Tinkering with Anesthesia Machines
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Learning Objectives:
- Describe function of each component of the anesthetic machine
- Troubleshoot malfunction of the various components of the anesthetic machine
- Properly perform a leak test

Veterinary technicians or nurse anesthetists depend on gas anesthesia machines to safely anesthetize patients large and small, on a regular basis. Truly understanding your machine involves unveiling a deeper understanding of each component and how each part contributes to the overall function.

In the simplest form, anesthetic machines are designed to deliver volatile gases (inhalant anesthetics) and carrier gases (oxygen, +/- nitrous oxide) to the patient. They also provide a means for manual ventilation as well as remove carbon dioxide and corral waste anesthetic gases (WAGs). After becoming properly introduced to your machine, the first rule of order is to follow the flow of gas as it travels throughout the machine, ala 1966 Fantastic Voyage style.

Circle system voyage- oxygen supply>flow meter > (oxygen flush) >vaporizer>inspiratory valve> wye hose>patient >wye hose >expiratory valve >pressure manometer> APL (pop off valve) >carbon dioxide absorber > scavenger system. The reservoir bag is usually located off the expiratory limb but can be located off the inspiratory limb for some anesthetic machine models (Matrix).

Non-rebreathing system voyage- oxygen supply>flow meter>vaporizer>NRB>patient > scavenger system

Anesthesia Machine Components- Anatomy & Physiology

Oxygen supply- The oxygen supply consists of a high and low pressure system. Compressed oxygen may be sourced in a gas cylinder, as liquid oxygen or extracted from room air via oxygen concentrators. The most common cylinder sizes, H (carrying 7000 liters of oxygen) or E (carrying 700 liters of oxygen), both contain 2200 psi of gas. Calculate the tank volume formula as follows: E tank: 0.3 x psi. H tank: 3 x psi. The oxygen is piped through a pressure regulator, which maintains a consistent gas pressure in the anesthetic machine (40-55 psi).

Flow meter- The oxygen enters the bottom of the fluted (Thorpe) tube, and exits at the top. Read the center of the ball, or top of the float. The flow of oxygen through the tube is controlled by an aperture, or needle valve, which allows more oxygen to enter as the valve is gradually opened. Appropriate oxygen flow rates for rebreathing circuits is 22-44 mL/kg/min, while a non-rebreathing circuit requires 200-300 mL/kg/min, to avoid rebreathing of carbon dioxide. The anesthetist should use higher oxygen flow rates immediately after induction, as well as anytime rapid plane changes are needed. Always run higher oxygen flow rates (2-3 L/minute) for the first 3-5 minutes of anesthesia to remove room air from the circuit (that develops after a period of disuse) and to eliminate dilution of the inhalant.
Oxygen flush - the oxygen flush valve completely bypasses the vaporizer, and delivers 35-75+ liter per minute of pure oxygen. Therefore, activating the oxygen flush valve can greatly dilute out the inhalant concentration present in the circuit. Exuberant oxygen flush mechanisms on some anesthetic machines can also be associated with barotrauma. Never activate the oxygen flush valve while using non-rebreathing systems.

Vaporizer - The vaporizer converts a liquid inhalant into a gas, based on the unique vapor pressure of each. Once each vaporizer has been calibrated for a specific inhalant, do not fill that same vaporizer with a different agent. Most vaporizers today are temperature compensated, variable by-pass vaporizers, which ensures reliable output over a wide range of temperatures. These vaporizers consist of 2 separate chambers - one contains the inhalant liquid and the other, oxygen. Calculate liquid inhalant usage based on the following formula: % inhalant x liters per minute x 3 = mLs/hour. If the vaporizer is tipped > 45 degrees, contents of these 2 chambers can intermix, causing erratic vaporizer output. A tipped or jarred vaporizer needs to be completely drained and dried, or serviced by a reputable anesthetic equipment repair company.

Once inhalant gases and oxygen exit the vaporizer through the common fresh gas outlet, they enter the breathing circuit. The breathing circuit is described as the portion of the machine where the patient breath passes through, and includes the one-way directional flutter valves, wye hose, endotracheal tube (ETT), patient, adjustable pressure limiting (APL) valve, carbon dioxide absorber assembly, and scavenger system.

Inhalation and exhalation valves - The 22 mm flutter discs located on the inspiratory and expiratory limb of the anesthetic machine direct the flow of gases through the breathing circuit and carbon dioxide absorber in only one direction around the circle. Clear domes allow visual confirmation of breathing as gases pass through them. However, excess condensation can build up beneath the domes and cause the flutter disc to stick, resulting in greatly increased inspiratory and expiratory carbon dioxide levels within the breathing circuit. Additionally, moisture droplets present on top of the flutter discs can create increased resistance to breathing. The presence of a negative pressure relief valve facilitates admission of room air directly into the circuit in the event of an inadvertent loss of the oxygen supply. A non-rebreathing circuit completely bypasses these valves and the carbon dioxide absorber entirely, and utilizes high gas flows to prevent rebreathing of carbon dioxide.

Reservoir bag and breathing circuits - The reservoir bag allows visual confirmation of breaths during spontaneous respiration, as well as facilitate manual ventilation, if needed. Calculate the reservoir bag based on lean body weight: 60 mL/kg. For borderline calculations, round up to the next sized reservoir bag.

Non-rebreathing circuits are recommended for patients weighing < 3-7 kg. Various configurations available for non-rebreathing circuits include Mapleson (A-D, F), Ayre’s T-piece, Jackson Rees, and coaxial Bain, which often lack a pressure manometer. A Bain block is a non-rebreathing circuit with a pressure manometer and can be used with a ventilator, if desired. Appropriate oxygen flow rates for a
non-rebreathing circuit is 200-300 mL/kg/minute. Higher oxygen flow rates are intended to prevent rebreathing of carbon dioxide.

Pediatric wye hoses (15mm) are intended for patients < 7kg, while adult wye hoses (22mm) are intended for patients > 7 kg. Wye hoses are available in uni-limb and coaxial designs. Appropriate oxygen flow rates for rebreathing circuits is 22-44 mL/kg/minute.

**Carbon dioxide absorber**- contains absorbent granules that remove carbon dioxide from exhaled gases. Gases can be recycled and returned to the patient with carbon dioxide removed, which decreases the need for higher oxygen flow rates, thereby reducing costs and lessening the amount of waste gases created. Heat and moisture are created by the chemical reaction of calcium hydroxide or barium hydroxide removing carbon dioxide, and must be changed once they become exhausted. A pH indicator causes the granules to change from white to lavender when this occurs. Absorbent granules should be replaced when the color change covers ½ to ¾ of the canister, or per the manufacturer’s instructions for use. Always fill the canister to within 1 inch of the top, and gently tap the canister to help settle granules and prevent channeling. Channeling occurs when carbon dioxide finds an unobstructed exit path through the canister, bypassing filtration through the granules.

**Pressure manometer**- The pressure manometer measures the amount of pressure within the anesthetic circuit, and, indirectly, the amount of pressure exerted into the patient. To avoid barotrauma either when hand bagging a patient or using a mechanical ventilator, do not exceed 15-20 cm of water, or 10-14 mmHg.

**Adjustable pressure limiting (APL)/ pop-off valve**- facilitates pressure build up within the breathing circuit, such as when providing manual ventilation ‘bagging’, or to check the anesthetic machine for leaks. Some APL valves are designed to maintain 1-3 cm of water positive pressure when fully open, which simulates nasal resistance. A closed APL valve can be a cause of serious lung injury—or even death—to a patient. Always open the APL valve after performing a leak test or disconnecting a mechanical ventilator. Positive pressure relief safety valves can be inserted into the breathing circuit at either the inspiratory or expiratory limb of the anesthetic machine, and can be real life savers when it comes to preventing iatrogenic lung injuries.

There are also secondary, ‘quick’ APL valves present on some anesthetic machines, which are used for convenience during manual ventilation of a patient. Pressure is maintained in the circuit only while the valve is depressed. The pressure within the circuit is released once the anesthetist releases pressure on the quick APL valve. Some quick APLs include a safety feature which releases pressure in the circuit once > 25-30 cm of water is detected.

**Scavengers & Waste Gas Management**

Scavenging is the single most important thing that can be done to eliminate waste anesthetic gas (WAG) pollution. Scavenger systems function to collect WAGs from the anesthetic machine and dispose of them outside of the building. The systems consist of a gas capturing system (APL/pop-off valve or scavenger hosing attached to a non-rebreathing circuit), interface (gas capture mechanism joining the
disposal system), and a disposal system to vent WAGs outdoors.

There are two types of scavenging systems available—active and passive. Active scavengers use mechanical means to eliminate the WAGs, by creating suction using a vacuum pump or fan to draw gases into the scavenger. Caution must be used with active scavengers, as it is possible to create a negative pressure within the anesthetic circuit if the suction is too strong. A negative pressure relief valve can negate this effect. Utilizing either passive or active systems creates the potential for blockage and resistance to exhalation, causing excessive pressure to build within the anesthetic circuit (think of a closed pop-off valve). Positive pressure relief valves can be inserted in the anesthetic circuit to prevent this phenomenon.

Passive scavenging systems involve non-mechanical methods to discharge the waste gases, away from air intakes, windows and doors, and uses positive pressure of the gas in the machine to move the WAGs outdoors. There are several ways to scavenge passively. One example would involve the use of one-way directional valves to facilitate movement of WAGs outdoors. Another method involves using a transfer hose (maximum length of 10 feet) placed adjacent to the room ventilation exhaust or non-re-circulating air conditioning system. Re-circulation of air within the building must be avoided when using this system. Additionally, since anesthetic molecules are heavier than room air, the hose should travel downwards toward the exit. Passive systems are ineffective for interior rooms, when the outlet exceeds a distance of twenty feet.

The last alternative involves the use of activated charcoal cartridges. Charcoal cartridges are the least desirable option, due to numerous limitations. Activated charcoal cartridges (ex. f/air, by A.M Bickford) are effective for scavenging halogenated vapors. They are not effective for nitrous oxide, if tipped onto the side, or at higher flow rates. They are good for only 12 hours of use, or when the cartridge weighs 50-120 grams heavier than when new, based on manufacturer. It is important to not occlude the holes located on the bottom of the cartridge as this is where the filtered air escapes.

**Leak Test**

Leakage from anesthetic machines can be a significant source of waste anesthetic gases, and can occur from missing, worn, or damaged ‘O’ rings, washers or other seals, loose flutter valve caps, poorly sealed carbon dioxide canisters, loose hose connections, holes in hoses or reservoir bags, or vaporizer caps not completely tightened. Damaged hoses, reservoir bags, and endotracheal tubes should be discarded. Leak test anesthetic machines on a routine basis, or whenever the integrity of the anesthetic machine has been compromised (as when changing the carbon dioxide canister).

Checking anesthetic machines for low-pressure leaks is easy, and all anesthetists should know how to perform this simple task. Place a wye hose and reservoir bag on the machine. Close the pop-off valve. Occlude the end of the wye hose. Fill the reservoir bag to a pressure of 30 cm of water. Observe the needle on the pressure manometer. Pressure within the circuit should not decrease by > 5 cm of water in 30 seconds. Excessive leaks must be located and corrected.

**Anesthetic Equipment**
**Induction Chambers** - Reserve the use of anesthetic chambers only for patients that cannot be handled. Anesthetic chambers allow large amounts of gas to escape into the room when opened, and is very stressful for the patient. For best results use the smallest chamber possible, ensure the chamber has a good seal and is not damaged, and is equipped with two outlets, one for delivery of the inhalant and one for scavenging. Complete the induction procedure as quickly as possible. Only use chambers in well-ventilated areas. Residual anesthetics can be removed from the chamber (as well as all anesthetic hoses and reservoir bags) after use by thoroughly cleaning with soap and water.

**Masks** - Avoid masks for maintaining anesthesia. If masks must be used, ensure a snug diaphragm fit over the patient’s face with an appropriately sized mask. Start with oxygen first, and do not turn on the vaporizer until the mask is securely in place. When the procedure is finished, turn the vaporizer off first, and continue oxygen for several minutes to help purge WAGs from the circuit.

**Endotracheal tubes (ETT)** - premasure and cut ETT to the correct length; the tube should sit at the level of the incisors, and extend no further than the thoracic inlet. Use cuffed endotracheal tubes that are properly inflated. Check proper inflation by closing the pop-off valve and exerting gentle pressure on the reservoir bag, or using cuff inflation gadget such as AG Cuffill® or Tru-Cuff (jorvet.com). The cuff should be inflated to the ‘minimum no leak volume.’ To protect the patient’s lungs, a leak should occur at slightly less than ~ 20 cm of water. Ensure the endotracheal tube and cuff are not damaged prior to use.

Do not turn the vaporizer on until the cuff has been inflated, and the endotracheal tube has been attached to the anesthetic circuit. There is no need to charge the circuit with the anesthetic agent prior to hook up to the patient.

At the conclusion of anesthesia, maintain the machine connection for several minutes after the cessation of anesthesia, and allow the patient to breathe 100% oxygen at 2-3 times maintenance rates for a period of several minutes. Periodically refill the circuit with fresh oxygen and expel previous gases into the scavenger to assist in WAG removal. Before disconnecting the patient, turn off the oxygen and then gently expel the contents of the reservoir bag into the scavenging system. Never expel the contents of the reservoir bag into the room.

It is imperative to regularly inspect all anesthetic equipment, and service machines on an annual basis. Maintenance logs should be kept for each anesthetic machine, vaporizer, and ventilator.

**References:**


