



REVIEW

## Recent advances in mechanical ventilation

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**ABSTRACT:** Important advances have been made over the past decade towards understanding the optimal approach to ventilating patients with acute respiratory failure. Evidence now supports the use of noninvasive positive pressure ventilation in selected patients with hypercapnic respiratory failure and chronic obstructive pulmonary disease, cardiogenic pulmonary edema, and for facilitating the discontinuation of ventilatory support in patients with chronic pulmonary disease. The concept of a lung protective ventilatory strategy has revolutionized the management of the acute respiratory distress syndrome. The process of liberation from mechanical ventilation is becoming more standardized, with evidence supporting daily trials of spontaneous breathing in all suitable mechanically ventilated patients. This article critically reviews the most important recent advances in mechanical ventilation and suggests future directions for further research in the field.

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In the past decade, remarkable progress has been made toward understanding the optimal use of noninvasive ventilation, the management of the acute respiratory distress syndrome, and approaches to discontinuation of ventilatory support. This article reviews the evidence behind the most important recent developments in mechanical ventilation and practical issues in the application of this new data. Although this article is not a systematic review by definition, over 300 articles published within the past decade were evaluated via MEDLINE searches, review of Cochrane Library articles, and examination of selected articles' bibliographies; over 150 articles were considered in detail for inclusion. The goal of this article is to provide a concise review of landmark, representative or particularly illustrative recent trials in ventilator management and their contributions to current clinical practice.

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Although important advances have been made in recent years in the area of prevention of ventilator-associated pneumonia, this topic has been recently reviewed elsewhere and will not be covered in this article.<sup>1,2</sup>

### Noninvasive positive pressure ventilation

Noninvasive positive pressure ventilation, commonly referred to as bi-level positive airway pressure, has gained broader acceptance in recent years as studies have demonstrated efficacy in several clinical settings. The evidence most strongly supports the use of noninvasive ventilation in acute exacerbations of chronic obstructive pulmonary disease, cardiogenic pulmonary edema, immunocompromised patients with acute respiratory failure, and selected patients with difficulty weaning from the ventilator. Although noninvasive ventilation has been proven effective in various causes of chronic respiratory insufficiency, this article will only address its applications in the acute hospital setting.<sup>3</sup>

**Table 1** Contraindications to use of noninvasive ventilation

Impending cardiovascular collapse or respiratory arrest
Excessive secretions or massive upper gastrointestinal bleeding
Upper airway obstruction
Recent facial, upper airway, or upper gastrointestinal surgery
Patient unable to protect airway, including altered mental status
No monitored beds available (relative)

## Introduction to noninvasive ventilation

At the outset, a few epidemiologic issues should be considered. First, nearly all studies of noninvasive ventilation are by necessity unblinded, introducing the possibility of bias. Second, most of the studies are small, and their relative contributions should be weighed as such. Finally, many of the studies in this field suffer from a heterogeneity of underlying disease, whether by design or necessity, making the results all the more difficult to interpret or apply with confidence.

In this review, as in most of the literature on this subject, the term “noninvasive ventilation” will be used to refer to positive pressure ventilatory support delivered through a nasal or full face mask with different levels of pressure support set for inspiration and expiration (frequently 10–15 and 5–8 cm H<sub>2</sub>O); it may be delivered with or without a backup rate. This type of ventilation should be clearly distinguished from continuous positive airway pressure, in which a constant level of pressure support is delivered without regard for the respiratory cycle.

Patients should be carefully assessed for possible contraindications to the use of noninvasive ventilation before its implementation (Table 1). When employed in the care of patients with acute respiratory failure, noninvasive ventilation should always be used in a highly monitored setting such as an intensive care unit, step-down unit, or emergency department. Noninvasive ventilation should not be used in patients with impending cardiovascular collapse or respiratory arrest, because those patients will soon require endotracheal intubation. Patients who are unable to protect their airway, usually from altered mental status, should not receive noninvasive ventilation. Although it may be tempting to use noninvasive ventilation in this setting, particularly when hypercarbia is present, such patients are at very high risk for failure of noninvasive ventilation. Other important issues in the management of patients on noninvasive ventilation such as patient-ventilator interface, cost-benefit analyses, and specific ventilator settings are beyond the scope of this article and will not be addressed.<sup>4</sup>

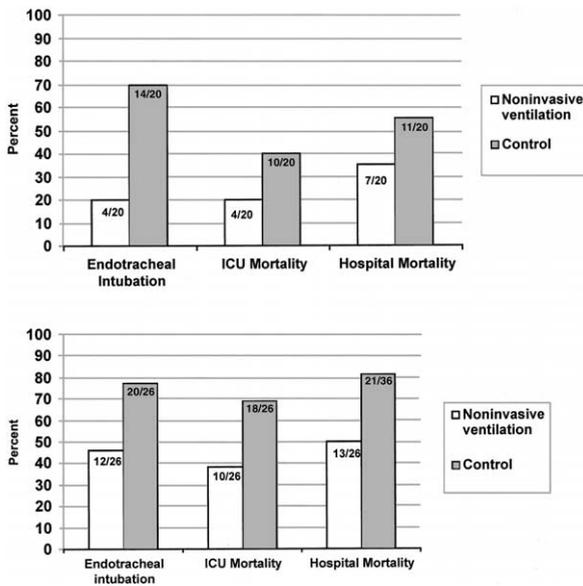
## Noninvasive ventilation in chronic obstructive pulmonary disease

Noninvasive ventilation was first and has been most extensively demonstrated to be effective in acute, severe

exacerbations of chronic obstructive pulmonary disease. Many randomized controlled trials have compared noninvasive ventilation to usual care in this setting and found noninvasive ventilation to be associated with a reduced rate of endotracheal intubation.<sup>5-9</sup> In addition, most published trials have suggested a reduction in mortality with noninvasive ventilation compared with conventional therapy.<sup>5,8-10</sup> In the past 2 years, 3 systematic reviews were published confirming that noninvasive ventilation reduces in-hospital mortality and decreases the need for intubation in patients with acute, severe chronic obstructive pulmonary disease exacerbations.<sup>11-13</sup> One meta-analysis suggested that most of the benefits of noninvasive ventilation extend to those patients with severe chronic obstructive pulmonary disease exacerbations as measured by a pH of <7.3;<sup>12</sup> this finding was not, however, confirmed in a more recent systematic review of 14 randomized controlled trials.<sup>13</sup> In addition, multiple articles have noted that the response to noninvasive ventilation within the first 2 hours as measured by improvements in pH and PaCO<sub>2</sub> is predictive of the modality’s success or failure.<sup>14,15</sup> This concept may also be applied to the use of noninvasive ventilation in other disorders.<sup>16</sup>

## Noninvasive ventilation in immunosuppressed patients with acute respiratory failure

Noninvasive ventilation may be useful in patients who are profoundly immunosuppressed, particularly those who have undergone solid organ transplantation or those with hematologic malignancy, in whom mortality after endotracheal intubation is particularly high. One study randomized 40 patients with acute hypoxemic respiratory failure after solid organ transplant to conventional treatment, including high flow oxygen by face mask, or noninvasive ventilation.<sup>17</sup> Patients randomized to noninvasive ventilation had a lower rate of endotracheal intubation, shorter intensive care unit stays, and lower intensive care unit mortality, although in-hospital mortality did not differ significantly between the two groups (Figure 1). A second study also randomly assigned patients to either noninvasive ventilation or usual care but included febrile immunosuppressed patients with acute hypoxemic respiratory failure and pulmonary infiltrates.<sup>18</sup> Most patients in the study were immunosuppressed as a result of therapy for hematologic malignancy. In this study sample, intermittent noninvasive ventilation was associated with lower rates of endotracheal intubation, serious complications, and intensive care unit and all-cause mortality (Figure 1). Although these 2 studies were fairly small and captured slightly different patient samples, taken together they suggest that noninvasive ventilation may be beneficial in severely immunocompromised patients with acute hypoxemic respiratory failure.



**Figure 1** Outcomes of noninvasive ventilation versus usual medical care in immunocompromised adults with acute respiratory failure. In Antonelli et al.,  $P = 0.002$  for endotracheal intubation;  $P = 0.05$  for ICU mortality;  $P = 0.17$  for hospital mortality. In Hilbert et al.,  $P < 0.03$  for all comparisons between noninvasive ventilation and control arm. Data from Antonelli et al., 2000 (top);<sup>17</sup> Hilbert et al., 2001 (bottom).<sup>18</sup>

## Noninvasive ventilation in acute hypoxemic respiratory failure

Noninvasive ventilation has also been evaluated as a potential therapy for acute hypoxemic respiratory failure of any etiology. Put differently, what would happen if every patient presenting with respiratory failure and moderate to severe hypoxemia received a trial of noninvasive ventilatory support?

The first major randomized trial in this patient population studied 41 patients with a room air  $\text{PaO}_2$  of  $<60$  mm Hg who were randomized to noninvasive ventilation or conventional treatment.<sup>19</sup> There were no significant differences in rates of endotracheal intubation, length of intensive care unit stay or mortality, although a post hoc analysis indicated that hypercapnic patients seemed to benefit from noninvasive ventilation. A subsequent similar study of 61 patients who were either hypoxemic ( $\text{PaO}_2:\text{FiO}_2 < 200$ ) or hypercarbic (excluding only patients with an arterial pH  $< 7.2$ ) found that noninvasive ventilation was associated with a decreased rate of endotracheal intubation compared with usual medical care but had no significant impact on mortality.<sup>20</sup> One of these studies reported that patients with hypercarbia appeared to benefit most from noninvasive ventilation,<sup>19</sup> whereas the other found that those with hypoxia but not chronic obstructive pulmonary disease benefited most.<sup>20</sup> However, these conclusions were drawn from post hoc sub-group analyses in small numbers of patients.

The largest and most rigorous study examined 105 patients with acute hypoxemic respiratory failure ( $\text{PaO}_2$

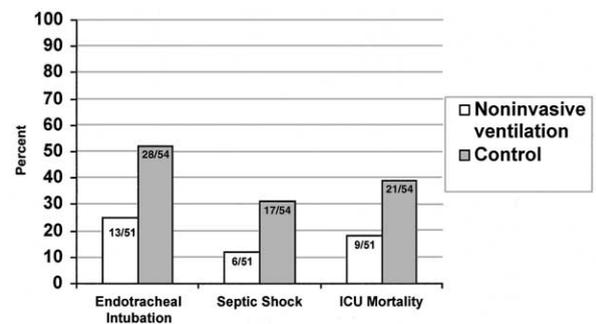
$< 60$  mm Hg or oxyhemoglobin saturation  $< 90\%$  on oxygen by face mask) who were assigned randomly to noninvasive ventilation or usual care;<sup>21</sup> patients with hypercapnia were excluded. Marked reductions in the rates of endotracheal intubation, septic shock, intensive care unit and cumulative 90-day mortality were demonstrated in those patients treated with noninvasive ventilation (Figure 2).

A different question is whether noninvasive ventilation can be utilized in patients who would otherwise need intubation for acute hypoxemic respiratory failure. This question was studied in 64 patients, excluding patients with chronic obstructive pulmonary disease, randomized to noninvasive ventilation or endotracheal intubation.<sup>22</sup> The authors defined acute hypoxemic respiratory failure as the acute onset of tachypnea and a  $\text{PaO}_2:\text{FiO}_2$  ratio of less than 200. Patients randomized to noninvasive ventilation had less pneumonia and sinusitis and shorter intensive care unit stays; however, no mortality difference was found.

In sum, while some evidence suggests that noninvasive ventilation may be beneficial in the setting of acute hypoxemic respiratory failure, lingering doubts about its utility persist, in part due to the variable rigor of the existing literature on the subject and in part due to the heterogeneity of the patients studied. A large, multicenter trial of noninvasive ventilation utilizing objective criteria for hypoxemia and specifically excluding patients with cardiogenic pulmonary edema and chronic obstructive pulmonary disease would clarify this issue.

## Noninvasive ventilation versus continuous positive airway pressure in cardiogenic pulmonary edema

Continuous positive airway pressure has demonstrated efficacy in cardiogenic pulmonary edema, reducing the rate of endotracheal intubation and showing a trend in a meta-analysis toward decreasing mortality.<sup>23</sup> Although the data on bi-level noninvasive ventilation is more mixed, it may be beneficial in this setting as well. One early study demonstrated an increased rate of acute myocardial infarction in patients with cardiogenic pulmonary edema treated with



**Figure 2** Outcomes of noninvasive ventilation compared with usual medical care in patients with acute hypoxemic respiratory failure.  $P < 0.03$  for all comparisons between noninvasive ventilation and usual medical care. Data from Ferrer et al., 2003.<sup>21</sup>

**Table 2** Low tidal volume and plateau pressure limited ventilation for acute lung injury and the acute respiratory distress syndrome: protocol summary

Variable	Protocol
Ventilator mode	Volume assist-control
Tidal volume	≤6 mL/kg predicted body weight
Plateau pressure	≤30 cm H <sub>2</sub> O
Ventilation set rate/pH goal	6–35/min, adjusted to achieve arterial pH ≥7.30 if possible
Inspiratory flow	Adjust flow to achieve ratio of duration of inspiration to expiration of 1:1–1:3
Oxygenation goal	55 ≤ PaO <sub>2</sub> ≤ 80 mm Hg or 88 ≤ oxyhemoglobin saturation by pulse oximetry ≤ 95%
Fraction of inspired oxygen/ Positive end-expiratory pressure combinations	0.3/5, 0.4/5, 0.4/8, 0.5/8, 0.5/10, 0.6/10, 0.7/10, 0.7/12, 0.7/14, 0.8/14, 0.9/14, 0.9/16, 0.9/18, 1.0/18, 1.0/22, 1.0/24. Further increases in positive end-expiratory pressure to 34 cm H <sub>2</sub> O were allowed but not required.
Weaning	Attempts to wean by pressure support required when the fraction of inspired oxygen was ≤0.40 and the positive end-expiratory pressure was ≤8

Adapted with permission from Brower et al., 2001.<sup>55</sup>

bi-level noninvasive ventilation, generating anxiety about further trials in this area.<sup>24</sup> Since then, however, several trials have been published that both refute the increased risk of myocardial infarction with noninvasive ventilation and suggest some benefit. Two small randomized controlled trials of about 40 patients each found that noninvasive ventilation (as compared with usual medical care, including oxygen) reduced the rate of intubation in patients with severe cardiogenic pulmonary edema; neither study found an increased rate of myocardial infarction in patients on noninvasive ventilation.<sup>25,26</sup> Recently, a larger multicenter trial randomizing 130 patients with cardiogenic pulmonary edema to bi-level noninvasive ventilation or conventional therapy found that noninvasive ventilation was associated with faster improvements in oxygenation, respiratory rate, and dyspnea; there was no difference between the two groups in the rate of intubation, hospital mortality, length of stay, or myocardial infarction.<sup>27</sup> Although bi-level and continuous positive airway pressure have been compared with each other in 2 small studies and several unpublished abstracts, a definitive direct comparison between the 2 approaches is still lacking.<sup>24</sup>

### Noninvasive ventilation in other causes of acute respiratory failure

Although noninvasive ventilation might theoretically be of benefit in other cases of acute respiratory failure, the evidence supports only the uses described above. Insufficient evidence exists to recommend noninvasive ventilation for acute respiratory failure associated with cystic fibrosis or restrictive lung disease or in the setting of acute lung injury or the acute respiratory distress syndrome.<sup>16</sup> In other instances, noninvasive ventilation seems clearly not to be of benefit. For one, noninvasive ventilation has been examined in the setting of severe community-acquired pneumonia and was not beneficial, except in those patients with an accompanying chronic obstructive pulmonary disease exacerbation.<sup>28</sup> Similarly, noninvasive ventilation was of no benefit

when applied to patients with post-extubation respiratory distress and may even be harmful when applied in lieu of endotracheal intubation in this setting.<sup>29,30</sup>

### Acute respiratory distress syndrome

The standard of care for mechanical ventilation in patients with acute lung injury and the acute respiratory distress syndrome has undergone a transformation over the past decade. The prior standard of ventilation emphasized higher tidal volumes (12 mL/kg ideal body weight) because this approach was associated with better oxygenation. However, several animal studies suggested that these higher tidal volumes, which were associated with higher inspiratory airway pressures, may aggravate the initial lung injury.<sup>31–34</sup> In 2000, the Acute Respiratory Distress Syndrome Network published the largest study to date in this patient population, comparing a low tidal volume ventilation strategy with standard of care.<sup>35</sup> The study randomized 861 patients to either a low tidal volume (6 mL/kg predicted body weight) ventilation protocol (Table 2) with a plateau pressure of less than 30 cm H<sub>2</sub>O or a conventional treatment arm (12 mL/kg predicted body weight). After an interim analysis, the trial was stopped early due to a significantly lower mortality in the low tidal volume, plateau pressure limited group (31% vs. 40%,  $P = 0.007$ ). A subsequent secondary analysis of the data from this trial found that the benefit of low tidal volume ventilation extended to patients with different clinical risk factors for the acute respiratory distress syndrome.<sup>36</sup> Since that time, low tidal volume ventilation per the Acute Respiratory Distress Syndrome Network protocol has become a standard for many patients with this clinical disorder.

Building on this study, the Acute Respiratory Distress Syndrome Network has recently reported the results of another large study designed to examine whether higher levels of positive end-expiratory pressure confer addi-

tional benefit when used in conjunction with a low tidal volume strategy.<sup>37</sup> Higher positive end-expiratory pressure levels might theoretically be beneficial by reducing regions of nonaerated lung and decreasing the need for supplemental oxygen, thereby reducing oxygen toxicity. Although designed to reach an enrollment of 750 patients, the trial was stopped after the enrollment of 549 patients given the equivalence of the 2 treatment arms and a very small chance of finding a significant effect. While no benefit to a high positive end-expiratory pressure strategy was found, this trial did confirm the benefit of a low tidal volume and plateau pressure limited strategy, finding a mortality rate of 26% across the board in acute respiratory distress syndrome, notably lower than the mortality rates in this condition before the low tidal volume era.

While low tidal volume ventilation has gained widespread acceptance as a lung protective ventilatory strategy for the acute respiratory distress syndrome, several other therapies have been investigated as potential accessory modalities for patients with particularly severe disease. Nitric oxide, thought to perhaps ameliorate ventilation-perfusion mismatch via its vasodilatory properties, has been employed as an adjunct to mechanical ventilation in severe acute respiratory distress syndrome. A recent systematic review of nitric oxide in acute hypoxemic respiratory failure (predominantly the acute respiratory distress syndrome or acute lung injury) found only 5 trials that met standards for inclusion in the review and found no impact on mortality; however, there was a transient improvement in oxygenation.<sup>38</sup> Similarly, prone ventilation has been considered a rescue option for patients with the acute respiratory distress syndrome who are particularly difficult to oxygenate. In the largest, most rigorous trial to date of this technique in patients with acute lung injury, 6 hours per day of prone positioning was associated with a transient improvement in oxygenation but no mortality benefit.<sup>39</sup> Finally, high-frequency oscillatory ventilation, a technique in which patients are ventilated with very low tidal volumes at 4–250 times usual respiratory rates, has been shown in observational studies to lead to transient improvements in oxygenation. However, a recent systematic review concluded that there was insufficient evidence to recommend its use in the acute respiratory distress syndrome.<sup>40</sup> Thus, although nitric oxide, prone positioning, and high-frequency ventilation may improve oxygenation in patients with the acute respiratory distress syndrome, at this time the evidence does not support their routine use, and none of these strategies have yet demonstrated a mortality benefit.

## Discontinuation of ventilatory support and weaning

The timing of and approach to discontinuation of mechanical ventilation are among the most extensively stud-

**Table 3** Suggested criteria for consideration of extubation readiness

Underlying disease process that necessitated intubation is improving
Hemodynamically stable
Appropriate mental status
Capable of upper airway protection
Ventilator settings: fraction of inspired oxygen $\leq 0.40$ ; positive end-expiratory pressure $\leq 8$ cm H <sub>2</sub> O

ied and controversial areas of modern ventilator management. The basic questions investigators have been attempting to answer are the following: when should a patient be evaluated for possible extubation, and how should their readiness for extubation be assessed?

## When to consider extubation, and the spontaneous breathing trial

Contemplating tests of readiness for extubation presumes that the patient has met multiple preconditions (Table 3): the underlying disease process that necessitated intubation is improving; the patient is hemodynamically stable and neurologically capable of spontaneous breathing and airway protection; and the patient is able to oxygenate well on minimal ventilatory support.<sup>41</sup> Once these conditions have been met, the patient should undergo a spontaneous breathing trial with minimal ventilatory support; measurements made during that trial can then be used to evaluate the likelihood of successful extubation. The spontaneous breathing trial may be conducted using either a T-piece or low levels of continuous positive airway pressure and need be no longer than 30 minutes.<sup>42,43</sup> In a landmark trial published in 1996, implementation of a protocol in which all patients on mechanical ventilation were screened daily for appropriateness of a spontaneous breathing trial decreased the total number of ventilated days as well as the complications of mechanical ventilation, including reintubation.<sup>44</sup> Later trials subsequently confirmed that these spontaneous breathing trial protocols can be driven by nonphysician personnel (eg, respiratory therapists) with no loss of safety or efficacy.<sup>45</sup>

## Predictors of successful extubation

Once a spontaneous breathing trial is performed, how should its results be judged? Perhaps the best known and most widely used measure of extubation readiness is the respiratory rate to tidal volume ratio, also known as the rapid shallow breathing index or the Yang-Tobin index.<sup>46</sup> In their well-known study, Yang and Tobin challenged the traditional markers of extubation readiness, minute ventilation, and maximal inspiratory pressure, and proposed the rapid shallow breathing index as an alternative.

**Table 4** Predictors of successful extubation

Parameter	No. studies	Threshold values	Likelihood ratio range*
Measured on ventilator			
Minute ventilation	20	≤10–15 L/min	0.8–2.4
Negative inspiratory force	10	≥−20 to −30 cm H <sub>2</sub> O	0.2–35.8
Maximal inspiratory pressure	16	≥−15 to −30 cm H <sub>2</sub> O	1.0–3.0
Mouth occlusion pressure 0.1 seconds after onset of inspiratory effort/maximal inspiratory pressure	4	≤0.30	2.1–25.3
CROP score (index incorporating compliance, rate, oxygenation, and pressure)	2	≥13	1.1–19.7
Measured during spontaneous breathing			
Respiratory rate	24	≤30–38 breaths/min	1.0–3.9
Tidal volume	18	≥325–408 mL (4–6 mL/kg)	0.7–3.8
Respiratory rate/tidal volume	20	≤60–105	0.8–4.7

Adapted with permission from MacIntyre et al., 2001.<sup>50</sup>

\*The range of likelihood ratios reported for the given parameter in published studies.

They defined the index as respiratory rate over tidal volume (in liters), measured during spontaneous breathing for 1 minute; low values are thereby derived from a low respiratory rate and high tidal volume. Using a cutoff for the rapid shallow breathing index of ≤105 maximized sensitivity and specificity. Their finding has since been confirmed in other prospective studies, including one that suggested that the rapid shallow breathing index measured after 30 minutes of minimal support outperforms the rapid shallow breathing index measured immediately after support is decreased.<sup>47</sup> In one of a series of systematic reviews on the topic of ventilator discontinuation published in 2001, the rapid shallow breathing index and respiratory rate alone were found to have the largest area under the receiver-operator curve, suggesting the best combination of sensitivity and specificity.<sup>48</sup>

However, the rapid shallow breathing index is by no means the only well-studied marker of extubation readiness; in fact, a 1999 systematic review from McMaster University found 66 measures with at least some evidence to support their use.<sup>49</sup> Of those 66 proposed measurements, 8 were found to have consistently positive (but low) likelihood ratios for predicting successful extubation (Table 4).<sup>50</sup> Be-

cause of the plethora of potential markers and the variable performance of any one of those markers in an individual patient, the 2001 consensus statement on this subject by the American College of Chest Physicians recommended a more holistic approach to interpretation of the success or failure of a spontaneous breathing trial, incorporating both objective measures of clinical stability and subjective assessments of the patient's comfort, work of breathing, and mental status<sup>50</sup> (Table 5).

### Noninvasive ventilation and ventilator discontinuation

In the past several years, several studies have examined the potential role of noninvasive ventilation in ventilator discontinuation, particularly for patients with acute or chronic respiratory failure secondary to chronic obstructive pulmonary disease. The first major study in this area randomized 50 patients with a chronic obstructive pulmonary disease exacerbation who had failed a spontaneous breathing trial to either extubation and immediate noninvasive ventilation, or continued daily spontaneous breathing

**Table 5** Subjective and objective criteria for tolerance of a spontaneous breathing trial

Criteria	Description
Objective measurements	Adequate gas exchange (oxyhemoglobin saturation ≥88% to 90% or PaO <sub>2</sub> ≥55 mm Hg on ≤40% inspired oxygen; increase in PaCO <sub>2</sub> ≤10 mm Hg) Hemodynamic stability (failure to develop new tachycardia, hypertension or hypotension on spontaneous breathing trial; no pressors required) Stable ventilatory pattern (respiratory rate <30–35 breaths/min)
Subjective clinical assessments	Change in mental status (eg, somnolence, coma, agitation, anxiety) Diaphoresis Signs of increasing work of breathing (use of accessory muscles, abdominal paradox) Onset or worsening of discomfort

Adapted with permission from MacIntyre et al., 2001.<sup>50</sup>

trials.<sup>51</sup> Noninvasive ventilation was associated with a lower number of patients requiring ventilatory support at 3 weeks and lower 60-day mortality. A second similar study of 33 patients with underlying lung disease (mostly chronic obstructive pulmonary disease) found that noninvasive ventilation shortened the duration of intubation but increased the total duration of ventilatory support without impacting mortality.<sup>52</sup> In a third similarly designed, recently published trial of 43 patients with underlying lung disease (the majority of which was chronic obstructive pulmonary disease), noninvasive ventilation was associated with significant reductions in duration of invasive ventilation, intensive care and hospital length of stay, intensive care unit mortality, serious complications of mechanical ventilation, and cumulative 90-day survival.<sup>53</sup> A meta-analysis of these 3 studies and 2 smaller studies found that noninvasive ventilation in this setting seems to decrease mortality, hospital length of stay, incidence of ventilator-associated pneumonia, and total duration of mechanical ventilation.<sup>54</sup>

Although the results of these trials are noteworthy and largely concordant, some important caveats remain. Patients enrolled in these trials were by definition those that had failed spontaneous breathing trials; therefore, those randomized to the “conventional weaning” arms were consigned to undergo tests that they had already been shown not to pass. In other words, perhaps noninvasive ventilation is successful in this setting in part because it mandates extubating patients who could be successfully extubated but did not meet conventional extubation criteria, which may be inappropriate for patients with chronic lung disease. Secondly, patients in these studies were both carefully selected as otherwise good candidates for extubation and closely monitored for signs of impending need for reintubation, important issues to consider in the practical application of this data.

## Conclusions

Major advances have been made in the past decade in determining the optimal ventilatory strategy for some of the most common causes of acute respiratory failure. Noninvasive ventilation can be strongly recommended as an effective therapy for severe chronic obstructive pulmonary disease exacerbations and cardiogenic pulmonary edema; it should be considered as potentially beneficial in acute respiratory failure in immunocompromised patients and as a weaning modality in patients with underlying chronic lung disease. Lung protective ventilation with a low tidal volume and plateau pressure limited strategy has revolutionized the management of the acute respiratory distress syndrome with an associated sharp decrease in mortality, while adjunctive therapies like nitric oxide and high-frequency ventilation have not reduced mortality. Mechanically ventilated patients should be evaluated on a daily basis for the appropriateness of a spontaneous breathing trial, and the success or

failure of the trial should be judged based both on subjective criteria and objective measurements like the rapid shallow breathing index.

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