Respiratory failure and Ventilation theory – with some COVID-19 specific points

This is not a clinical guideline or standard operating procedure. This is a summary of respiratory failure and ventilation for those who will be managing patients with acute respiratory illness in the ward environment up until transfer to critical care. It is aimed at, but not exclusively for, medical trainees, emergency department doctors and those re-deploying to the front-line.

If you only retain/understand/don't want to read anything else from this document then remember these points:

Breathing has 2 purposes – get oxygen in and carbon dioxide out

There are only 2 ways to get more oxygen in:
1. Increase FiO₂
2. Apply PEEP

There are only 2 ways to get more carbon dioxide out:
1. Increase respiratory rate
2. Increase tidal volume

Ventilation is based on these principles and the stuff below can over-complicate it.

The majority of critically unwell COVID-19 patient will have T1RF. Invasive ventilation in those patient's who it is deemed clinically appropriate is the optimal treatment.

Purpose of breathing:

1. Oxygenation
2. Carbon dioxide removal (this is ventilation – ie, ventilation is really all about CO₂ control)

There are 2 ways to improve oxygentation:

1. Increase FiO₂
   a. Increase the percentage of oxygen inspired with each breath.

2. Apply PEEP
   a. This improves oxygenation by ‘recruitment’ - ie, splinting open alveoli at end of expiration and therefore providing an increased surface area for gas exchange.

There are 2 ways to reduce carbon dioxide:

1. Increase respiratory rate
   - Breathe quicker. Think about the hyperventilating patient with low carbon dioxide and a respiratory alkalosis.
   - This is a difficult thing to alter in an awake patient who is sick – they’ll often be doing this to the maximum anyway until they tire.
   - When a patient is invasively ventilated and paralysed then this is something that can be controlled.

2. Increase tidal volume
   - Breathe deeper. This is something we can influence and is the basis of Non-Invasive Ventilation (NIV).

Respiratory rate (RR) x Tidal Volume (Vt) = Minute Ventilation (something anaesthetists and intensivists will talk about).

Respiratory failure:

1. Type 1 – hypoxia – parenchymal lung problem (pneumonia including COVID, pulmonary oedema etc), pulmonary vascular problem (PE)
2. Type 2 – hypercapnoea with or without hypoxia (aka; ventilatory failure, hypercapnic respiratory failure) – can be due to problem with airways (COPD), chest wall (obesity, kyphoscoliosis), muscles (Duchenne’s), or CNS (Guillian-Barre, Myaesthenia, drugs causing CNS depression).

**Oxygenation/Ventilation terminology:**

1. PEEP (Positive End Expiratory Pressure) is exactly the same as CPAP (Continuous Positive Airway Pressure) or EPAP (Expiratory Positive Airway Pressure). This is the pressure in the alveoli at the end of expiration, ie, the lowest pressure in the lung during respiratory cycle.
2. IPAP (Inspiratory Positive Airway Pressure). This is the maximal pressure reached during inspiration – ie, the highest pressure in the lung during the respiratory cycle.
3. PS (Pressure support) – this is the difference between PEEP and IPAP. The bigger the difference between the two, the bigger the tidal volume will be and therefore the more CO$_2$ you will remove.
   (ie PS = IPAP – PEEP)

Key point: if you increase the PEEP because you want to improve oxygenation then you need to increase the IPAP an equal amount to maintain the same pressure support (ie maintain the same effective tidal volume and CO$_2$ control)

**Delivery device terminology:**

1. High flow nasal oxygen (aka optiflow, high flow nasal cannula)
   - This is humidified, warmed oxygen delivered at upto 60L per minute. The major advantages it has over standard oxygen off the wall (max flow rate 15L/min) are:
     i. that it provides some PEEP (possibly up to 5cmH$_2$O))
     ii. it can deliver an FiO$_2$ of near 100%.
iii. It is delivered by nasal prongs so patients can talk, eat and drink

iv. It is warmed and humidified and therefore doesn’t dry out the upper airway like wall oxygen.

- The major disadvantage in COVID is that it is an aerosolizing procedure so increases risk of transmission and full PPE must be worn.

- Other disadvantages:
  i. Patients can not be transferred whilst on HFNO
  ii. It uses lots of oxygen (this could become a problem for trusts as oxygen pressure may not be able to cope)

- I suggest setting the flow rate at 60 L/minute as this will provide maximal PEEP, then titrate the FiO₂ as required.

2. CPAP – THIS IS NOT NIV
   - Use in T1RF
   - This is usually delivered by a mask that covers nose and mouth.
   - It is given to improve oxygenation (see notes on PEEP above) or to treat chronic upper airway obstruction (Obstructive Sleep Apnoea)
   - It does little for CO₂ removal (ie ventilation)
   - This also counts as an aerosolising procedure therefore full PPE must be worn.

3. Non-invasive Ventilation (NIV) aka BiPAP (Bilevel Positive Airway Pressure) – THIS IS NOT CPAP
   - Use in T2RF
   - This is usually delivered by a mask that covers the nose and mouth
   - This is used to remove carbon dioxide
   - It involves the use of 2 pressures:
     i. IPAP
     ii. EPAP/PEEP/CPAP (all the same thing)
   - You can use it to improve oxygenation by increasing the PEEP but this is not the primary purpose.
- Choosing appropriate starting pressures can cause confusion.

General principles:

i. It can be difficult for patients to tolerate, especially to begin with so start gently.

ii. An IPAP of 14 and EPAP of 4 is a reasonable start

iii. Patients with a high BMI will need a higher EPAP (somewhere between 6 and 10) – and remember to increase IPAP by the same amount to maintain PS

iv. Follow local protocols when commencing and titrating, with an ABG after an hour of NIV important to guide further treatment.

4. Mechanical ventilation (aka invasive ventilation)

- Patient is intubated, sedated and possibly paralysed

- All these patients should be looked after in critical care by those with the airway skills to re-intubate the patient should the need arise.

- However, the principles of controlling oxygenation and carbon dioxide remain the same – so remember those basics.