

AN INTRODUCTION TO MECHANICAL VENTILATION IN THE INTENSIVE CARE UNIT

Dr Fran O'Higgins, Consultant in Anaesthesia and Intensive Care , Bristol, UK

Indications for mechanical ventilation

Categories of mechanical ventilation

- Types of ventilation
- Modes of ventilation

Initiating mechanical ventilation

- Ventilator settings
- Optimizing oxygenation and carbon dioxide elimination
- Sedation

Tracheostomy in the ICU

Trouble shooting

- Low tidal volumes or high airway pressure
- 'Fighting' the Ventilator

Weaning

- Indications to wean
- Modes of Weaning
- Failure to wean

One of the main functions of an Intensive Care Unit (ICU) is the provision of advanced respiratory support. An understanding of the indications and types of mechanical ventilation is therefore essential for anyone working in this environment.

INDICATIONS FOR MECHANICAL VENTILATION

The main indication for mechanical ventilation is respiratory failure. However, other clinical indications include a prolonged postoperative recovery, altered conscious level, inability to protect the airway or exhaustion when the patient is likely to proceed to respiratory failure. The aim of mechanical/artificial ventilation is to improve gas exchange, to reduce the work of breathing and to avoid complications while maintaining optimal conditions for recovery. Whatever the indication for respiratory support, the underlying condition of the patient must be reversible, otherwise subsequent weaning may not be possible.

Respiratory failure

This is the primary indication for respiratory support. It occurs when pulmonary gas exchange is sufficiently impaired to cause hypoxaemia with or without hypercarbia. The causes of respiratory failure are diverse and the problem may occur due to disease at the alveolar / endothelial interface (eg pulmonary oedema) or in the respiratory pump mechanism resulting in inadequate minute ventilation (eg flail segment accompanying fractured ribs).

Criteria for starting mechanical ventilation are difficult to define and the decision is often a clinical one. Indicators include:

- Respiratory rate >35 or <5 breaths/ minute
- Exhaustion, with laboured pattern of breathing
- Hypoxia - central cyanosis, $\text{SaO}_2 <90\%$ on oxygen or $\text{PaO}_2 < 8\text{kPa}$
- Hypercarbia - $\text{PaCO}_2 > 8\text{kPa}$
- Decreasing conscious level
- Significant chest trauma
- Tidal volume $< 5\text{ml/kg}$ or Vital capacity $<15\text{ml/kg}$

Causes of Respiratory Failure

Inadequate gas exchange

- Pneumonia, pulmonary oedema, acute respiratory distress syndrome (ARDS)

Inadequate breathing

- Chest wall problems eg fractured ribs, flail chest
- Pleural wall problems eg pneumothorax, haemothorax
- Respiratory muscle failure eg myasthenia gravis, poliomyelitis, tetanus
- Central nervous system depression eg drugs, brain stem compression

Obstructed breathing

- Upper airway obstruction eg epiglottitis, croup, oedema, tumour
- Lower airway obstruction eg bronchospasm

Other indications for ventilation

Patients in this category are ventilated to assist in the management of other, non-respiratory conditions and may include:

- Control of intracranial pressure in head injury
- Airway protection following drug overdose
- Following cardiac arrest
- For recovery after prolonged major surgery or trauma

TYPES OF MECHANICAL VENTILATION

The most commonly used type of artificial ventilation is intermittent positive pressure ventilation (IPPV). The lungs are intermittently inflated by positive pressure generated by a ventilator, and gas flow is delivered through an endotracheal or tracheostomy tube. Tracheal intubation is usually achieved by the oral route although nasal intubation may be better tolerated by the patient during prolonged ventilation.

Although more secure, nasotracheal intubation is technically more challenging and has a higher incidence of bleeding and infective complications such as sinusitis.

Tracheal intubation not only allows institution of IPPV, but also reduces dead space and facilitates airway suctioning. However, it is also possible to deliver positive pressure ventilation to cooperative patients in a non-invasive manner through a tight-fitting face or nasal mask (NIPPV).

In general, there are two main types of ventilators commonly in use in ICU - those that deliver a preset tidal volume and those that deliver a preset inspiratory pressure during each inspiration. Modern ventilators allow different modes of ventilation and the clinician must select the safest and most appropriate mode of ventilation for the patient.

Types of Ventilation

- Volume-cycled ventilation occurs when the ventilator delivers a preset tidal volume regardless of the pressure generated. The lung compliance (stiffness) of the lungs determines the airway pressure generated, so this pressure may be high if the lungs are stiff, with the resultant risk of barotrauma (rupture of the alveoli resulting in pneumothoraces and mediastinal emphysema).
- Pressure-preset ventilation is where the ventilator delivers a preset target pressure to the airway during inspiration. The resulting tidal volume delivered is therefore determined by the lung compliance and the airway resistance.

Modes of ventilation

- Controlled Mechanical Ventilation (CMV). Ventilation with CMV is determined entirely by machine settings including the airway pressure/tidal volume, respiratory rate and I:E ratio. This mode of ventilation is not often used in ICU as it does not allow any synchronisation with the patient’s own breathing. As a consequence, CMV is not well tolerated and patients require heavy sedation or neuromuscular blockade to stop them ‘fighting’ the ventilator, thereby resulting in inefficient gas exchange. CMV is normally used in theatre when the patient is receiving a full general anaesthetic to optimise surgical conditions.
- Assisted Mechanical Ventilation (AMV). There are several different modes of ventilation designed to work with the patients’ own respiratory effort. The patient’s inspiratory effort is detected and triggers the ventilator to ‘boost’ the inspiratory breath. These modes have two important advantages; firstly they are better tolerated by the patient and so reduce the requirement for heavy sedation, and secondly they allow patients to perform muscular work throughout the breath, thereby reducing the likelihood of developing respiratory muscular atrophy. The ventilator-assisted breaths can be supported either by a preset inspiratory pressure or by a preset tidal volume. There are several variations of assisted ventilation.

Intermittent mandatory ventilation (IMV) is a combination of spontaneous and mandatory ventilation. Between the mandatory controlled breaths, the patient can breathe spontaneously and unassisted. IMV ensures a minimum minute ventilation, but there will be variations in tidal volume between the mandatory breaths and the unassisted breaths.

Synchronised intermittent mandatory ventilation (SIMV). With SIMV, the mandatory breaths are synchronised with the patient’s own inspiratory effort which is more comfortable for the patient.

Pressure-support ventilation (PSV) or Assisted spontaneous breaths (ASB). A preset pressure-assisted breath is triggered by the patient’s own inspiratory effort. This is one of the most comfortable forms of ventilation. The preset pressure level determines the level of respiratory support and can be reduced during weaning. There are no mandatory breaths delivered, and ventilation relies on the patient making some respiratory effort. There is, however, no back up ventilation should the patient become apnoeic, unless this mode is combined with SIMV.

Positive End Expiratory Pressure (PEEP) is used with all forms of IPPV. A positive pressure is maintained during expiration expanding underventilated lung, and preventing collapse of the distal airways. This results in improved arterial oxygenation. However, PEEP causes a rise in intrathoracic pressure and can reduce venous return and so precipitate hypotension, particularly in hypovolaemic patients. With low levels of PEEP (5-10cmH₂O), these effects are usually correctable by intravenous volume loading.

Continuous Positive Airway Pressure (CPAP) is effectively the same as PEEP, but in spontaneously breathing patients.

Initiating Mechanical Ventilation

When initiating artificial ventilation the aim is to provide the patient with a physiological tidal volume and ventilatory rate adapted to meet the patient’s underlying condition.

<i>Initial ventilator settings:</i>	
FiO ₂	1.0 initially but then reduce
PEEP	5 cmH ₂ O
Tidal volume	7-10 ml/kg
Inspiratory pressure	20 cmH ₂ O (15cmH ₂ O above PEEP)
Frequency	10 - 15 breaths per minute
Pressure support (ASB)	20 cmH ₂ O (15cmH ₂ O above PEEP)
I:E Ratio	1:2
Flow trigger	2 l/min
Pressure trigger	-1 to -3 cmH ₂ O
‘Sighs’	Nil - formerly thought to prevent atelectasis, but no longer considered effective

These settings should be titrated against the patient’s clinical state and level of comfort.

OPTIMIZING OXYGENATION

When settling a patient on the ventilator, it is good practice to initially set FiO₂ at 1.0 and then wean rapidly to a FiO₂ adequate

to maintain SaO_2 of $>93\%$. FiO_2 of greater than 0.6 for long periods should be avoided if possible because of the risk of oxygen-induced lung damage.

Strategies to improve oxygenation (other than to increase FiO_2) include increasing the mean airway pressure by either raising the PEEP to $10\text{cmH}_2\text{O}$ or, in pressure-preset ventilation modes, by increasing the peak inspiratory pressure. However, care should be taken to avoid very high inflation pressures (above $35\text{cmH}_2\text{O}$) as this may cause barotrauma to the lungs.

More complex strategies to improve oxygenation may be required in severely hypoxic patients eg acute respiratory distress syndrome (ARDS) or acute lung injury from a variety of causes. In severe hypoxia, it may be possible to improve oxygenation by increasing the PEEP further to $15\text{cmH}_2\text{O}$ (or above) and using small (6-8mls/kg) tidal volumes more frequently. However, this may cause a reduction in blood pressure and may be poorly tolerated by the patient requiring intravenous fluid loading and inotropic or vasopressor therapy.

Another strategy is to prolong the inspiratory time. Normal inspiratory to expiratory ratio is 1:2 but oxygenation may be improved if this ratio is changed to 1:1 or even 2:1. However, these alterations are often not well tolerated by the patient who may require heavy sedation. Not infrequently, due to a reduced minute volume the PaCO_2 may rise. This is not usually a problem provided the patient does not have raised intracranial pressure and the arterial pH is above 7.2. In some patients this technique is used deliberately "Permissive Hypercapnia".

In severe ARDS the patient can be repositioned and ventilated in the prone (face down) position. This may improve oxygenation by re-expanding collapsed alveoli and improving the distribution of blood perfusion in the lung relative to ventilation. In this position, patient monitoring and care is obviously difficult, and this approach should be undertaken with careful monitoring and care.

Optimising carbon dioxide elimination

Carbon dioxide elimination is improved by increasing minute ventilation either by increasing the tidal volume or the respiratory rate.

Sedation (see page 000)

Most patients require sedation in order to tolerate the endotracheal tube. Ideally, only light sedation should be given so that the patient can understand and cooperate with ventilation as well as continue to make some respiratory effort reducing the risk of respiratory muscular atrophy.

PROBLEMS DURING MECHANICAL VENTILATION

"Fighting the ventilator"

When the patient starts to breathe out of phase with the ventilator or becomes restless or distressed during IPPV, there is a fall in the delivered tidal volume due to a rise in respiratory resistance. This results in inadequate ventilation and hypoxia. There are a number of causes including:

- Patient factors - Breathing against the ventilator's inspiratory phase, breath holding and coughing.
- Decreased pulmonary compliance - pulmonary pathology, including oedema or infection and pneumothorax.
- Increased airway resistance - bronchospasm, aspiration, excess secretions
- Equipment - ventilator disconnection, leak, failure. ET tube blocked, kinked, dislodged

Management of patient 'fighting' the ventilator

- Is the patient hypoxic? If yes - follow ABC:
 - Is the endotracheal tube patent and correctly positioned? Reintubate if necessary.
 - Give 100% O_2 by manual ventilation via self-inflating bag
 - Check chest expansion is adequate
 - Auscultate chest to assess bilateral air entry
 - Check heart rate and blood pressure
 - Check ventilator and apparatus for disconnection/leak/failure

Diagnosing the problem

- High airway pressure due to blocked ET tube.
 - Patient may be biting - insert oral airway & sedate patient
 - Blocked with secretions - suction with catheter +/- 5mls saline flush. Reintubate if necessary
 - ET tube overinserted into right main bronchus - pull back tube
- High airway pressure due to intrapulmonary factors
 - Bronchospasm? (Expiratory and inspiratory wheeze). Ensure ET tube not overinserted stimulating the carina. Give bronchodilators
 - Pneumothorax, haemothorax, lung collapse or pleural effusion? (Unequal chest movements and breath sounds). Chest Xray and treat appropriately.
 - Pulmonary oedema? (Blood stained frothy secretions & crepitations). Diuretics, treat cardiac failure or arrhythmias, suction tube.
- Sedation/Analgesic Factors
 - Hyperventilating due to hypoxia or hypercarbia (cyanosis, tachycardia, hypertensive and sweating). Increase FiO_2 and the mean airway pressure with PEEP. Increase minute ventilation (if hypercarbic).
 - Coughing, discomfort or pain (raised HR & BP, sweating & grimacing). Look for causes of discomfort eg endotracheal tube irritation, full bladder, pain.

Review analgesia and sedation. Change ventilation mode to one better tolerated eg SIMV, PSV. Neuromuscular blockade - only if all other options explored.

Weaning

There are a number of complications associated with mechanical ventilation, including barotrauma, pneumonia and decreased cardiac output. For these reasons, it is essential to discontinue ventilatory support as soon as the patient improves.

Weaning is indicated when the underlying condition is resolving. Many patients are ventilated for a short period or time, for example those recovering from major surgery. Others undergoing many days of ventilation (eg ARDS). During long periods of prolonged ventilatory support, the respiratory muscles weaken and atrophy. As a consequence, the speed of weaning is often related to the duration and mode of ventilation. Assisted modes of ventilation and good nutritional support are important to prevent atrophy of the respiratory muscles.

Patients recovering from prolonged critical illness are at risk of developing 'critical illness polyneuropathy'. In this condition, there is both respiratory and peripheral muscle weakness, with reduced tendon reflexes and sensory abnormalities. Treatment is supportive. There is evidence that long-term administration of some aminosteroid muscle relaxants (such as vecuronium) may cause persisting paralysis. For this reason, vecuronium should not be used for prolonged neuromuscular blockade.

Indications for weaning

The decision to start weaning is often subjective and based on clinical experience. However, there are some guidelines that may be helpful:

- Underlying illness is treated and improving
- Respiratory function:
 - Respiratory rate < 35 breaths/minute
 - $\text{FiO}_2 < 0.5$, $\text{SaO}_2 > 90\%$, $\text{PEEP} < 10 \text{ cmH}_2\text{O}$
 - Tidal volume > 5ml/kg
 - Vital capacity > 10 ml/kg
 - Minute volume < 10 l/min
- Absence of infection or fever
- Cardiovascular stability, optimal fluid balance and electrolyte replacement

Prior to trial of weaning, there should be no residual neuromuscular blockade and sedation should be minimised so that the patient can be awake, cooperative and in a semirecumbent position. Weaning is likely to fail if the patient is confused, agitated or unable to cough.

Modes of Weaning

There is debate over the best method for weaning and no one technique has been found to be superior to others. There are several different approaches.

- Unsupported spontaneous breathing trials. The machine support is withdrawn and a T-Piece (or CPAP) circuit can be attached intermittently for increasing periods of time, thereby allowing the patient to gradually take over the work of breathing with shortening rest periods back on the ventilator.

- Intermittent mandatory ventilation (IMV) weaning. The ventilator delivers a preset minimum minute volume which is gradually decreased as the patient takes over more of the respiratory workload. The decreasing ventilator breaths are synchronised to the patient's own inspiratory efforts (SIMV).

- Pressure support weaning. In this mode, the patient initiates all breaths and these are 'boosted' by the ventilator. This weaning method involves gradually reducing the level of pressure support, thus making the patient responsible for an increasing amount of ventilation. Once the level of pressure support is low (5-10 cmH_2O above PEEP), a trial of T-Piece or CPAP weaning should be commenced.

Failure to wean

During the weaning process, the patient should be observed for early indications of fatigue or failure to wean. These signs include distress, increasing respiratory rate, falling tidal volume and haemodynamic compromise, particularly tachycardia and hypertension. At this point it may be necessary to increase the level of respiratory support as, once exhausted, respiratory muscles may take many hours to recover.

It is sensible to start the weaning process in the morning to allow close monitoring of the patient throughout the day. In prolonged weaning, it is common practice to increase ventilatory support overnight to allow adequate rest for the patient.

Tracheostomy in the intensive care unit

The commonest indication of tracheostomy in an ICU setting is to facilitate prolonged artificial ventilation and the subsequent weaning process. Tracheostomy allows a reduction in sedation and thus increased cooperation to the weaning process. It also allows effective tracheobronchial suction in patients who are unable to clear pulmonary secretions either due to excessive secretion production or due to weakness following critical illness.

Tracheostomy can be performed as a formal surgical procedure in theatre or at the bedside in the intensive care unit using a percutaneous method (see Update in Anaesthesia Number 15). The timing of conversion from an endotracheal tube to a tracheostomy remains controversial. In general, tracheostomy is considered if the patient is likely to need prolonged ventilation or when weaning will not be straightforward. Complications are few but include tube blockage, misplacement or dislodgement, infection and bleeding. Haemorrhage can occur either at the time of the procedure or at a later date caused by erosion of the tube into a major vessel such as the innominate artery.

Other indications for tracheostomy are to bypass an upper airway obstruction, protect the lungs from soiling if the laryngopharyngeal reflexes are depressed or as part of a surgical or anaesthetic technique eg larygectomy.