Weaning from mechanical ventilation

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Weaning is the process of becoming independent from ventilatory support. It is often rapid and uneventful, with over 90% of intensive care unit (ICU) admissions needing mechanical ventilation for less than a week.[1] However, the remainder consume 40% of total resources during their stay, with a mortality of 25–60%. Overall, 2–5% have a prolonged and difficult course and fail to wean in three weeks. Recent evidence suggests that this group benefits from an experienced approach to weaning, which may involve a transition to long-term domiciliary ventilation. This article will review the key developments centred on optimising weaning.

Weaning protocols and when to initiate weaning

In practice, weaning begins when there is an improvement in gas exchange, reduction in inotropic support and sedation, and some evidence of spontaneous respiratory effort (Table 1). This usually coincides with recovery from the precipitating illness. Therefore, initial appropriate medical treatment is paramount.

Studies suggest that nurse-implemented protocols can result in faster weaning and fewer complications.[2,3] Such protocols involve periodic screening after intubation for the opportunity to reduce ventilatory support, bypassing erroneous clinical intuition; they may be particularly effective in open, non-intensivist run units.[4] However, only 17% (33/195) of ICUs surveyed by the NHS Modernisation Agency in 2002 used nurse-led protocols,[1] possibly reflecting staff-to-patient ratios and practice culture in different units.

Ventilatory strategies in the weaning process

There are three steps in the process of weaning:

- switch from controlled to supported modes of ventilation
- progressive reduction in ventilatory support before assessing the adequacy of spontaneous breathing, and
- extubation.

Switch from controlled to supported modes of ventilation

If muscle paralysis is no longer required, for example because of improved respiratory mechanics and gas exchange, the switch from controlled mechanical ventilation is often made soon after admission to the ICU. Support modes are preferred to controlled as spontaneous inspiratory effort may contribute to respiratory muscle conditioning and prevent disuse atrophy,[5,6] allowing lightening of sedation and quicker weaning.

Progressive reduction in ventilatory support

There is then a gradual decrease in ventilatory support until it is appropriate for a trial of spontaneous breathing (Table 2). Reducing mandatory delivered breaths (synchronous intermittent mandatory ventilation) has proved inferior to reducing pressure support ventilation.[7] Signs of respiratory fatigue at any stage (Table 3) may be due either to the increased ventilatory load or to the

Table 1. Daily screening criteria used to identify patients ready to wean.

- Evidence for some reversal of the underlying cause for respiratory failure
- Adequate gas exchange:
  - FiO_2 = <0.5
  - PaO_2/FiO_2 ratio >150
  - PEEP <10 cm H_2O
  - no significant respiratory acidosis (pH >7.3)
- Haemodynamic stability on low-dose inotropes:
  - MAP ≤60 mmHg
- Level of sedation:
  - patient awake and comfortable, coherent

FiO_2 = fractional concentration of oxygen in inspired gas; MAP = mean arterial pressure; PaO_2 = partial arterial oxygen tension; PEEP = positive end-expiratory pressure.

Table 2. Inclusion criteria for a spontaneous breathing trial.

- Co-operative patient requiring no sedation, adequate analgesia
- Pressure support ≤5–7 cm H_2O
- PEEP ≤5, FiO_2 ≤40%
- No or low-dose inotropes
- Adequate cough, secretions not excessive

FiO_2 = fractional concentration of oxygen in inspired gas; PEEP = positive end-expiratory pressure.

Table 3. Possible signs of respiratory fatigue.

- Respiratory rate >35/min
- Fall in O_2 saturation <90%
- Sustained heart rate >140 or 20% increase/decrease
- Rise in pCO_2 and respiratory acidosis
- Agitation/restlessness
- Reduced conscious level

development of new complications which can necessitate increasing support or even return to controlled modes. A stable level of pressure support is recommended for at least 24 hours after a failed weaning attempt.[8,9]

Extubation

The role of non-invasive ventilation (NIV) in facilitating extubation is discussed later.

Can any criteria predict eventual weaning success?

Clinical judgement and physiological parameters (eg tidal volume (V_T) and minute ventilation) have poor positive predictive values.[10] The rapid shallow breathing index, respiratory rate/V_T measured during the first minute of spontaneous breathing (f/Vt $s^{-1}l^{-1}$), is the most validated.[11,12] However, assessment of respiration during a formal spontaneous breathing trial (SBT) appears to be the best predictor of successful extubation and therefore of weaning success.[3]

Determining the time of extubation

Studies have found that over 75% of patients tolerant of SBTs 30–120 min in duration can proceed to successful extubation.[2,3] Those who fail can have a repeat trial 24 hours later.

Spontaneous breathing trials

The SBT is performed on low levels of continuous positive airways pressure, pressure support (7 cm H_2O) or as T-piece breathing. Failure is marked by signs of respiratory fatigue (Table 3). Prolongation of a failed SBT can precipitate haemodynamic instability, worsen gas exchange and delay weaning.[5] However, there was only one adverse event in a cohort of over 1,000 patients in whom monitored SBTs were carried out.[2]

Is it safe to remove the artificial airway?

Glottic oedema and other causes of reduced upper airway patency are not directly assessed by the SBT and are a potential cause of extubation failure. A low air leak detected during endotracheal tube cuff-deflation on mechanical ventilation indicates possible upper airway obstruction.[13]

Successful extubation also requires the patient to be able to protect their airway, cough adequately and clear secretions.[14] Cuff deflation may promote the return of upper airway reflexes, as well as encouraging speech and oral intake (whilst watching closely for signs of aspiration). Cough assist devices (cough in/exsufflator) can prevent intubation and reduce tracheostomy rates in patients with bulbar weakness.[15] These devices augment coughs by applying a positive pressure during inspiration via a facial mask and then a negative pressure (exsufflation).

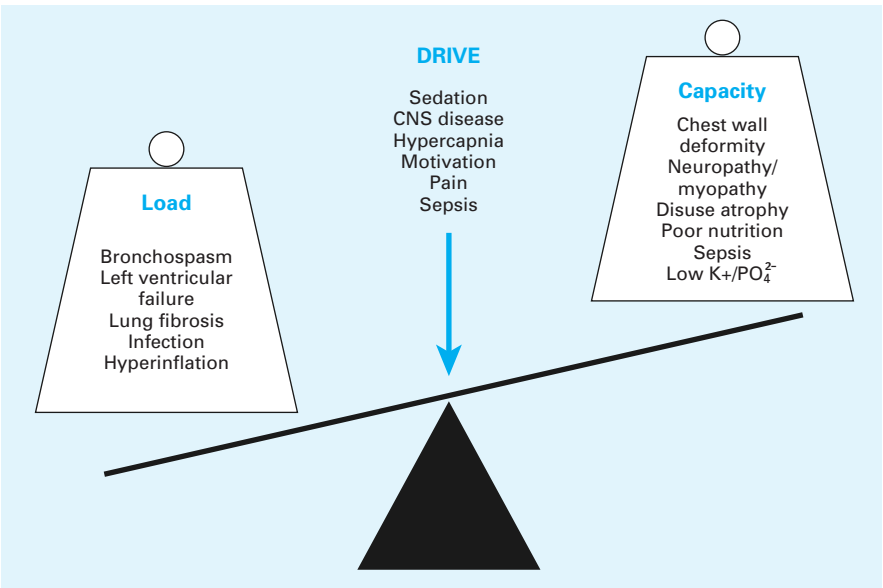

Fig 1. Common causes of failure to wean (CNS = central nervous system).

Tracheostomy

Percutaneous tracheostomy is usually performed in patients who fail to wean rapidly. Optimal timing is unclear (studies range from 2–21 days) but it is considered earlier when prolonged ventilation is anticipated (eg neuromuscular disease). Benefits include:

- improved patient comfort, allowing reduction in sedation
- more secure airway and effective suctioning
- reduced anatomical dead space, thus increasing alveolar ventilation
- the ability to be used intermittently (eg overnight support)
- allowing speech, oral feeding and ambulatory ventilation, and
- psychological boost for the patient.

Failure to wean

Failure to wean is defined as requiring ventilatory support for more than three weeks in the absence of a non-respiratory cause such as catastrophic stroke. In the 2–5% patients on the ICU in whom this occurs,[2,7] ventilatory independence is introduced more gradually whilst the responsible factors are corrected. The importance of recovery of diaphragmatic function and muscular retraining is unclear.[5]

Failure to wean can be thought of as an imbalance between the drive, load and capacity of the respiratory pump (Fig 1). There are many important aspects to address in this situation:

- *Sedation/analgesia* (influences *drive*): there is good evidence that a protocolised daily interruption of sedative infusions decreases the duration of mechanical ventilation in some patients.[16] This allows more accurate clinical assessment (particularly of mental status) and retitration of sedation/analgesia,

avoiding tissue accumulation and delayed weaning.

- *Ventilator settings*: 'over-ventilation' with a low pCO_2 increases respiratory work and reduces the drive for spontaneous breathing. Trigger sensitivity and pre-set inspiratory/expiratory times can cause ventilator-patient disharmony and may need adjustment.[17]
- *Signs of cardiac failure* (*increased load*): the development of cardiac ischaemia/failure has been linked to reductions in ventilatory support.[18] Appropriate treatment can lead to weaning success by improving oxygen delivery to respiratory muscles.
- *Hyperinflated lungs* reduce the pressure that respiratory muscles can generate. Bronchospasm should be treated and positive end-expiratory pressure levels adjusted.[11]
- *Signs of respiratory muscle weakness* (*reduced capacity*): for example, abdominal paradox (suggests diaphragm weakness). Use of contributing agents like muscle relaxants and high-dose steroids should be limited.[5] EMG and muscle biopsy may identify a treatable cause (eg myasthenia or polymyositis). It is often appropriate to 'rest' respiratory muscles overnight with full ventilatory support and aim to wean on to nocturnal NIV when self-ventilating throughout the day.
- *Is there a new complication that requires treatment*, for example, abdominal distension, sepsis or pneumothorax?
- *Are upper airway function, cough and swallow adequate?*
- *Are there signs of malnutrition or electrolyte imbalance?*
- *Psychological factors*, for example depression and fear. These are important; good staff communication, environmental stimulation and ambulatory ventilation reduce anxiety and reinforce progress.[9] Restoration of the normal sleep–wake cycle with melatonin or benzodiazepines allows more effective daytime rehabilitation and may have other benefits.
- *Is the patient appropriate for extubation on to NIV?* (see below)

Key Points

A significant number of critically ill patients require prolonged invasive mechanical ventilation and are difficult to wean from support

A protocolised approach to weaning, with daily screening for the ability to breath spontaneously and cessation of sedation, improves outcome

Some modes of ventilation (pressure support) are better than others (synchronised intermittent mandatory ventilation) at promoting weaning

Elective non-invasive ventilation after extubation may prevent re-intubation in certain patients, particularly those with chronic obstructive pulmonary disease

A small number of patients will need long-term ventilatory support; these are best assessed and managed by specialist units

KEY WORDS: chronic obstructive pulmonary disease, critical care, ventilation, weaning

Non-invasive positive pressure ventilation

There is already overwhelming evidence that the use of NIV in acute exacerbations of chronic obstructive pulmonary disease (COPD) can prevent the need for mechanical ventilation.[1] In a comparison of extubation on to NIV after 48 hours with standard continued invasive ventilation in a cohort of COPD patients there was a reduced mean duration of ventilation and improved 60-day survival in the NIV group.[19] These results were replicated in a more heterogeneous group of patients with persistent weaning failure (although more than 50% had COPD).[20]

NIV should be considered before intubation, early in the weaning process and in weaning failure, particularly in patients with COPD. Contraindications include upper airway obstruction, reduced conscious level and severe bulbar weakness with risk of aspiration.

Long-term ventilatory units

What further can be offered for the resource-intensive cohort who fail to wean? The NHS Modernisation Agency has recommended the UK-wide provision of specialist long-term weaning centres. These units focus on ventilatory care and rehabilitation and free up ICU beds for patients with multi-organ failure.[4,21] They are experienced in domiciliary

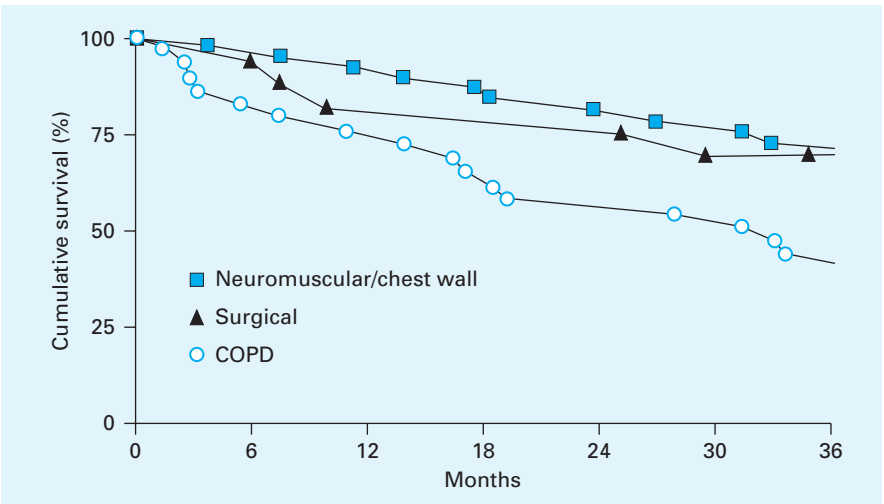

Fig 2. Three-year survival of main diagnostic subgroups of patients from a regional weaning centre (COPD = chronic obstructive pulmonary disease).

Table 4. Data from regional weaning centre (n = 153).

Demographics		Outcomes		
	No.		No.	%
Median age (years) (range)	62 (49–72)	Ventilator free	58	38
Male:female	70:83	Non-invasive ventilation	40	27
No. referred from external hospital (%)	59 (39%)	Tracheostomy ventilation	12	8
Median ICU length of stay (days) (range)	26 (12–48)	Negative pressure ventilation	1	0.7
Median weaning centre stay (days) (range)	19 (6–41)	DEATHS	42	27

non-invasive and tracheostomy ventilation and offer training and support to patients and carers. Survival is improved, particularly in the patient groups who benefit from long-term NIV – that is, those with chest wall deformity or neuromuscular disease (Fig 2).

In one series of 153 patients admitted to a regional weaning centre over a four-year period the largest diagnostic subgroups were neuromuscular/chest wall disorders, COPD and postsurgical (Table 4).[21] Approximately one-third became ventilator-free during admission and a further third required long-term ventilatory support; 27% died as inpatients.

The future

It is estimated that approximately £400,000 a year could be saved in the north of England if patients whose primary problem is ventilator-dependence were managed on less intensive units with fewer staff. This extrapolates to a saving of more than £5 million per year for the whole of England.[22] The ideal location of such units remains undecided, but both within-hospital and stand-alone solutions appear to be successful in other countries.

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