

REVIEW SERIES

The pulmonary physician in critical care • 11: Critical care management of respiratory failure resulting from COPD

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Thorax 2002;57:1079–1084

Survival to hospital discharge of patients suffering exacerbations of COPD is better than other medical causes for ICU admission. Although non-invasive ventilation (NIV) may prevent progression to tracheal intubation, its failure in most cases should lead to a period of controlled mechanical ventilation aiming for early extubation, possibly supported by NIV and tracheostomy if this fails. A greater understanding of the physiological principles behind ventilatory support of patients with COPD should reduce patient-ventilator disharmony and avoid the excessive use of sedation. The risk of nosocomial infection increases with the length of time the patient remains in the ICU and commonly further prolongs the period of ventilator dependency. Weaning centres with an emphasis on general rehabilitation may offer the best support for such individuals.

term, combined with insufficient provision of critical care facilities in the UK has limited access to the ICU. This was especially so when “end stage” COPD was considered to be present. This might be inferred if there is no apparent precipitating cause such as pneumonia or pneumothorax. In these circumstances, as there is no apparent reversible cause, it could be argued that recovery is unlikely. Survival following mechanical ventilation (MV) is, however, better in the absence of a major precipitating cause.¹ This apparent paradox probably arises because patients who require a longer period of ventilatory support—which will be the case if, for instance, pneumonia is present—are exposed to the secondary complications of ICU admission. Just as survival in the acute respiratory distress syndrome is more closely related to associated multi-organ failure or nosocomial infection than to the severity of the initial lung injury,⁶ so the complications that arise during the ICU stay of a patient with COPD may have a greater influence on outcome than the severity of airflow obstruction. Nevertheless, age, severity of airflow obstruction, co-morbidity, and general pre-admission health status are important in determining survival.^{1 7–10}

Acute episodes of respiratory failure in patients with chronic obstructive pulmonary disease (COPD) account for 5–10% of emergency medical admissions to hospital and failure of first line treatment therefore is a common reason for referral to the intensive care unit (ICU). In recent years such patients have become better characterised and the driving force in this has often been the need to define those suitable for treatment by non-invasive ventilation (NIV) rather than intubation. Bacterial infection has traditionally been considered aetiologically dominant but its importance has been overstressed. Heart failure, cardiac arrhythmia, pulmonary embolism, and “uncertain causes” are common.¹ Acute deterioration precipitated by viral infection is also increasingly recognised.² Consideration of all the ways in which the co-morbidity of COPD influences ICU management is beyond the scope of this review. Its presence affects both ventilator strategy and the outcome of patients after elective or emergency surgery. COPD also contributes to delay in the weaning of patients from mechanical ventilation.^{3–5} This review will therefore focus on the common problem of the patient with respiratory failure arising from an exacerbation of chronic airflow obstruction.

There are national and international differences in both the institution and withdrawal of MV in COPD. The prevalence of COPD in the community and admission practices will determine how costly ICU management of COPD will be locally. For instance, in one UK report withdrawal of treatment was the most common cause of death,¹¹ while in an Italian study two thirds of patients were still being actively weaned 60 days after admission.¹² The European Human Rights Act¹³ might increase the pressure to admit patients to the ICU and there is some evidence that this is occurring. This is probably desirable in the UK where, in the past, respiratory physicians may not have sufficiently championed the cause of the patient with COPD. Short term survival following invasive MV can be expected in 63–86%,^{1 7–10 14} a figure well above that for unplanned medical admissions. Although long term survival is less good—in one study 52%, 42%, and 37% at 1, 2 and 3 years, respectively¹⁴—this is similar to survival following myocardial infarction when left ventricular dysfunction is present. A better long term outcome is reported following an episode of respiratory failure managed with NIV.^{15–17} It is also possible that survival may subsequently be improved by domiciliary NIV in selected patients,¹⁸ although interim results of controlled trials of domiciliary ventilation have been negative.

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In the past the perception that survival of patients with COPD was poor, especially long

Box 1 Mechanisms involved in decompensated COPD

- Increased resistive load
 - Widespread airflow obstruction
- Decreased respiratory system compliance
 - High lung volume
- Dynamic hyperinflation
 - Shortened expiratory time
 - Poorly emptying lung units
- Reduced power of respiratory pump
 - Impaired mechanical efficiency
 - Effects of acidosis and hypoxaemia
- Impaired drive
 - Sleep deprivation
 - CO₂ narcosis

Despite reasonable survival to hospital discharge, the decision to admit to the ICU in advanced cases is frequently difficult¹⁹ and involves balancing health status with an estimate of expectation of survival and quality of life issues. This often needs to be established on the basis of scant information and in the face of sometimes unreasonable expectations from distraught relatives. Furthermore, these difficult decisions commonly fall on the least experienced doctors as hospital presentation is often “out of hours”. A recent report found that co-morbidity, need for MV beyond 72 hours, and failure following extubation were strong predictors of a poor outcome.¹⁰ Survival to discharge for the whole group (166 patients) was 72% and increased to 88% in those without co-morbidity. This report therefore suggests that an active policy, with early review once MV has been initiated, may be appropriate. Ideally, the value and complications of MV should be discussed prior to the medical emergency.²⁰ Such discussion may be difficult to initiate in the outpatient clinic and primary care is probably a better setting. The recovery period following a period of MV is an ideal opportunity and it is well suited for inclusion in rehabilitation programmes.²¹

RECOGNISING THE NEED FOR VENTILATORY SUPPORT

The recognition that MV is required is commonly an “end of the bed” assessment by an experienced clinician. No one clinical feature or investigation is absolute except respiratory arrest or loss of consciousness.¹⁹ In most cases failure to improve with medical treatment in the hours following admission triggers ICU referral. Late failure several days after admission to hospital is less common and may indicate a worse prognosis.²² In many, a downward spiral of increasing carbon dioxide retention and sleep deprivation eventually leads to impaired consciousness as the ventilatory pump fails to cope with the increased respiratory “load”. The mechanisms involved in decompensated COPD (box 1) are an increase in airflow resistance related to widespread bronchial wall inflammation, and progressive dynamic hyperinflation that maximises expiratory flow at the cost of increasing inspiratory muscle work.^{23–24}

In addition to this resistive work, reduced respiratory system compliance associated with operating towards the top of the pressure-volume curve is combined with decreased mechanical efficiency of the diaphragm at high lung volumes. Premature expiratory closure of small airways, either because of lack of support in emphysema or functional narrowing from airway inflammation or smooth muscle contraction, results in impaired gas exchange. Positive end expiratory intrathoracic pressure—so called intrinsic PEEP—further loads the inspiratory muscles. Recruitment of abdominal muscles during expiration is common. This may not increase expiratory airflow as dynamic expiratory resistance, the choke effect, may occur and will then only accentuate gas trapping.

Sudden relaxation of abdominal muscle contraction at end expiration, a feature of the failing patient, may be employed to unload the inspiratory muscles by natural recoil at the start of inspiration.²³ Additionally, as respiratory rate increases, gas exchange is further impaired by increased dead space ventilation and further muscle loading is the result of additional dynamic hyperinflation as expiratory time shortens. Increased pulmonary vascular resistance and reduced venous return impair right heart function and decrease cardiac output. Inadequate systemic oxygen delivery to meet energy requirements then adds a metabolic component to the respiratory acidosis. Hypoxaemia and acidosis further impair respiratory muscle function.²⁵ Unless controlled oxygen therapy, bronchodilators, and fluid replacement can both improve gas exchange and reduce the load on the respiratory muscles, mechanical ventilatory support will be required.

At what stage in this process should intervention occur and how can this state be recognised? The need for MV is better predicted by arterial pH and carbon dioxide (Paco₂) levels than the degree of hypoxaemia. For instance, in a study investigating the value of NIV in acute COPD, 74% of patients randomised to management without NIV (mean pH 7.26) reached the a priori criteria for tracheal intubation.¹⁵ The use of uncontrolled oxygen therapy may have precipitated further deterioration in this study, resulting in a high frequency of ventilatory support. In a similar study which included less severely affected patients,¹⁶ 27% of patients with a ward admission pH of 7.25–7.35 progressed to fulfil intubation criteria compared with 36% of those with a pH of <7.25. Soo Hoo *et al*⁷ found a higher overall need for intubation at 54% with a 70% risk in those with an initial pH <7.2. Subsequent multivariate analysis from the study by Plant *et al*²⁶ reveals that both pH and Paco₂ levels contribute to risk, although the sensitivity and specificity of these factors alone do not allow sufficiently accurate prediction on an individual basis. For instance, the odds ratio for reaching intubation criteria for a patient with an arterial pH of 7.30 and Paco₂ 8 kPa was 3.84 compared with 16.8 for pH 7.25 and Paco₂ 10 kPa. Data from this study also showed that pH often improves between arrival in the emergency department and ward admission with conventional non-ventilator management. Accordingly, in the absence of a clear need for tracheal intubation such as a Glasgow coma score of <8 or respiratory rate >40 or <10, conservative therapy or the use of NIV may be used initially. Usually, it is the failure to improve that signals the need for assisted ventilation.^{19–27}

MODES OF VENTILATORY SUPPORT

Non-invasive ventilation

Several studies have demonstrated the superiority of NIV over tracheal intubation and MV in acute COPD.^{15–16–26–28} NIV is indicated after initial treatment if the pH remains <7.30 and after exclusion of reversible precipitating causes such as a pneumothorax, the depressant effect of uncontrolled oxygen therapy, or the excessive use of sedatives. Depending on the circumstances, NIV may be delivered either in the admissions ward, HDU, or the respiratory ward.²⁷ Generally accepted exclusions to the use of NIV (box 2) are impaired consciousness (with uncontrolled oxygen therapy as an exception), vomiting, cardiovascular compromise, and the uncooperative patient.

The benefit of NIV in patients with more profound acidosis (pH <7.25) is unclear.¹⁶ In such patients NIV should, ideally, only be used in the ICU so that tracheal intubation can be rapidly performed. The decision about the appropriateness of resuscitation, which necessarily includes intubation, should be made at the start of ventilatory support. In some patients NIV may be the “ceiling” of therapy, depending on co-morbidity, the presence of reversible factors, and consideration

Box 2 Contraindications to NIV

- Impaired consciousness (except O₂ induced)
- Uncooperative patient
- Significant vomiting risk
- Cardiac arrhythmia or hypotension (if severe)
- Profound hypoxaemia (unless in ICU)
- Excessive secretions

of health status or advance directives. It should be remembered that NIV fails in up to 30% of patients,^{15, 27} with a significant proportion being late failures.²² Failure with NIV may result from a number of causes including patient intolerance because there is inadequate offloading of the respiratory muscles. This may arise when there is a failure of triggering with the spontaneous mode of ventilatory support. Alternatively, there may be inadequate augmentation of tidal volume because of insufficient pressure, autotriggering arising from excessive trigger sensitivity with bi-level ventilators, or machine delivered breaths that are not synchronised with glottic opening. In the patient naïve to NIV, a full face mask is usually required but leaking is then more problematic and this may also affect ventilator triggering. Not uncommonly, apparent early success is not matched by a fall in the Paco₂. Rebreathing with the increased dead space of a face mask may be the cause, but an ineffective cough and retained bronchial secretions are more commonly responsible. In these situations a nose mask and chin strap may be beneficial by allowing spontaneous coughing. Excessive secretions may also cause impairment of gas exchange resulting in refractory hypoxaemia.

Monitoring the impact of NIV is essential. A greater expansion of the chest during assisted breathing should be the primary aim with good matching of the patient's breathing effort with the ventilator or effective ventilation with machine timed breaths. Whichever mode is employed, a reduction in respiratory distress is an important prognostic feature and both cardiac and respiratory rate will fall with a gradual reversal of respiratory acidosis when NIV is effective. In our experience the need for frequent arterial blood gas analysis and appropriate monitoring of physiological variables is best provided in the HDU or level 2 facility. In some hospitals, where specialist medical wards are available, NIV may be provided in level 1 beds. This is particularly the case when used in patients with less physiological disturbance such as a higher pH, using spontaneous mode only ventilators.¹⁶ With increased recognition of the value of NIV in such patients, greater availability of equipment and the necessary skill mix of staff required, NIV will hopefully be effectively used outside the ICU. Excellent reviews and comprehensive guidelines for NIV are available.^{27, 28}

Tracheal intubation and mechanical ventilation

Impending cardiorespiratory arrest is indicated by profound hypoxaemia on disconnection from oxygen or NIV, significant hypotension, or an altered mental state. Immediate intubation may then be required. As cardiovascular collapse is common after intubation, transfer of the spontaneously breathing patient to the ICU may, however, be safer. Collapse arises from a combination of reduced venous return secondary to positive intrathoracic pressure, and direct vasodilation and reduced sympathetic tone induced by sedative agents. Before intubation pre-oxygenation is essential. Intubation with the rapid sequence induction and cricoid pressure to reduce the risk of aspiration should ideally be performed by an experienced clinician. Suxamethonium is classically used for muscle relaxation as its short effect makes it safer in the event of a failure to intubate. Concerns about hyperkalaemic cardiac arrest²⁹ have led to the increased use of short acting non-depolarising

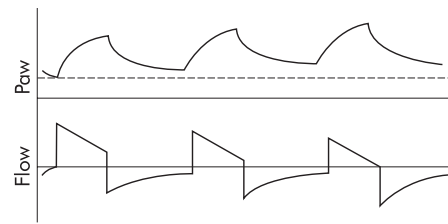


Figure 1 Progressive hyperinflation results from either excessive tidal volume, insufficient expiratory time, or both. If machine delivered breath occurs before flow has ceased (positive end expiratory pressure, PEEP), peak airway pressure (Paw) will increase and tidal volume will fall as progressive hyperinflation develops. If this results from premature airway collapse, externally applied PEEP will increase tidal volume without an increase in Paw.

agents such as rocuronium. Doubts about the effectiveness of cricoid pressure in preventing aspiration³⁰ have also resulted in a move to “head up” non-paralytic intubation. This is a high risk period in which profound hypotension may result in cardiac arrhythmia or arrest. Unless hypotension resolves rapidly with fluid replacement, cardiac tamponade induced by hyperinflation (bagging) should be suspected. In these circumstances, temporary disconnection of the endotracheal tube from positive pressure will lead to a return in cardiac output.

Controlled mechanical ventilation

Having secured the airway and corrected hypoxaemia, management is aimed at correcting the respiratory acidosis while avoiding further hyperinflation. This is best achieved by a combination of slow MV with a prolonged expiratory time and a limited tidal volume. A degree of permissive hypercapnia is well tolerated,³¹ while bronchial toilet and bronchodilation—usually with a combination of intravenous and nebulised agents—will improve alveolar ventilation. The benefit of steroids has been established in acute COPD,³² but these probably take hours to effect an improvement. Inotropes such as epinephrine (adrenaline) are well known to cause a metabolic acidosis but this may also occur with β_2 stimulants, largely by stimulating metabolism.³³ In the first 12–24 hours of MV, paralysis is normally required. This reduces the chest and abdominal wall contributions to the reduced respiratory system compliance and prevents patient ventilator dysynchrony or fighting, which will impair alveolar ventilation and result in high airway pressures. Airflow resistance and hyperinflation both contribute to the need for high inflation pressures to achieve an effective tidal volume and these may progressively increase if the set ventilatory parameters are causing further hyperinflation (see fig 1). The immediate complications of high airway pressures are impaired cardiac output, pneumothorax, and mediastinal and subcutaneous emphysema.

The ventilator may be set either to control volume or pressure. In volume controlled ventilation, conventional settings would be a tidal volume of 8–12 ml/kg at a frequency of 10–14 breaths/minute and an inspiratory:expiratory (I:E) ratio of 1:2.5 or 3.0. The disadvantage of volume control is the potential for high airway pressures; pressure limitation provides protection and is available on most modern machines. Alternatively, pressure controlled ventilation may be preferred as high airway pressures are avoided and the inspiratory flow pattern, which better resembles normal breathing, tends to equalise ventilation between lung units rather than preferentially ventilating, and possibly overinflating, the less obstructed (or faster filling and emptying) lung units (fig 2). This mode of ventilation has gained favour as it has become recognised that additional lung injury may result from relatively high tidal volumes that accompany the use of high ventilatory pressures rather than from high airway pressure

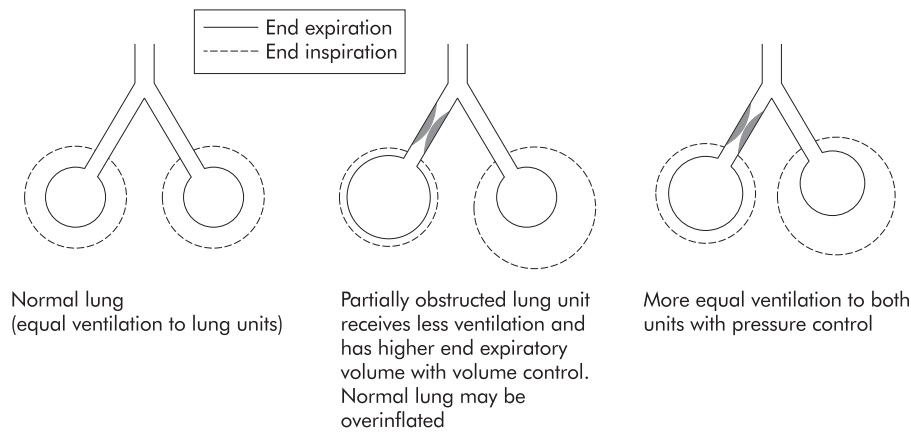


Figure 2 Improved distribution of ventilation with pressure controlled mandatory ventilation.

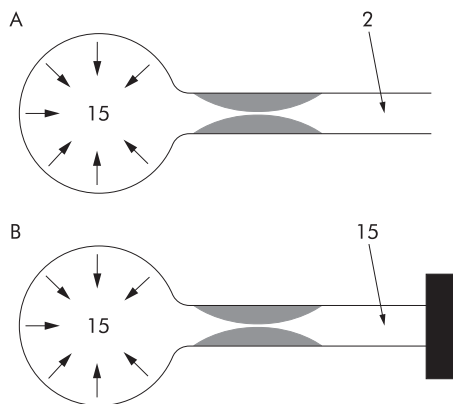


Figure 3 Measurement of intrinsic positive end expiratory pressure (PEEPi). (A) Tracheal end expiratory pressure is low with open expiratory port. (B) Measurement of auto-PEEP or intrinsic PEEP by occlusion of expiratory port at end expiration. The balloon represents the ventilated lung with expiratory flow obstruction. Intrinsic PEEP will be overestimated if there is active abdominal muscle contraction.

per se.³⁴ Although the importance of this concept has so far only been demonstrated in ARDS where a reduced mortality accompanies limited tidal volume ventilation,³⁵ the same mechanisms probably operate in other indications for MV.

The use of PEEP when ventilating patients with airflow obstruction is controversial. It was argued that externally applied positive airway pressure (PEEPe) would be harmful as it would increase hyperinflation. When small airway collapse develops during expiration from the structural changes associated with emphysema, the application of PEEPe will reduce gas trapping by stenting open the airways. The value of PEEPe to offset intrinsic PEEP is also important when supporting spontaneous breathing and is considered below. In controlled ventilation, a practical method to judge the use of is to monitor tidal volume and airway pressure (PEEPi). As PEEPe is applied, tidal volume will increase without an increase in airway pressure until PEEPe exceeds PEEPi. Intrinsic PEEP can be measured by measuring plateau pressure following a prolonged expiratory pause, so called static PEEPi (see fig 3).³⁶ Intrinsic PEEP will, however, be overestimated if there is active abdominal expiratory effort. Accurate measurement of dynamic PEEP (PEEPi dyn) in spontaneously breathing patients is more difficult and requires simultaneous measurement of gastric pressure (Pga) when $PEEPi = PEEPi_{dyn} - Pga$.³⁷

Assisted modes of ventilatory support

In many patients correction of acidosis and the need for a high inspired oxygen concentration (F_{iO_2}) rapidly resolves. Sponta-

neous breathing may still be inadequate but partial ventilatory support is possible with synchronised intermittent mandatory ventilation (SIMV). It provides a background of machine delivered breaths whilst spontaneous breathing effort is enhanced by positive pressure (pressure support) acting to increase the tidal volume of such triggered breaths. These breaths then delay the next machine delivered breath (synchronisation). It would seem an attractive mode during the weaning period. Excessive amounts of respiratory work may, however, occur with SIMV³⁸ unless attention is paid to optimise triggering by adjustment of PEEPe, and to titrate the degree of pressure support. At this point, knowing the level of PEEPi is useful but more difficult to measure.³⁷ By adjusting PEEPe to approximate PEEPi, the inspiratory pressure required to trigger a breath can be reduced (gas flow cannot begin until a negative deflection in airway pressure is registered by the ventilator). Flow triggers are more sensitive than pressure triggers but are only available on newer ventilators. A bias flow, usually 1–5 l/min, is provided by the ventilator during expiration. When the flow signal changes with the onset of inspiration, the ventilator is triggered to deliver pressure support.

An additional cause of patient distress may, however, occur before the ventilator begins to provide flow. If the inspiratory flow rate, which commonly has a default setting of 60–80 l/min, is insufficient for patient demand (which may be up to 120 l/min), a sense of “air hunger” occurs which may result in premature cessation of inspiratory effort. On the other hand, if the mandatory machine delivered breaths are too large or too long, expiratory effort will occur before the end of inspiration and result in unnecessary work and patient distress. This phenomenon also occurs if the level of support is excessive (to ensure a “normal” tidal volume). Disentangling the primary problem leading to patient-ventilator dyssynchrony versus more straightforward causes such as the discomfort of the endotracheal tube or anxiety may be difficult.³⁹ Accordingly, accepting a high respiratory rate and small tidal volume with pressure support may be preferable to SIMV. With either mode, examination of the real time pressure and volume traces, available on modern ventilators, will provide clues to the setting of PEEPe, the presence of inspiratory effort that fails to produce triggering or of expiratory effort before the end of inspiration. Occasionally, however, direct measurement of the oesophageal or gastric pressure is necessary.

One disadvantage of pressure support occurs during sleep when prolonged apnoeic periods, potentiated by lowering $Paco_2$ below normal, may result in repeated ventilator alarms. It is our preference to ensure adequate ventilatory support and allow restorative sleep at night using a controlled mode and then progressively to reduce the degree of pressure support during the day. An alternative is to use timed bi-level pressure

support⁴⁰ which ensures adequate ventilation during sleep and, if adjusted appropriately, comfortable pressure support by day. As this method does not involve triggered breathing (it can be conceptualised as CPAP with a timed higher pressure period superimposed), inadvertent triggering during suctioning or coughing is avoided—another mechanism for patients becoming distressed. With bi-level pressure support (BiPAP) there is the potential for increasing hyperinflation if inappropriate timing results in expiratory effort during the high pressure period.

Although conventional extubation criteria⁴¹ such as an F_{iO_2} of <0.4 and tidal volume >10 ml/kg can be encountered soon after admission to the ICU, up to 30% of patients with COPD meeting such criteria fail in the period following extubation.⁴² A significant delay in the weaning process or failure following extubation may result from airflow obstruction, continued hypersecretion, impaired left ventricular function, or over-sedation.⁴³ Propofol, a short acting sedative, may allow good titration of sedation in the period leading up to extubation and permit good synchrony between patient and ventilator, an essential requirement when deciding upon the likelihood of successful extubation. Nava *et al*¹² have provided evidence that early extubation is possible in patients who would be at high risk of post extubation failure by using NIV as a bridge. Although another study was unable to confirm more successful weaning with this approach, the use of NIV had some benefits.⁴⁴ It is our practice to aim for extubation at the 48–72 hours “window of opportunity” before secondary infections or other complications occur. Should this then fail, especially if stridor from glottic or supraglottic oedema is present after extubation, we proceed immediately to percutaneous tracheostomy on days 3–4 (see below).

NON-VENTILATORY CONSIDERATIONS

Steroids are useful in speeding the resolution of airway inflammation but are implicated in the myopathy associated with critical illness⁴⁵ and our practice is to taper the dose rapidly. The value of nebulised steroids has not been established in this situation. Adequate nutritional support is essential but should not be excessive. There is no convincing evidence that manipulation of the metabolic costs of feeding by energy substitution with fats speeds weaning. The risk of nosocomial pneumonia increases with longer ventilatory support. Nursing in the head up position may reduce the incidence,⁴⁶ while the risk/benefits of ulcer prophylaxis⁴⁷ and gut sterilisation⁴⁸ continue to be debated. Adequate hydration is clearly important in mobilising tenacious secretions. Inhaled or nebulised β_2 stimulants are more effective than saline in aiding sputum clearance, and mucolytics such as N-acetyl cysteine or DNase may occasionally be helpful. High inspired oxygen ($>50\%$) inactivates N-acetyl cysteine but is rarely required in COPD. The value of cough assist devices (Exsufflator; Emerson & Co) is increasingly recognised in neuromuscular causes of respiratory failure when cough is ineffective and may prove to be of use in COPD.

In the past the morbidity and inconvenience of surgical tracheostomies often resulted in prolonged ventilation with an endotracheal tube. The advantages of the percutaneous technique and the recognition that the resulting comfort of a tracheostomy allows less sedation has resulted in percutaneous tracheostomy being performed earlier in the clinical course. It allows intermittent ventilatory support and access to the lower respiratory tract for suctioning when ventilatory support is no longer required. A further advantage is that rehabilitation can be more active without the risk of inadvertent extubation. Fenestrated tracheostomy tubes will provide phonation, which improves communication and is an important milestone when weaning. One-way speaking valves (Passy Muir) provide an even better voice and can be inserted into

the single lumen ventilation circuits employed with bi-level ventilators when used to support patients during the weaning process.

WEANING FAILURE

This aspect of management has been considered in this series by Goldstone.⁴⁹ Weaning protocols⁵⁰ may be helpful, principally by identifying patients who no longer require ventilatory support. COPD accounts for approximately 25% of weaning failures, defined as those still ventilator dependent 3 weeks or more after recovery from the condition precipitating ICU admission.^{3–5} The negative aspects of a continued stay in the modern ICU environment, especially when only single organ (respiratory) failure persists, justifies considering referral to specialist weaning centres^{4–5} which may be regionally provided in the future. On the other hand, sensitivity to the wishes of patients and/or judicious withholding of an escalation in therapy when deterioration occurs is also good practice in the irreversibly ventilator dependent patient.¹³

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