA- (High-Efficiency Particulate Airborne) grade filter for the anesthesia and respiratory market that maintains a HEPA flow up to 60 L/min. According to the manufacturer, the Iso-Gard filter offers excellent filtration as well as heat- and moisture-exchange characteristics. This filter features a clear, lightweight housing with 22- and 15-mm connectors, and minimal dead space. The hydrophobic filter media prevents moisture from damaging the ventilator. The Iso-Gard HEPA filter is supplied individually polybagged in cartons of 50. Contact your exclusive Gibeck-Dryden distributor or call (800) 428-5321. Don’t forget to mention RESPIRATORY CARE when you call.

OXIMETRY SENSOR. Criticare introduces a cost-effective, easy-to-clean, reusable oximetry sensor. The 934 Shell sensor features a durable plastic outer shell that encloses the
sensor components and is easily removable for easy cleaning and disinfection. According to the manufacturer, the Shell sensor is the only product on the market that allows the removal of the contact pads for cleaning. If the outer shell is damaged, only this part needs to be replaced not the entire unit including more costly sensor components; this could represent a cost savings of up to 85% of the complete-sensor cost. Contact Pat Van Ryzin, Criticare Systems Inc, (414) 798-8282; don't forget to mention RESPIRATORY CARE when you call.

HAND-HELD PULSE OXIMETER. Armstrong Medical Industries introduces the AD-1000—an ergonomically designed pulse oximeter designed to provide fast, accurate $S_{PO_2}$ and pulse rate on any patient from neonate to adult. This compact (weighs 9 oz) and easy-to-use unit is designed for spot-checking and is ideal for ICU, respiratory care, emergency rooms, outpatient clinics, and emergency transport. The display includes bright LED numerals and quantitative pulse strength bar. High-intensity, reusable, and disposable probes are available. The AD-1000 stores data for up to 99 patients allowing hard-copy documentation via an optional printer. The monitor runs on 3 C-cell batteries and has an automatic shutoff to prolong battery life. Contact Armstrong Medical Industries Inc, Dept RC, PO Box 700, Lincolnshire IL 60069-0700, or call (800) 323-4220; western states: (800) 442-6991. Please mention RESPIRATORY CARE when you call.

CPR PROMPTER. CPR PROMPT Corporation introduces the CPR Prompt Rescue Aid. This battery-operated device uses synthetic speech to aid trained rescuers to recall the proper sequence and timing of CPR procedures during emergency situations. An electronic voice provides prompts for adult, child, and infant victims. Prompting includes rescue breathing, 1 and 2 rescuer CPR, and both conscious and unconscious choking. The manufacturer believes that the CPR PROMPT system is one solution to problems of instantaneous recall. It is available in a wall-mounted version and one that can be packed in emergency medical cases. Contact CPR PROMPT Corporation, Dept RC, 60 Brookdale Drive, Springfield MA 01104, (413) 730-2625; don't forget to mention RESPIRATORY CARE when you call.

POINT-OF-CARE TESTING. Mallinckrodt Sensor Systems has introduced several innovations to its GEM Premier Point-of-Care blood-gas analyzer to enhance the system's operation. The new features include a 150-sample testing cartridge, quality control ampule bar coding, and a data management software program. They are designed to meet evolving testing and patient management needs in the hospital critical care and laboratory settings. The GEM Premier cartridges allow analysis of up to 150 samples over 7 days of operation, resulting in more economical usage in hospital settings with lower test-volume needs. The cartridge allows analysis of pH, $P_{CO_2}$, $P_{O_2}$, Na+, K+, Ca++, and Hct from a single sample. Contact Roxanna Motchan, (314) 895-2078; please mention RESPIRATORY CARE when you call.

PATIENT MONITOR INTERFACE. SpaceLabs Medical's Quicknet interface allows hospitals to create monitored beds quickly and cost-effectively in response to fluctuations in patient census and acuity. When used in combination with PC Express, the Quicknet interface facilitates bedside and central display and alarms for ECG, NIBP, $S_{PO_2}$, and other monitored parameters. Quicknet interfaces allow hospital units to use one portable PC Express monitor among several rooms at a substantial cost-savings over permanently installing monitors in each room. They eliminate the need to move a patient to another unit for monitoring and also allow clinicians to quickly convert a telemetry patient to hardware monitoring. SpaceLabs Medical is a manufacturer of clinical information systems and patient monitoring products. Contact Karyn Beckley (206) 882-3700. Please mention RESPIRATORY CARE when you call.

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