The Mechanics of Ventilation

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Objectives:

To explain the following:

a) Pressure cycled ventilation
b) Compliance and its implications to IPPV
c) The changes in dynamics that occur when using IPPV
d) The implications of measuring pressure at the mouth vs the lungs.
e) How to connect a pressure-cycled device to a patient and get going.

Why mechanical ventilation?

It is often said that many nurses (or vets) have a “gifted hand” and can adequately ventilate their patients as well as, if not better, than a mechanical ventilator.
I challenge this on two levels:

1) The nurse (or vet) may feel they are ventilating at the right pressure but they have no idea of what pressure they are giving.
2) Even if they could reliably ventilate to a given pressure they could not sustain this consistently for long periods of time.

You must remember that the lungs were not designed to be pressurised, they were designed to be filled at atmospheric pressure by a pressure gradient of only 3 or 4 centimetres of water. By using IPPV we are totally changing the physics of lung ventilation and by creating pressure gradients that are 4 or more times greater than intended we are at risk of causing lung damage at whatever level.

For any nurse or vet that would like to try their hand at ventilating then please feel free to come to the stand to try the demo.

The other benefit of mechanical ventilation is that, should ventilation be necessary for protracted periods, a member of staff is not tied up with this and sustained correct pressures and volumes can be maintained for hours.

Why Pressure cycling and what is it anyway?

All mechanical ventilators must have some means of controlling their cycle. In other words how does the ventilator change from the inspiratory phase to the expiratory phase? There are basically two types – volume cycling and pressure cycling. (time cycling is really volume cycling by another name).
Volume cycling – give a set volume in a set time irrespective of the pressure reached.
Pressure cycling – give gas until a set pressure is reached irrespective of the volume delivered or the time taken.

Looked at in this way you might be led to believe that pressure cycling was less desirable than volume cycling. However for small animals (<10kg) pressure cycling is to be preferred since it avoids the complication of lung over-inflation. Take the example of a rat with a tidal volume of 5mls. Suppose that the actual delivered volume could only be accurately controlled to +/- 1 ml then it is possible that the delivered volume could be 6mls or 4mls. 4 mls is only 80% of the required volume and could result in under-ventilation whereas 6 mls is 120% of required volume and may lead to increased intra-pulmonary pressures. Also if the rat is moved such that the expansion of the chest is restricted to an equivalent tidal volume of 4 mls then the 6 ml tidal volume, being 50% more than required, will almost inevitably result in excess pressure being developed in the chest. Whether this is a problem or not will depend on the tightness of fit of the ET tube, the condition of the respiratory tissue and whether the chest is open or closed. Obviously this is less than ideal. Conversely if the rat had been pressure cycled then the changes in effective tidal volume would have been accommodated for and air would have been delivered until the required pressure was reached. Some volume cycled ventilators can not accurately control volumes delivered when they fall below 100mls.

As animals get bigger the errors associated with volume delivery tolerances reduce and so the advantages of pressure cycling over volume cycling are not so great.

What pressure setting do I use?

If we are pressure cycling this obviously raises the question of what pressure setting to use. This may seem bewildering since you are unlikely to know intuitively what pressure is right. However things are not as bad as they seem. Throughout the species there is a relatively small band of pressures required. Typically anything can be ventilated between 3 and 20cm water pressure and most lie within 5 – 12 cm water pressure. So to get going, set the pressure at 3cm H_2O pressure and adjust the pressure until normal respiratory movements are observed. By adjusting for normal respiratory movements you are automatically adjusting for the animals approximate tidal volume assuming that the animals chest compliance has not changed dramatically.

What is compliance?

Compliance is defined as the volume change per unit of pressure required to inflate the lung and is a measure of the elasticity of the lung system.

Compliance = volume change/pressure change.

The higher the value, the greater the elasticity of the lung system. For example if it takes 180mls of air to inflate a dogs chest to a working pressure of 12cm H_2O then the compliance is calculated as being 180/12 = 15mls/cmH_2O and is generally stated as 15. If for some reason the chest of this dog became stiffer and wouldn't expand as easily as before then we might find that it took only 120 mls of air to reach a pressure of 12 cmH_2O. The compliance would then be 120/12 = 10mls/cmH_2O or 12. Thus there has been a fall in compliance or elasticity of the chest. Note that the compliance value relates to the combined compliance of the lungs and the chest wall.

What controls compliance?

Compliance is affected by several factors. Any factor which changes the elasticity of either the chest wall or the lungs themselves will change the compliance. Therefore loss of movement in the joint between the rib and the thoracic vertebrae will reduce the compliance as will pressure on the diaphragm from a distended abdomen. Also conditions such as feline asthma or bronchial disease will reduce the lung compliance and therefore the compliance overall, as will a surgeon putting his (her) weight on the chest during surgery.

Why do I need to understand compliance?

Because C = V/P and we are pressure cycling. Therefore any change in compliance will affect the volume of gas delivered to the lungs. Also if the compliance changes during surgery you will need to adjust the pressure settings to accommodate this. A good example is the ruptured diaphragm in the cat. When the abdomen is closed the compliance will be fairly low, say 7 or 8. When the abdomen is open and the lungs are free to extend out of the rib cage into the abdomen and open air, the compliance may rise to say 14 or 15. This means that with the current settings the volume will be almost doubled. There will still be no problem from over-inflation but there could be problems caused by sheer distension of the lung tissue. Reduce the pressure setting to accommodate. Similarly when the thorax is again closed you will need to re-adjust to take into account the changed compliance.

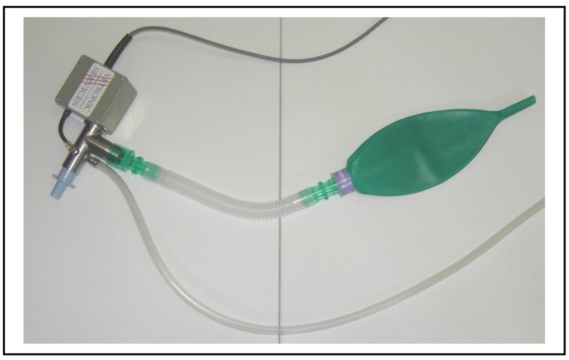
Do I need to maintain the animal's normal respiratory rate?

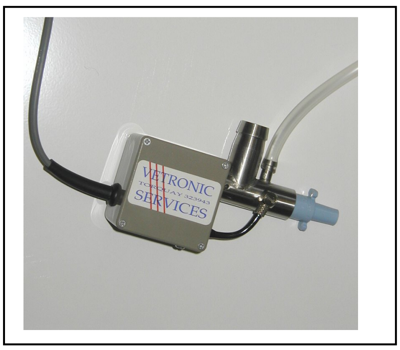
Respiratory rate is governed by two phases – inspiration and expiration. Obviously adjusting either will change the respiratory rate. What may not be so immediately apparent is that the smaller the animal the less important it is to adhere to the natural breathing rate. Why? Because the smaller the animal the greater the percentage of its total energy expenditure is due to breathing. (See Dukes Eighth edition page 305). For example the work/body weight of a dog is a ratio of about 0.55 whereas the work/body weight of a rat is 1.9, nearly a four-fold increase. Thus in our rat, once we take over the role of ventilation the metabolic requirement for oxygen will fall dramatically and with it the need to eliminate CO2 at such a rate. It is for this reason that we can safely reduce the breathing rate to say a half or a third of their normal. However it becomes more imperative to maintain body temperature in these cases otherwise a lot of metabolic energy is expended keeping up the body temperature and the benefits of reduced workload are lost. This applies equally to birds or other animals with high respiratory rates.

Duration of expiration. Settable by a dial
Duration of inspiration. Dependent on one main factor – incoming gas flow rate. The lungs are a set volume so the greater the flow rate the quicker they will fill and so the shorter the inspiratory phase. So to decrease the inspiratory phase length, increase the flow rate. In very small animals this may cause a paradox of reducing the tidal volume – see later.

Rebreathing and the anaesthetic circuit configuration.

The two circuits below could both be used for IPPV. Which is the correct configuration?

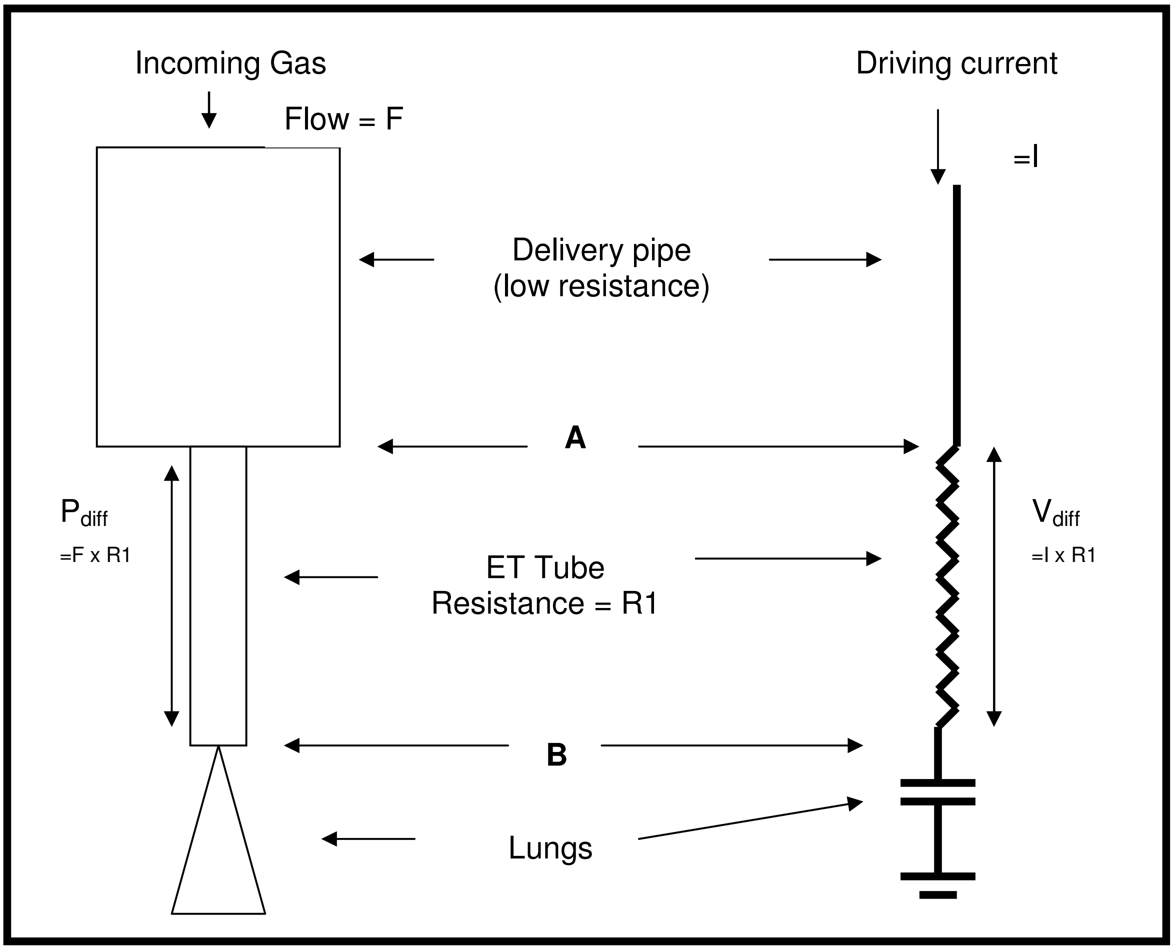




Both are. Why? Because, during IPPV the expiratory circuit plays no part in the respiratory cycle.

The paradox of reduced tidal volume when increasing the flow rate.

As mentioned above, increasing the flow rate acts to reduce the inspiratory phase time and should not affect the tidal volume. Why then, does increasing the flow rate in very small animals deprive them of gas? The answer lies in the fact that very small animals have very small airways and are subsequently intubated with very small tubes. These will be the smallest in the circuit and their functional resistance will dominate the circuit. The diagram below shows the equivalent circuit.



Pressure, for obvious reasons, can only be easily measured at the proximal end of the ET tube. The pressure at A will always be slightly higher than at B because of the resistance of the ET tube. The value above that measured at B is given by the formula V_{diff} = Flow x R1 or P_{diff} = Flow x R1. If R1 is high then there is a pressure drop across the tube and the sensor reaches target pressure before the lungs. The observer sees a reduced tidal volume but the pressure setting seems OK. To “get more gas into the patient” the user increases the gas flow rate. This increases the term V_{diff} and ***less*** gas gets to the patient. The correct way to manage this situation is to reduce the gas flow rate to the minimum compatible with desired respiratory rate and then to increase the pressure setting for normal breathing movements.

Summary

Mechanical ventilation offers benefits of controlled gas delivery and consistency when compared to manual IPPV.
Pressure cycled ventilation is inherently safer in smaller animals because it avoids inadvertent over-inflation.
Pressure settings do not need to be learned. The ventilator is “tuned” to the patient.
Understanding compliance helps in understanding the need to adjust settings during surgery.
Respiratory rates can be reduced for animals with a high respiratory rate and relatively small body mass.
The implication of a small Et tube must be understood to avoid underinflation.