Dogs and cats with respiratory diseases can be challenging to anesthetize. During induction of general anesthesia and recovery the animal should be closely monitored and being ready for complications may save the patient’s life. During general anesthesia oxygenation via pulse oximeter and ventilation via capnograph should be considered. Animals with respiratory disorders may have problems exchanging oxygen at the alveolar/pulmonary capillary level and oxygen supplementation may be required during general anesthesia and pre- and post-procedure.

For these patients it is paramount minimizing stress during induction and recovery, pre-oxygenating, securing the airway after induction as soon as possible, ventilating, and monitoring closing during and after the procedure.

1. Upper airway disorders
   a. Brachiocephalic Syndrome
   Characterized by stenotic nares, elongated soft palate, everted laryngeal sacculles, and hypoplastic trachea. Redundant soft tissue in pharyngeal and laryngeal areas may cause difficulty breathing. These patients may be challenging to intubate and severe complications may present during extubation and recovery. Prepare your equipment before sedating the dog and be ready to induce and intubate if the animal has trouble breathing. Opioids and acepromazine can be used for premedication. Have a wide selection of endotracheal tubes (ETTs), since these patients may take a much smaller tube that you would expect due to their hypoplastic trachea. This author’s preference is to induce these animals using propofol. This drug will cause apnea, but will also abolish the swallowing reflex allowing for a faster intubation. Plan of having extra injectable anesthetic agents, in case the procedure requires extubation and re-intubation of the animal. Before induction, have suction ready and plan of delivering oxygen flow-by after induction but before intubation, if a laryngeal exam is required. To do this, an insufflation line connected to an oxygen source can be taped to the blade of the laryngoscope (Fig 1).

   Figure 1. Insufflation line connected to the common gas outlet of the anesthesia machine and taped to the blade of a laryngoscope to use during laryngeal exams

At the end of the anesthetic event, extubate after the animal is completely awake. These dogs usually tolerate the ETT in place very well. Have and induction agent ready (i.e. propofol) just in case the animal stops breathing after extubation. Monitor closely for complications during the next few hours and have an ETT 0.5-1 size smaller than the one you used for the procedure tide to the cage or close by, just in case you need to re-intubate should complications arise.

b. Laryngeal paralysis
   Usually diagnosed in older medium/large breed dogs (i.e. Labradors and Golden Retrievers). Some dogs may present with severe difficulty breathing. Administration of acepromazine (0.01-0.02 mg/kg IV or IM) and oxygen supplementation may be beneficial before doing any diagnostics. Pre-oxygenation and rapid control of the airway is very important. Regurgitation should be avoided during before and after the anesthetic event, since these animals are at high risk of aspiration pneumonia. Use antiemetic and prokinetic drugs preoperatively (i.e. maropitant and metoclopramide). This author prefers avoiding full mu agonist opioids and alpha-2 agonists before induction to decrease the chance of vomiting. These drugs will also interfere with the laryngeal exam. After induction with propofol, administer O2 flow-by (see Fig 1) and wait until the animal breath again to perform the laryngeal exam. Doxapram 0.5-1 mg/kg IV can be used to stimulate the respiration and facilitate the exam. Anesthesia can be maintained with isoflurane or sevoflurane in O2. This author prefers to use ketamine and lidocaine CRI during the procedure and low dose of fentanyl CRI if needed. Be ready to extubate the patient after the tie-back procedure is done to examine the larynx. To do so, have propofol in case the animal gets light when extubated. Use a new ETT to re-intubate. Minimize stimulation during recovery. Ideally the patient should be pain-free, not dysphoric and awake enough to stay in sternal recumbency or standing. During extubation keep the animal in sternal and head up to decrease the chance of aspiration.

c. Tracheal collapse
   In small and toy breed (i.e. Yorkshire Terriers). Can be life-threatening. Avoid stress and use acepromazine (0.01-0.02 mg/kg IV or IM) if the animal is anxious. Oxygen supplementation should also be considered. Secure the airway as soon as possible after induction
and monitor closely after the anesthetic even. If the dog has severe difficulty breathing in recovery, consider inducing general anesthesia again and secure the airway.

d. Rhinoscopy and rhinotomy
The obstruction can be unilateral or bilateral (open mouth breathing?). Cats usually have difficulty breathing through their mouth, so they can be very severe distress if bilateral occlusion is present. Both procedures (rhinoscopy with biopsies and rhinotomy) can be very painful. Systemic analgesia and local blocks (i.e. maxillary block) should be considered. These animals may bleed a lot through their nose during the procedure and in recovery. Monitoring packed cell volume, total protein, and blood loss is recommended. During the procedure, pharyngeal packs are usually used. Remove them before recovery. Monitor animals in the post-operative period for blood loss and pharyngeal/tracheal obstruction.

2. Lower airway disorders
   a. Infiltrative and chronic obstructive diseases
These animals may need to be anesthetized for diagnostic procedures related to their disease or for unrelated causes. Common pathologies are feline asthma, atelectasis, neoplasia, lung contusion, pulmonary edema, and pneumonia. It is important to minimize stress and provide oxygen supplementation when possible. It is important to protect the airway when possible. In small size animal, when bronchoscopy is required, removing the ETT may be necessary. In this case it is paramount to supplement oxygen (use flow-by or working channel of the scope) and monitor SpO2 and color of mucous membranes. Be ready to re-intubate if complications arise. Recovery should be quiet and stress/noise should be avoided. Oxygen supplementation should be considered.
   b. Lung lobe torsion
This is considered a surgical emergency. The animal (usually dogs with narrow and deep chest) may present in respiratory distress and depressed. The torsion is generally associated with chronic respiratory disease, trauma, neoplasia, and chylothorax. The venous circulation and the bronchus become obstructed, but the arterial flow persists. This causes severe congestion of the lobe with possible edema and pleural effusion. The patient may need to be sedated and a chest tube may need to be placed. During surgery, when the chest is open, the negative intrathoracic pressure is lost and the patient will require supported ventilation. Thoracotomies are painful procedures, make sure that the patient receives sufficient analgesia during surgery and in recovery. Systemic drugs such as opioids, alpha-2 agonists, ketamine, lidocaine can be use and local techniques should be considered (i.e. intercostal block or epidural injection). When the chest is closed, make sure to aspirate the air from the thoracic cavity until you reach negative pressure. Monitor in recovery for respiratory distress due to complications, such as pneumothorax, and pain.

3. Extrapulmonary diseases
   a. Pneumothorax and pleural effusion
Sedation may be required if the animal presents in respiratory distress (acute onset). Provide oxygen and perform a thoracentesis to evacuate the fluid of gas. If there is a big amount of fluid or air in the pleural space, place a chest tube. If tension pneumothorax is present, place a chest tube. See “Lung Lobe Torsion” for management during surgery and recovery.
   b. Diaphragmatic hernia
The animal can present in respiratory distress (acute/traumatic onset) or it can be asymptomatic if chronic or congenital. Part of the abdominal content is relocated in the thoracic cavity, compressing the lung and causing atelectasis. If possible, pre-oxygenate and prepare the patient for surgery before induction (if this doesn’t cause stress to the animal). Induction of anesthesia should be rapid and mechanical ventilation should be used. When anesthetized, the animal should be placed in sternal recumbency or in lateral with the herniated side down. When the abdomen is open, the chest is open too, since they communicate though the hernia. Use intermittent positive pressure ventilation if you haven’t started yet. If the diaphragmatic hernia is chronic, there is higher risk of morbidity/mortality due to reperfusion injury and prolonged pulmonary atelectasis. Lidocaine CRI can be used as an analgesic and as a free radical scavenger during surgery. A dose of corticosteroids can be administered before removal of abdominal contents from chest. The lungs should be re-expanded very slowly.
   c. Other extrapulmonary diseases
Chest wall injuries, neurological diseases, obesity and abdominal distention can all cause respiratory dysfunction. Minimizing stress, providing oxygen support and intermittent positive pressure ventilation may be required for these diseases. Close monitoring, especially oxygenation (SpO2) and ventilation (end tidal CO2) are recommended. Titrate drugs to effect, especially if central neurological disease is present and use drugs that can be reversed. These patients should be monitored closely during recovery.
Main components of the anesthesia machine

The anesthesia machine consists of four main parts:

1. A source of carrier gas. This gas is oxygen (O2), but nitrous oxide (N2O) can be added to it. Different source of O2 can be used:
   a. O2 cylinders (or tanks). They come in different sizes and the two commonly used in veterinary medicine are:
      i. E-cylinders. They contain 660 L with a capacity pressure of 1900 at 70°F. E-cylinders are commonly mounted on anesthesia machines to transport patients under general anesthesia. H-cylinders. They contain 6900 L with a capacity pressure of 2200 at 70°F. H-cylinders are placed on dollies or chained to the wall.
   b. The following formula is used to calculate the amount of O2 left in an E-cylinder
      \[ \text{Volume (L)} = \frac{\text{pressure on gauge (psig)}}{1900 \text{ (psig)}} \times 660 \text{ (L)} \]
   c. Oxygen bank. It is comprised of several H-cylinders connected to the pipeline system.
   d. Oxygen concentrators. They use the pressure swing adsorber technology, which increases the O2 concentration by adsorbing nitrogen into a molecular sieve and allows O2 and trace gases, especially argon, to pass through. They can reach concentrations of O2 between 90-96% and they can be used when compressed or liquid O2 are not available to generate O2 to supply the pipeline system.

3. A pressure regulator, which converts variable high gas pressure from cylinders to constant lower pressure suitable for the anesthesia machine. Regulators in the pipeline systems decrease the pressure to 50 psig, while regulators connected to E-cylinders decrease it to 45 psig. A second regulator further decreases the pressure to 16 psig to isolate the flowmeter from any fluctuations in the pipeline pressure.

4. A flowmeter, which measures and indicates the flow of the carrier gas and enables precise control of O2 (or N2O). The flowmeter is positioned downstream from the O2 source and upstream from the vaporizer(s). The gas enters the bottom and exits at the top of the glass tube. When the gas goes through the tube, it raises an indicator (float). A scale, associated with the glass tube, indicates the rate of gas flow in mL/min or L/min. A flowmeter indicator should be read at the top, except for a ball-type float, which is read at the center.

5. A vaporizer, which converts a liquid anesthetic (e. g. isoflurane, sevoflurane, and desflurane) into its vapor, and adds a specific amount of this vapor into the carrier gas. Modern vaporizers are concentration-calibrated (meaning that the vaporizer delivers a concentration that is close to the setting on the vaporizer dial), variable-bypass (meaning that after the carrier gas enters the vaporizer, part is directed to and part bypasses the vaporization chamber), temperature, flow, and back pressure compensated (meaning that the vaporizer has a means to compensate for fluctuations of temperature, flow of carrier gas, and back pressure in order to keep the delivered inhalant constant), and are positioned out of the circuit (meaning that the vaporizer in positioned outside and upstream from the breathing system).

Other components that are part of the anesthesia machine are

1. Safety devices for oxygen pressure and flow. The safety device can be an alarm or a mechanism that cuts off the supply of all other gases (e.g. N2O) when the pressure of oxygen flow reaches dangerously low values.

2. Flush valve. This valve delivers high flow of O2 (35 to 75 L/min) directly into the common gas outlet and bypassing the vaporizer. The flush valve is used when the operator wants to decrease the amount of inhaled anesthetic present in the rebreathing system and in the anesthesia machine (e.g. at the end of the procedure or in case of emergencies). It should never be used with a non-rebreathing system, due to high risk of overpressurizing the patient’s respiratory system.

3. Common gas outlet. It represents the interface between the anesthesia machine and the breathing system. This outlet is the site from which gases that have passed through the flowmeter and vaporizer (or flush valve) exit the anesthesia machine.
Breathing systems
A breathing system is connected to the anesthesia machine, to allow proper delivery of carrier gas (O2 or O2 with N2O) and inhaled anesthetic to the patient.

The main functions of the anesthesia machine and the breathing system are:

1. To provide O2 to the patient. The fraction of inspired O2 (FiO2) should never be less than 30%. In veterinary medicine, an FiO2 close to 100% is normally used. When N2O is used, the FiN2O is 60-70% and the FiO2 is 40-30%.
2. To deliver inhaled anesthetic to the patient. Inhaled anesthetics used in veterinary medicine in United States are isoflurane, sevoflurane, and, less frequently, desflurane.
3. To support ventilation. General anesthesia induces hypoventilation, due to the depression of the respiratory center. It is important to ventilate for the patient and, even if the animal is breathing on his own, one breath per minute or every other minute is recommended. This ensures delivery of O2 and inhalant, and stimulates the release of surfactant, which prevents atelectasis. Ventilatory support can be achieved by squeezing the reservoir bag or by using a mechanical ventilator.
4. To remove carbon dioxide (CO2) from the patient. When a rebreathing system or circle system (see below for definition) is used, the CO2 is removed by a chemical absorbent. The most commonly used in veterinary medicine is soda lime. When a non-rebreathing system or Mapleson system (see below for definition) is used, the CO2 is removed by the high O2 flow rate (100-200 ml/kg/min). If lower flow rates are used, CO2 may be rebreathed by the patient.
5. To remove waste inhaled anesthetic agent from the work environment. The use of a scavenging system is required by the Occupational Safety and Health Administration (OSHA). There are active and passive scavenging systems. Active systems include piped-vacuum (or central vacuum systems, usually used in hospitals) and active duct systems (with high volume of flow and low negative pressure generated by a pump or a fan). Passive systems include non-recirculating ventilation systems, piping directly to the atmosphere, and absorption devices, such as F-canisters (usually seen mounted to movable anesthesia machines).

Types of breathing systems

Rebreathing systems or circle systems
As a general guideline, pediatric circle systems are used for patients between 5 and 10 kg, and adult circle systems for dogs weighing more than 10 kg. However, choosing the size of the circle system may be influenced by the species, the practical availability of equipment, the type of ventilation used, and the veterinarian’s preference. The universal F-circuit is a type or rebreathing system, where the inspiratory tube is placed inside the expiratory tube (co-axial configuration). Advantages of this system include compactness (important when the veterinarian needs to work in the patient’s mouth) and moderately increased inspiratory heat and humidity. Disadvantages include increased gas flow resistance and work of breathing, and difficulty in detecting possible leaks in the inner tube.

The inspiratory and expiratory tubes are usually corrugated (except for the inspiratory tube of the universal F-circuit). Corrugations prevent inhalation of dust coming from the CO2 adsorbent, inhalation of moisture, water, and condensation that gets trapped in the grooves of the tubes, and they reduce the likelihood of obstruction if the tubes are bent. The breathing tubes come in different length. Longer tubes do not increase mechanical dead space (volume of gas re-breathed as the result of use of mechanical devices, such as endotracheal tube, gas sampling line adaptors, etc.), but they will only add to the overall volume of the rebreathing apparatus. Mechanical dead space ends at the point where inspired and expired gas streams diverge (the Y-connector).

The gases flow only in one direction in the rebreathing system. This is guaranteed by the correct function of the one-way valves (the inspiratory one-way valve opens during inspiration, while the expiratory valve is closed, and the opposite occurs during expiration). On inspiration, gases exit the reservoir bag and travel through the inspiratory one-way valve, the inspiratory tube, and the Y piece to the patient. On expiration, the exhaled gases enter the Y piece, the expiratory tube, and the expiratory one-way valve. Gases may enter the reservoir bag before or after going through the CO2 adsorbent canister. The excess gases exit the breathing system through the pop-off or adjustable pressure limiting (APL) valve an move into the scavenging system. The APL valve should be left open when the patient breathes on his own, since it is a safety device that prevents dangerous rise of the pressure in the breathing system and in the animal respiratory system. It can be partially or completely closed when the operator delivers a breath to the patient, but it should be reopened after the breath. It should be completely closed when mechanical ventilation is initiated (mechanical ventilators have their own pressure release valves and an open APL valve will cause leakage in the system).

The reservoir bag provides compliance in the system during exhalation and provides a means for assisted or controlled ventilation. Commonly used sizes in small animals are 0.5, 1, 2, 3, and 5 L. The volume of the bag should exceed the patient’s inspiratory capacity, therefore a spontaneous deep breath should not empty the bag. The bag size should be about 6 times the patient’s tidal volume (Example: a 30 kg dog has a tidal volume of 300-600 ml, since the tidal volume is 10-20 ml/kg. For this patient a 2 or 3 L bag is appropriate).
The CO2 chemical adsorbent removes CO2 from the rebreathing system preventing inhalation of this gas by the patient. Before using the rebreathing system, the operator should always confirm that the adsorbent is functional. Some CO2 absorbents have indicators that change color when the absorbent is expended. Most of them, though, return to their original color after their use. The best way to determine if the CO2 absorbent is fresh is to crush a couple of granules between the fingers. If the granules crumble easily, the CO2 absorbent is fresh, if they are hard it is time to change the CO2 adsorbent. The lifespan of CO2 absorbents varies based on O2 flow rate used, size of the animal, and size and number of canisters (some anesthesia machines have a double canister), but in general it lasts about 6 to 8 hours.

The circle systems can be used as a closed system or semiclosed system. The only difference is that in the close system the O2 flow rate has to meet the O2 metabolic demand of the patient (4-10 ml/kg/min, depending on the patient’s body weight and body surface area, temperature, state of consciousness, and type of anesthetic). In the semiclosed circle, the most used in veterinary medicine, the O2 flow rate is set at 22-44 ml/kg/min. This means that we use a closed system for a 30 kg dog, the O2 flow rate should be 0.2-0.3 L/min. If we use a semiclosed system for the same patient we will turn up the O2 flow rate to 0.7-1.3 L/min.

Advantages of rebreathing systems include reduced cost related to inhaled anesthetics and decreased environmental pollution thanks since O2 and inhalants are rebreathed by the patient, decrease of loss of heat and moisture from the respiratory system, and large buffer for barotrauma if the APL valve is inadvertently left closed, thanks to the volume of the CO2 adsorbent canister, reservoir bag, and other components. The main disadvantages include greater resistance to breathing (especially due to the one-way valves and the CO2 adsorbent), maintenance of the CO2 adsorbent, longer time to change the concentration of inhalant delivered to the patient, bulkier design, and high number of connections (one-way valves, CO2 adsorbent canister, rebreathing tubes, etc.) where leaks might develop.

Non-rebreathing systems or Mapleson systems
As a general guideline, these systems are used in patients weighing less than 5-7 kg. They could be used for bigger patients, but the cost and the amount of waste gases will increase, since the O2 flow rate should be 100-200 ml/kg/min. This means that a 20 kg dog, on a non-rebreathing system, should receive 2-4 L/min of O2. These systems use no chemical adsorbent for CO2, but depend primarily on high fresh gas flow rates to flush exhaled CO2 from the system.

Mapleson systems comprise 6 configurations and some of them include modifications of their configuration. The classification of these 6 groups is based on the location of the patient’s connection, scavenging system, APL valve, and reservoir bag within the breathing system. A commonly used non-rebreathing system in veterinary medicine is the Bain system or Mapleson D and its coaxial modification. The inspiratory tube is generally smooth and smaller than the expiratory tube (which is corrugated) and it connects directly to the common gas outlet of the anesthesia machine. This allows for rapid changes in the concentration of inhalant anesthetics delivered to the patient.

Advantages of non-rebreathing systems include simple design and easy to use, can be easily cleaned and sterilized, lightweight and compactness, few moving parts and less chance of developing leaks, relatively inexpensive, do not require CO2 adsorbent, and changes in inhaled anesthetics can be rapidly achieved. The main disadvantages include high flow rate of fresh gas, which promotes patient’s heat and moisture losses, increases cost and environmental pollution, and higher risk of barotrauma if the APL valve is inadvertently left closed.
How to Test and Troubleshoot the Anesthesia Machine
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There are several tests that can be used to check the anesthesia machine and rebreathing systems for leaks, some of them tests different parts of the machine and others only test for 1 or 2 components. Below is a list of most commonly used leak tests.

1. Anesthesia machine tests
These tests can identify leaks in the anesthesia machine (flowmeter, vaporizer, machine tubing…) but do NOT test the breathing system components (breathing tubes, reservoir bag, unidirectional valves, canister…).

   a. Negative pressure test or universal test
You will need a squeeze bulb leak tester (Fig. 1). This can be bought or easily made using a sphygmomanometer bulb and reversing the air inlet valve in the bulb. When reversed, the valve will pull air from the anesthesia machine creating a negative pressure (see below step-by-step procedure).

   1. Make sure the O2 flowmeter is turned off. If the anesthesia machine has a minimum mandatory flow, close/disconnect the O2 source.
   2. Disconnect the fresh gas line and connector from the common gas outlet (you will not test the breathing system components with this test!)
   3. Connect the 15-mm connector to the common gas outlet of the anesthesia machine.
   4. Squeeze the bulb several times, until it stays collapsed.
   5. If the bulb stays collapsed for 10 seconds, there is no leak.
   6. If the bulb inflates, there is a leak.
   7. Repeat these steps with the vaporizer on.

   Figure 1. Squeeze bulb leak tester connected to the common gas outlet

   b. Positive pressure test
This test can only be used for machines that don’t have a minimum mandatory flow. The pressure used during this procedure CANNOT increase beyond the prescribed limits (see below step-by-step procedure), since there is only little room for compression in the machine tubing and high pressures can damage flowmeters and other components.

   1. Connect a pressure gauge manometer to the common gas outlet. You can use the manometer from a sphygmomanometer (Fig. 2).
   2. Slowly open the flowmeter until the manometer reads 30 cmH2O (22 mmHg).
   3. Turn flowmeter off.
   4. If the indicator of the manometer stays at 30 cmH2O, the machine passes the test.
   5. If the indicator moves back to a lower pressure, there is a leak.
   6. To quantify the leak slowly turn on the flowmeter until the indicator of the manometer stays still at 30 cmH2O.
   7. The flow of O2 that allows to maintain this pressure represents the leak.
   8. If this leak is 50 ml/min or less, the machine still passes the test.

   Figure 2. Pressure gauge manometer connected to the common gas outlet

   c. Fresh gas line occlusion
   1. Set O2 flow at 50 ml/min.
   2. Kink the fresh gas line.
   3. The flowmeter indicator should move downward (no leak)
   4. If the flowmeter indicator doesn’t move, the machine does not pass the test.

2. Combination of breathing and machine leak tests
   a. Retrograde fill test
   1. Close the APL valve and the patient port of the breathing system using your hand.
   2. Fill the reservoir bag using high O2 flow by opening the flowmeter or using the flush valve.
   3. Pressurize the system to 30 cmH2O (pressure gauge manometer).
• Turn the flowmeter of the is used it to fill the reservoir bag and pressurize the system.
• If the indicator of the manometer stays at 30 cmH2O, the machine passes the test.
• If the indicator moves back to a lower pressure, there is a leak.
• To quantify the leak slowly turn on the flowmeter until the indicator of the manometer stays still at 30 cmH2O.
• The flow of O2 that allows to maintain this pressure represents the leak.
• If this leak is 350 ml/min or less, the machine still passes the test.
• To test for leaks in the vaporizer, repeat these steps with the vaporizer on.
• To release the pressure open the APL valve and do not remove your hand from the patient port. Reasons:
  • You will also test that the APL is working
  • You won’t release inhalant in the room (remember you test the machine with the vaporizer on as well)
  • You will prevent a quick drop of pressure in the anesthesia machine (better if this occur gradually)
  • Dust from the CO2 absorbents will not go into the rebreathing corrugated tubes and, potentially, into the patient’s airway.

When a leak is suspected, the components of the machine and the breathing system should be checked, following the route of gas travel. A leak can be located by placing some alcohol and the hands and moving them over the components while the O2 is flowing. Alternatively, soapy water can be sprayed over the components while the O2 is flowing. Bubbles from the soapy water will reveal the leak (and you also cleaned the anesthesia machine!).

  b. Squeeze bulb test
  • Make sure the O2 flowmeter is turned off. If the anesthesia machine has a minimum mandatory flow, close/disconnect the O2 source.
  • Remove the reservoir bag and connect a suction bulb with a 22-mm connector to the reservoir bag mount.
  • Close the APL valve and the patient port of the breathing system using your hand.
  • Squeeze the bulb repeatedly until the pressure reaches 50 cmH2O.
  • If the pressure drops from 50 cmH2O to 30 cmH2O in 30 seconds or longer, the leak is acceptable.

3. Unidirectional valve tests
These tests only check for competency of the unidirectional valves (inspiratory and expiratory valves). The rebreathing tubes can be removed before performing these tests.

  a. Valve tester
You will need a bulb with a 22-mm female connector for this test.

    Inspiratory valve
    • Compress the bulb and connect it to the inspiratory port.
    • The bulb should immediately reinflate.
    • When you compress the bulb (still connected to the inspiratory port), you should meet firm resistance.
    • Expiratory valve
    • Connect the bulb (inflated) to the expiratory port
    • Squeeze the bulb.
    • The bulb should collapse easily and should remain deflated.

  b. Pressure decline method
You will need a second reservoir bag to preform this test.

  • Place one reservoir bag on the reservoir bag mount.
  • Place the second bag on the inspiratory port.
  • Close the APL valve.
  • Pressurize the system to 30 cmH2O using the O2 flush.
  • If the reservoir bag on the mount remains inflated, the expiratory valve is competent.
  • Now open the APL valve.
  • If the reservoir bag on the inspiratory port remains inflated, the inspiratory valve is competent.
Local Anesthetic Blocks for Dental Procedures
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General anesthesia or heavy sedation is required to perform these blocks. Needle size and volume of the local anesthetic injected varies from location and size of the animal. Generally 25- to 30-gauge, 12-25 mm long needles are used. Bupivacaine or lidocaine are usually selected and volumes injected are between 0.2 and 2.5 mL. Always calculate the maximum dose you can inject and do not exceed that limit. For bupivacaine stay under 1.5-2 mg/kg in dogs and cats, for lidocaine 6 mg/kg in dogs and 2-3 mg/kg in cats. Once the needle is placed close to the nerve that needs to be desensitized, always aspirate to make sure you are not injecting the local anesthetic in a vessel before performing the block.

Inferior alveolar nerve block
This block desensitizes the ipsilateral lower lip, mandibular teeth and associated soft tissues. It can be performed using 2 approaches:

1. **Intraoral;** the mandibular foramen is palpated just caudal to the last molar while the mouth is kept open (use mouth gag to protect the operator hand). The needle is directed ventrocaudally on the medial side of the mandible aiming towards the angle of the mandible. Stay as close as possible to the mandible to avoid the lingual nerve.

2. **Extraoral;** with the animal in lateral recumbency, the uppermost mandibular foramen is palpated intraorally (use mouth gag). The needle is placed close to the foramen by inserting it through the skin perpendicular to the ventral margin of the mandible and on its medial side. Stay as close as possible to the mandible to avoid the lingual nerve.

Maxillary nerve block
This block desensitizes the ipsilateral upper lip, skin of the nose, mucosa of soft and hard palate, maxilla including the teeth and associated soft tissues. This block can be performed using 3 approaches:

1. **Intraoral;** the animal’s mouth is kept open (use mouth gag) and the needle is inserted caudal to the last molar perpendicular to the hard palate.

2. **Subzygomatic;** the needle is inserted through the skin perpendicular to the median plane of the head. The point of insertion is ventral to the zygomatic arch and between the caudal aspect of the maxilla and the coronoid process of the mandible.

3. **Infraorbital;** after identification of the infraorbital foramen via palpation (dorsal to the 3rd maxillary premolar, rostroventral to the eye) a thin needle is inserted in the infraorbital canal to reach the caudal position and exit the maxillary foramen where the local anesthetic is deposited. Higher risk of damaging neurovascular structures in the canal.

Infraorbital nerve block
The identification of the infraorbital canal can be done via palpation (see “Maxillary Nerve Block, infraorbital approach” for location). The needle is inserted through the skin (transcutaneous approach) or the mucosa (transmucosal approach) with the syringe parallel to the median plane of the head. The area desensitized by the block depends on placement of the needle and the volume used. If the local anesthetic is placed outside of the canal, only the ipsilateral skin of the nose and the upper lip are desensitized. If the drug is placed in the canal (by inserting the needle in the canal and/or by increasing the volume and gentle pressure with the finger on the injection site) some premolar, canine, incisor teeth and associated soft tissues will be desensitized as well.

Mental nerve block
This block is performed with the animal in lateral recumbency with the side to be blocked facing up. The middle mental foramen can be identified by palpating the root of the second premolar in dogs and the area between the canine and third premolar in cats. A transcutaneous or transmucosal approach can be used. The needle is placed between the finger palpating the foramen and the lateral aspect of the mandible and the local anesthetic is injected. This block only desensitizes the rostral lower lip. If the needle is placed inside the mental canal, the rostral inferior alveolar nerve can be blocked desensitizing also premolar, canine, and incisor teeth.

Palatine nerve block
This block is performed when only the mucosa of the soft and hard palate need to be desensitized. If other structures have to be blocked, such as maxilla and upper teeth, a maxillary block should be performed. The animal is positioned in dorsal recumbency with the mouth open (use a mouth gag). The needle in inserted midway between the palatine midline and the dental arcade at the level of the last premolar. A small volume is injected when preforming this block to avoid ischemic injury and pain after the effects of the local anesthetic wears off. Usually only 0.1 mL of local anesthetic is injected in small patients and 0.2-0.4 mL in larger animals.
Microanatomy of peripheral nerves
The nervous system is classified in central and peripheral nervous system. For the purpose of these proceedings on local anesthetic drugs and techniques only the anatomy of peripheral nerves will be discussed.

Peripheral nerves are made of several components. The outermost structure of the nerve is the epineurium, made of dense and irregular connective tissue. The epineurium holds together the vessels that supply the peripheral nerve and multiple fascicles, small bundles of nerve fibers. Each fascicle is surrounded by the perineurium, a protective structure composed of connective tissue with laminar arrangement. Each nerve fiber contained in the perineurium is surrounded by a protective sheath of connective tissue called endoneurium. When peripheral nerves are temporarily blocked with local anesthetics, the drug is injected in the vicinity of the nerve. This technique is known as regional or nerve block anesthesia.

Most of the peripheral nerves are composed by different types of nerve fibers. These nerve fibers are classified based on presence of myelin, diameter, and conduction velocity.

The A fibers are large, myelinated, and have high conduction velocity. They modulate muscle and reflex activity (α) muscle tone (γ) and transmit information about pressure and touch (β). The Aδ fibers are responsible for transmission of touch, pressure, and fast, sharp, well-localized pain. The group B is composed by small, myelinated fibers, which are responsible for modulating the autonomic functions. The C fibers are small and non-myelinated and transmit slow, dull, and non-well localized nociceptive information (pain). As general rule, when local anesthetics are used for regional anesthesia, fibers with smaller diameters are affected first. Most local anesthetics will cause sensory blockade before peripheral motor blockade. This difference may not be noticed if lager volumes or high concentrations of local anesthetics are used.

Pharmacology
Local anesthetics are divided into amino-esters and amino-amides, based on their chemical structure. Examples of amino-esters are cocaine, benzocaine, procaine, chloroprocaine, and tetracaine. Examples of amino-amides are lidocaine, prilocaine, etidocaine, mepivacaine, bupivacaine, levobupivacaine, ropivacaine, and articaine. Amino-esters are hydrolyzed by cholinesterase in the plasma and liver (cocaine is an exception, because it undergoes significant liver metabolism), while amino-amides are metabolized in the liver by microsomal enzymes.

Local anesthetics are weak bases, with pKa (dissociation constant or negative logarithm of the dissociation constant) between 8 and 9. When the pH of the environment equals the pKa, the drug is 50% dissociated (or ionized, or charged) and 50% non-dissociated (or unionized, or neutral). Unionized drugs are more lipid soluble and will cross the cell membrane. If the pH of the environment increases (becomes more alkaline), weak bases like local anesthetics dissociate less and will present more unionized drug, which is more lipid soluble and will pass through the cell membrane.

Once the unionized form is in the cytosol, it has to be ionized again to be able to block the Na+ channels. These channels have to be in the activated-open conformation to allow binding with local anesthetics. Once this happens, the local anesthetic will change the channel conformation into inactivated-close, which will prevent the Na+ from entering the cell and, consequently, will block the action potential of the nerve fiber (and transmission of the signal). This phenomenon is known as frequency-dependent block, meaning that repetitive stimulation of nerve fibers increases the binding affinity of the receptor site for local anesthetics and facilitates the development of neural blockade.

The chemical structure of local anesthetics determines the properties of the drug. Lipid solubility, as mentioned above, influences penetration through the nerve membrane, but it also promotes sequestration of local anesthetics in lipid soluble compartments, such as myelin. Compounds that are more lipid soluble have a longer onset and duration of action compared to less lipid soluble drugs. Lipid solubility is directly correlated with the potency of local anesthetics. The pKa also influences the onset of the local anesthetic, since it will determine how much of the compound will be unionized (and more lipid soluble) in a given pH. Drugs with higher lipid solubility also show higher degree of protein binding. The “free” (unbound) drug is the active form, which can block Na+ channels. Local anesthetics with high degree of protein binding are metabolized slower and have longer duration of action.

Mixing two local anesthetics has become common practice. The main theoretical advantage is to decrease the onset and increase the duration of action by mixing a local anesthetic with short onset and another with long duration. Unfortunately, this is not the case. When two drugs are mixed together, the pKa of the mixture in unknown and the onset and duration are unpredictable. In addition, a 50:50 mixture will have half strength concentration of each drug. This may influence the property of both local anesthetics, by decreasing the onset and shortening the duration of action (1,2). Due to the lack evidence showing the advantage of mixing different
local anesthetics, it is recommended to choose only one drug per block based on pharmacokinetics and pharmacodynamics of the local anesthetic and the type of block and procedure performed.

**Adjuvants**

Adjuvants are often added to local anesthetics, to increase the duration and the analgesia of the block. The most commonly used are: epinephrine, sodium bicarbonate, opioids (especially buprenorphine), and alpha2-agonists (dexmedetomidine).

Epinephrine causes vasoconstriction when used for regional anesthesia, which decreases bleeding in the surgical field, decreases systemic absorption of the local anesthetic, and increases the duration of action. The usual concentration of epinephrine is 5 μg/ml or 1:200,000. Market preparations of local anesthetics containing epinephrine have a lower pH than plain solutions or solutions freshly prepared. The pH of 2% lidocaine and 0.5% bupivacaine are 6.78 and 6.04, respectively. When epinephrine is freshly added to these drugs, the pH becomes 6.33 and 5.99, respectively. In market preparations of 2% lidocaine with epinephrine and 0.5% bupivacaine with epinephrine, the pH is 4.55 and 3.73, respectively. Decreasing the pH of the solution will increase the percent of the ionized form of the drug and, consequently, slowing the onset of action. When epinephrine is used in regional block anesthesia, it is important to avoid injection of the solution in terminal arterioles, which can cause necrosis of the supplied area, and intraneural injection, which can cause ischemic nerve injury.

Sodium bicarbonate is added to local anesthetic to increase the pH of commercial solutions. Although local anesthetics are weak bases, the pH of their commercial solutions ranges between 3.9 and 6.7. Alkalinizing the solution increases the unionized fraction of the drug, which shortens the onset and increases the duration of action. Unfortunately, local anesthetics cannot be alkalinized to pH values greater than 6-8, because this cause precipitation of the resulting solution. Increasing the pH to these values only increased the unionized fraction by 10%. Modifying the pH of the solution has also the advantage of decreasing discomfort on injection.

Opioids have been mixed with local anesthetic to increase the duration and enhance the quality of the regional block. Buprenorphine is commonly used, due to its long duration on peripheral μ receptors and its local anesthetic-like mechanism of action involving Na+ channel block (3). There are few studies in people that showed that buprenorphine enhances analgesia following sciatic nerve block (4) and, when combined with bupivacaine for minor oral surgery, provides a 3-fold increase in the duration of postoperative analgesia when compared to bupivacaine alone (5) This has not yet been documented in veterinary medicine.

Alpha2-agonists, and more specifically dexmedetomidine, can be mixed with local anesthetics to enhance duration and sensory analgesia. It has been shown that in rats dexmedetomidine prolongs the duration of sciatic nerve block when combined with either ropivacaine or bupivacaine (6-9). In people when dexmedetomidine is added to either levobupivacaine or ropivacaine, it shortens the onset and increases the duration of axillary brachial plexus block (10-12) and prolongs postoperative analgesia after cleft palate repair when mixed with bupivacaine for palatine nerve blocks (13).

**Toxicity**

Signs of systemic toxicity caused by local anesthetics can be seen if high plasma levels are achieved. This can happen if toxic doses are administered to the patient and/or if a local anesthetic, such as bupivacaine, is accidentally injected intravenously. In general neurological signs manifest first. Unbalanced excitation (i.e. nystagmus, muscular twitching, and seizures) can be seen due to the depression of cortical inhibitory pathways, followed by generalized depression of the central nervous system (CNS) resulting in coma and respiratory arrest. The first CNS signs may be difficult to identify when the patient is under general anesthesia. If the awake patient shows neurological signs, oxygen administration, intubation and assisted or controlled ventilation, and treatment for seizures (benzodiazepines, propofol, levetiracetam) should be initiated. Cardiovascular (CV) toxicity is usually seen after seizures, with the exception of bupivacaine, the most cardiotoxic local anesthetic. CV signs are characterized by depression of contractility and conduction velocity through the heart. An overdose of lidocaine usually results in hypotension and bradycardia, whereas bupivacaine and ropivacaine can induce sudden CV collapse or ventricular dysrhythmias that are refractory to treatment. Depending on the CV signs, intravenous fluids, vasopressors, inotropes, anticholinergics, CPR (cardiac massage, bretylium, magnesium, defibrillation) should be considered. Administration of 20% lipid emulsion (4 ml/kg bolus, followed by 0.5 ml/kg/min for 10 minutes) is also recommended.

**References**


Case 2

Signalment:
Buster, 6-year-old, miniature Schnauzer, intact male, body weight 8 kg

History
Buster becomes tired soon after he starts exercising

Physical exam
- T: 100.1° F  P: 210 bpm (irregular) RR: 20 bpm
- Buster is BAR and overall calm
- Auscultation
- Lung field is normal
- Cardiac auscultation -> irregular rhythm
- Blood-work within normal limits

Presenting complaint and plan
Buster needs a dental prophylaxis and extraction of a fractured 104 (canine)

1) Before anesthetizing Buster, you decide to perform an ECG. What do you think (ECG provided during presentation)?

2) Do you proceed with anesthesia or do you reschedule the procedure?

Anesthetic protocol:
Pre-medications
Morphine 0.5 mg/kg IM
Acepromazine 0.02 mg/kg IM

Induction
Propofol 4-6 mg/kg IV to effect

Maintenance
Sevoflurane in 100% O2 (adult rebreathing system)

3) What else could you do to prevent and manage nociception and pain caused by this procedure?
4) During the procedure the heart rate increases up to 200 beats per minute (it was 140 beats per minutes before the procedure). Look at the ECG (PowerPoint). What do you think?

5) Would you treat this arrhythmia? If so, how?

6) What about Buster’s capnograph? What is your diagnosis?

7) What is the technology used by capnography and how many types of capnographs can you name and what are their advantages and disadvantages?