Non-invasive ventilation: initiation and initial management

Non-invasive ventilation is the provision of ventilatory support using techniques that do not require endotracheal intubation or tracheostomy. It is an essential component of the management of acute and chronic hypercapnic (type 2) respiratory failure. It can be set up quickly in the acute setting and can be used on a domiciliary basis.

This article covers the use of non-invasive ventilation in the acute setting, focusing on when to use non-invasive ventilation, how to set it up and monitor response to therapy, and subsequent management of the patient established on non-invasive ventilation. It accompanies an article (https://doi.org/10.12968/hmed.2017.78.9.497) summarizing the recent National Confidential Enquiry into Patient Outcome and Death (NCEPOD) review of the quality of care provided to patients receiving non-invasive ventilation (Juniper et al, 2017), which found >50% of non-invasive ventilation was initiated by senior or junior specialty trainees. This article provides these doctors with a framework for delivering optimal non-invasive ventilation.

Evidence supports the use of acute non-invasive ventilation for patients with hypercapnic respiratory failure secondary to acute exacerbations of chronic obstructive pulmonary disease, neuromuscular weakness and hypoventilation syndromes (Davidson et al, 2016).

Terminology

Continuous positive airway pressure devices provide constant positive pressure throughout inspiration and expiration (at the same level), splinting open the upper airways and alveoli. As such it is not a form of ventilation. It is used in the acute setting in type 1 respiratory failure (hypoxaemia with normocapnia). It is also used in the management of obstructive sleep apnoea in the domiciliary setting.

Non-invasive ventilation is the provision of bi-level positive airway pressure during inspiration and expiration. These are set at different levels by the prescriber and the difference between inspiratory positive airway pressure and expiratory positive airway pressure is the pressure support delivered to aid ventilation. A minimum level of expiratory positive airway pressure is required to eliminate exhaled air through an expiratory port and prevent rebreathing; higher levels of expiratory positive airway pressure serve the same function as continuous positive airway pressure.

Acute hypercapnic respiratory failure refers to partial pressure of carbon dioxide (PCO_2) >6.5 kPa and pH <7.35 with co-existing hypoxaemia. It results from the insufficiency of respiratory mechanisms and the lungs to sustain sufficient alveolar ventilation to maintain normal arterial CO_2 levels.

The two predominant modes of ventilation are volume pre-set and pressure pre-set. In volume pre-set ventilation, the tidal volume and duration of inspiration are set by the operator and the machine generates the required pressure, whereas in pressure pre-set mode the operator sets the inspiratory and expiratory pressure. Pressure pre-set strategies have been used in the majority of trials in the UK (Ram et al, 2004) and this is the mode of choice for non-invasive ventilation. The advantages of pressure pre-set ventilation include the elimination of rapid pressure shifts (uncomfortable for the patient), compensation for air leaks, and a constant expiratory positive airway pressure eliminating CO_2 from the circuit while maintaining upper airway patency (Mehta et al, 2001).

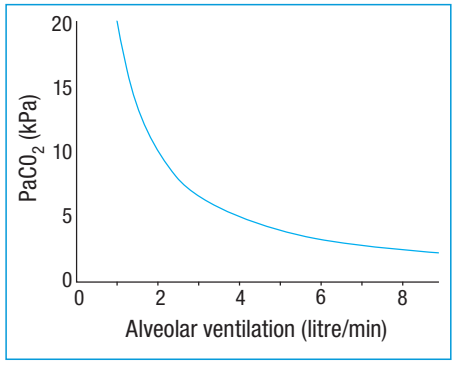
Physiology

In patients with chronic obstructive pulmonary disease, hypercapnia develops primarily as a result of increased dead space (high ventilation to perfusion ratio), secondary to airflow obstruction and hyperinflation, reduced lung compliance, and destruction of capillaries by emphysema. Lower tidal volumes are in part the result of the shortened inspiratory time as an increased expiratory resistance leads to a prolonged expiratory phase in order to return to functional residual capacity.

In patients with neuromuscular disorders or chest wall deformity, along with those with obesity hypoventilation syndrome, there is a restrictive deficit, precipitating an insufficiency of tidal volume and minute ventilation. It is important to note that not all morbidly obese patients develop obesity hypoventilation syndrome and other factors such as reduced central responsiveness to hypercapnia and hypoxia can precipitate a reduction in respiratory drive. The co-existence of sleep-disordered breathing can also exacerbate hypercapnia (Mokhlesi et al, 2008).

The physiological underpinning of the success of non-invasive ventilation in improving hypercapnia is illustrated in *Figure 1*, wherein a small improvement in alveolar ventilation can result in a large improvement in CO_2.

Figure 1. Arterial CO_2 ($PaCO_2$) *vs* alveolar ventilation – a modest improvement in alveolar ventilation precipitates a major improvement in $PaCO_2$.



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Indications for acute non-invasive ventilation

Patient selection is paramount in maximizing the chances of success of acute non-invasive ventilation, requiring assessment of the underlying condition, acid–base status, conscious level and severity of illness.

Conditions

The most common condition requiring non-invasive ventilation in clinical practice is acute exacerbations of chronic obstructive pulmonary disease, with 100 000 admissions per year in the UK and up to 20% of these presenting with hypercapnia (Plant et al, 2000). There are three main cohorts of patients warranting non-invasive ventilation in acute exacerbations of chronic obstructive pulmonary disease:

1. Patients with moderate respiratory acidosis (pH >7.25 but <7.35), where non-invasive ventilation is used to prevent deterioration and the need for invasive ventilation
2. Patients with severe respiratory acidosis (pH <7.25) with a view to invasive mechanical ventilation if non-invasive ventilation fails
3. Patients with respiratory acidosis who are deemed to be unsuitable for invasive ventilation for a valid reason, where non-invasive ventilation is the 'ceiling' of therapy.

A subset of patients with restrictive chest disorders may also present with acute hypercapnic respiratory failure, in particular neuromuscular disorders such as motor neurone disease and myotonic dystrophy, chest wall deformity and obesity hypoventilation syndrome. Often the acute precipitant in these patients is an acute stress on the patient's physiology, including respiratory or systemic infection, cardiac failure or in some cases, idiopathic (Carrillo et al, 2012).

Physiological parameters

A number of physiological parameters guide the initiation of non-invasive ventilation in the acute inpatient setting. After a history and physical examination, the arterial blood gas is central to the decision-making process. In all the above listed conditions, a pH of <7.35 and a $PaCO_2$ of >6.5 kPa despite optimal initial medical management should prompt consideration of non-invasive ventilation without delay (Davidson et al, 2016). Optimal medical management should involve controlled oxygen in all conditions, physiotherapy for sputum retention and mucus plugging, and prompt antibiotics in cases where infection is a precipitant. Additionally, in acute exacerbations of chronic obstructive pulmonary disease, sequential nebulized bronchodilators and systemic steroids should be given promptly (National Institute for Health and Clinical Excellence, 2010).

In contrast to acute exacerbations of chronic obstructive pulmonary disease where the severity of disease is guided by pH, patients with neuromuscular disorders or chest wall deformity may present with quite modest alterations in gas exchange but may be at risk of imminent decompensation (Bourke et al, 2006). The presence of acute illness and worsening respiratory symptoms or signs (e.g. respiratory rate >20 breaths per minute) should be taken seriously, even if the $PaCO_2$ is not >6.5 kPa. Non-invasive ventilation should be considered in such patients, even in the absence of respiratory acidosis. In a patient with obesity hypoventilation syndrome, a daytime $PaCO_2$ >6 kPa and somnolence should prompt consideration of non-invasive ventilation initiation in the acute setting.

Contraindications

The above criteria provide a broad framework of conditions and physiological parameters within which non-invasive ventilation should be considered. However, there are a number of conditions that preclude the use of non-invasive ventilation and these should always be considered before initiation.

The presence of hypercapnia or acidosis in patients with acute exacerbation of asthma or pneumonia (in the absence of an evidence-based indication for non-invasive ventilation, such as acute exacerbations of chronic obstructive pulmonary disease) should prompt referral to intensive care for consideration of invasive ventilation and higher level care (high dependency unit or intensive care unit). While selected patients with pneumonia may benefit from non-invasive ventilation, risks of non-invasive ventilation failure and death are higher than in the absence of consolidation (Ucgun et al, 2006). Patients in whom non-invasive ventilation would be inappropriate include those in whom a palliative pathway should be considered (such as patients with end stage cancer) or those with an advance care plan noting that they do not want non-invasive ventilation.

The presence of facial burns and fixed upper airway obstruction are considered absolute contraindications to initiation of non-invasive ventilation, often in practice making non-invasive ventilation impossible to maintain. Acute pneumothorax should be drained before non-invasive ventilation and, if too small for drainage, non-invasive ventilation may commence with increased monitoring and may be stopped if the patient deteriorates. Relative contraindications often do not provide an absolute barrier to non-invasive ventilation but warrant enhanced consideration and observation. These include confusion or agitation, Glasgow Coma Scale <8, and vomiting (may require rapid mask removal or nasogastric tube). Hypotension is not in itself a contraindication to non-invasive ventilation but does act as a marker for the severity of physiological compromise and may prompt escalation to an area with capacity for more intensive monitoring and intervention.

Before starting non-invasive ventilation

The increasing use of non-invasive ventilation and its relative versatility has led to use in a variety of clinical settings – from medical assessment units to intensive care environments. As such the following basic principles should be observed to ensure safety. Before commencing non-invasive ventilation, the patient's wishes should be assessed and the clinician making the decision to start non-invasive ventilation needs to be competent to do so. Escalation decisions to include resuscitation status should be documented before starting non-invasive ventilation. If the need for invasive mechanical ventilation is an imminent risk, then critical care involvement should be sought as soon as possible.

Finally the setting of non-invasive ventilation must be considered; hospitals should have a local policy that specifies areas where non-invasive ventilation can be delivered. Such areas include emergency department resuscitation beds, acute medical units, respiratory high care areas, high dependency and intensive care units (Roberts et al, 2008). These should be able to provide continuous monitoring of oxygen saturations and have the capacity to provide electrocardiogram monitoring. Point of care blood gas testing must be nearby. Direct care should only be delivered by a nursing team who are competent in the use of non-

invasive ventilation, and with a higher nurse to patient ratio. If non-invasive ventilation is started in other areas (while awaiting transfer), staff with non-invasive ventilation competence must remain with the patient until transfer to a non-invasive ventilation area is achieved.

Before initiating non-invasive ventilation, review of the arterial blood gas is necessary, and chest X-ray review (to assess for pneumonia or pneumothorax) is recommended but not essential in patients with severe acidosis.

Initiating non-invasive ventilation

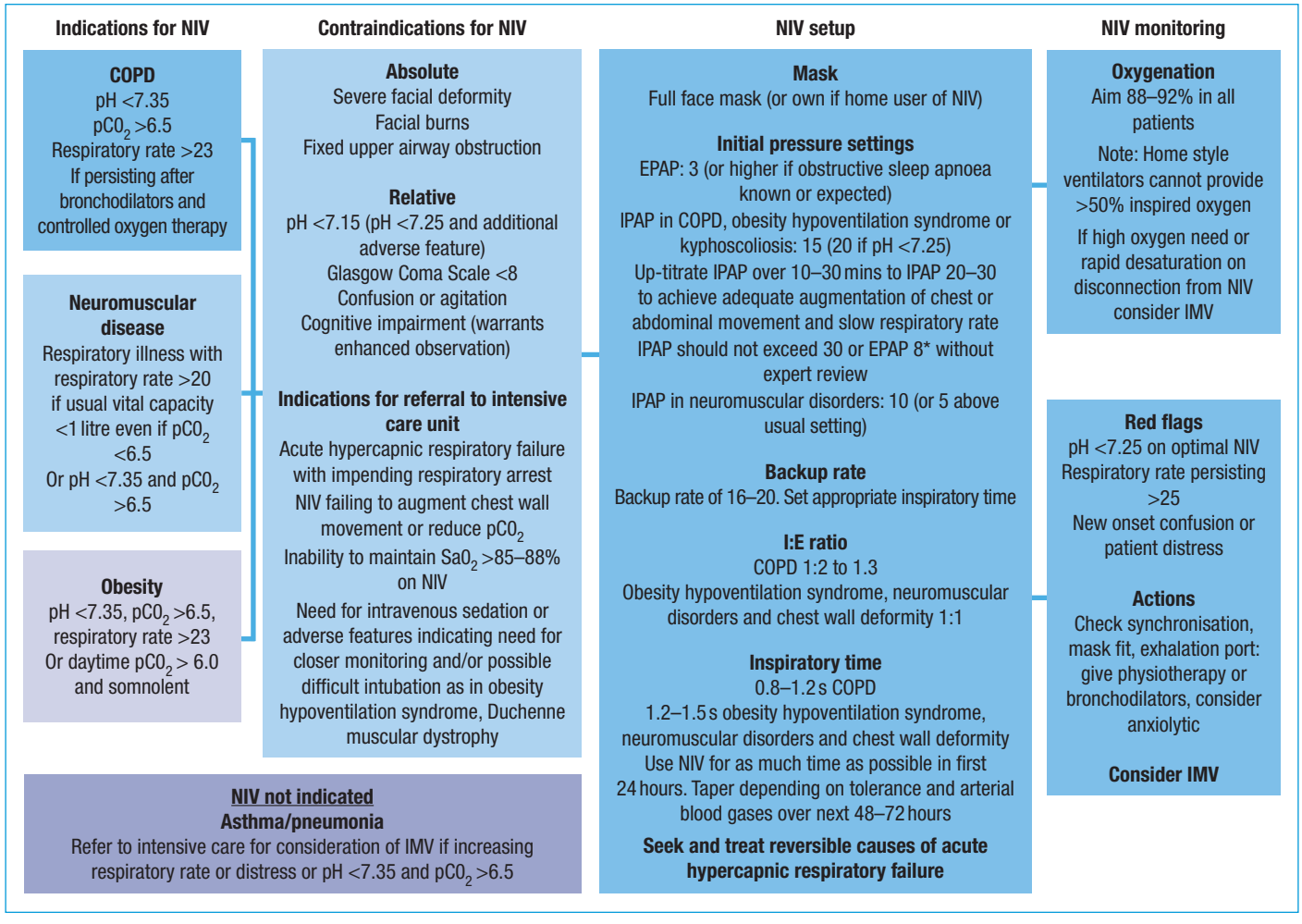
Figure 2 gives a flowchart for starting non-invasive ventilation. The preferred method of delivering non-invasive ventilation is via a full face mask, a range of which is available, which can be tailored to the patient. Ideally the patient should be positioned upright to optimize lung expansion. Typically, one should start at low pressure settings (inspiratory positive airway pressure of 15 cmH_2O, expiratory positive airway pressure of 3 cmH_2O). Practically, within the first 10–30 minutes the inspiratory positive airway pressure should be up-titrated at the bedside as quickly as patient comfort allows to 20–30 cmH_2O.

The clinician should monitor the patient over this period – chest wall movement should improve and respiratory rate will reduce if the settings are appropriate. These clinical parameters can give an indication of response before the repeat arterial blood gas is carried out. Ventilator adjustments are individualized; those who are easier to ventilate (e.g. patients with neuromuscular conditions) may respond to lower settings (start with an inspiratory positive airway pressure of 10 cmH_2O). In contrast, for patients with obesity-related respiratory failure, one should typically aim for higher inspiratory positive airway pressure settings in the first hour, and an expiratory positive airway pressure of up to 8 cmH_2O may be required. The treatment target is improved ventilation and this should be assessed by repeated blood gas measurement within 1 hour or sooner in the event of deterioration.

Intolerance of non-invasive ventilation may be overcome by a period of holding the mask for the patient and varying the degree of tightness. Oxygen can be entrained and should be titrated to maintain saturations of 88–92% (O'Driscoll et al, 2017).

Other starting settings include a backup rate of 16–20 breaths per minute, an inspiratory to expiratory ratio of 1:2 in patients with chronic obstructive pulmonary disease or 1:1 in those with neuromuscular disorders or chest wall deformity.

Figure 2. Flowchart for starting non-invasive ventilation (NIV). From Davidson et al (2016). COPD = chronic obstructive pulmonary disease; EPAP = expiratory positive airway pressure; IMV = invasive mechanical ventilation; IPAP = inspiratory positive airway pressure. *Possible need for EPAP >8 in severe obesity hypoventilation syndrome (body mass index >35 kg/m^2), lung recruitment, e.g. hypoxia in severe kyphoscoliosis, oppose intrinsic positive end-expiratory pressure in severe airflow obstruction or to maintain adequate pressure support when high EPAP required.



Monitoring and titrating the patient on non-invasive ventilation

Monitoring of patients on non-invasive ventilation comprises clinical assessment, continuous oxygen saturation monitoring and blood gas parameters. These should be carried out at regular intervals and within 1 hour of any setting change. The key physical parameters that require assessment include patient comfort, respiratory rate, chest wall movement and use of accessory muscles. Improvement of these within the first 2 hours indicates successful implementation of non-invasive ventilation (Davidson et al, 2016).

For patients responding well to non-invasive ventilation, blood gas sampling should be undertaken at 1 and 4 hours after initiation and variably thereafter depending on response. Blood gases should be checked immediately in the event of clinical deterioration and this should also prompt clinical review. Markers of improvement are primarily the pH and $PaCO_2$. Target oxygen saturations should be 88–92% and monitored continuously for the first 24 hours and thereafter during periods of non-invasive ventilation.

The primary adjustments required after starting non-invasive ventilation include increasing pressure support to achieve lower respiratory rate, work of breathing and improve CO_2 levels, adjusting fraction of inspired oxygen to maintain peripheral oxygen saturation 88–92%, and in chronic obstructive pulmonary disease extending the inspiratory to expiratory ratio (1:3) to improve ventilator synchronization given the prolonged expiratory phase in many of these patients.

Weaning non-invasive ventilation

Use of non-invasive ventilation is ideally maximized over the first 24 hours (semi-continuous use), with breaks only for nebulizers, nutrition and medication. Return to clinical stability and normalization of the pH are used as markers to discontinue non-invasive ventilation. A $PaCO_2$ <6.5 kPa should also be targeted in those without chronic hypercapnia. It is important to note that in patients with chronic hypercapnia, targeting $PaCO_2$ <6.5 kPa may be inappropriate and as such clinical parameters and pH should be used.

In obesity-related respiratory failure and chronic obstructive pulmonary disease, the time on non-invasive ventilation can be gradually reduced during the day (continuing non-invasive ventilation at night) over a period of 48–72 hours. Nocturnal non-invasive ventilation may be discontinued once sufficient normalization to baseline has been achieved. Some patients may wean to complete discontinuation of non-invasive ventilation, especially if the acute precipitant (e.g. infection) is quite significant.

Patients with persistent hypercapnia following acute non-invasive ventilation should be referred to the local respiratory or sleep and ventilation service for consideration of domiciliary non-invasive ventilation. Chronic ventilatory impairment contributes to the acute clinical presentation for significant numbers of patients, especially those with neuromuscular disorders or chest wall deformity, obesity-related respiratory failure, and selected patients with chronic obstructive pulmonary disease.

Initial failure of non-invasive ventilation

The major precipitants of non-invasive ventilation failure are deterioration of the underlying condition (further optimization or escalation required), complications (pneumothorax), over-oxygenation or technical issues (leak, asynchrony or inadequate pressure support). The presence of technical issues may be ascertained from the non-invasive ventilation machine, whereby inconsistencies in the leak and tidal volume should alert the operator to poor mask fit or ventilator asynchrony, while clinical assessment of the patient is also essential; asymmetrical or erratic chest wall movement indicate possible pneumothorax or asynchrony respectively. Patient agitation and distress can cause problems with tolerating non-invasive ventilation. This may improve with improved ventilation on non-invasive ventilation but if it is persistent then should prompt consideration of anxiolytics and sedation. The latter should only be used in a high dependency or intensive care environment (Davidson et al, 2016).

Table 1 summarizes an approach to the patient failing initial non-invasive ventilation.

Table 1. Management of non-invasive ventilation failure

Is the treatment of the underlying condition optimal?	■ Check medical treatment prescribed and that it has been given ■ Consider physiotherapy for sputum retention	
Have any complications developed?	Consider a pneumothorax, aspiration pneumonia, etc	■ Repeat chest X-ray
$PaCO_2$ remains elevated	Is the patient on too much oxygen?	■ Adjust fraction of inspired oxygen to maintain peripheral oxygen saturation between 88% and 92%
	Is ventilation inadequate?	■ (Observe chest expansion) ■ Increase inspiratory positive airway pressure ■ Consider increasing respiratory rate (to increase minute ventilation)
	Is there excessive leakage?	■ Check mask fit
	Is the circuit set up correctly?	■ Check connections ■ Check circuit for leaks
	Is re-breathing occurring?	■ Check patency of expiratory valve (if fitted) ■ Consider increasing expiratory positive airway pressure
	Is the patient synchronising with the ventilator?	■ Adjust rate and/or inspiratory:expiratory ratio (with assist/control) ■ Consider increasing expiratory positive airway pressure
$PaCO_2$ improves but PaO_2 remains low	Increase fraction of inspired oxygen	■ Consider increasing expiratory positive airway pressure (with bi-level pressure support)

Adapted from British Thoracic Society guidelines (British Thoracic Society Standards of Care Committee, 2002). $PaCO_2$ = partial pressure of arterial carbon dioxide; PaO_2 = partial pressure of arterial oxygen.

KEY POINTS

- Non-invasive ventilation is a safe and evidence-based strategy in hypercapnic respiratory failure.
- Non-invasive ventilation should be considered in patients with chronic obstructive pulmonary disease, neuromuscular disease, chest wall deformity and obesity hypoventilation syndrome and pH <7.35 or $PaCO_2$ >6.5 kPa. Pneumonia or asthma should not routinely be treated with non-invasive ventilation without specialist support.
- The intention of treatment and escalation plan should be determined before initiating non-invasive ventilation.
- Key markers of improvement include work of breathing, pH and CO_2 levels at 1–2 hours post-initiation.
- Acute deterioration should prompt the clinician to check for complications, optimize treatment of the underlying condition and check technical factors.
- Should non-invasive ventilation fail, escalation to invasive mechanical ventilation is indicated in appropriate patients, or comfort-based/end of life measures in those not suitable for invasive mechanical ventilation.

Escalation or withdrawal from non-invasive ventilation

Current data show that a relatively small proportion of patients with acute exacerbations of chronic obstructive pulmonary disease that fail non-invasive ventilation are escalated to invasive mechanical ventilation, with evidence that clinicians are too pessimistic about likely outcomes (Roberts et al, 2011). *Table 2* lists some prognostic factors influencing outcomes in non-invasive ventilation in acute hypercapnic respiratory failure.

Invasive mechanical ventilation should be considered in the peri-arrest situation, severe acidosis (pH <7.15) and where acidosis persists despite non-invasive ventilation and efforts to optimize settings and delivery have failed. Deteriorating Glasgow Coma Scale (particularly <8) or concerns over airway patency should lead to consideration of invasive mechanical ventilation.

All patients treated with acute non-invasive ventilation should have a documented escalation plan (including suitability for invasive mechanical ventilation and cardiopulmonary resuscitation status) before starting non-invasive ventilation. In practice, end of life conversations in chronic obstructive pulmonary disease are often delayed but current recommendations favour early discussion (Lanken et al, 2008). Patients with non-invasive ventilation as their ceiling of care who deteriorate despite non-invasive ventilation, after reasonable attempts to optimize technical factors and the underlying condition, warrant end of life care and symptomatic management.

Non-invasive ventilation may be continued for palliation and symptom relief, such as breathlessness and respiratory distress. Anxiolytics and sedatives may be used as adjuncts in this process (Kühnlein et al, 2008). BJHM

Table 2. Prognostic indicators in acute hypercapnic respiratory failure

Predictors of positive outcome in non-invasive ventilation	Initial pH 7.25–7.35
	Improvement in respiratory rate at 1–2 hours
	Improvement in pH at 1–2 hours
	Good level of consciousness
Predictors of negative outcome in non-invasive ventilation	Increasing acidosis after presentation
	No improvement in pH at 4 hours
	No improvement in respiratory rate at 4 hours
	Glasgow Coma Scale <8
	Consolidation on chest X-ray
	Lower admission pH

From Davidson et al (2016)

Figure 2 *is reproduced from Davidson et al (2016) with permission from BMJ Publishing Group Ltd.*
Conflict of interest: none.

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