Respiratory Mechanics in the Patient Who Is Weaning From the Ventilator

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Ventilator management of the patient recovering from acute respiratory failure must balance competing objectives. On the one hand, aggressive efforts to promptly discontinue support and remove the artificial airway reduce the risk of ventilator-induced lung injury, nosocomial pneumonia, airway trauma from the endotracheal tube, and unnecessary sedation. On the other hand, overly aggressive, premature discontinuation of ventilatory support or removal of the artificial airway can precipitate ventilatory muscle fatigue, gas-exchange failure, and loss of airway protection. To help clinicians balance these concerns, 2 important research projects were undertaken in 1999–2001. The first was a comprehensive evidence-based literature review of the ventilator-discontinuation process, performed by the McMaster University research group on evidence-based medicine. The second was the development (by the American Association for Respiratory Care, American College of Chest Physicians, and Society of Critical Care Medicine) of a set of evidence-based guidelines based on the latter literature review. From those 2 projects, several themes emerged. First, frequent patient-assessment is required to determine whether the patient needs continued ventilatory support, from both the ventilator and the artificial airway. Second, we should continuously re-evaluate the overall medical management of patients who continue to require ventilatory support, to assure that we address all factors contributing to ventilator-dependence. Third, ventilatory support strategies should be aimed at maximizing patient comfort and unloading the respiratory muscles. Fourth, patients who require prolonged ventilatory support beyond the intensive care unit should go to specialized facilities that can provide gradual reduction of support. Fifth, many of these management objectives can be effectively carried out with protocols executed by nonphysicians. *Key words: ventilator discontinuation, evidence-based guidelines, weaning, waveform.* [Respir Care 2005;50(2):275–284. © 2005 Daedalus Enterprises]

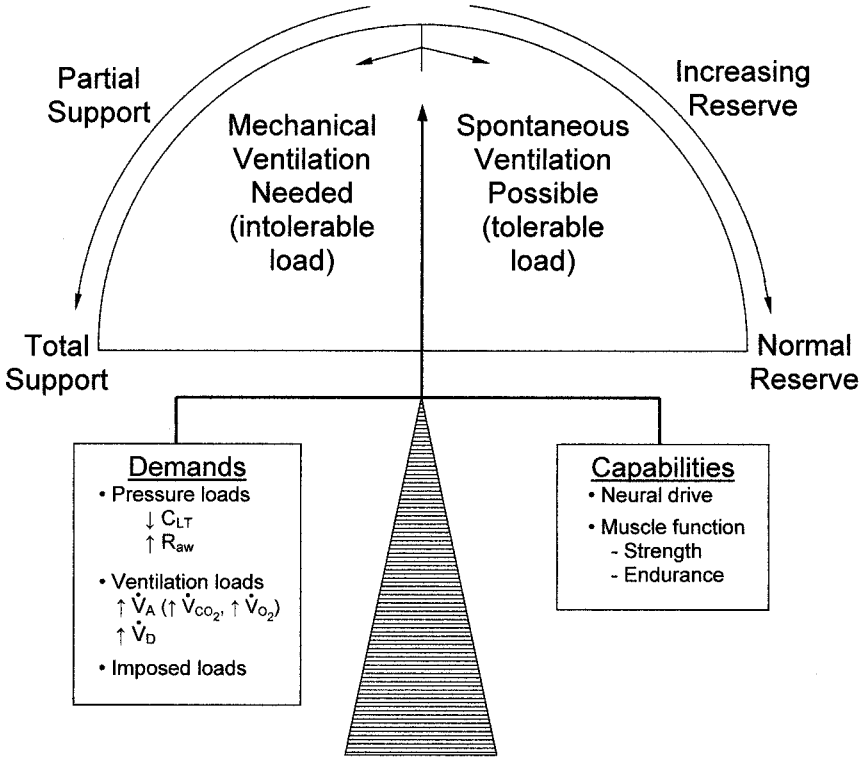

Fig. 1. The relationship between patient capabilities and demands. When demands outstrip the capabilities, the balance swings to the left and a high level of ventilatory support is required. As the patient recovers, the balance shifts rightward. The clinical challenges during this period are 2-fold: (1) recognize when ventilatory assistance is no longer necessary, and (2) provide appropriate levels of assistance until that happens. C_{LT} = compliance of the lungs and thorax. R_{aw} = airway resistance. $\dot{V}_A$ = alveolar ventilation. $\dot{V}_{CO_2}$ = carbon dioxide production. $\dot{V}_{O_2}$ = oxygen consumption. $\dot{V}_D$ = dead-space volume. (Adapted from Reference 1.)

Introduction

Patients are generally provided with positive-pressure mechanical ventilation when their own ventilatory capabilities are outstripped by the demands imposed by various disease states (Fig. 1). Positive-pressure mechanical ventilation is also needed when the respiratory drive is reduced by disease or drugs and the patient is incapable of initiating ventilatory activity. As these reasons for providing mechanical ventilatory support stabilize and begin to resolve, the clinical focus must be directed toward strategies that remove the ventilator as quickly as possible. Unnecessary delays in this withdrawal process increase the complication rate of mechanical ventilation (eg, pneumonia, discomfort) and drive up cost. Aggressiveness in removing ventilatory support, however, must be balanced against the risks of prematurely withdrawing that support, including difficulty in re-establishing the artificial airway, ventilatory muscle fatigue, and compromised gas exchange.

There are 2 fundamental issues involved in the management of mechanically ventilated patients whose disease process has begun to stabilize and/or reverse. First, appropriate assessment techniques are needed to identify patients capable of ventilator withdrawal. Once identified, these patients should have the device removed promptly. Second, in patients judged to still require mechanical ventilatory support, appropriate management strategies are needed, which should include regular withdrawal reassessments. This article focuses on these 2 issues and emphasizes applied respiratory physiology as an adjunct in the decision-making processes. As much as possible, my comments will be evidence-based. Indeed, this discussion will rely heavily on the comprehensive evidence-based review, by the McMaster University evidence-based-research group, of the ventilator withdrawal process and the sub-

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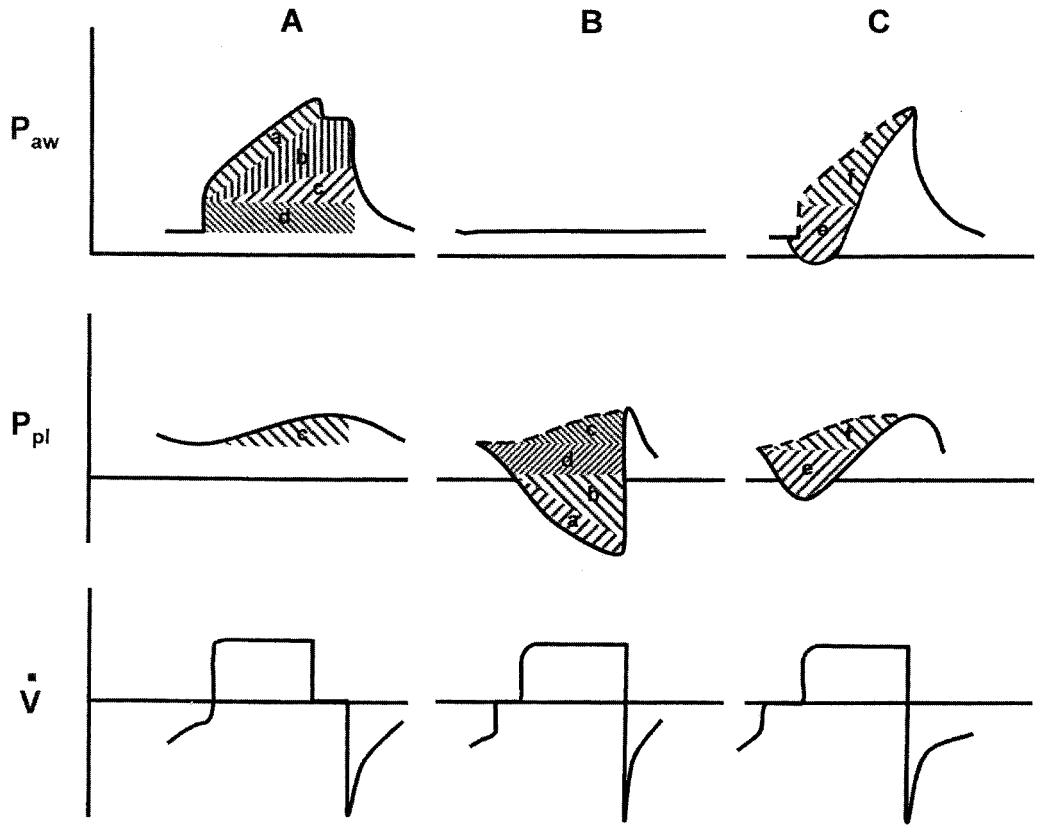

Fig. 2. Using ventilator waveforms to determine the components of pressure loads placed on the ventilatory muscles. Plotted are airway pressure (P_{aw}), pleural pressure (P_{pl}, often estimated with an esophageal pressure sensor), and flow ($\dot{V}$). Column A illustrates a controlled breath (no patient activity) with a short inspiratory pause (no flow) at end-inspiration. The shaded areas represent load components. Shaded area *a* is the pressure load imposed by airway resistance (tubes, circuits, patient airways) for the flow provided. Shaded area *b* is the pressure load imposed by lung compliance. Shaded area *c* is the pressure load imposed by chest wall compliance (seen in both the P_{aw} and P_{pl} waveforms). In this example, there is intrinsic positive end-expiratory pressure (PEEP), and shaded area *d* is the pressure load imposed by PEEP. Another clue to the presence of intrinsic PEEP is that the expiratory flow waveform has not returned to zero before the next breath begins. In column B, the same patient takes a spontaneous, unassisted breath with similar flow characteristics. Now, all the pressure loads are measured from the pleural pressure waveform with the upper border (dashed line) determined by the passive waveform in column A. Areas *a*, *b*, *c*, and *d* in panel B represent the same load components as in column A. Column C depicts a ventilator-assisted breath (patient triggers the breath and interacts with flow delivery) a flow pattern similar to the controlled breath of column A. The pressure profile of the controlled breath in column A is superimposed (dashed line). Shaded area *e* represents pressure loads imposed by intrinsic PEEP and ventilator trigger sensitivity/responsiveness. Shaded area *f* represents loads imposed on the ventilatory muscles from patient flow demands in excess of ventilator flow delivery.

sequent evidence-based guidelines from the American College of Chest Physicians, the Society of Critical Care Medicine, and the American Association for Respiratory Care.[2]

Assessing Withdrawal Potential

Assessing Patient Load

There are both volume and pressure loads placed on the ventilatory muscles in the patient with respiratory failure.[3,4] Volume loads can be assessed by measuring the patient's minute ventilation requirements, the proportion of the minute ventilation that is "wasted" as dead space (the ratio of dead space volume to tidal volume [$V_D/V_T = (P_{aCO_2} - P_{\bar{E}CO_2})/P_{aCO_2}$], in which P_{aCO_2} is arterial partial pressure of carbon dioxide, and $P_{\bar{E}CO_2}$ is mixed expired partial pressure of carbon dioxide), or the ventilation requirements for the metabolic demands of oxygen consumption ($\dot{V}_{O_2}$) and carbon dioxide production ($\dot{V}_{CO_2}$).

The pressure loads on the ventilatory muscles may be more important than the volume loads (see below), and can be expressed in several ways. During a controlled breath (ie, no patient activity), the airway pressure waveform can be used to estimate the various components of pressure loads that would be imposed during a spontaneous unassisted breath (Fig. 2A). If an esophageal pressure sensor is available (a reflection of pleural pressure), 3 additional analyses can be done. First, the pressure loads

from the chest wall can be determined during a controlled breath (see Fig. 2A). Second, a direct measurement of the pressure load on the ventilatory muscles can be made during a spontaneous unassisted breath (see Fig. 2B). Third, comparing assisted and controlled breaths, the pressure waveforms can be used to assess the pressure loads imposed during the breath-triggering process and during the flow-delivery phase (see Fig. 2C).

Pressure loads are often expressed with respect to the volume delivered or the time that pressure is applied.[3,4] For example, the integral of pressure over volume is the work of breathing ($W = \int PdV$), and the integral of pressure over time is the pressure-time product ($PTP = \int Pdt$).

Not surprisingly, ventilatory muscle loads correlate with ventilatory-muscle oxygen consumption and the tendency for muscles to be overloaded and fatigued.[5–7] Ventilatory muscle $\dot{V}_{O_2}$ requirements can be determined by subtracting total $\dot{V}_{O_2}$ during controlled ventilation from total $\dot{V}_{O_2}$ during spontaneous ventilation. Interestingly, the ventilatory-muscle pressure or tension component of load is most closely correlated with ventilatory-muscle oxygen consumption.[5,6] That is why it is much easier to fatigue ventilatory muscles under experimental conditions using high pressure loads rather than hyperventilation loads. Thus, the PTP is actually more closely correlated with oxygen demands and fatigue than is work. Ironically, many clinicians and investigators use the term "work" but then divide the actual work value (in joules) by a volume measurement (eg, joules/L). That, in essence, converts $\int PdV$ into $\int PdV/V$ which, in fact, is simply the mean pressure over the inspiration.

Loads associated with inability to be removed from the ventilator are minute volume $>$ 10–15 L/min, ventilatory-muscle $\dot{V}_{O_2} > 50$–100 mL/min, and work/min $>$ 10–17 J/min.[2,8] Conceptually, assessments of withdrawal potential should be based on the loads imposed by the disease and not those imposed by the support mechanism.

Assessing Patient Capabilities

Ventilatory muscle strength is commonly measured during the peak inspiratory pressure maneuver (P_{Imax}, which is measured during the patient's maximum inspiratory effort against a closed shutter). Recommendations are that the closed shutter should be in place for at least 20 seconds and perhaps 30 seconds to achieve a maximum result. Values more negative than –20 to -30 cm H_2O are thought to be necessary for ventilator withdrawal.[2,8] Another assessment of patient capacity is a simple vital capacity maneuver, in which the patient is asked to voluntarily take a maximal inspiration and subsequent inspiration. Vital capacity $<$ 1 L is associated with less ability to be removed from mechanical ventilatory support.[2,8]

An interesting measurement of patient capabilities is the inspiratory pressure generation after 100 milliseconds of effort against a closed circuit ($P_{0.1}$).[8] This measurement actually reflects 2 properties. First, it is a reflection of inspiratory drive. The more vigorous the patient's inspiratory drive, the greater the $P_{0.1}$. Some suggest that the increase in $P_{0.1}$ after inhalation of carbon dioxide may be a further indicator of the responsiveness of patient ventilatory drive. However, $P_{0.1}$ also reflects ventilatory muscle strength. Because of these multiple determinants, interpreting $P_{0.1}$ can be challenging. For example, a low $P_{0.1}$ may reflect either muscle weakness (bad) or a low respiratory drive, which may be good if it indicates that the patient is comfortable, or bad if it indicates a depressed respiratory drive. In contrast, a high $P_{0.1}$ may reflect strong muscles (good) or a vigorous respiratory drive, which may be good if it indicates an intact patient drive, or bad if it indicates that the patient is uncomfortable.

$P_{0.1}$ is readily attainable with most modern ventilators, because there is a delay of $>$ 100 milliseconds between the initiation of patient effort and the opening of the inspiratory valve. Thus, inspection of the airway pressure waveform during breath triggering can give a $P_{0.1}$ value.

Load-Capacity Balance Assessment

Conceptually, assessing loads with respect to capacity would make more sense than measuring either alone. There are several approaches to this. An interesting integrated assessment is the CROP index,[8] which incorporates *c*ompliance, respiratory *r*ate, *o*xygenation, and inspiratory *p*ressure in a straightforward formula:

$$CROP = (C_{dyn} \times P_{Imax} \times (P_{aO_2}/P_{AO_2}))/f \quad (1)$$

in which C_{dyn} is dynamic compliance, P_{Imax} is maximum inspiratory pressure, P_{aO_2} is arterial partial pressure of oxygen, P_{AO_2} is alveolar partial pressure of oxygen, and f is respiratory rate. CROP values $>$ 13 are thought to indicate high likelihood of ventilator withdrawal success. Another approach is to assess ventilatory pressure requirements with respect to the ventilatory-muscle pressure-generation capabilities. The most common way to do that is to calculate a pressure-time index (PTI), with the equation:

$$PTI = (PTP/\text{respiratory cycle time})/P_{Imax} \quad (2)$$

In several studies, a PTI $<$ 0.15 was highly predictive of respiratory-muscle overload and fatigue.[9]

Perhaps the most direct assessment of the load-capacity relationship is the patient's tolerance of a 30–120 min spontaneous breathing trial (SBT).[10–13] The criteria used to define SBT tolerance are often integrated indices, which

Table 1. Criteria Used in Several Large Trials[1] to Define Tolerance of a Spontaneous-Breathing Test

Objective Measurements Indicating SBT Tolerance/Success
- Gas exchange acceptability ($S_{pO_2} \geq 85$–90%, $P_{aO_2} \geq 50$–60 mm Hg, pH ≥ 7.32, P_{aCO_2} increase < 10 mm Hg)
- Hemodynamic stability (heart rate $<$ 120–140, heart rate not changed $> 20\%$, systolic blood pressure $<$ 180–200 mm Hg and $>$ 90 mm Hg, blood pressure not changed $> 20\%$, no vasopressors required)
- Stable ventilatory pattern (eg, respiratory rate $\leq$ 30–35 breaths/min, respiratory rate not changed $> 50\%$)
Subjective Clinical Assessments Indicating SBT Intolerance/Failure
- Change in mental status (eg, somnolence, coma, agitation, anxiety)
- Onset or worsening of discomfort
- Diaphoresis
- Signs of increased work of breathing (use of accessory respiratory muscles, thoracoabdominal paradox)

S_{pO_2} = oxygen saturation measured via pulse oximetry

usually include several physiologic variables as well as clinical judgment, incorporating difficult-to-quantify factors such as anxiety, discomfort, and clinical appearance. Table 1 shows the criteria that have been used in several large trials.

There is evidence that serious respiratory-muscle overload, if it is going to occur, often occurs early in the SBT.[11,14] Thus, the initial few minutes of an SBT should be closely monitored, before a decision is made to continue (often referred to as the screening phase of an SBT). Thereafter, the patient should continue the trial for at least 30 min, but no more than 120 min,[13] to assure maximum sensitivity and safety. It also appears that whether the SBT is done with a low level of continuous positive airway pressure (eg, 5 cm H_2O), a low level of pressure support (eg, 5–7 cm H_2O), or with a T-piece (no pressure support) has little effect on SBT outcome.[15,16] Continuous positive airway pressure, however, conceivably could enhance breath-triggering in patients who have substantial intrinsic positive end-expiratory pressure.[17]

Reviewing the Evidence Base on Assessing Ventilator Withdrawal Potential

In 1999, the McMaster University Evidence-Based Medicine Group published an extensive review of the world's literature on the ventilator-withdrawal process.[2,18] That report found evidence supporting a possible role for 66 specific clinical measurements as predictors of withdrawal success. From that list the McMaster group identified 8 predictor variables that had consistently significant likelihood ratios of predicting successful discontinuation in several studies (Table 2). Some of these measurements are made while the patient is still receiving ventilatory support; others require an assessment during a brief period of spontaneous breathing. It should be noted that, despite the statistical significance of these predictor variables, the generally low likelihood ratios indicate low clinical applicability to individual patients.

In the McMaster review the conclusion was that, although the variables (in Table 2) could yield important information about ventilator-discontinuation potential, assessments done during a formal, carefully monitored 30–120 min SBT appeared to provide the most useful information to guide clinical decision making regarding discontinuation. Indeed, because of the efficacy and safety of a properly monitored SBT, the other assessments in Table 2 are generally unnecessary.

Several randomized clinical trials indicate that incorporating a routine daily SBT into a ventilator management protocol reduces ventilator weaning days and duration of intensive-care stay.[19,20] A recent report challenged whether this approach needs to be conducted in a formal protocol, if the medical staff is plentiful, is well versed in ventilator-withdrawal techniques, and has a disciplined rounding schedule that includes formal consideration for SBT.[21] Intensive care units that meet those criteria, however, would seem to be the exception rather than the rule.

Removing the Artificial Airway From a Patient Judged Ready for Ventilator Withdrawal

If a patient successfully completes an SBT, the assessment should then focus on whether the patient can tolerate removal of the artificial airway. This assessment focuses on the patient's ability to protect the airway—specifically, assessment of cough and the need for suctioning.[2,22–25] These are difficult to quantify, and many experts use the frequency of airway suctioning (eg, every $\geq$ 2 h) as a surrogate.[2] Peak cough flows of $>$ 160 L/min predict successful extubation or decannulation of patients with neuromuscular or spinal-cord injuries.[26]

Managing a Patient Who Has Failed an SBT

Nonventilatory Support Issues

With a patient who fails an SBT, the clinicians should review all the medical issues involved in ventilator depen-

Table 2. Variables That Predict the Outcome of Ventilator Discontinuation*

	Variable	Number of Studies	Threshold Values	Range of Positive Likelihood Ratios
Measured While Patient Was On the Ventilator	$\dot{V}_E$ (L/min)	20	10–15	0.81–2.37
	P_{Imax} (cm H_2O)	10	−20 to −30	0.23–2.45†
	$P_{0.1}$/NIF (cm H_2O)	4	0.30	2.14–25.3
	CROP	2	13	1.05–19.74
Measured During 1–2 Minutes of Spontaneous Breathing	f (breaths/min)	24	30–38	1.00–3.89
	V_T (mL)	18	325–408 (4–6 mL/kg)	0.71–3.83
	f/V_T (breaths/L)	20	60–105	0.84–4.67

*A statistically significant likelihood ratio indicates that the variable predicted the outcome of ventilator discontinuation effort.
$\dot{V}_E$ = minute volume
P_{Imax} = maximum inspiratory pressure
†One study reported a likelihood ratio of 35.79
$P_{0.1}$ = airway occlusion pressure 0.1 s after the onset of inspiratory effort
NIF = negative inspiratory force
CROP = index of compliance, respiratory rate, oxygenation, and pressure (see text)
f = respiratory rate
V_T = tidal volume
f/V_T = ratio of respiratory rate to tidal volume

dence and address all the reversible aspects of the patient's load/capacity imbalances. Specific examples include lowering loads by improving respiratory mechanics (eg, reduce edema, improve airway function) and lowering metabolic demands such as $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$. The patient's capabilities also need to be optimized. Attention should be paid to nutrition, fluids, electrolytes, and potentially toxic drugs. Oxygen-delivery considerations are also important. Oxygen delivery is the product of cardiac output times hemoglobin times arterial oxygen saturation. Manipulations in any of those 3 variables can help improve oxygen delivery. The ideal hemoglobin level is not well defined, although some recommendations suggest that intensive-care patients can tolerate hemoglobin concentration as low as 7 g/dL.[27] It is not clear, however, if that recommendation should be applied to a patient with overloaded respiratory muscles. With a patient who fails an SBT, a cardiac issue that should be considered is the role of abrupt withdrawal of intrathoracic pressure, precipitating heart failure through edema formation and increase in left-ventricular afterload.[28,29]

Managing the Ventilator

The 2 goals of ventilator management for the patient who fails an SBT are (1) normalize the loading, and (2) optimize patient comfort by maximizing patient-ventilator synchrony. Along with this is the consideration of daily re-assessing, with an SBT, the need for ventilatory support.

Excessive load clearly predisposes the patient to further ventilatory-muscle fatigue.[30] In contrast, total unloading of the ventilatory muscles can predispose to atrophy and loss of ventilatory-muscle capabilities.[31] Therefore, the goal in managing these patients is to set the ventilator such that the patient performs some of the work of breathing, ideally in the near-normal range.[32] The goal, however, is more than simply reducing the total work of breathing. Specifically, the pattern of work should also be normalized as much as possible, which requires optimizing patient-ventilator synchrony.[33]

Issues involving patient-ventilator synchrony include the breath-triggering process, the flow-delivery process, and the breath-termination process. Important considerations in achieving patient-ventilator synchrony and comfort and minimizing imposed loads include sensitive/responsive ventilator-triggering systems,[34] applied positive end-expiratory pressure in the presence of a triggering threshold load from intrinsic positive end-expiratory pressure,[35] flow patterns matched to patient demand,[36,37] and appropriate ventilator cycling to avoid air trapping.[38] This usually means assisting each breath or effort with ventilatory support that "shapes" the ventilatory muscle loading to resemble normal loading—a goal that is usually best accomplished with pres-

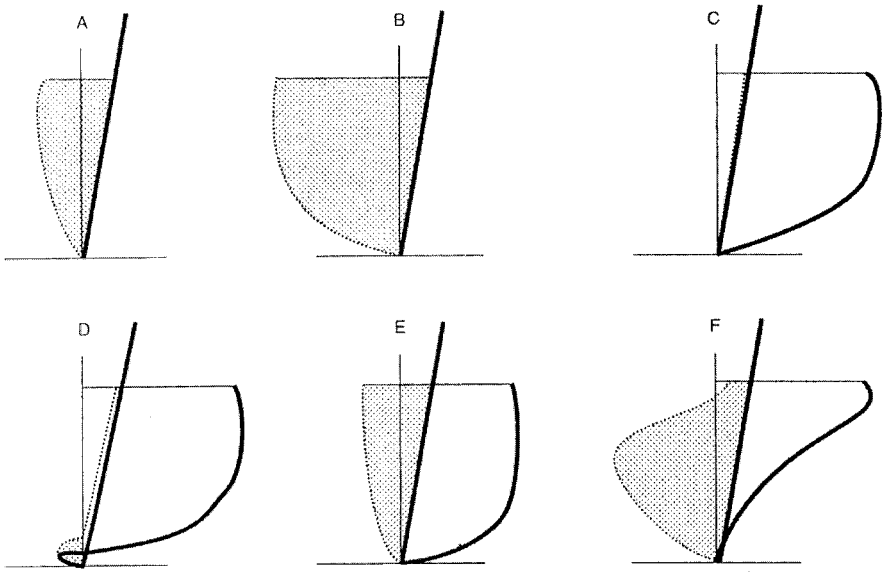

Fig. 3. Pressure-volume curves depicting various patient-ventilator interactions with a constant tidal volume. In each curve, volume is on the vertical axis and pressure is on the horizontal axis. Airway pressures are depicted by solid lines. Esophageal pressures are depicted by dashed lines. The bold, angled line directed upward and to the right from the origin reflects passive inflation esophageal pressure (chest wall compliance). The shaded area reflects patient work. A: A normally loaded spontaneous (unsupported/unassisted) breath. B: An abnormally loaded spontaneous breath. C: A ventilator-controlled breath in an abnormal patient. D: A synchronous-assisted breath designed to virtually unload an abnormal patient (only triggering load is evident). E: A synchronous-assisted breath designed to partially unload an abnormal patient; under these circumstances, synchrony is defined as a smooth airway pressure bias that converts the patient's loading pattern to a more normal configuration (ie, resembling curve A). F: A dyssynchronous-assisted breath in an abnormal patient; high-pressure patient loads exist through much of this breath because of inappropriate ventilator flow delivery. (From Reference 39, with permission.)

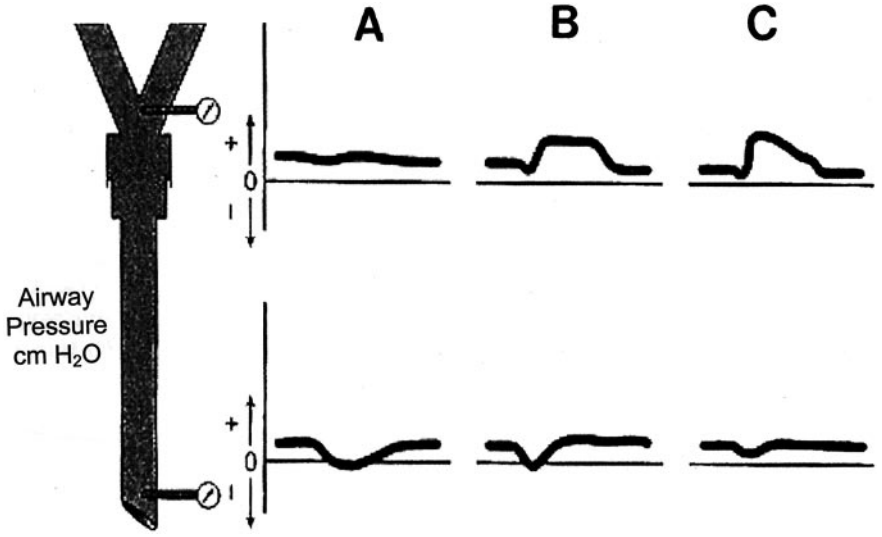

Fig. 4. Using tracheal "targeting" to provide more appropriate continuous positive airway pressure (CPAP) within the airways. The upper 3 curves represent pressures at the top of the artificial airway (ventilator circuit). The bottom 3 curves represent pressures at the bottom of the artificial airway (patient trachea). Column A: Conventional CPAP provides a constant pressure in the ventilator circuit. Patient effort to drive gas flow through the artificial airway is reflected by the downward distortion of the pressure waveform in the trachea. Column B: Pressure support ventilation involves a constant elevation of inspiratory circuit pressure, which assists the patient's effort. However, this assistance is constant and not able to meet the initial pressure requirements in the trachea. Column C: Tracheal targeting of CPAP makes the ventilator deliver a higher initial circuit pressure, which tapers off as the lungs fill. This creates a more stable CPAP pattern in the trachea. Tracheal targeting can be done directly with pressure sensors in the airway or can be approximated mathematically by the ventilator when airway resistance and flow are known (automatic tube compensation). Note that on some ventilators, automatic tube compensation, as well as CPAP, can be applied to pressure support.

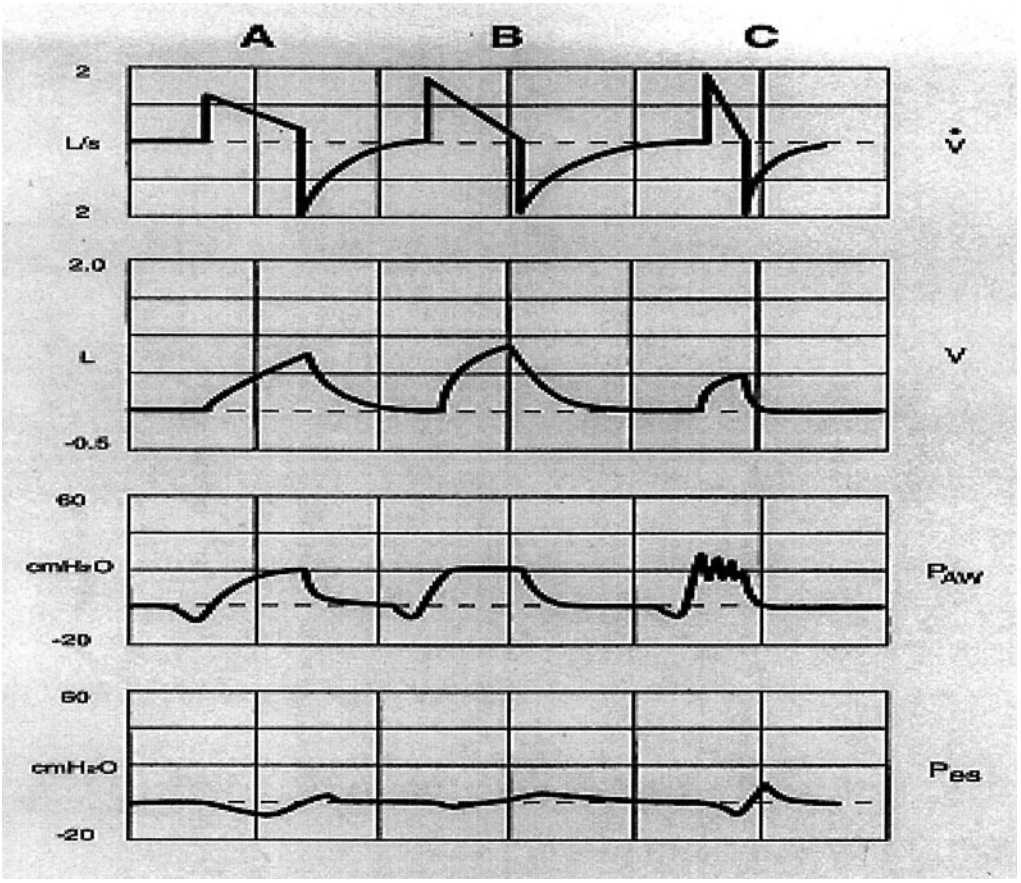

Fig. 5. Slope (rate of pressure-rise) adjustments of pressure-controlled breaths. Depicted are flow ($\dot{V}$), volume (V), airway pressure (P_{aw}), and esophageal pressure (P_{es}) waveforms from 3 breaths, each with 20 cm H_2O inspiratory pressure. In column A the pressure-rise is quite slow and is insufficient for the patient's flow demand. In column B the slope is more appropriate for patient demand; note that the patient effort in the P_{es} waveform is less and that the volume is higher than in column A. In column C the pressure rise is too fast and prompts a premature expiratory effort.

sure-controlled modes that supply assistance with virtually every breath (Fig. 3). The use of modes that involve alternating breath types (eg, synchronized intermittent mandatory ventilation), especially those that use a fixed flow and are thus unresponsive to patient effort, should be discouraged.

Two features were recently introduced that may improve patient-ventilator synchrony. The first is "tracheal targeting" of pressure. This approach in essence eliminates the endotracheal tube resistance, and can be accomplished either by using a tracheal pressure sensor or by mathematically accounting for the tube resistance in the flow-delivery algorithm. This "automatic tube compensation"[40] can create a more stable continuous positive airway pressure in the trachea (Fig. 4) or can be added to pressure-controlled breaths on some ventilators. A recent study suggested that automatic tube compensation can markedly improve patient comfort.[41]

The other recently introduced approach is adjusting the pressure rise time during pressure-controlled breaths (Fig. 5).[42] This rise-time adjustment does not affect the set pressure target, but rather only the rate of pressure-rise to that target. Conceptually, the rise time should be set such that a smooth square wave of pressure is applied to the patient (middle breath in Fig. 5). This setting is usually associated with the most comfort and the largest tidal volume. Excessive rise time can cause patient discomfort and even premature termination of the breath, whereas excessively slow rise times may not keep up with patient demand and thus create excessive imposed loading.

A new mode that is not currently available is proportional assist ventilation.[43,44] This is an assisted form of ventilation that involves a flow and volume gain on every effort. It has sometimes been likened to "power steering" and conceptually may have even greater ability to normalize load and synchronize with patient effort.

Summary

The ventilator-discontinuation process may take up to 50% of the time the patient is deemed to still require

mechanical ventilatory support. It is thus a very important time for proper assessment and management. Assessment of respiratory physiologic signals can give an insight into the loads placed on the patient and the capabilities the patient may have. Indeed, assessment of respiratory mechanics during an SBT can give valuable information on the patient's potential for withdrawal. Respiratory physiology signals can also be extraordinarily helpful in managing the patient who is not yet ready to be discontinued. Specifically, these patients require interactive forms of ventilatory support, and the clinical goal is to supply that support in a fashion that normalizes both the amount and the characteristics of patient load.

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Discussion

Campbell: Do you think the term "weaning" ought to just go away? I noticed that you didn't even use it in your talk.

MacIntyre: My short answer is yes. However, the problem with trying to get rid of the term is that everybody still uses it a lot, and communication, I think, may suffer without it. But I think the idea of gradually reducing support is, at least in the acute care setting, probably something we ought to get away from, especially if it takes us away from daily discontinuation assessments. Having said that, with long-term ventilated patients (21 days and beyond) there may be a role for gradually reducing support and getting patients more comfortable with the idea of coming off the ventilator. But in the acute care setting I'm not sure the term "weaning" has much meaning anymore, or should.

Durbin: You mentioned that the endotracheal tube itself may be a problem in providing comfortable ventilation. It also might be a problem for performing a spontaneous breathing trial. In the absence of a ventilator that can provide automatic tube compensation, would you ever consider just saying, "OK, This is close enough. Let's extubate and see."?

MacIntyre: Yes, of course. There are patients who break all the "rules" in terms of tachypnea and other predictors of extubation success/failure, and you just get that feeling that it's the tube that is causing a lot of the trouble. Therefore, an extubation trial is not a bad idea. Obviously I wouldn't do that without having good airway support ready to go and being ready to replace the tube if need be.

But even Wes Ely, who is a major proponent of protocols and a spontaneous-breathing-trial regimen, points out over and over again that there is a small but important number of patients who do just fine off the ventilator.[1] They don't look good, but you just get the feeling that the tube is causing more trouble than it's worth, and sure enough, the extubation succeeds.

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Benditt: Henning et al[1] studied patients who failed the traditional weaning attempts. If you calculate the imposed work of breathing versus the physiologic work, you *might* be able to separate those people out. Ninety-five percent of patients are extubatable in a pretty straightforward manner, but in the remaining 5% there's this issue of the extra load from the tube or whatever is a problem.

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MacIntyre: Regarding the imposed work of breathing, Mike Banner's group has been saying for years that you don't have to do an esophageal pressure measurement to find the imposed work of breathing.[1] You could actually just slip a small catheter down just past the end of the endotracheal tube and calculate what's going on in the endotracheal tube. There's one ventilator that actually has an incorporated esophageal pressure sensing site on it. You can also use it for a tracheal sensing site and make the measurements you just described.

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Dhand: There is a group of patients who look good when you extubate them, and then some patients will fail soon after you extubate them, and that

is not so difficult to understand. But there are some people who do *well* for a time and *then* they start to fail. Do you have any thoughts on what causes that and what ought to be the best strategy for detecting that?

MacIntyre: That's a tough one. Some people just take longer to get sicker, so that doesn't surprise me. Another problem is patients who really look good but can't adequately protect their airways and therefore suffer an aspiration episode at 36 or 72 hours. Those are much more problematic, because that's an airway issue. With patients who fail just because their pulmonary edema or airway obstruction hasn't cleared well enough, you can put them back on the ventilator and tune them up with a little more diuretic or bronchodilator. But the patient who aspirates is a really difficult patient, because that's an airway issue that may be much harder to manage.

Benditt: I have a potential explanation for that. John Bach believes that expiratory-muscle and cough function might be as important a predictor of extubation failure as are other factors.[1] With neuromuscular patients, such as people with Guillain-Barré syndrome in acute settings, cough function is a very important predictor of whether we can maintain them off the ventilator. If they can't cough and clear airway secretions, then the work of breathing goes up and you get into this vicious spiral. So it's possible that the late failure patients may have poor cough.

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MacIntyre: Yes, airway protection is a key assessment goal. With patients who successfully complete the spontaneous breathing trial, there's a separate set of assessments for taking the tube out. Some people have proposed putting a peak flow meter on the endotracheal tube and measuring the patient's cough. If I remember correctly, they are considered to have an adequate cough if they can generate a flow of 160 liters per minute.

There's also another test I like—the "white card" test, in which you disconnect the ventilator circuit, hold a 3×5 white card in front of the tube, and have the patient cough. If the goober hits the card, that's considered an adequate cough. If it just dribbles off the end of the tube, that's not so good.

Bigatello: Regarding patients who fail extubation later, all the possible reasons you have brought up could be summarized as "something *new* has happened to the patient." He has new secretions, a new infiltrate, or he doesn't develop enough cough to clear those new secretions.

But I think a more difficult question is, if this patient has done well from a muscular standpoint for an hour or 2 hours of a spontaneous breathing trial, there shouldn't be any reason why he should fail a day or 2 later—unless something *new* happens. So the answer is, if the patient successfully completes a spontaneous breathing trial and then fails extubation 2 days later, we have to figure out what *new* has happened to him.

MacIntyre: Most of the randomized trials that have considered ventilator-free days have used 48 hours of spontaneous breathing off the ventilator to define weaning success, the assumption being that anything occurring after 48 hours is probably a new event.

Bigatello: But I think some physiologists and clinicians would say much earlier than 48 hours. From a muscular standpoint, if you do well for an hour or 2, you should be all set. I don't know the details about the muscular physiology to confirm that, but certainly some people believe that.

MacIntyre: Maybe I'm oversimplifying this, but I see plenty of patients in acute respiratory failure who we don't intubate immediately. We think they might be OK, and we start pumping them full of antibiotics or diuretics or whatever they happen to need, and they don't get intubated until 12, 24, or even 36 hours later. So I don't have any difficulty thinking about the patient who fails at 24 or 36 hours as being somebody who slowly dwindled, just like a patient you admit to the floor who doesn't require intubation until 24 or 36 hours later.

Nilsestuen: Perhaps part of the problem with those late-failing patients is nutrition? In endurance athletic events, athletes go through cycles where they get nutritionally depleted but then they eat a power bar and they're back up and going like crazy. Could the same apply to patients who have been on mechanical ventilation and they're low on nutrition, and then they get extubated and they make it for a while but at some point they run out of energy?

Dhand: That's an interesting idea. We routinely withhold their feed before we extubate them, and they remain off their feed until they show that they are not aspirating anymore. But I'm sure sometimes something new develops, and obviously that is why they are deteriorating, though sometimes it can be subtle and you can't pick out what happened.

The patient was doing well for 2 or 3 hours, and then suddenly he returns to rapid shallow breathing and requires reintubation—and that might be anywhere from 6 to 36 hours after what looked like a good phase. It often remains unknown what really happened to that patient.

Pierson:* I think more of our Journal Conferences have been related to mechanical ventilation than to any other general topic of respiratory care, and I believe at every Journal Conference related to mechanical ventilation for about the last 20 years, one or more of the speakers has said, "Proportional assist ventilation is a really neat idea, kind of like power steering for the respiratory system, and it's not quite available yet, but it will be a really good deal." Now, I wonder if 20 years from *now* we will still have speakers saying that proportional assist ventilation is going to be really neat when it appears?

Hess: And we hope that will be you, Neil.

MacIntyre: Actually, Warren Sanborn can answer that question best. Will we by saying it 20 years from now, Warren?

Sanborn: I agree with David. It has to get out before we can say it's out.

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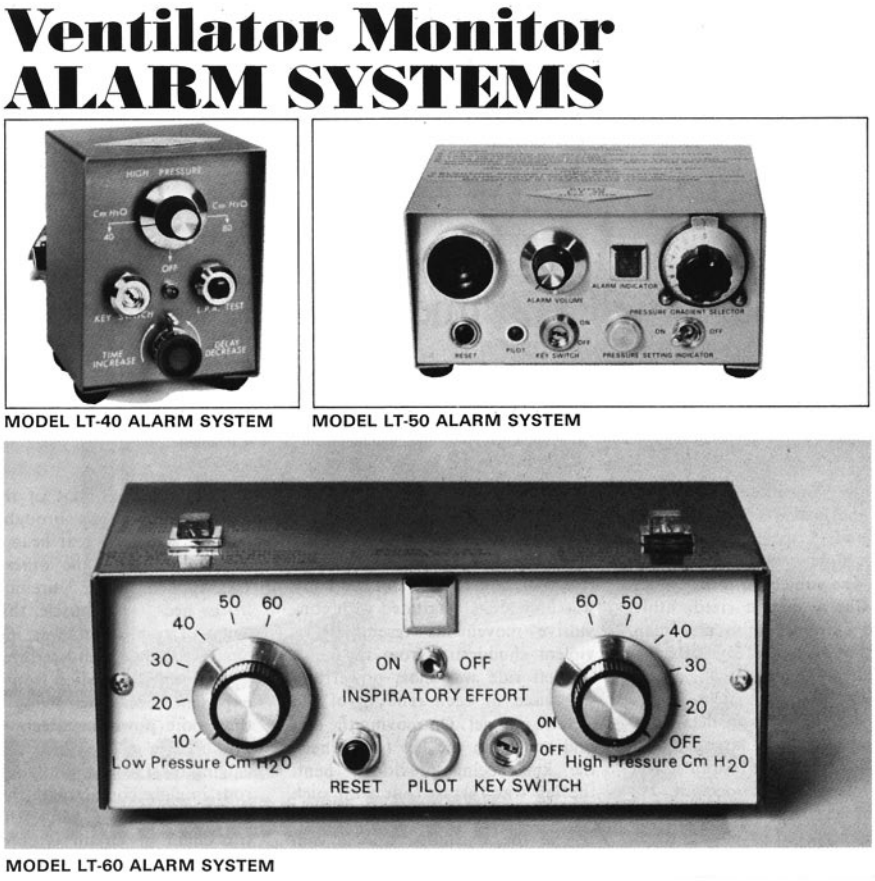

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