Intermittent positive pressure ventilation using mechanical ventilators has not been used traditionally in veterinary practice.

Modern mechanical ventilators have become more affordable and easier to operate, allowing an increase use in clinical practice.

Understanding the mechanics, function, and physiological effects of mechanical, intermittent, positive pressure ventilation is necessary in order to safely, and effectively, ventilate anesthetized veterinary patients.

**Terminology and physiology**

- Minute ventilation (VE) = Respiratory rate (f) X Tidal volume (TV).
- Under normal physiological conditions PCO2 dictates minute ventilation (VE). Oxygen has little effect on VE unless the PO2 falls below 60 - 70 mmHg.
- CO2 crosses the blood brain barrier where it combines with water in the CSF. Carbonic anhydrase in the CSF facilitates the formation of carbonic acid which then dissociates into hydrogen and bicarbonate ions. The hydrogen ions then interact with the chemoreceptors of the dorsal respiratory group:
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  \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-
  \]
- Hypoventilation is synonymous with increased PCO2 whereas hyperventilation is synonymous with decreased PCO2.
- With increased PCO2, respiratory drive will increase, with decreased PCO2, respiratory drive will decrease.
- IPPV = intermittent positive pressure ventilation, PIP = peak inspiratory pressure, PEEP = positive end expiratory pressure
- There are many ways one can control ventilation with anesthetized patients: the reservoir bag, a demand valve, or a mechanical ventilator to name a few.

**Indications for controlled ventilation**

- Hypoventilation: Hypercapnea, drug induced respiratory depression, trauma, disease, and others.
- Poor oxygenation: Five causes of hypoxemia include: low fraction/pressure of inspired oxygen; inadequate VT; O2 diffusion impairment; ventilation to perfusion mismatch (V/Q mismatch), and pulmonic/anatomic cardiac shunt.
- Depth of inhalant anesthesia: Anesthetized patients, while breathing anesthetic vapors spontaneously, cycle naturally between levels of light and deep planes of general anesthesia. Controlled ventilation provides a constant rate of inhaled anesthetics, thus eliminating the variability of inhalant general anesthesia.
- Surgeries that involve the loss of negative pressure and mechanical tethering between the visceral and parietal pleurae require intermittent positive pressure ventilation.
- Specific pulmonary diseases require assisted ventilation during general anesthesia, examples include: chest trauma, diaphragmatic hernia repair, severe alveolar diseases, and pleural diseases.
- Patients with conditions that may significantly limit VT, such as pregnancy or obesity, should receive ventilatory support during general anesthesia.
- In reality, indications for controlled ventilation are not always well defined. Ventilators are useful tools during general anesthesia, however; they should be used according to each patient’s individual and should never replace human intervention. Always monitor patients under general anesthesia receiving mechanical ventilation closely. Mechanical ventilators can induce serious patient pulmonary damage, even death, if not set-up and monitored correctly.

**Controlled ventilation**

- Mechanical ventilation is based on VE, which is function of f X VT
- Adjustment of VT requires changes in ventilation frequency and or volume.
- Volume mode: Volume mode ventilator will deliver a controlled volume of gas (patient’s VT), regardless of the peak inspiratory pressure. The variable factor is pressure. Small animal patient VT is approximately 10-20 ml/kg. Most anesthetic mechanical ventilators are set volume mode or have a volume mode option. During long periods of mechanical ventilation volume mode ventilators can cause pathological changes to the pulmonary tissues.
- Pressure mode: Pressure mode ventilator will deliver a volume gas until a set pressure is reached. The variable factor is volume. Most mechanical ventilators that have pressure mode also have volume mode option. Pressure mode ventilation causes fewer pathologic changes to pulmonary tissues than volume mode ventilation.
• Time-cycled ventilation: Despite volume vs. pressure mode ventilation, almost all mechanical ventilators are time-cycle controlled based on respiratory frequency (breaths per minute). Typically, timing is controlled electronically.

Basic anatomy of an anesthesia mechanical ventilator
• Most anesthetic mechanical ventilators have two gas sources. The driving gas is any type of high pressure gas that drives the bellows, from outside, thus pushing (positive pressure) the tidal volume into the patient (compressed O₂, medical gas, N₂, CO₂). Maximum pressure of the driving gas should not exceed 50 psi. The breathing system gas is on the inside of the bellows and is continuous with the patient’s breathing circuit. Remember, the driving gas and breathing gas are two, separate gases and should not mix.
• Bellows. Most anesthetic mechanical ventilators use a bellows to push the breathing gas VT into the patient. Bellows are classified as ascending or descending, based on the direction the bellows move during exhalation.
• Control panel. Anesthetic mechanical ventilators have a control panel that allows adjustment of patient VT, breathing frequency, and sometimes I:E ratios.
• Scavenging system. Because the inside of the ventilator bellows is continuous with the patient’s breathing gases, the ventilator attaches to the anesthetic machine scavenging system for evacuation of waste gases.
• Connecting hose and wall plug-in. Anesthetic mechanical ventilators have a hose that connects to the high pressure gas driving the bellows. The hose should be color-coded according to the driving gas; for example, oxygen is green, and medical air is yellow.

Capnography
• Under normal physiological conditions the primary indication for mechanical ventilation during general anesthesia is patient CO₂. There are two ways to monitor patient PCO₂: arterial blood gas analysis and/or end-tidal PCO₂ (PETCO₂, capnography). Although arterial blood gas analysis is more accurate, it is also expensive and impractical. Capnography provides a useful, and practical, means to monitor patient PCO₂, and is recommended for all anesthetized patients undergoing mechanical ventilation under general anesthesia.
• There are two categories of capnographs: main-stream, which analyzes the patient’s exhaled breath adjacent to the endotracheal tube, and side-stream, which removes a sample of the patient’s breath and delivers it to an analyzer away from the patient.
• Capnography is based on the principle that end-tidal exhaled PCO₂ (Paco₂) is roughly equal to pulmonary arterial PCO₂ (PaCO₂).
• Graphical illustration of the PETCO₂ over time is called a capnogram. Capnograms are useful for visually monitoring an anesthetized patient’s PCO₂ and other problems that can develop, such as a leak in the breathing system.

Final considerations
• A patient’s delivered VT should be set according to a desired PIP and PETCO₂ rather than to the calculated VT.
• Maximum PIP for small animal patients is 20 cm H₂O; otherwise, barotrauma could occur to the patient’s pulmonary tissues (alveoli).
• IPPV causes a decrease in mean arterial pressure due to a reversal of the physiological thoracic blood pump.
• Positive end-expiratory pressure can be used to help facilitate oxygenation via maintaining opened alveoli.

References