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Intermittent positive pressure ventilation: Basic principles

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ABSTRACT: Artificial ventilation of the lungs is not something that is reserved for use only in emergency situations or in certain procedures, such as thoracotomy. It can be a useful adjunct to a good, balanced anaesthetic and can be of great benefit in many situations. However, problems can arise if the technique is used incorrectly, so it is vital to have a basic understanding of the potential disadvantages. This article discusses the indications for intermittent positive pressure ventilation (IPPV), its physiological effects and practical considerations.

Introduction

A good anaesthetic should provide unconsciousness, analgesia and adequate muscle relaxation, but, unfortunately, all anaesthetic drugs have other (unwanted) effects, especially on the cardiovascular and respiratory systems. The goals should be to:

- make sure that all components of a balanced anaesthetic are provided
- maintain homeostasis (e.g. normothermia, normal oxygenation, normal carbon dioxide concentrations, normal cardiac output); the ultimate aim is to keep oxygen delivery to the tissues within normal limits
- detect any adverse effects of anaesthesia, especially on the cardiovascular and respiratory systems, as soon as possible and take corrective measures immediately.

Monitoring ventilation

Ventilation is the movement of gas (oxygen) between the environment and the lungs into the blood. For organisms with lungs, ventilation is synonymous with breathing.

When a patient is breathing spontaneously, the primary drive for respiration is the amount of carbon dioxide (CO_2) in the blood, which is usually expressed as a partial pressure (in mmHg or in kilopascals, kPa). This should be 35–45 mmHg. Low levels of oxygen can also stimulate breathing, although only severe hypoxia has a significant effect. Anaesthetic drugs depress respiration, so that the amount of CO_2 in the blood, and consequently in the gas expired by the patient, increases. Consequently, measuring the amount of CO_2 in expired gas gives a good indication of how well an animal is breathing, and whether we need to provide any assistance. If the patient is unable to remove the excess CO_2 which has built up, this will affect the pH of the blood and have severe consequences if left untreated.

Capnography

The easiest way to measure exhaled CO_2 during anaesthesia is with a *capnograph*. Modern devices provide a real-time graphic display of the amount of CO_2 in respired gas throughout the respiratory cycle (**Figure 1**). The most important measurement provided is the amount of CO_2 in the gas right at the end of an exhalation, known as *end-tidal carbon dioxide* ($ETCO_2$). In most circumstances, this value reflects the amount of CO_2 in the alveoli, and consequently in arterial blood, and provides a measure of the efficiency of a patient's ventilation. The great advantage of capnography is that it provides a continuous, non-invasive measure of CO_2. The shape of the capnogram also provides extra information about the respiratory system.

Pulse oximetry

In animals with compromised lung function (e.g. lung collapse from a diaphragmatic hernia), the anaesthetist will see significant reductions in oxygenation, even when the patient is breathing 100%

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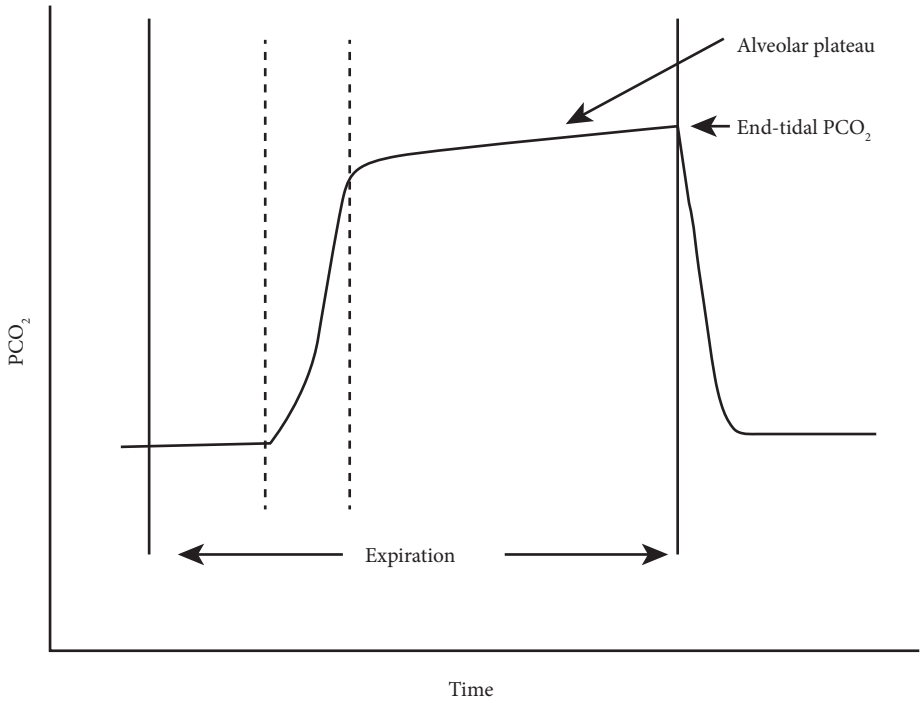


Figure 1. A normal single-breath capnogram

Failure to ventilate:	Arterial PCO_2	> 60 mmHg
Failure to oxygenate:	Arterial PO_2 *or* SpO_2	< 60 mmHg < 90%

Figure 2. Triggers for institution of artificial ventilation: PCO_2 = partial pressure of carbon dioxide; PO_2 = partial pressure of oxygen; SpO_2 = saturation of haemoglobin with oxygen measured with a pulse oximeter

oxygen, because of problems matching ventilation with blood flow through the lungs. In these situations, pulse oximeters can be used to measure how well changes in the pattern of artificial ventilation, as well as other methods of improving oxygenation, are working.

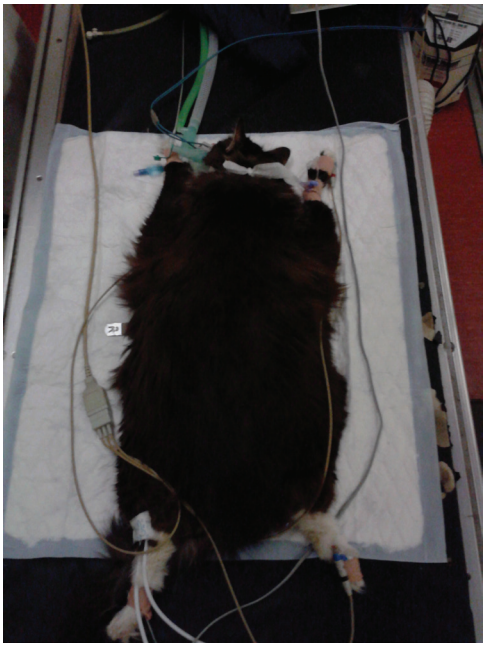
Blood gas analysis

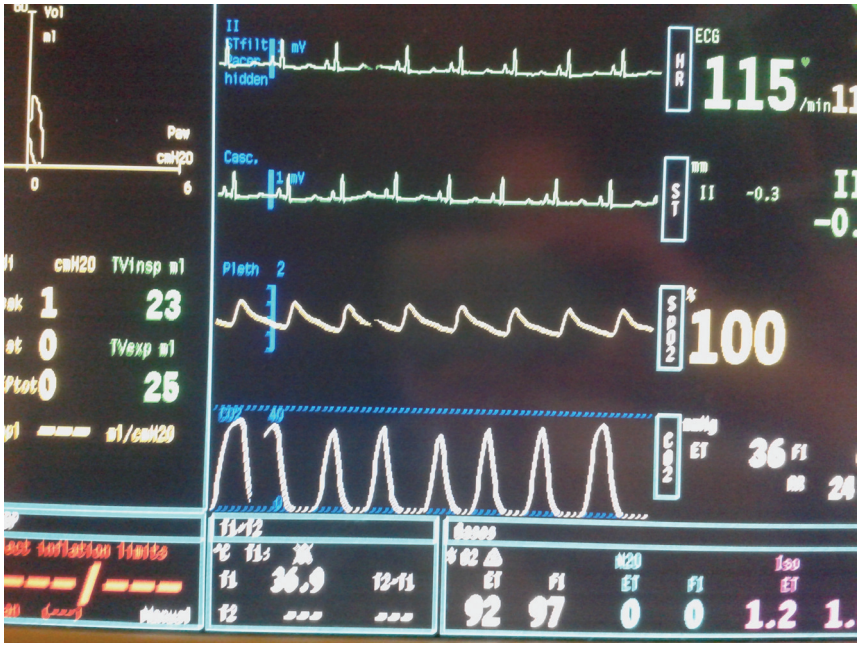
Ventilation efficiency can also be monitored by analysis of arterial blood gases; however, these do not provide continuous information, and the technique does have some potential problems (e.g. haemorrhage, haematoma formation and infection at the sample site).

When should we use artificial ventilation in patients?

It is a common misconception that artificial ventilation (usually called intermittent positive pressure ventilation [IPPV]) should be reserved only for those patients who are apnoeic, those undergoing thoracic surgery or for those which have been given neuromuscular blocking agents. Any patient that is hypoventilating or unable to maintain adequate oxygenation (**Figure 2**) is a candidate for IPPV, and this includes patients with a low respiratory rate and/or low tidal volume, such as obese patients or those with lung disease (**Figures 3a and b**).

Patients who are tachypnoeic with low tidal volumes (**Figure 4**) may also benefit from IPPV to maintain a stable plane of anaesthesia - we've probably all





Figures 3a and 3b. (a) This obese patient is unable to achieve an adequate tidal volume; (b) note that the capnography waveforms obtained in this patient do not have a good alveolar plateau, due to the rapid respiratory rate and low tidal volume

experienced the panting Yorkie that won't stay anaesthetized, simply because it is shuffling gas back and forth in its trachea and bronchi without actually delivering any anaesthetic to its lungs! A list of absolute and relative indications for IPPV is shown in **Table 1**.

Patients who are failing to oxygenate adequately despite breathing oxygen may also require IPPV. These patients are usually defined as having an SpO_2 <90%, an arterial partial pressure of oxygen <60 mmHg (if measuring blood gases), or are showing signs of cyanosis.

The main aim is to restore oxygenation and ventilation to acceptable levels, whilst at the same time minimizing harmful effects.

What are the potential harmful effects of IPPV?

When an animal is breathing spontaneously, inspiration causes expansion of the thorax, which generates a negative interpleural pressure and draws gas into the lungs. During expiration, the interpleural pressure rises as the lungs deflate, but remains negative throughout the respiratory cycle. This is very important, because negative interpleural pressure is essential to draw venous blood into the chest (venous return) and so maintain a proper stroke volume and cardiac output. During IPPV, interpleural pressures remain above zero throughout the respiratory cycle, which reduces stroke volume and cardiac output. This effect is exacerbated with high pressures and long inspiratory times, and in animals that are hypovolaemic or in heart failure.

Other disadvantages include the possibility of lung damage if the lungs are overstretched by excessive tidal volumes.

Practical considerations

Manual ventilation

An appropriate breathing system should be selected. The Magill and Lack systems are not suitable for prolonged IPPV because in that situation they require higher fresh gas flows (3 × normal) to prevent rebreathing of exhaled carbon dioxide. The T-piece, Bain, Humphrey and circle systems are more suitable for continuous IPPV (**Figures 5a and 5b**).

Squeezing of the reservoir bag should be gentle, with a regular rhythm, and provide the patient with an appropriate tidal volume, i.e. one that seems to produce what appears to be a normal chest excursion. Normal tidal volume is 10–15 ml/kg, so an average cat will have a tidal volume of around 50 ml - ***about one-tenth the volume of a 500 ml reservoir bag on a T-piece*!**

As stated in the previous section, it is also important that positive pressure during inspiration is not applied for too long, to minimize the effects on venous return. Think how long inspiration would normally last in your patient and try to maintain that patten. The length of expiration is also important - try to have a ratio of inspiratory:expiratory time of 1:3 (i.e. expiration is three times longer than inspiration).

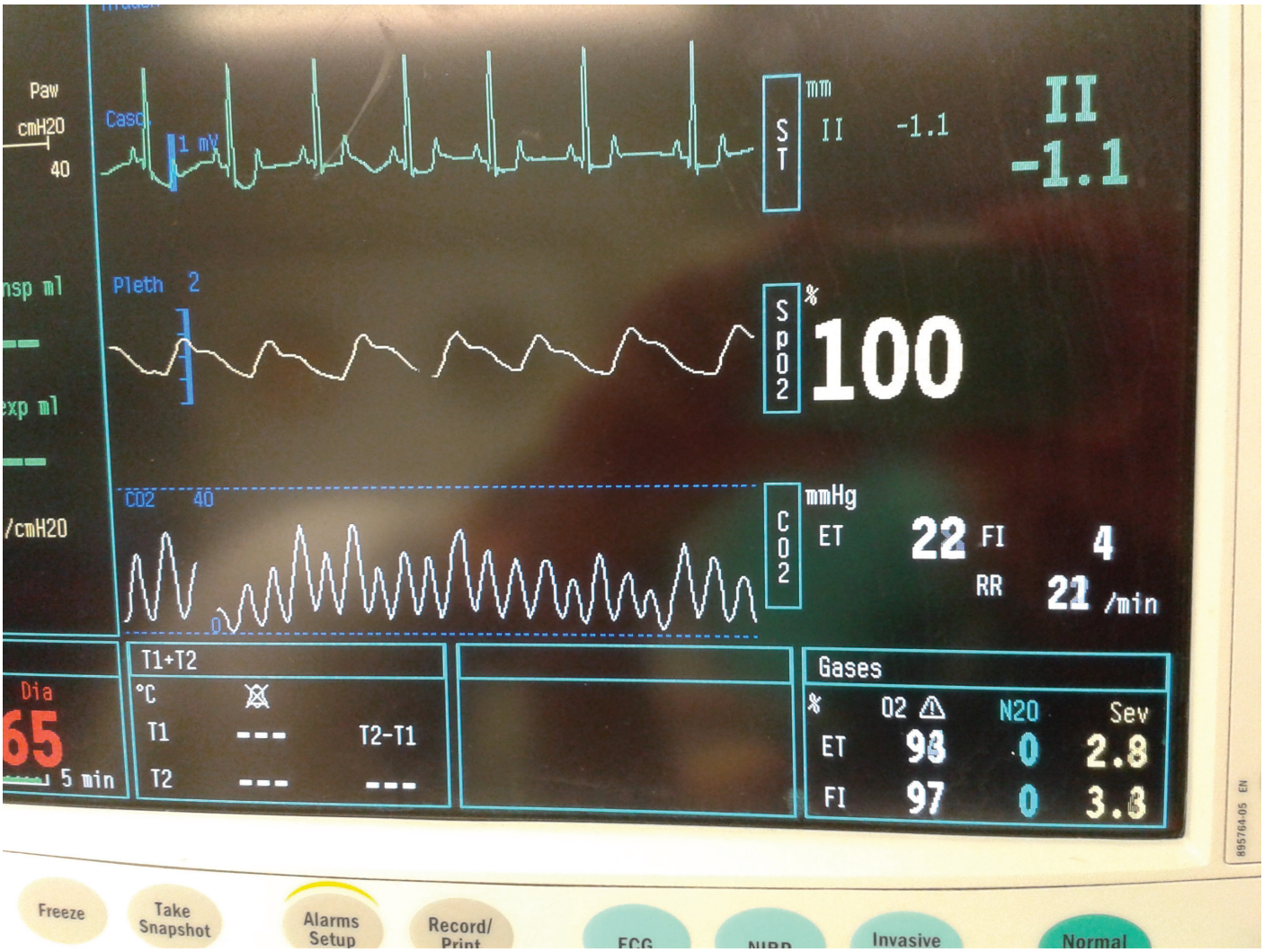
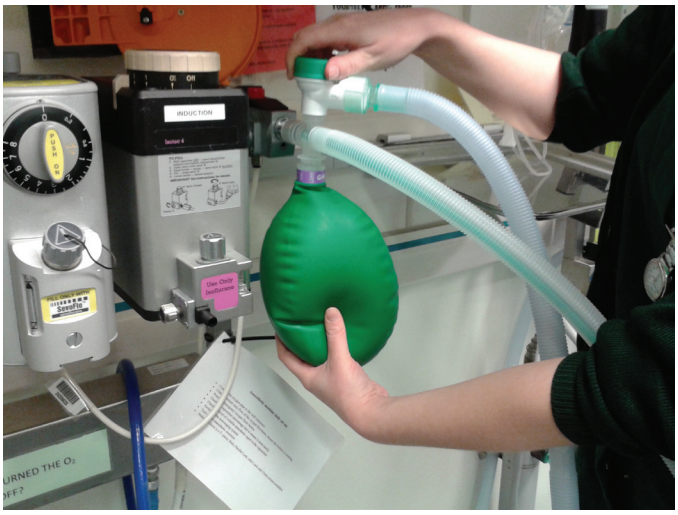
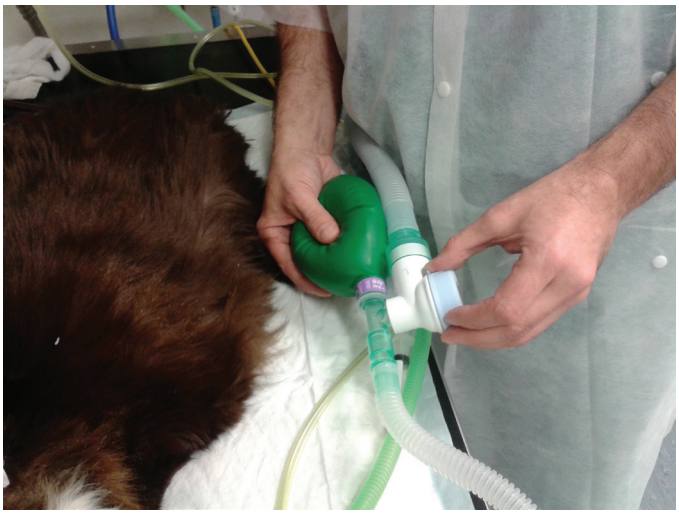


Figure 4. Capnograph waveform (lower trace) in a tachypnoeic patient, resulting in low end-tidal CO_2 and rebreathing of expired CO_2





Figures 5a and 5b. (a) Intermittent positive pressure ventilation (IPPV) using a Bain system and (b) using a modified T-piece

Table 1. Indications for intermittent positive pressure ventilation (IPPV)

Absolute indications	Relative indications
• open chest (thoracotomy, thoracoscopy, ruptured diaphragm) • use of neuromuscular blocking agents • increased intracranial pressure	• increased pressure on diaphragm (obesity, ascites, sternal recumbency, horses and other large animals) • debilitated animals (muscle weakness) • long-duration anaesthesia • when using potent respiratory depressants, e.g. fentanyl • animals breathing erratically

Table 2. Advantages and disadvantages of mechanical and manual intermittent positive pressure ventilation (IPPV)

	Advantages	Disadvantages
Mechanical	• more accurate application of variables • leaves anaesthetist available to monitor patient	• equipment can be expensive • problems may not be noticed as quickly • requires additional staff training
Manual	• aware of problems instantly • no special equipment needed • can titrate each breath	• less accurate • likely risk of high pressures and lung over-inflation • tedious • requires another anaesthetist to monitor the patient

Table 3. Hazards of intermittent positive pressure ventilation (IPPV) and ways to avoid them

Parameter	Consequence of wrong setting	Advice
Peak inspiratory pressure	• High pressures can cause lung damage	• Maintain at 8–15 cm H_2O • Do not exceed 20 cm H_2O
End-tidal CO_2	• Values above 45 mmHg cause progressive cerebral vasodilatation, which can increase intracranial pressure • Values below 35 mmHg cause progressive vasoconstriction, which can reduce blood supply to the heart • Disturbances in acid-base balance	• Maintain at 35–45 mmHg
Tidal volume	• High tidal volumes result in over-inflation, which can traumatize lung tissue • Low tidal volume may result in inadequate gaseous exchange	• Monitor and adjust tidal volume as necessary
Respiratory rate and the inspiratory:expiratory (I:E) time ratio	• Allowing adequate expiratory time promotes better venous return to the heart	• Maintain respiratory rate similar to normal and an I:E time ratio of 1:3

We recommend that, when using the Bain and T-piece systems, where higher gas flows are used, the 'pop-off' valve is left partially open when squeezing the bag: this provides a small leak in the system so that excessive inflation pressures cannot be applied. It also avoids the need to keep opening and closing the valve and makes the process easier as well as safer.

Mechanical ventilators

Mechanical ventilators were designed to relieve the anaesthetist from the task of repetitive bag squeezing, leaving them available to monitor the patient more closely. However, there are some disadvantages, which are shown in **Table 2**.

There are many different mechanical ventilators available, and the way they are classified is even more confusing! However, only a few are commonly used in veterinary practice. The most important point is that before you use one, you *must* know how it works, as well as its advantages and limitations.

How ventilators work can be classified in separate steps:

- *how gas is delivered to the patient during inspiration* - they can be classified as volume controlled (constant flow delivered) or pressure controlled (constant pressure delivered)
- *how they cycle from inspiration to expiration*: they can be classified as time-cycled, volume-cycled or pressure-cycled
- *how they cycle from expiration to inspiration*: this usually happens after a set period of time (time-cycled)

Not all machines can be used in the full range of patient sizes, although some (such as the Ventipac and Nuffield) provide an interchangeable valve: this allows the user to ventilate patients under 10 kg, with a paediatric valve, and patients over 10 kg, with an adult valve. Changing the valve, however, does alter the way in which the ventilator functions, so it is vital that the user fully understands the ventilator being used.

Complications and how to avoid them

The respiratory rate, end-tidal CO_2, tidal volume and peak inspiratory pressure should ideally be monitored, as all provide key information about efficiency of ventilation. **Table 3** shows variables which can be controlled and the complications that may arise from inappropriate ventilator settings.

Weaning from IPPV

IPPV is not usually needed when the procedure is finished, as anaesthetic drugs which may have had respiratory depressant effects can also be stopped. Patients should still be monitored closely, as some may still need a degree of support until normal spontaneous breathing returns. A few breaths per minute can be given, allowing the carbon dioxide levels to increase gradually and stimulate respiration. If neuromuscular blockers have been used, extra caution is required to ensure the effects have worn off or been reversed before stopping IPPV.

Acknowledgement

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Further reading

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