In order to perform anesthesia with inhalant anesthetics the anesthetist should have a good working knowledge of the anesthesia equipment, their parts and their functions. This handout is designed as a brief overview of the different pieces of equipment commonly encountered in order to perform general anesthesia with inhalants.

The anesthesia machine can be subdivided into the following four components:

1) **High pressure system** - where the pipeline and cylinder gas supplies are attached
2) **Low pressure system** - where oxygen and volatile anesthetics are mixed
3) **Breathing system** - where the anesthetic gas mixture is delivered to the patient
4) **Scavenging system** - where excess gas from the breathing system is collected and diverted into the waste gas evacuation system

**Gas Cylinders**

A. Medical gases can be supplied to the anesthesia machine by two methods.

1. Hanger Yokes
   a. Small gas cylinders attach directly to the machine via the hanger yokes. Each type of medical gas cylinder (i.e. oxygen, nitrous oxide, etc) has a specific pin sequence that is specific to a hanger yoke. This prevents interchanging of gases on the machine. Although this method is effective, pins that are bent, broken or removed can defeat the system.
   b. A small washer, called a Bodock seal, is needed around the yoke to form a tight attachment between the gas cylinder and hanger yoke.
   c. Most private practice veterinarians utilize this system to supply oxygen to their anesthesia machine.

2. Central gas supply
   a. Gases enter the machine at pipeline inlets that connect to the machine either with a threaded diameter index safety system (DISS) or a non-threaded quick connector. Large cylinders are usually located in a central location and supply numerous inlets throughout the hospital.
   b. Commonly seen in veterinary teaching hospitals or large referral/specialty practices.

B. Classification of gas cylinders

1. Size
   a. Labeled alphabetically with size A being the smallest.
   b. Size E, G and H are most common to veterinary medicine

2. Color
   a. Each type of medical gas is designated a specific color for the cylinder:
      - Oxygen→ green (USA)
      - Nitrous oxide→ blue
      - Oxygen→ white (international)
      - Compressed air→ yellow
      - Helium→ brown
      - Carbon dioxide→ Gray
      - Nitrogen→ black or orange

3. Labeling
   a. Signal words
      - **Danger:** immediate threat to health if gas is released
      - **Warning:** less than immediate threat
      - **Caution:** no immediate threat
   b. Hazard class
      - Indicated by a diamond shape label that is color coded
      - Yellow→ oxidizer
      - Green→ nonflammable
      - Red→ flammable
c. Tag
   - Attached to the valve body with perforated tabs stating full, in use, and empty. This tracks the use of the cylinder.

C. Storage
   1. Keep all cylinders away from flammable material.
   2. Keep in cool, dry, clean, well ventilated room constructed of fire-resistant material.
   3. Secure cylinders to a concrete object or place in a secure storage rack.
   4. Cylinders should remain in the upright position for long term storage.

D. Pressure
   1. Oxygen
      - Cylinder pressure = 2200psi when full
      - E cylinder = 700L gaseous oxygen when full
      - H cylinder = 7000L gaseous oxygen when full
      - Pressure is proportional to the contents so when an E cylinder is half full the pressure will be 1100psi and contains 350L of gaseous oxygen.
   2. Nitrous Oxide
      - Cylinder pressure = 750psi at normal room temperature when full
      - E cylinder ≈ 1600L gaseous nitrous oxide when full
      - H cylinder ≈ 16,000L gaseous nitrous oxide when full
      - Contents of cylinder is not proportional to pressure so the only way to determine the cylinders true content is by weight.

Pressure Gauges
A. Each compressed gas should have its own pressure gauge indicating the pressure in the cylinder.
B. The pressure gauge reading on an oxygen tank can be used to estimate the remaining amount of oxygen as the tank depletes by multiplying by a ‘fudge factor’ depending on the size of the tank. (E tank ≈ 0.3, H tank ≈ 3)
   Example:
   If the pressure gauge on an E tank reads 1000psi, then the oxygen in the cylinder is estimated to contain 300L (0.3 x 1000). If the oxygen flow rate was 2L/min then the tank should last approximately 150 minutes before running out of oxygen.

Regulators
A. Reduces the high and variable storage pressure of the cylinder gases to a lower and more constant pressure (usually around 50psi).
B. Maintains constant flow of gas to the flowmeter.
C. Produces a safe operating pressure of gas to be used in the anesthesia machine.

Flowmeter
A. Measures and indicates the rate of flow of gas into the system.
B. Calibrated for a specific gas (i.e. Oxygen, Nitrous oxide, etc).
C. Allows precise control of gas delivery to an out of circuit vaporizer.
D. Scale located on the tube indicates the rate of gas flow in ml/min or L/min.
E. The float located inside the tube moves in relation to gas flow. The most common type of float is a ball or bobbin. To determine the rate of gas flow read the widest diameter of the ball or bobbin.
F. Control knobs should never be over-tightened or cranked ‘on’ or ‘off’ in a rapid fashion.
G. If multiple flowmeters are located on one machine the oxygen flowmeter should be located last in the series (closest to the vaporizer).

Flush Valve
A. Oxygen is supplied to the breathing circuit at approximately 50psi. According to manufacture standards an oxygen flush valve must be able to deliver a flow rate between 35-75L/min.
B. Bypasses the vaporizer and dumps pure oxygen into the system. This means that any inhalant left in the circuit will become diluted with oxygen and the patient may go to a lighter plane of anesthesia. Therefore, it is not recommended that you use the flush valve to fill the breathing bag. Instead you should turn up the flow rate of oxygen for a brief period.
C. NEVER use the flush valve on a patient connected to a non-rebreathing circuit. It can over-pressurize the lungs and may result in lung trauma (barotrauma, pneumothorax).
D. This valve should only be used to pressure check your machine prior to induction.

Vaporizer
A. A vaporizer changes a liquid anesthetic into its vapor state and provides a specific concentration of anesthetic vapor to the carrier gases (oxygen, nitrous oxide) that are being delivered to the patient.
B. Classifications of vaporizers

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of output regulation</td>
<td>1. Variable bypass&lt;br&gt;2. Measured flow</td>
</tr>
<tr>
<td>Method of vaporization</td>
<td>1. Flow over&lt;br&gt;2. Bubble through&lt;br&gt;3. Injection</td>
</tr>
<tr>
<td>Temperature compensation</td>
<td>1. Thermocompensation&lt;br&gt;2. Supplied heat</td>
</tr>
<tr>
<td>Location</td>
<td>1. Out of circuit (VOC)&lt;br&gt;2. In the circuit (VIC)</td>
</tr>
<tr>
<td>Agent specificity</td>
<td>1. Agent specific&lt;br&gt;2. Multiple agents</td>
</tr>
<tr>
<td>Resistance</td>
<td>1. High resistance&lt;br&gt;2. Low resistance</td>
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C. Another simplified way and perhaps a more common way to classify vaporizers is by using the terms precision and non-precision. These terms refer to the accuracy with which the anesthetist can control the vaporizer output and takes into account the above mentioned characteristics.
1. Precision vaporizers are more widely used today in both veterinary and human medicine. These vaporizers can be classified as concentration calibrated, variable bypass, flow over, thermocompensated, VOC, agent specific and high resistance.
   Examples include Flutec Mark 2/Tec 2, Tec 3 (Flutec Mark 3, Pentec 2, Isotec 3), Tec 4 and 5, Ohio 100, Drager Vapor 19.1, Vapor 2000, Foregger and Penlon.
2. The Tec 6 vaporizer is another example of a precision vaporizer that is specifically made for desflurane. It is classified as a dual circuit, injection, supplied heat, agent specific and high resistance. The characteristics of desflurane prevent it from being used in the same fashion as the other inhalants.
3. Non-precision vaporizers include the Boyle’s bottle, Ohio 8 bottle, Stephens Universal, Goldman, Copper kettle and Vernitrol. The first 4 are classified as VIC, multiple agents, low resistance vaporizers and are not manufactured in the USA any longer. The Copper kettle and Vernitrol are
classified as measured flow, bubble through, non-temperature compensated, mulitple agent and VOC.

D. Vaporizer Maintenance
1. Always follow manufacturer’s guidelines for care and servicing.
2. Service should include an evaluation of operation, cleaning, changing of filters, replacement of worn parts and re-calibration. Depending on use, vaporizers should be serviced every year (heavy use) to every 2-3 years (moderate use).
3. Avoid tipping precision vaporizers more than 45 degrees from vertical. Liquid inhalant may enter the bypass chamber or outlet which could alter the concentration of vapor output.
4. If multiple vaporizers are located on one machine, ensure that the interlock system is functioning properly to allow only one vaporizer to be turned on at a time.
5. Most precision vaporizers will only produce accurate concentrations of inhalant at fresh gas flows between 500ml/min and 10L/min.

E. Filling Vaporizers
1. Make sure the vaporizer dial is turned OFF before unscrewing the cap and drain valve in the filler port. Likewise, make sure that the cap and drain valve are completely screwed on tight before turning ON the vaporizer.
2. It is best to fill vaporizers right before leaving to go home for the night to minimize personnel exposure to the inhalant vapors.
3. Do not overfill the vaporizer, fill only to the top of the etched line on the sight glass.
4. Anti-spill devices are available for each inhalant and are color coded to match the given color for each inhalant. The funnel or filler port vaporizers have the increased risk of having the wrong inhalant poured into an agent specific vaporizer. Keyed vaporizers have an agent specific filler tube that will only fit on the appropriate inhalant bottle and slots into the vaporizer in a “lock and key fashion”. This helps prevent accidentally using the wrong inhalant to fill the vaporizer.

Common Gas Outlet
A. Site from which gases that have passed through the flowmeters, vaporizer (VOC) and flush valve exit the anesthesia machine on the way to the breathing circuit.
B. Rubber tubing usually connects the common gas outlet to the fresh gas inlet.

Breathing Systems
A. Breathing systems function to deliver anesthetic gases (oxygen, nitrous oxide) and inhalant to the patient, remove carbon dioxide from exhaled gases and to provide a means to manually support ventilation.
B. Breathing systems add resistance to the flow of gases. The diameter of the breathing tubes and other conduits play a major role in determining the amount of resistance. The breathing tubes should be as short as practical with minimal bends and restrictions in the path of gas flow.
C. Rebreathing Circuit (Circle system)
1. Part or all of the exhaled gases, after extraction of carbon dioxide flow back to the patient.
2. Conserve anesthetic, oxygen, heat and moisture but impart more resistance to ventilation. Commonly used on patients over 7kg.
3. Rebreathing hoses come in many different diameters and volumes. The most common systems are pediatric, standard adult and large animal.
4. All rebreathing circuits have the same basic components arranged so that gases move in only one direction. Components of a rebreathing circuit include the following:
   Y-piece
   • Usually made of plastic and attaches to the endotracheal tube and to the inspiratory and expiratory breathing hoses.
• Contributes to mechanical dead space however a septum will help minimize this volume.

Breathing tubes
• Made of rubber or plastic and serve as flexible tubing between the Y-piece and the one way valves.
• Adds length and volume to the system, which increases resistance to ventilation.
• Tubes should have an internal diameter larger than the internal diameter of the patient’s endotracheal tube.
• Length of the tubes does not contribute to mechanical dead space as long as the one way valves are functional.

One-way (uni-directional) valves
• Directs gas flow away from the patient on expiration and towards the patient on inspiration.
• Prevents the rebreathing of exhaled gases before they pass through the absorbent canister.
• Contributes to resistance of breathing.
• Should be checked on a regular basis because moisture can build up in the expiratory valve and cause the disc to stick. If this occurs during operation of the machine the carbon dioxide will not be filtered out of the system and the patient will experience hypercapnia.

Fresh Gas Inlet
• Location at which gases from the common gas outlet of the anesthesia machine or from the outlet of the vaporizer enter the breathing circuit.
• Connected by a hose to the common gas outlet.
• Located next to the absorbent canister near the inspiratory one way valve.
• Entry of the fresh gases on the inspiratory side of the rebreathing system minimizes dilution of fresh gases with exhaled gases, prevents absorbent dust from being forced towards the patient and reduces loss of fresh gas through the pop off valve.

Pop Off Valve (adjustable pressure limiting valve)
• Vents gases to the scavenging system to prevent the buildup of excessive pressure within the breathing circuit and allows rapid elimination of anesthetic gases from the circuit when 100% oxygen is indicated.
• Position of pop off valve (open or closed) DOES NOT define the type of breathing system.
• Pop off valve should remain completely open on all breathing systems except during manual or mechanical ventilation. Failure to open the pop off valve during spontaneous ventilation will build up pressure in the circuit and could potentially cause lung trauma because the patient is unable to exhale.

Reservoir Bag (also called breathing bag)
• Located on the absorber side of the breathing system either upstream or downstream from the absorbent canister.
• Gas from an appropriately sized reservoir bag meets the patient’s peak inspiratory flow demands and provides compliance to the system during exhalation.
• Provides mechanism for assisted or manual controlled ventilation.
• Excursions from bag allow anesthetist to assess respiratory rate.
• Minimum size of the reservoir bag should be four to six times the patient’s tidal volume but the bags volume should not exceed the patient’s inspiratory capacity.
• Common sizes include 1, 2, 3 and 5 liter bags for small animals and 15, 20 and 30 liter bags for large animals.

Manometer
• Pressure gauge that is usually attached to the top of the absorbent canister.
• Calibrated in cmH2O or mmHg.
• Used to assess inspiratory pressure during positive pressure ventilation.
Air Intake Valve
- Also called the negative pressure relief valve.
- Not present on every machine but it is usually located on the dome of the inspiratory one way valve.
- If fresh gas flow is interrupted or nonexistent, the valve allows ambient air (21% oxygen) to enter the system which prevents the patient from inspiring against a negative pressure and becoming hypoxic.

Absorbent canister
- The chemical absorbent for carbon dioxide is contained in one or two stacked canisters and is located after the expiratory one-way valve in the breathing circuit.
- The two most common absorbents for carbon dioxide are soda lime and baralyme. The primary component of either absorbent is calcium hydroxide.
- Fresh granules are soft enough to be easily crushed, while expended granules change to calcium carbonate and are hard to crush. Silica and diatomaceous earth (kieselguhr) are added to soda lime to increase hardness. Increasing hardness is important to decrease dust formation.
- Ethyl violet is a color indicator that is added to soda lime and changes from white to violet as the granules are exhausted. The violet color may revert to white during storage but will reappear when the granules are exposed to carbon dioxide again.
- Heat and water are generated when the absorbent is exposed to carbon dioxide. If CO₂ absorption is effective the canisters will feel warm and moisture will be present on the inside.
- When using a breathing circuit with chemical absorbent the inspired carbon dioxide should be near zero. The most accurate way to determine if the absorbent is functional is to use a gas analyzer to measure the concentration of carbon dioxide in the inspired gases.

The absorbent granules should be changed after 6-10 hours of use or when the color reaction is apparent in approximately two thirds of the granules.
- The canister(s) should be removed on a regular basis to change the absorbent and to check for proper seal function. When refilling the canister(s), the granules should fill the entire canister leaving only a 2-3 cm space at the top of the canister. This will prevent pooling of gases in the canister. Proper packing is important to prevent channeling of gases and creating excessive dead space. Gently shake the granules in the canister to avoid loose packing, however, do not pack the granules too tightly as this will increase resistance to ventilation.
- Failure to adequately create a seal when replacing the canister(s) will cause a leak in the system and the machine will not pressure check properly.

5. Additional Rebreathing Systems
- Universal F Circuit
  a. Functions exactly like a rebreathing circle system.
  b. The only difference between a universal F circuit and a circle is the configuration of the breathing hoses.
  c. An F circuit has the inspiratory hose inside the expiratory hose so only one hose connects to the patient but at the machine end they split so that each hose connects to its corresponding one-way valve.
  d. It helps reduce the clutter around the patient and take the weight off the endotracheal tube.
- Water’s To and Fro System
  a. Rebreathing circuit that allows for bi-directional flow of gases with absorption of carbon dioxide.
  b. Carbon dioxide absorption is less efficient than a circle rebreathing circuit. The canister lies horizontal and close to the patient; dead space increases as the soda lime is used up.
c. Increased risk that patient will breathe in soda lime dust and weight of canister may kink endotracheal tube.

d. This circuit was widely used in the past but now it is mostly used for research.

6. Old Terminology used to classify rebreathing systems

- **Closed**
  a. The fresh gas flow equals the uptake and metabolism of oxygen by the patient.
  b. The patient’s oxygen consumption will vary depending on the patient’s metabolic rate.
     Metabolic rate can be influenced by the patient’s body weight and body surface area, body temperature, state of consciousness, age, etc.
  c. Primary advantage is economical because less oxygen and inhalant are used. Also, heat and humidity are retained and there is less operating room pollution.
  d. One major disadvantage is the inability to change the inspired concentration of gases quickly. Changes in anesthetic depth take longer to occur when changes are made on the vaporizer dial.
  e. Nitrous oxide should not be used because of the potential for developing hypoxic gas mixtures with the low inflow of oxygen.
  f. Closed circuits are completely dependent on chemical absorption of carbon dioxide and fresh granules should be used each time.
  g. Monitoring of the patient and machine are imperative because there is an increased risk for delivery of a hypoxic mixture of gas to the patient.
  h. Need to start the patient on high flow rates (2-4L/min) to flush the system with oxygen and inhalant for the first 5 minutes. The system should be flushed with fresh gas every 30 minutes thereafter to prevent the exhaled nitrogen from diluting the oxygen in the system.
  i. Oxygen flow rate for a closed circuit: 6-10ml/kg/min
  j. NOTE: Most vaporizers require a minimum flow rate of 500ml/min to ensure proper performance and output of anesthetic vapor.

- **Low flow**
  a. Advantages and disadvantages of a low flow system are similar to a closed system.
  b. Offers more protection against hypoxic gas mixtures because the flow rate exceeds the patient’s metabolic consumption of oxygen.
  c. Oxygen flow rate for low flow: 10-22ml/kg/min.

- **Semi-closed**
  a. Fresh gas flow exceeds the uptake of oxygen and anesthetic by the patient.
  b. The patient inspires a mixture of fresh and exhaled gas because the flow rates are higher than what the patient can consume.
  c. Excessive gases are eliminated through the pop off valve.
  d. Most popular type of circuit used in veterinary medicine today.
  e. Oxygen flow rates are 3-5 times greater than the patient’s metabolic oxygen consumption. Generally 22-44ml/kg/min.

D. Non-rebreathing circuit

1. Breathing system does not use chemical absorbent for carbon dioxide removal but depends on high fresh gas flow rates to flush the exhaled carbon dioxide from the system.
2. There are 6 different types of non-rebreathing circuits. They are classified as Mapleson systems A through F.
3. The two most common non-rebreathing circuits used today are the Bain coaxial (Modified Mapleson D) and the Jackson Rees modified Ayre’s T-piece (Mapleson F).

4. A Bain system requires a fresh gas flow of 100-200ml/kg/min and the Jackson Rees requires 300-400ml/kg/min for spontaneous ventilation.

5. Rebreathing of CO2 will occur with these circuits if the fresh gas flow rate is too low.

6. Commonly used on patients under 7kg.

7. Advantages include decreased resistance to breathing, system is lightweight, allows for rapid changes in anesthetic depth and it is inexpensive to purchase and maintain these systems.

8. The disadvantages include the cost to operate the system (use more oxygen and inhalant with high flow rates), minimal conservation of heat and moisture, may contribute to hypothermia and drying of the respiratory tract, increased operating room and atmospheric pollution if scavenging system is ineffective.

9. Very important to NEVER use the oxygen flush valve when a non-rebreathing system is attached to the patient. It can over pressurize the lungs and cause barotrauma and possible pneumothorax.

**Scavenging System**

A. Collects waste anesthetic gases (WAG) from the breathing system and eliminates them from the work place.

B. Consists of a hose that is coming off of the pop-off valve (gas collecting assembly) and connects to a scavenging interface or F-air canister.

C. Scavenging systems can be active or passive.

1. Active systems consist of a piped vacuum and duct system that carries the WAG away from the circuit. Active systems are commonly found in veterinary teaching hospitals or large referral/specialty centers.
   - The interface of an active system helps prevent the transfer of pressure changes in the scavenging system to the breathing system. Contains a knob that can be adjusted to increase or decrease the amount of suction from the system.

2. Passive systems include non-recirculating ventilation systems, piping directly to the atmosphere and absorption devices. Passive systems are commonly found in general veterinary practices.
   - The distance between the gas collecting assembly and the non-recirculating ventilation systems (discharge of WAG through an exhaust vent) or piping directly to the atmosphere needs to be relatively short to ensure proper scavenging.
   - Absorption devices (F-air Canisters)
     a. Contain activated charcoal to absorb halogenated hydrocarbon anesthetics (isoflurane, halothane, sevoflurane).
     b. Easy to use and portable making them very popular in private practices.
     c. The effectiveness of absorption may vary between brands, styles and flow rates through the canisters.
     d. Canisters must be changed when a 50 gram weight gain has occurred to ensure proper scavenging of WAG. Frequent changing of canisters can be expensive.
     e. They DO NOT absorb nitrous oxide.
     f. Canisters must be maintained in the upright position for effective absorption and the filter located on the bottom cannot be blocked by a solid object.
     g. Absorption devices must be used in case of power outage because the active systems will not function.

**Anesthesia Machine Checks**

**All checks on a machine should be done BEFORE operation every time.**
A. Check central oxygen and nitrous oxide supplies for adequate quantities of gases and pipeline pressures.
B. Inspect the flowmeters, vaporizers, gauges and supply hoses. Assure correct mounting of cylinders in the hanger yokes and the presence of a wrench for the cylinder valve.
C. Check breathing system hoses and make sure they are complete and undamaged.
D. Ensure fresh absorbent for carbon dioxide is present and canisters are in good condition.
E. Ensure scavenging system is connected to the pop off valve and is working properly. Make sure system is attached to appropriate active or passive connections.
F. Ensure vaporizer is filled, filler cap closed and control dial off.
G. Check oxygen cylinders on machine. Assure proper hook up and slowly open the valve to check the pressure and determine the presence of leaks. Test all other cylinders in this manner.
H. Test the flowmeters for each gas by slowly turning on and adjusting flow through the full range of values.
I. Test the function of the expiration uni-directional valve by wearing a surgical mask and exhaling through the breathing tubes. The expiration disc should move. Close the pop off valve, turn on the oxygen flowmeter and compress the reservoir bag to test the inspiration uni-directional valve. The inspiration valve should move.
J. Test for leaks in the breathing system.

1. Rebreathing Circuit
   • Close the pop off valve, occlude the Y-piece with thumb or palm of hand and fill the system with oxygen using the oxygen flush valve until a pressure of 20cmH₂O is reached on the manometer. Pressure should remain constant (for at least 15 seconds) if no leaks are present in the system.
   • Open the pop-off valve slowly and observe the release of pressure from the reservoir bag. This ensures that the scavenging system is working properly.
2. Non-rebreathing Circuit (Bain coaxial system)
   • Follow the same procedures outlined above for a rebreathing system.
   • In addition, even if the pressure remains constant it does not guarantee that the inner tube of the coaxial system is leak free. To evaluate the inner tube turn the flowmeter onto 2L/min and occlude the inner tube with an eraser of a pencil. If the float in the oxygen flowmeter drops then the inner tube is leak free.

Ventilators
A. Provides mechanical ventilation for patients being maintained with inhalant anesthetics.
B. An anesthesia ventilator is a reservoir bag (bellows) in a closed container (bellows housing) that substitutes for the reservoir bag on an anesthesia machine.
C. Within limits, the ventilator has the capability of driving its bellows to produce a specific tidal volume or a specific inspiratory pressure at a pre-selected respiratory rate.
D. Ventilators can be stand alone units that are attached to an anesthesia machine when needed or they can be manufactured as an integral part of the anesthesia machine.
E. Classifications of ventilators
   1. Power source
      • May be electric, compressed gas or both.
   2. Drive mechanism
      • Compressed gas is generally the drive mechanism even when electric controls are present.
      • Most units are double-circuit meaning that they have two gas sources.
         a. The driving gas circuit (outside the bellows) compresses the bellows.
         b. The patient circuit (inside the bellows) originates at the anesthesia machine and provides oxygen and inhalant to the breathing system and patient.
3. Cycling mechanism
   - Determines when the ventilator switches between the inspiratory and expiratory phases.
   - Ventilators can be time cycled (change after a set time frame), volume cycled (change after a preset volume is reached) or pressure cycled (change after a preset pressure has been reached).

4. Type of bellows
   - Direction that the bellows move during expiration (ascending or descending)
   - Newer anesthesia ventilators usually have ascending bellows. These bellows will not fill if a disconnection occurs between the ventilator and the breathing circuit. When not in use the ascending bellows fall to the bottom of the bellows housing.
   - Descending bellows will continue to cycle even with complete disconnection of the ventilator from the breathing system.

F. Types of Ventilators

1. Small Animal
   - Drager SAV
   - Hallowell EMC model 2000
   - Mallard 2400 V
   - Metomatic (Ohio)
   - Ohmeda 7000
   - Vet-Tec SAV-75
   - ADS 1000 (Engler)

2. Large Animal
   - Drager AV
   - Narkovet E
   - Mallard 2800
   - LAVC 2000
   - Anesco
   - Bird Mark 7

Airway management

A. Protecting and maintaining a patent airway during general anesthesia is the number one goal of airway management.

B. Endotracheal intubation is considered the most efficient way to manage the airway in veterinary patients.

C. The advantages of endotracheal intubation include complete control of a patent airway, efficient means to deliver O2 and inhalant to patient, provides way to assist with ventilation, decreases anatomical dead space, protects against aspiration of foreign material into the lungs and decreases exposure to WAG with properly inflated cuff.

D. Endotracheal tubes can be made from silicone, polyvinyl chloride (PVC) or rubber.
   - Silicone tubes are expensive but can be cleaned, sterilized and reused multiple times.
   - PVC tubes are inexpensive, contain a natural curve and are intended for single use. However, they can be cleaned and reused to some degree.
   - Rubber tubes have a solid color lumen making it impossible to check for occlusions from mucus. They can be reused but they are difficult to clean and disinfect increasing the risk for cross contamination. Longevity is minimal because they become hardened and are prone to cracking with repeated use.

E. Types of endotracheal tubes

1. Cole
   - Diameter of distal end is tapered and smaller than the rest of the tube. There is no cuff.
   - Only the narrow end fits into the larynx and trachea. The larger diameter of the tube fits against the laryngotracheal opening creating a seal.
   - Commonly used in birds and very small pediatric patients.

2. Magill
   - Similar to the Murphy tube, can be cuffed or uncuffed, but does not contain a Murphy eye at the distal end of the tube.
3. Murphy
   - Can be cuffed or uncuffed although the cuffed version is more commonly used.
   - Contains a Murphy eye at the distal end of the tube.
   - Most common type of endotracheal tube used in veterinary medicine.

4. Armored or reinforced tubes
   - Contains a wire that is embedded in the wall and spirals around the length of the tube.
   - Helps prevent kinking when the head and neck of the patient are flexed. Procedures in which these tubes are beneficial include ophthalmic surgeries, oral surgeries, cervical spinal taps, myelograms and craniotomies.
   - The outside wall of the tube is thicker in order to accommodate the wire which makes the internal diameter smaller than what it would be in a standard tube of the same size. This increases resistance to gas flow and therefore should only be used when absolutely necessary.
   - Extreme care must be taken to prevent the patient from biting the tube during extubation. The tube will become permanently deformed and unusable if the tube is bitten. Bite guards are often placed on the proximal end of the tube to prevent this from happening.

5. Laryngeal mask airway (LMA)
   - Considered a supraglottic device because these tubes are positioned proximal to the trachea. They still create an air tight seal at the larynx and therefore function like an endotracheal tube.
   - Beneficial in procedures involving the trachea; radiation patients that are anesthetized consecutive days (decrease risk of tracheitis); and in animals prone to difficult intubations (brachycephalic breeds of dogs and cats, rabbits and pigs).

F. Anatomy of a Murphy Endotracheal Tube
1. Bevel
   - Distal end (patient end) of endotracheal tube.
   - The end hole is beveled at an angle to help guide the tube past the arytenoids and into the trachea.

2. Murphy eye
   - Side hole opposite the bevel that allows for gas flow to continue should the end hole become occluded.

3. Cuff system
   - Purpose of the cuff is to create an airtight seal against the tracheal wall in order to prevent the mixing of airway gases with room air and to prevent aspiration of foreign material such as blood, mucus, gastric fluid and dental debris.
   - Consists of an inflatatable cuff, inflating tube, inflating valve and pilot balloon.
   - Multiple variations in styles of cuff are available but the two most commonly found on endotracheal tubes for veterinary medicine include the low volume, high pressure cuff (LVHP) and the high volume, low pressure cuff (HVLP).
     a. LVHP cuffs require a low volume of air to create a seal with the trachea but they exert a high pressure on the tracheal wall causing an increased risk of necrosis if used for long periods of time.
     b. HVLP cuffs require a larger volume of air to create a seal with the trachea but the pressure is exerted over a wide surface area allowing the pressure on the tracheal wall to be low.
     c. HVLP cuffs should be used for longer procedures.
     d. Excessive cuff inflation will cause a HVLP cuff to act like a LVHP cuff.
   - Proper cuff inflation
     a. To properly inflate the cuff once the patient is intubated, close the pop off valve and squeeze the reservoir bag until an inspiratory pressure of 20cmH₂O is reached. Do not hold the breath longer than 2-3 seconds. While administering the breath listen for an airway leak and
ONLY inflate the cuff with air until the sound stops. Pressure will not hold in the reservoir bag if the cuff is not properly sealed. If you do not hear a leak then DO NOT put any air in the cuff.

b. You may have to repeat the cuff inflation process about 2-5 minutes after the inhalant is turned on because as the patient’s anesthetic depth deepens the laryngeal and tracheal muscles relax causing a leak to develop.

c. Over inflation of the cuff can lead to pressure necrosis of the trachea and possible collapse of the endotracheal tube leading to airway obstruction.

d. The fullness of the pilot balloon and back pressure from the inflation syringe are NOT reliable indicators of proper cuff inflation.

- Always place air in the cuff of the endotracheal tube at least 5-10 minutes prior to use to check for any slow leaks and test the integrity of the cuff.

4. Tube

- Most endotracheal tubes have several pieces of information listed on the tube such as length, diameter and manufacturer.
- The length of the tube starting from the distal end is measured in centimeters. These numbers are located along the tube length and are universal for all tube sizes and brands (i.e. 5mm tube that measures 13cm in length is comparable to the 13cm length on an 11mm tube).
- The diameter of the endotracheal tube is measured in millimeters. Some tubes list both the internal and outside diameter on the tube. The internal diameter is what determines the size of endotracheal tube placed in the patient.
- The manufacturer or supplier name is usually listed along the length of the tube or on the pilot balloon.
- Some endotracheal tubes contain a radiopaque marker that will show up on radiographs to help confirm placement of the tube.

5. Connector

- Proximal (machine) end of the endotracheal tube.
- Contains a 15mm outside diameter connector to connect with the breathing hoses.

G. Tube selection

1. Size

- Select the largest diameter endotracheal tube that will comfortably fit the patient without causing damage to the larynx or trachea. Never force a tube into the trachea.
- The most reliable method to judge the appropriate diameter is by gentle palpation of the trachea. DO NOT select the tube based solely on body weight. This method can be misleading for brachycephalic breeds or overweight patients.
- Using too small of a tube will greatly increase the resistance of gas flow and therefore increase the work of breathing by the patient. This could result in labored breathing.

2. Length

- The length of the endotracheal tube should not extend past the thoracic inlet on the distal end and not past the incisor teeth on the proximal end.
  a. Too long of tube at the distal end can result in bronchial intubation leading to one lung ventilation.
  b. Too long of tube at the proximal end will contribute to mechanical dead space and a decrease in alveolar ventilation.

- Before use the tube should be measured to the patient and cut to fit within these limits.

H. Cleaning endotracheal tubes

1. Endotracheal tubes should be cleaned as soon as possible after extubating the patient.
2. Use a mild soap detergent (such as dawn) and gently scrub the tube inside and out to remove blood, mucus or debris present on or in the tube. Slightly inflate the cuff of the tube while cleaning since the folds in a deflated cuff are a common place for material and debris to hide. Follow with a warm water rinse and allow to air dry.

3. Endotracheal tubes can be soaked in chemical disinfectants such as chlorhexidine or Glutaradehyde. Do not soak for longer than 30 minutes. After soaking, the tubes must be thoroughly rinsed with water and allowed to air dry. Improper rinsing, too long of soak time and using too concentrated of solution can all lead to tracheal irritation and should be avoided.

4. Silicone tubes are the only ones that can be heat sterilized with steam from an autoclave.

5. Rubber and PVC tubes must be sterilized with ethylene oxide or hydrogen peroxide gas plasma because they break down in the presence of extreme heat.

**Laryngoscope**

1. Helps facilitate endotracheal intubation by allowing direct visualization of the glottis and opening of the trachea.

2. Composed of two basic parts, the handle and a blade that contains a light source.

3. The light source is the main benefit to using the laryngoscope but it can also be used to depress the tongue to better visualize the arytenoids.

4. The laryngoscope blade should only touch the base of the tongue; it should NEVER be used directly on the epiglottis. The blade can cause trauma to the epiglottis resulting in airway complications.

5. Blades come in many different lengths ranging from 0 (small) to 5 (large). These blades are adequate for use in small animals.

6. Customized blades with extra length are helpful to visualize the arytenoids in some species such as the llama, alpaca, pig, goat and exotic cats.

7. The style of blade determines the type of laryngoscope. The two most common types are the Miller (straight blade) and the Macintosh (curved blade).

**Special equipment for intubation**

1. **Stylet**
   - Made of flexible metal and placed inside the endotracheal tube to help strengthen and shape the tube.
   - Entire length of the stylet should remain inside the lumen of the tube and NOT protrude out the distal end. Improper use can cause damage to the arytenoids and trachea.
   - Commonly used for cats and brachycephalic breeds of dog.

2. **Guide tube**
   - Common guide tubes include a canine polyethylene urinary catheter or a pediatric stomach tube.
   - Place the guide tube into the larynx and trachea and then thread the endotracheal tube over the guide tube. Once the endotracheal tube is in the proper place, the guide tube is removed.
   - Guide tubes should be made of soft plastic to avoid injury to the laryngeal tissues and trachea.

**Intubation techniques**

1. Direct visualization
   - Able to visualize arytenoids and place endotracheal tube with relative ease.
   - Commonly used in dogs, cats, small ruminants, etc.

2. Digital palpation
   - Commonly used in cattle.
   - Use arm to manually feel arytenoids with fingers and slide endotracheal tube between fingers into the trachea.

3. Blind
• Commonly used in the horse.
• Once in lateral recumbency, extend the head and neck and guide the endotracheal tube to the larynx. If you feel resistance, pull the tube back about 1 inch, rotate 90 degrees and proceed again. The tube should slide into the trachea without resistance. Do not push too hard to place tube as this may cause laryngeal and tracheal damage.

**Miscellaneous equipment**

1. Induction tank
   • Useful for inducing fractious cats.
   • Use a clear plastic or glass container so the patient can be visualized.
   • Can remove the Y-piece on the breathing tubes and attach the inspiration and expiration limbs to the induction tank.
   • High anesthetic concentration and high oxygen flow rate are needed to achieve unconsciousness.
   • Once patient is unconscious remove them from the induction tank and finish induction via face mask or proceed with intubation.
   • High exposure of waste anesthetic gases to personnel. After use, remove induction tank from area and place outside or in a large area with good ventilation.

2. Face mask
   • Many different sizes of masks are available for use in small animals.
   • Can be used without the diaphragm to pre-oxygenate patients prior to induction with injectables or can be used with diaphragm for mask inductions with inhalant.
   • Use the smallest mask that will fit the patient’s nose to minimize dead space.
   • They DO NOT protect the airway from aspiration.
   • They DO NOT provide a patent airway.
   • Limited ability to provide ventilation should apnea or hypoventilation occur.

3. Demand valve
   • Commonly used to supply 100% oxygen to horses and other large animals after general anesthesia has been discontinued.
   • Attaches directly to oxygen source and can deliver approximately 200L/min if the oxygen supply is 50psi.
   • Compressing the activation button will provide positive pressure ventilation to the patient until spontaneous ventilation occurs.

4. Ambu-bag
   • Commonly used to ventilate a patient during cardio-pulmonary resuscitation.
   • Bag continues to inflate after each breath in order to ventilate the patient with either room air (21% oxygen) or it can be attached to 100% oxygen.

**References**


Oklahoma State University Website: [http://instruction.cvhs.okstate.edu/vmed5412/](http://instruction.cvhs.okstate.edu/vmed5412/)


Monitoring a patient under general anesthesia and keeping a thorough record of the vital signs should be a standard practice in every veterinary hospital. However, monitoring the patient involves so much more than just simply writing numbers down on the chart. The anesthetist must be able to interpret these values and understand what they mean in order to identify and correct a problem before it becomes life threatening. This handout will discuss some of the common hypo’s that may occur during the anesthesia period.

**Hypoventilation**

Hypoventilation can be defined as the insufficient elimination of carbon dioxide (CO₂) from the body relative to CO₂ production. The most accurate way to determine the efficiency of ventilation is by assessing the PaCO₂ from an arterial blood gas. The PaCO₂ is defined as the partial pressure of CO₂ in arterial blood. During anesthesia the PaCO₂ should remain between 35-45mmHg. An increase in PaCO₂ greater than 45mmHg is known as hypercapnia. So in effect, hypoventilation results in hypercapnia or increased PaCO₂.

Hypoventilation can also be described as a reduction in alveolar minute ventilation (MV). Alveolar minute ventilation is a product of respiratory rate and effective tidal volume (MV = RR x TV). Effective tidal volume is the volume of gas inspired minus dead space volume. Dead space (DS) volume is the volume that does NOT effectively take part in gas exchange and results from the sum of apparatus DS, anatomical DS and alveolar DS. From these equations we can see that anything that causes a decrease in respiratory rate and tidal volume or causes an increase in dead space volume will likely lead to hypoventilation.

Mild hypercapnia (PaCO₂ of 45-60mmHg) may be beneficial in some cases (excluding brain cases) because it stimulates the sympathetic nervous system and causes catecholamine release; therefore it may result in increased blood pressure and cardiac output. However, a PaCO₂ > 60mmHg can lead to respiratory acidosis, myocardial depression, ventricular arrhythmias and increased cerebrospinal fluid pressure. PaCO₂ values between 90-120mmHg will cause CNS depression, bradycardia and unconsciousness. It is especially important to maintain normal PaCO₂ levels in patient’s with intracranial disease. Increases in CO₂ will cause dilation of the cerebral blood vessels which will increase intracranial pressure.

Clinical signs associated with hypoventilation include changes in respiratory rate and effort (patient may “buck” the ventilator or make spontaneous attempts to breathe), brick red mucous membranes, peripheral vasodilation and signs associated with sympathetic nervous system stimulation (tachycardia, hypertension, cardiac arrhythmias).

**Monitoring for hypoventilation**

Arterial blood gas analysis is the gold standard for evaluating the PaCO₂. Capnography is a non-invasive monitoring tool that measures the partial pressure of CO₂ that is present at the end of expiration and is termed end-tidal CO₂ (ETCO₂). In normal, healthy patients it is usually assumed that alveolar and capillary CO₂ are equilibrated and therefore the ETCO₂ can be used to estimate the PaCO₂. However, it should be noted that the ETCO₂ underestimates the actual PaCO₂ by 5-7mmHg due to alveolar dead space ventilation. Situations in which the ETCO₂ would not be an accurate reflection of PaCO₂ include open chest procedures such as...
Causes of hypoventilation
1. Anesthesia- Most anesthetic drugs will cause a dose-dependent depression of respiration. If alveolar ventilation decreases by 50% but the CO₂ production remains the same, the alveolar and arterial CO₂ will double. Additional causes of hypoventilation related to anesthetic drugs include apnea caused by large doses of induction drugs (propofol, thiopental) and the use of neuromuscular blocking agents without the concurrent use of a ventilator or manual controlled ventilation.
2. Excessive depth of anesthesia- As the depth of anesthesia increases the body’s response to elevated CO₂ becomes diminished due to CNS depression. This makes it more difficult for the patient to hyperventilate and blow off excessive CO₂ while under the effects of anesthetic drugs.
3. Equipment- Malfunctioning, missing or stuck exhalation one-way valves will cause an elevated CO₂; likewise, using exhausted CO₂ absorbent granules will also contribute to a build up of CO₂. Equipment such as adapters, ETCO₂ monitor, apnea alert monitor, etc., that are placed between the patient’s endotracheal tube and the breathing hoses as well as using too long of endotracheal tube will all contribute to excessive apparatus dead space and will lead to a build up of CO₂.
4. Inadequate oxygen flow rates- Using too low of oxygen flow rates with a non-rebreathing system (Bain coaxial) will cause the rebreathing of CO₂.
5. Partial obstruction or increased work of breathing- Possible causes of obstruction include an endotracheal tube plugged with mucus or blood and a kinked endotracheal tube. Increased work of breathing can be caused by using too small of endotracheal tube relative to the tracheal size; brachycephalic breeds and patient’s with laryngeal paralysis.
6. Abdominal distension- pregnancy, ascites, uroabdomen, hemoabdomen, GI obstruction
7. Obesity
8. Pain- Especially thoracic pain related injuries such as flail chest, fractured ribs, etc.
9. Severe Hypotension or Hypothermia- Causes inadequate perfusion to CNS respiratory centers and causes depression of CNS respiratory centers, respectively.

Treatment/Prevention of hypoventilation
1. Hypoventilation is one of the most common complications of anesthetized animals because most patients are allowed to spontaneously ventilate on their own during the anesthetic procedure. Simply giving the patient a breath 1-2 times a minute will likely help prevent hypoventilation from becoming an issue. If the PaCO₂ is > 60mmHg, then intermittent positive pressure ventilation (IPPV) should be started at a controlled respiratory rate and tidal volume. This can be performed either manually by the anesthetist or mechanically with a ventilator.
2. A thorough investigation of the anesthesia machine should take place while ventilating the patient to rule out any equipment problems. Make sure that oxygen flow rates are appropriate for the type of breathing circuit being used.
3. Use largest size of endotracheal tube that will comfortably fit into the trachea without excessive force. Ensure that the endotracheal is the appropriate length and that no obstructions or kinks are present.
4. Assess the depth of anesthesia and decrease the inhalant concentration if possible.
5. If patient is < 3 kg, then keep apparatus dead space to a minimal. Only use one monitoring device between the breathing circuit and endotracheal tube and make sure that it is a pediatric connector.
6. Relieve abdominal distension as quickly as possible during surgery. Make sure that the surgeon is not leaning or resting instruments on the thorax once the patient is draped for surgery.
7. Improve CNS perfusion with fluids or sympathomimetic drugs.
8. Maintain normal body temperature.

### Hypoxemia

Hypoxemia refers to the inability to oxygenate the blood. This means that there is an insufficient amount of oxygen in arterial blood to meet the body’s metabolic demands. The amount of oxygen present in the blood can be expressed in three different ways; the partial pressure of oxygen dissolved in arterial blood ($\text{PaO}_2$); the percent of oxygen saturation with hemoglobin ($\text{SaO}_2$); and the arterial oxygen content ($\text{CaO}_2$).

The $\text{PaO}_2$ is the partial pressure of oxygen dissolved in arterial blood. This value is affected by the alveolar partial pressure of oxygen ($\text{P}_{\text{A}}\text{O}_2$) present in the lungs and the exchange of oxygen from the alveoli to the blood. The $\text{PaO}_2$ can be determined using blood gas analysis. Normal values at sea level for an animal breathing room air (21% $\text{O}_2$) are between 80-100mmHg. A $\text{PaO}_2$ of less than 80mmHg is considered moderate hypoxemia while a $\text{PaO}_2$ less than 60mmHg is considered severe.

It is important to interpret the $\text{PaO}_2$ with regard to the fraction of inspired oxygen (FiO$_2$). The $\text{PaO}_2$ should be 4-5 times the FiO$_2$. An animal on 100% $\text{O}_2$ during anesthesia should have a $\text{PaO}_2$ of 400-500mmHg. If the animal is receiving 100% $\text{O}_2$ and only has a $\text{PaO}_2$ between 80 and 400mmHg, they are said to have a lower-than-expected $\text{PaO}_2$ but they are not considered hypoxemic until the $\text{PaO}_2$ falls below 80mmHg.

The $\text{SaO}_2$ measures the percent of hemoglobin in arterial blood that is bound to oxygen. The saturation of hemoglobin with oxygen is responsible for the majority of oxygen transport to the tissues. The $\text{SaO}_2$ is dependent on the $\text{PaO}_2$ because that is the driving force to get the oxygen to bind with the hemoglobin in the red blood cell. A distinct relationship exists between the $\text{PaO}_2$ and the $\text{SaO}_2$ and is represented by the oxyhemoglobin dissociation curve.
The oxyhemoglobin dissociation curve is sigmoid in shape with the PaO2 on the x-axis and the SaO2 on the y-axis. Since the SaO2 represents the percent of hemoglobin that is bound to oxygen it can never be more than 100%. The steep part of this curve represents the area where small changes in the PaO2 result in large changes in the SaO2. At a PaO2 of 60mmHg the curve begins to flatten out and represents the area where large changes in the PaO2 result in small changes in the SaO2. Normal SaO2 for a healthy animal is 99-100% and correlates to a PaO2 of anything from 100-500mmHg. From this curve, a SaO2 of 95% is equivalent to a PaO2 ~ 80mmHg, and a SaO2 of 90% is equivalent to a PaO2 ~ 60mmHg. Ideally, an anesthetized patient should have a SaO2 of 99-100% while on 100% O2. Under anesthesia a SaO2 of less than 96% is cause for concern.

The arterial oxygen content (CaO2) is determined by the concentration of hemoglobin [Hb], saturation of hemoglobin with oxygen (SaO2) and the partial pressure of dissolved oxygen in arterial blood (PaO2). The CaO2 can be calculated using the following formula:

\[ \text{CaO2} = ([\text{Hb}] \times \text{SaO2} \times 1.34) + (0.003 \times \text{PaO2}) \]

The hemoglobin concentration is the most important contributor to oxygen content. This is an important concept because an anemic patient can have a normal PaO2 and a normal SaO2 but still have very low oxygen content and therefore would still be at risk for hypoxemia. The hemoglobin concentration makes up roughly 1/3 of the packed cell volume; therefore the PCV (hematocrit) can be used to estimate the hemoglobin concentration by dividing the PCV by 3 (Hb = PCV/3). This stresses the importance of obtaining a PCV/TP prior to anesthetizing any patient!

The CaO2 also plays a role in the overall delivery of oxygen to the body. Oxygen delivery (DO2) to the tissues depends on arterial oxygen content and blood flow. The relationship is represented in the following equation: DO2 = blood flow (CO) x blood oxygen content (CaO2). This equation will be discussed in more detail in the hypotension section.

**Clinical signs of hypoxemia**

1. Cyanosis (blue discoloration) of the mucous membranes is often times a late indicator of severe hypoxemia. There has to be 5g/dl of deoxygenated hemoglobin present before signs of cyanosis will occur. In patients with normal hemoglobin this would not manifest until a PaO2 <50mmHg.
2. Transient tachycardia may be present for a brief period of time as the body attempts to increase cardiac output in order to maintain oxygen delivery to the tissues. As the heart becomes deprived of oxygen the heart rate will fall leading to an unresponsive bradycardia and cardiac arrest.
3. Hypoxic drive (agonal gasping) may be present in severely hypoxemic patients and is characterized by large inspiratory efforts made by the accessory muscles of respiration. If a patient is on a ventilator it can appear as if they are “bucking the ventilator” or trying to breathe against it, a sign that is often associated with inadequate depth of anesthesia. Always check your patient and ensure that other signs indicate a light plane of anesthesia before turning up the inhalant as you might be dealing with a completely different issue.

**Monitoring for hypoxemia**

The most accurate way to assess oxygenation is to obtain an arterial blood gas sample and perform a blood gas analysis. This will directly measure the PaO2 and the SaO2. For those clinics that do not have a blood gas machine the next best option to evaluate oxygenation is with a pulse oximeter. The pulse oximeter is a non-invasive technique that indirectly measures the SaO2 by sensing a pulse and emitting two wavelengths of light through the skin to differentiate
oxygenated hemoglobin from deoxygenated hemoglobin. Since the pulse oximeter does not directly measure the SaO₂ it is referred to as SpO₂. While it is important to recognize that the values for SaO₂ and SpO₂ come from different sources, they are often used interchangeably when discussing hemoglobin-oxygen saturation.

The pulse oximeter has some limitations that the anesthetist should understand in order to use this monitoring tool correctly.

1. A detectable pulse must be present where the probe is placed. Hypotension, hypothermia, vasoconstriction and motion may prevent the pulse oximeter from reading accurately.
2. The pulse oximeter only reads two wavelengths of light (red and infrared). It cannot distinguish other forms of hemoglobin such as methemoglobin and carboxyhemoglobin. The presences of either of these forms will cause inaccurate readings. Likewise, pigmented skin, hair and ambient white light will all affect the accuracy of the readings.
3. The pulse oximeter is NOT a sensitive indicator of reduced lung function in patients receiving 100% oxygen during anesthesia. This is due to the relationship shown on the oxyhemoglobin dissociation curve. The SpO₂ will continue to register 100% until the PaO₂ drops below 100mmHg so the pulse oximeter is a late indicator of any pulmonary dysfunction.
4. The pulse oximeter does not give any indication of adequacy of ventilation.
5. The pulse oximeter does not measure oxygen content or oxygen delivery (will not indicate there is a problem in anemic patients).

Causes of hypoxemia

1. **Hypoventilation** - The elevated CO₂ level can cause significant dilution of the partial pressure of oxygen in the alveolus (PₐO₂) and lead to hypoxemia. This is more of a concern during the post operative period when the patient is breathing room air (21% O₂). It is less likely to be an issue when the patient is breathing 100% O₂. Patients easily respond to oxygen therapy.

2. **Diffusion Impairment** – Caused by any condition that prevents the normal uptake of O₂ from the alveoli to the pulmonary capillary blood. Conditions may include pulmonary edema, interstitial pneumonia and pulmonary fibrosis. Diffusion impairments are rarely the primary cause of hypoxemia in animals.

3. **Anatomical Shunts** - These are congenital heart abnormalities that cause blood to be shunted from the right side of the heart to the left without passing through the lungs to become oxygenated. Examples of conditions include tetralogy of Fallot, reversed PDA (patent ductus arteriosus) and ventricular septal defects. These conditions are not responsive to oxygen therapy.

4. **Ventilation to Perfusion Inequality** - This means that ventilation and blood flow are mismatched at the level of the alveoli resulting in inefficient gas exchange between the lungs and the pulmonary blood. This is the most common cause of reduced ability to oxygenate in an anesthetized patient and is often called V/Q mismatch. Maximum gas exchange occurs when the ratio between ventilation (V) and perfusion (Q) is equal to 1. A V/Q ratio of <1 means that perfusion is occurring but ventilation is not. This contributes to venous admixture because the blood does not become fully oxygenated as it passes through the lungs. Therefore, the arterial blood is diluted with deoxygenated blood as it goes into systemic circulation. Conditions which might cause a V/Q <1 include atelectasis, bronchial intubation, pneumonia and pulmonary edema.

Dead space ventilation produces a V/Q >1 because ventilation is present but perfusion is not. This is termed “wasted ventilation” and will also contribute to V/Q mismatch. Other contributors to V/Q mismatch include positioning the patient in dorsal recumbency or in the head down position for long periods and low cardiac output which will directly impair oxygenation of arterial blood and therefore promote V/Q mismatch.
5. **Low inspired oxygen** - The causes of low inspired oxygen are mostly due to human error and include things such as running out of oxygen during the procedure; using nitrous oxide at too high of concentration when combined with oxygen; and using too low of O₂ flow rate for type of breathing circuit.

**Treatment/Prevention of hypoxemia**
1. Provide 100% O₂.
2. Pre-oxygenate for 5 minutes prior to intubation.
3. Intubate all patients under general anesthesia to secure the airway.
4. Ensure that the endotracheal tube is in the trachea and not the esophagus.
5. Rule out airway obstruction (endotracheal tube obstruction/kink, mucous plug, etc).
6. Examine the anesthetic machine-determine adequate O₂ source.
7. Provide IPPV-adequate ventilation to minimize the effect of CO₂ on O₂ tension in arterial blood.
8. Increase peak airway pressure (up to 40cmH₂O) during IPPV to re-expand atelectatic alveoli (alveoli recruitment maneuver).
9. Perform chest auscultations to check for pneumothorax and perform thoracocentesis if necessary.
10. Provide positive end expiratory pressure (PEEP) - it improves oxygenation by increasing alveolar volumes and recruiting collapsed alveoli.
11. Provide optimal cardiac output to minimize shunting (fluid therapy, sympathomimetic therapy).
12. Minimize surgical and anesthesia time.
13. Treat pulmonary disease (Bronchodilators (albuterol), diuretics, antibiotics).

**Hypotension**
Blood pressure is the force that the flow of blood exerts on the vessel walls. It is one of two components that determine blood flow and therefore perfusion to the tissues. Hypotension is defined as below normal arterial blood pressure.

Normal values for blood pressure in awake, healthy animals include: systolic (SAP) 100-160mmHg, diastolic (DAP) 60-100mmHg and mean (MAP) 80-120mmHg. A SAP of less than 80mmHg or MAP of less than 60mmHg in small animals is used to quantify hypotension. In large animals, a MAP of less than 70mmHg defines hypotension. Maintaining MAP above these values is essential during anesthesia as these values are thought to be the minimum driving pressure necessary to maintain vital organ perfusion and local autoregulation. MAP can further be defined using the following equations.

\[
\text{MAP} = \text{CO} \times \text{SVR}
\]
\[
\text{CO} = \text{HR} \times \text{SV}
\]

MAP is the product of cardiac output (CO) and systemic vascular resistance (SVR). Cardiac output, or the volume of blood pumped by the heart each minute, is defined as the product of heart rate (HR) and stroke volume (SV). Stroke volume is the volume of blood pumped by the heart during each contraction and is influenced by preload (blood volume), afterload and cardiac contractility. Systemic vascular resistance (SVR) is dependent upon vasomotor tone and blood viscosity. Any factor that causes a decrease in one or more of these variables will result in a decrease in systemic arterial blood pressure.
Hypotension is a very common complication during the anesthesia period because most anesthetic drugs will have some effect on the above variables (see table below).

<table>
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<tr>
<th>Drug</th>
<th>Heart Rate</th>
<th>Cardiac Output</th>
<th>Contractility</th>
<th>Systemic Vascular Resistance</th>
<th>Blood Pressure</th>
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<td>↑</td>
<td>NC</td>
<td>NC or ↑</td>
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<td>±↑</td>
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<td>NC or ↓</td>
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<tr>
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<td>↑ or ↓</td>
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<td>↓</td>
<td></td>
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</tr>
</tbody>
</table>

↑ = increase; ↓ = decrease; NC = no change; ± indicates change may or may not occur

Modified from Lumb and Jones Veterinary Anesthesia and Analgesia 4th ed, 2007, p. 83

One of the most important concerns during anesthesia is to maintain adequate oxygen delivery to the tissues. Oxygen delivery depends on arterial oxygen content AND blood flow (DO₂ = CaO₂ x CO (blood flow)). To accurately evaluate blood flow it would be necessary to directly measure cardiac output (CO). This can be performed by Doppler ultrasound (transthoracic or esophageal), lithium dilution or thermodilution techniques. These techniques are expensive, difficult to perform and are invasive which makes them uncommon in most veterinary practices. Therefore, blood pressure is commonly used as an indirect indicator of blood flow. Blood pressure is related to blood flow by the following equation.

\[
\text{Blood flow} = \frac{\text{blood pressure}}{\text{vascular resistance}}
\]

Vascular resistance is the second component which determines the overall blood flow to the tissues. Using this equation, we can say that adequate blood pressure is required to maintain perfusion but normal blood pressure does NOT always correlate to adequate tissue perfusion. To illustrate this point consider the effects of administering acepromazine compared to medetomidine. Acepromazine is associated with vasodilation and hypotension but has little effect on cardiac output; therefore adequate blood flow is maintained. Medetomidine is associated with vasoconstriction, decreased heart rate and an initial increase in blood pressure. Vasoconstriction is associated with a dramatic decrease in cardiac output so even though the blood pressure is increased the overall total blood flow and perfusion to the tissues is decreased. Despite this example it is generally assumed that blood flow is proportional to blood pressure as long as vascular resistance is not excessive.

The major consequence of hypotension is lack of tissue perfusion and delivery of oxygen which leads to ischemia of vital organs (brain, heart, lungs and kidney) and peripheral tissues. Hypotension can lead to renal failure, reduced hepatic metabolism, hypoxemia and worsening V/Q mismatch, delayed recovery from anesthesia, postanesthetic myopathy in recovery (especially in large animals) and CNS abnormalities (blindness). Untreated hypotension can lead to cardiac and respiratory arrest.
Monitoring for hypotension
Arterial blood pressure can be measured by direct or indirect methods. Direct monitoring involves placing a catheter in a peripheral artery (dorsal pedal, metacarpal, auricular (cattle, rabbits), facial and metatarsal (horse)) and then connecting the catheter to an aneroid manometer or a pressure transducer. The aneroid manometer will indicate the MAP while the pressure transducer will display values for SAP, DAP, MAP and provide a waveform. This is considered the most accurate way to obtain blood pressure values but it can be technically challenging to place the arterial catheter and there is a risk associated with it being an invasive procedure (i.e., bleeding, hematoma formation, infection, arterial thrombosis). The arterial catheter needs to be flushed on a regular basis to maintain patency. The pressure transducer must be placed at the level of the heart and zeroed in order to provide an accurate assessment of blood pressure values. Likewise, the air-to-water interface in the tubing of an aneroid manometer set up must be placed at the level of the heart to ensure accuracy. If they are placed lower than the heart it will give a false high reading and if they are placed higher than the heart it will give a false low reading.

The oscillometric technique is the most common indirect method to monitor blood pressure. This monitoring device will only provide an accurate assessment of blood pressure if an appropriately sized cuff is selected. Proper size of cuff is determined by measuring the width of the cuff to the circumference of the limb. The width of the cuff should be approximately 40% the circumference of the limb. A cuff that is too small will cause a false high reading and a cuff that is too big will cause a false low reading. It is also important to align the arrow of the cuff over a pulsating artery. The best results are usually obtained when the cuff is placed proximal to the carpus or tarsus in small animals and the tail in large animals. Also, no tape should be used to secure the cuff around the leg or tail. Ideally, if the velcro on the cuff is not working a new cuff should be used but this might not be economical for every veterinary practice. Placing tape around the entire cuff to hold it in place will mimic a cuff that is too small and might yield false high readings.

The oscillometric technique tends to be unreliable in patients with high heart rates (small dogs and cats) and in patients that are hypotensive.

The Doppler is also considered an indirect method for monitoring blood pressure. This device will only provide the SAP value. In cats and small animals less than 4kg it has been shown to read 10-15mmHg lower than the actual SAP value. In order to obtain the SAP reading, the probe has to be placed over an artery. Common locations in small animals include just proximal to the metacarpal or metatarsal pads and the coccygeal artery on the tail for large animals. An appropriately sized cuff (see above) must be used in order to obtain accurate results. The doppler has the advantage of providing an audible sound which can alert the anesthetist to any changes in rate or quality of the pulse.

Causes of hypotension
Hypotension can be caused by any factor that reduces systemic vascular resistance, heart rate and/or stroke volume.

1. Most of the anesthetic drugs commonly used for premedication, induction and maintenance will contribute to a dose-dependent reduction in one or more of these factors.
   • Drugs that will decrease SVR due to vasodilation include the inhalants and acepromazine. Thiopental and propofol will also contribute to a decrease in SVR for a brief period due to rapid redistribution of the drug.
   • Drugs that might cause a decrease in heart rate include opioids, alpha-2 agonists and the inhalants.
• Drugs that might cause a decrease in stroke volume include the inhalants, alpha-2 agonists (immediately after IV administration), ketamine, thiobarbiturates and propofol.

NOTE: The commonly used inhalants (halothane, isoflurane, sevoflurane and desflurane) probably have the most profound effect at decreasing SVR, heart rate and stroke volume and therefore are one of the most likely agents to cause hypotension. The anesthesia protocol should be tailored to keep the inhalant concentration to a minimum.

2. Factors that might reduce blood volume and/or vascular tone and therefore lead to a decrease in systemic vascular resistance include hypovolemia (hemorrhage), inadequate volume administration or replacement, dehydration, shock, sepsis and histamine release.
3. Excessive inspiratory pressure during IPPV will cause a reduction in preload and a decrease in stroke volume. Preload will also be decreased due to blood loss, dehydration and vasodilation.
4. Additional factors that may contribute to hypotension include hypothermia, electrolyte imbalances and hypercapnia.

Prevention of hypotension
1. Use a balanced anesthesia approach when deciding what anesthetic drugs to use. Remember it is better to use multiple drugs at lower doses than to use one drug at a high dose.
2. Keep the inhalant concentration to a minimum. Consider supplemental opioid administration perioperatively to decrease the inhalant concentration while maintaining adequate surgical anesthetic depth.
3. Ensure adequate fluid volume prior to anesthesia. If possible, treat any underlying hypovolemia or dehydration prior to induction of anesthesia.
4. Provide intravenous crystalloid fluids to all patients under general anesthesia.

Treatment of hypotension
1. Assess anesthetic depth and turn down vaporizer.
2. Give a 5-20ml/kg bolus of crystalloid fluid (LRS, Normosol-R).
3. Consider the use of inotropes. Dopamine and dobutamine will help increase contractility but should not be used unless adequate vascular volume is present.
4. Consider the use of colloids (hetastarch, pentastarch) if crystalloid therapy is not successful. Remember to not exceed 20ml/kg/day.
5. In severe cases, consider the use of norepinephrine, ephedrine or phenylephrine as additional inotropic agents.

Hypovolemia
Hypovolemia is defined as a reduction in effective intravascular circulating blood volume. It can be divided into two general classifications, absolute and relative. **Absolute hypovolemia** refers to an actual loss of intravascular volume and results when intravascular fluid losses exceed intravascular fluid gains. **Relative hypovolemia** is not due to an actual loss of intravascular volume, but rather due to an increase in intravascular space due to loss of vasomotor tone and resultant vasodilation. In other words, with relative hypovolemia there is a “normal intravascular volume” but there is a larger space in which it has to occupy. Relative hypovolemia may also result when there is a maldistribution and pooling of blood within the microcirculation causing volume depletion in the macrocirculation. The approximate blood volumes for dogs and cats are 90ml/kg and 60-70ml/kg, respectively. Most healthy anesthetized adult animals can tolerate a
loss of 10-20% of their total blood volume without any long term effects. However, any blood loss that exceeds 20% of the circulating blood volume requires treatment.

Hypovolemia is one of the most common causes of decreased tissue perfusion. Lack of effective circulating blood volume causes a sequential reduction in preload, stroke volume, cardiac output and ultimately a decrease in oxygen delivery to the tissues. Remember the following equation discussed in the hypotension section: \( DO_2 = CO \times CaO_2 \), where \( DO_2 \) is the delivery of oxygen to the tissues, \( CO \) is cardiac output (blood flow) and \( CaO_2 \) is the oxygen content in the blood. Based on this equation, the overall consequence of hypovolemia is inadequate oxygen delivery to the tissues to meet tissue oxygen demands.

There are four situations in which hypovolemia should be regarded as a pre-anesthetic concern.

1. **Relative hypovolemia** - Anesthesia is a common contributing factor to relative hypovolemia due to the vasodilative effects of the inhalants and some sedative drugs. This can usually be managed by administering fluids during the anesthetic period. Therefore, all patients under general anesthesia should receive intravenous crystalloid fluid.

2. **Pre-existing hypovolemia** - These are patients that are systemically challenged or are trauma patients with some form of acute hemorrhage. Resuscitative measures should be taken to restore circulating blood volume before anesthesia as this will reduce the mortality associated with hypovolemia. Trauma patients that must undergo a surgical procedure in order to stop acute hemorrhage pose a greater anesthetic risk.

3. **At risk patients** - These patients are showing no signs of hypovolemia prior to anesthesia but pose a greater risk for blood loss during the perioperative period because of the intended procedure or surgery. Examples include excisions of large tumors, splenectomies, maxillectomies, mandibulectomies, limb amputations, gastro-intestinal surgery and nasal or sinus surgery. Previous planning and being prepared to handle large amounts of blood loss will greatly improve the survivability of these patients.

4. **Iatrogenic hypovolemia** - These are the types of cases caused by something humans do to make the animal worse off. An example would be a stable patient during an adrenalectomy surgery and then suddenly the surgeon tells you that they just accidentally nicked the vena cava and now have uncontrolled bleeding. These types of cases pose the greatest challenge to the anesthetist to see if they were truly prepared to handle any anesthetic complication.

The anesthetic depth of hypovolemic patients must be monitored very closely. A reduction in cardiac output can actually increase the rate of inhalant delivery and uptake into the brain. This will cause a more rapid induction and the increased likelihood of the patient becoming too deep during the perioperative period.

**Clinical signs of hypovolemia**
The clinical response to hypovolemia usually progresses thru three overlapping stages, the compensatory, the early decompensatory and late decompensatory.

The initial compensatory stage is characterized by a hyperdynamic cardiovascular response. Decreases in blood flow activate the stretch receptors and the baroreceptors in the aortic arch, carotid body and splanchnic vessels which causes an increase in sympathetic stimulation. Sympathetic stimulation of the heart leads to increased heart rate and increased contractility which help to restore cardiac output. Sympathetic stimulation of the vasculature results in vasoconstriction in order to increase SVR and maintain blood pressure. Clinical signs during this stage are usually mild and may go unnoticed. They may include mild increases in heart rate.
and respiratory rate, increased capillary refill time (<1 sec), bright pink to red mucous membranes, normal blood pressure, normal to bounding pulse pressures and normal mentation.

As the hypovolemia and hypoperfusion persists, compensatory mechanisms begin to fail and the patient enters the decompensatory stage. During the early stages, blood is shunted away from the periphery and taken to the vital organs (heart and brain), while the oxygen delivery to all other tissues is compromised. Clinically, the patient may present with tachycardia, tachypnea, pale mucous membranes, prolonged capillary refill time (> 2 sec), decreased body temperature, decreased pulse pressure, decreased mentation and cool extremities.

The late decompensatory stage is characterized by massive circulatory collapse with bradycardia, pale to white mucous membranes, undetectable CRT and pulse pressure, severe hypotension, low body temperature and coma.

It is important to note that animals under anesthesia may not respond to hypovolemia with an increased heart rate. Also, most animals under anesthesia will already have subnormal body temperatures.

**Monitoring for hypovolemia**
It is clinically difficult to determine the degree of hypovolemia as specific modalities for routinely monitoring intravascular volume are not currently available. Instead, we must use the combination of the physical parameters and monitoring tools below to help assess adequate effective circulating volume and tissue perfusion.

1. Heart rate
2. Blood pressure
3. Mucous membrane color and capillary refill time
4. Pulse quality
5. Packed cell volume (hematocrit) and total protein
6. Extremity temperature
7. Adequate urine output (1-2 ml/kg/hr)
8. Central venous pressure (CVP)

CVP has often been used as an indicator of blood volume or preload. It is performed by placing a jugular catheter so that the tip of the catheter sits just proximal to the right atrium. Normal values for CVP include 0-10cmH₂O. Measurements that register less than 0cmH₂O are considered abnormal and suggest hypovolemia. Trends in the CVP numbers appear to be more beneficial than the actual numbers at any given measurement. For example, a decrease in blood volume will lead to a decrease in CVP and an increase in blood volume will lead to an increase in CVP.

**Causes of hypovolemia**
Common causes of absolute hypovolemia include water and electrolyte losses (diarrhea, vomiting, renal losses, heat stroke, intestinal obstruction, burns), hemorrhage, and plasma losses (dehydration, third space loss). Third space loss involves redistribution of fluid within the body such as from the intravascular space to the interstitial space or body cavity. Third space losses involve the accumulation of large fluid volumes in cavities such as the pleural or peritoneal space, intestinal or gastric lumen, and in tissues surrounding fractures or trauma sites.
Some causes of relative hypovolemia include adverse drug reactions, sepsis or anaphylaxis. Anesthesia drugs (acepromazine, inhalants) prone to causing vasodilation may also contribute to relative hypovolemia.

**Prevention of hypovolemia**
1. Perform resuscitative measures to restore circulating blood volume on all patients showing signs of absolute hypovolemia.
2. Provide crystalloid fluids to all patients under general anesthesia to account for the vasodilation from the inhalants. Research studies have shown that administering maintenance fluids during anesthesia is effective at counteracting the vasodilatory actions of the inhalants.
3. Previous planning prevents poor performance. In cases that are a high risk for perioperative bleeding place multiple peripheral IV catheters as well as a central line in the jugular vein. Place an arterial catheter to directly monitor blood pressure. Have all supplies, fluids and emergency drugs within hands reach to handle any crisis that may occur without warning.

**Treatment of hypovolemia**
1. Replacement crystalloid fluids- In cases of severe hypovolemia, shock doses (90ml/kg in medium to large dogs and 40-60ml/kg in cats and small dogs) should be used to replace intravascular volume. Crystalloids should be administered at a 3:1 ratio to blood loss to account for the rapid redistribution of the fluid to the extracellular fluid space. Calculate ¼ of the total volume of fluids and administer as a bolus as rapidly as possible (usually within 15 minutes) and then reevaluate the patient to decide if a second shock dose of crystalloid is warranted. Hemodilution is a common consequence of rapid fluid therapy with crystalloids.
2. Colloid therapy- Synthetic colloids such as hetastarch and pentastarch help maintain oncotic pressure and therefore keep fluid in the intravascular space longer. They should be considered if the TP is < 3.5g/dl. They can be used alone or concurrently with crystalloid fluids to increase effectiveness of volume expansion. Colloids can be administered as a bolus at a rate of 5-10ml/kg (dogs) and 2-5ml/kg (cats) over 5-10 minutes and repeated as needed. However, do not exceed the rate of 20ml/kg/day. If administered concurrently with crystalloids, the crystalloid dose should be reduced by 40-60%.
3. Blood products are indicated when the extent of volume replacement with crystalloid fluids will result in excessive hemodilution (PCV < 20% or TP < 3.5g/dl).
   **Whole blood**: Indicated when 30-40% of circulating blood volume is lost. Primarily used when both oxygen carrying capacity and intravascular volume need to be restored. Fresh whole blood (< 6-8 hours old) contains red blood cells, plasma, coagulation factors and platelets. Fresh whole blood (8-24 hours old) contains red blood cells, plasma and decreased levels of coagulation factors but does not contain active platelets. Stored whole blood (>24 hours old) is used primarily to treat anemia and hypoproteinemina with concurrent mild hypovolemia, as coagulation factor levels are markedly decreased.
   **Packed RBC**: Indicated when the PCV < 20% but TP is adequate (after restoration to normovolemia). Only restores oxygen carrying capacity within the vasculature.
   **Plasma**: Indicated when the PCV is adequate but the TP < 3.5g/dl. Fresh Frozen Plasma (< 1 year old) is used for treating any coagulation factor deficiency or hypoproteinemia, while frozen plasma (> 1 year old) is used for treating hypoproteinemia and some coagulation factor deficiencies. Restoring plasma proteins helps maintain oncotic pressure.
Hemoglobin based oxygen carrier: Oxyglobin is an oxygen carrying solution that can be used as a substitute when blood products are unavailable.

4. Provide 100% oxygen to help maximize hemoglobin saturation in order to improve arterial oxygen content.

5. Provide balanced anesthesia to keep inhalant concentrations to a minimum.

Hypothermia

Hypothermia is defined as a subnormal body temperature. The normal temperature range for canines and felines is 100-102.5°F (37.8-39.2°C). A decrease of just 2°F (1°C) from normal values can have adverse effects on patients, especially those that are already compromised or critically ill. Hypothermia can further be classified into mild (98-99.9°F; 36.7-37.7°C), moderate (96-98°F; 35.5-36.7°C), severe (92-96°F; 33-35.5°C) or critical (< 92°F; < 33°C).

The posterior hypothalamus is responsible for thermoregulation and controls the body’s compensatory responses to increases or decreases in core body temperature. Heat is produced by the body during cellular metabolism and the amount of heat that is produced is dependent on the individual tissue metabolic rates. The body can be divided into two thermal compartments:

1. The core compartment which is made up of the brain and vital organs.
2. The peripheral tissue compartment which contains the extremities.

The brain and major organs are responsible for the majority of heat production because they are the most metabolically active tissues. During normal thermal homeostasis the core temperature remains relatively constant while the peripheral fluctuates with changes in ambient temperature. Thermoreceptors that detect decreasing body temperature are located throughout the body. Upon stimulation they relay signals to the hypothalamus initiating a compensatory thermoregulatory response that includes vasoconstriction of the peripheral arteries (decrease heat loss), piloerection of the hair (trap heat next to the body) and increasing heat production through shivering and increased cellular metabolism. All of these actions function collectively to increase body temperature.

General anesthesia impairs the body’s thermoregulatory control mechanism. Therefore, some degree of hypothermia is always present when a patient is anesthetized. Perioperative hypothermia occurs in three phases.

Phase 1: Rapid redistribution of heat from the core to the peripheral causing heat loss.
- Anesthesia promotes this redistribution in two ways.
  1. Anesthesia increases the thermoregulatory threshold needed to cause reflex vasoconstriction. Therefore, a lower temperature is required before the thermoregulatory center in the hypothalamus is stimulated.
  2. Any anesthetic agent that produces some degree of vasodilation will increase heat loss.

Phase 2: Heat loss exceeds metabolic heat production.
- During anesthesia and surgery heat can be lost through four different mechanisms.
  1. Convection is the transfer of heat from the body to the air moving around the animal.
  2. Conduction is the direct transfer of heat from the body surface to another object touching the skin (i.e., surgery table).
  3. Radiation is the exchange of heat between the body and objects in the environment that are not in contact with the skin.
  4. Evaporation occurs when moisture (i.e., surgical prep solutions) that was in contact with the skin dissipates into the air, pulling heat with it.
Phase 3: The core temperature drops to a low enough level that initiates thermoregulatory vasoconstriction in an attempt to decrease heat loss and reestablish the temperature gradient between the peripheral and the core.

Small dogs, cats, neonates, pediatrics and small mammals are more susceptible to hypothermia due to having a high surface area to body mass ratio and possessing insufficient heat production capabilities (immature thermoregulatory response, lack of glycogen storage, immature metabolism).

**Consequences of hypothermia**

- **Metabolic**
  - Reduction in hepatic metabolism may lead to a prolonged action of anesthetic drugs.
  - Delayed recovery.
  - Severe hypothermia can lead to decreased renal blood flow and ultimately acute renal necrosis.
  - Mild hypothermia can cause prolonged platelet aggregation while severe hypothermia can lead to decreases in platelet aggregation and coagulation factor activity.

- **Cardiovascular**
  - Mild to moderate hypothermia causes increased heart rate and MAP due to catecholamine release.
  - Severe hypothermia decreases the responsiveness to catecholamines and baroreceptors which can result in bradycardia, hypotension and decreased cardiac output.
  - Shivering results in increased oxygen consumption.

- **Respiratory**
  - Severe hypothermia can lead to a decrease in respiratory rate and tidal volume because of decreased cellular metabolism. This causes a reduction in CO₂ production and therefore impedes the stimulation for ventilation.
  - Increase risk for tissue hypoxia, pulmonary edema, acute respiratory distress syndrome and pneumonia due to the shifting of the oxyhemoglobin dissociation curve to the left, blood sludging and a decline in alveolar ventilation.

- **Neurologic**
  - Mild to moderate hypothermia can impair cerebral autoregulation and cause a reduction in cerebral blood flow which may all lead to alterations in mentation.
  - Severe hypothermia can lead to central nervous system depression and coma.

- **Immunologic**
  - Severe hypothermia increases the incidence of perioperative infection by diminishing the function of the white blood cells. It can also lead to poor wound healing.

**Monitoring for hypothermia**

Temperature should be monitored on a regular basis throughout the entire anesthetic period. Esophageal or rectal temperature probes provide the most accurate measurement of core body temperature. They also provide a continuous value during the anesthetic period and can alert the anesthetist to a problem quicker. Rectal thermometers are the most convenient and widely used technique to monitor body temperature. Peripheral vasoconstriction and perfusion abnormalities may cause inaccurate results. Auricular thermometers have also been advocated but the accuracy is highly variable in animals. If continuous monitoring is not available, then the temperature should be taken every 15 minutes during the perioperative period. The temperature should be taken immediately in the recovery period and assessed every 5-10 minutes until the temperature is within normal range.
### Causes of hypothermia

1. Most anesthetic agents impair thermoregulation to some degree. The inhalants are by far the greatest contributor to vasodilation and therefore promote heat loss.
2. Cool ambient environment in operating room.
3. Prolonged surgical and anesthesia time.
4. Administration of cool intravenous fluids.
5. Intra-abdominal lavage with cool/cold saline.
7. Evaporative heat loss through the use of cold surgical scrub, water or alcohol.
8. Conduction heat loss through contact with cold operating table.
9. Large area of exposed skin due to clipping for surgical site.
10. High fresh gas flow rates needed to operate non-rebreathing systems can contribute to hypothermia and drying of the upper airways.

### Prevention/Treatment of hypothermia

1. Maintain acceptable ambient room temperature.
2. Minimize surgical and anesthesia time.
4. Use warm surgical scrub and minimize amount of alcohol used.

### Examples of Warming Modalities, Indications for Use and Methods of Action

<table>
<thead>
<tr>
<th>Type of Rewarming</th>
<th>Methods</th>
<th>Goal</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive surface</td>
<td>External covers (blankets, foil, bubble wrap, saran wrap)</td>
<td>Prevent further peripheral heat loss while the animal generates heat</td>
<td>Mild hypothermia in animals that are stable and possess adequate thermoregulatory control</td>
</tr>
<tr>
<td>Active surface</td>
<td>Warm water bottles**, heating pads**, warm water circulating air/water blankets, radiant heaters, forced air blankets, heat lamps, dryers</td>
<td>Apply heat to the surface of the body **Very important to monitor for overheating, tissue drying and thermal burns.</td>
<td>Moderate, severe or critical hypothermia. Provide volume support during rewarming to support circulatory system.</td>
</tr>
<tr>
<td>Active core</td>
<td>Heated, humidified inspired air; warm peritoneal/pleural lavage; warm IV fluids; warm water bladder lavage; warm water enema</td>
<td>Provide heat centrally to rapidly warm the core</td>
<td>Severe or critical hypothermia to prevent dilation of peripheral arteries.</td>
</tr>
</tbody>
</table>

Table modified from Oncken AK, Kirby R, Rudloff E: Hypothermia in Critically Ill Dogs and Cats. *Compendium* 23(6): 2001

**The use of electric heating pads or fluid bag/bottles placed in the microwave are NOT recommended due to the likelihood of extreme thermal burns if they come in direct contact with the skin. If they must be used, then ensure that a proper barrier (several towels or blankets) are placed between the heat source and the patient.

References available upon request