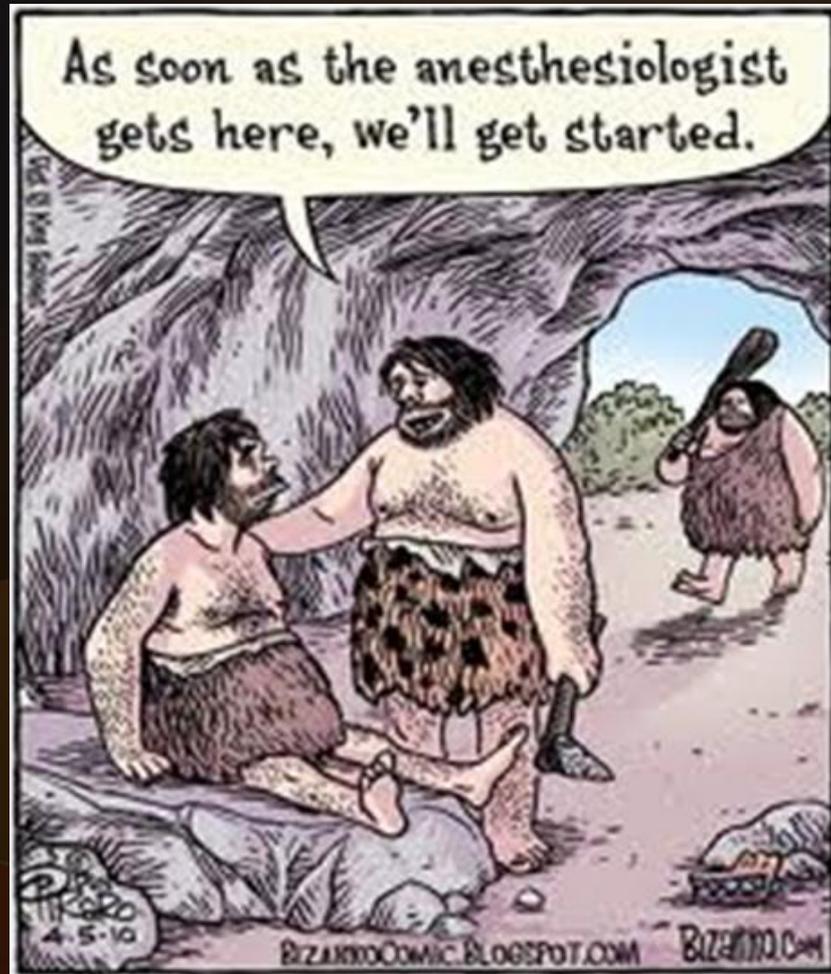# Inhalant Anesthesia

**Horatiu V. Vinerean DVM, DACLAM
Director, Laboratory Animal Research
Attending Veterinarian**

FIU | FLORIDA INTERNATIONAL UNIVERSITY

Inhalation Anesthesia

- This is the technique of administering anesthetic agents to the animals via the lungs.

- This consists of a volatile agent being vaporized by oxygen in a vaporizer and then being administered to the patient through an anesthetic breathing circuit.

Vaporization of volatile anesthetics

- A vapor is a gas below its critical temperature. Both liquid and gaseous phases exist simultaneously and in a closed container a state of equilibrium is attained when the number of molecules leaving the liquid phase equals the number of molecules re-entering it.

- In this situation, the vapor is said to be saturated and the partial pressure that the vapor exerts is the saturated vapor pressure (s.v.p.) that depends only upon the nature of the liquid and the temperature.

Anesthetic Uptake

- The depth of anesthesia is related to the partial pressure of anesthetic agents in the brain. This is in turn related to the partial pressure in the blood and this, in turn, is related to the partial pressure of the agent in the alveoli of the lungs.

- The mechanism for a gas to dissolve in the patients blood and other tissues relies on pressure and pressure gradients between the tissues or phases.

- For an anesthetic action to occur the anesthetic agent must be capable of crossing the blood brain barrier to the central nervous system (lipid soluble).

Physics laws of anesthetic uptake

- <u>Dalton's Law of Partial Pressure</u>: The constituent gases in gas mixtures act independently of each other and exert the pressure that each would have exerted in isolation in the given volume. Thus the pressure exerted by a mixture of gases is the sum of the individual pressures exerted by each gas. The component of total pressure that each gas exerts is termed its partial pressure.

- <u>Graham's Law</u>: The rate of diffusion of gases through certain membranes is inversely proportional to the square root of their molecular weight.

Physics laws of anesthetic uptake

- Fick's Law of Diffusion: The rate of diffusion is proportional to the concentration gradient.

- Partition Coefficient: The ratio of the amount of the solute present in equal volumes of the two phases, at a stated temperature and when the two phases are in equilibrium. It is independent of pressure. This partition, or distribution coefficient can be used to describe the uptake and distribution of anesthetic gases.

Physics laws of anesthetic uptake

- The greater the pressure gradient between the alveoli and the brain, the faster induction will occur. Since the blood flow in the body tissues varies there is a certain order in which the body tissues are saturated with anesthetic agent.

- During induction of anesthesia, the anesthetic agent molecules will move along a pressure gradient as follows:
  - » Inspired Gas > Alveoli > Tissues with high blood flow and / lipid (brain, heart, kidney, etc.) > Skeletal muscle > Fat

- The brain and other blood flow rich tissues will reach equilibrium with the alveoli fairly quickly, while equilibration in muscle and fat will take longer.

Physics laws of anesthetic uptake

There are other factors which will influence the rate at which the anesthetic partial pressure in the brain reaches the pressure in the alveoli:

- Ventilation: As ventilation increases, the amount of gas reaching the alveoli increases and therefore the amount of gas taken up and carried up to the brain increases.

- Cardiac Output: the effect of cardiac output on anesthetic uptake is perplexing. If there is more blood passing through the lungs to pick up the anesthetic agent it would seem logical to assume that a patient with a high cardiac output would be induced quickly but this is not true.

Physics laws of anesthetic uptake

- High cardiac output removes the anesthetic agent so quickly from the alveoli that the partial pressure in the alveoli does not have time to increase and neither does that in the blood. This is one reason why it is difficult to induce an excited patient with an inhalation agent (and why premedication and/or intravenous induction agents are used in healthy or excited patients). In ill or shocked patients, anesthetic uptake is faster, because of the reduced cardiac output in these patients. Induction of anesthesia will be faster than expected and the patient may `go too deep' sooner. (In sick patients the vaporizer should not be turned too high).

Physics laws of anesthetic uptake

- <u>Solubility</u>: If the anesthetic agent is highly fat soluble then the fat in the body will take up much of the anesthetic agent and slow down the rate of equilibration of the brain partial pressure with that of the alveoli.

    - This has the effect of slowing down the speed of induction and is why it takes longer to induce a patient with ether (highly fat soluble) compared to isoflurane (less fat soluble).

    - The fat solubility of the anesthetic agent also affects the recovery rate. The adipose tissue can `hold´ more of a highly fat soluble agent and its longer, gradual release from the tissues down a concentration gradient via blood to the lungs can slow recovery

Physics laws of anesthetic uptake

- <u>Delivered Concentration</u>: when inducing an animal with an inhalation agent, the vaporizer is set at a level much higher than that is required for maintenance. This helps to increase the pressure gradient and the `driving force' and get a more rapid uptake. Induction occurs more quickly.

- <u>Recovery</u>: the tension gradients are the reverse of those of induction. Recovery cannot be accelerated because inspired tensions cannot be decreased below zero.

Physics laws of anesthetic uptake

- Second Gas Effect: this effect occurs when a relatively insoluble gas is present in high concentrations with a gas of greater solubility e.g. N_2O and halothane in oxygen. The relatively insoluble gas (because the partial pressure is greater) crosses into the bloodstream quickly.

Inhalation Anesthetics

Ideal Characteristics of Inhalant Anesthetics

- Stable, nonflammable, non-explosive, high potency, low solubility in blood, nonirritating, not metabolized, cardiovascular and respiratory systems unaffected, compatible with other drugs, easily delivered and affordable.

Advantages of Inhalant Anesthetics

- Concentrations can be continuously measured

- Most potent: Methoxyflurane

- Least potent: Nitrous oxide

Inhalation Anesthetics

Minimum Alveolar Concentration (MAC)

- The MAC value is a measure of anesthetic potency and it is inversely proportional to MAC value: an inhalant having a low MAC value is more potent than an inhalant having a high MAC value.

- The value given is the concentration of the inhalant anesthetic that will prevent gross movement in response to painful stimulus in 50% of patients (MAC_{50}). To increase this to 95%, just multiply the MAC by 1.5 (MAC_{95}), this will provide a surgical plane of anesthesia.

- MAC values do not take into consideration any pre-medications that may have been given and they will lower the MAC.

Inhalation Anesthetics

Minimum Alveolar Concentration (MAC) Values

Inhalant Anesthetic	MAC
Halothane	0.8 – 0.9% both dogs and cats
Isoflurane	1.28% in dogs; 1.63% in cats
Sevoflurane	2.4% in dogs; 2.6% in cats
Desflurane	7.2% in dogs
Enflurane	2.1% in dogs

Inhalation Anesthetics

Factors that influence MAC

- Circadian rhythm in rats (high activity requires higher MAC).

- Body temperature - decreased body temperature leads to decreased anesthetic requirement.

- Age - old animals have lower MAC values versus neonates that have the highest MAC requirements.

- Hypercarbia above 95 mmHg is depressant and therefore will lower the MAC.

Inhalation Anesthetics

Inhalation Anesthetics

- Nitrous Oxide (NO_2)
- Ether
- Methoxyflurane
- Halothane
- **Isoflurane**
- Enflurane
- Sevoflurane
- Desflurane

Inhalation Anesthetics: Nitrous Oxide

- Weak anesthetic, mainly used in humans.

- Cardiovascular and respiratory depression is minimal.

- Low blood/gas solubility- rapid uptake/elimination

- Use 2nd gas effect to increase uptake of other inhalants (animals > 2kg)

Inhalation Anesthetics: Nitrous Oxide

- Supplied as a combination of liquid and gas in cylinders the same size as used for oxygen (the room temperature is below the critical temperature for nitrous oxide). The pressure within nitrous oxide cylinders is 750 psi (the saturated vapor pressure), and the pressure gauge will indicate this pressure while there is still liquid in the cylinder to vaporize. Once the liquid has been used the pressure gauge will indicate a falling pressure to `empty' over the following 5-10 minutes depending on the flow.

Inhalation Anesthetics: Ether

- Explosive Not recommended because explosive at concentrations used to produce anesthesia and highly irritating to respiratory system

Inhalation Anesthetics - Methoxyflurane

- Low volatility, high blood solubility- safe for use in non-precision systems, fruity smell.
- Very potent ED_{50} less than 0.25%
- Extensively metabolized
- <u>Renal toxicity in people</u>
- Causes nephrotoxicity in F344 rats and induces Diabetes Insipidus (from fluoride ion-induced renal damage).
- Respiratory depression: significant
- Cardiovascular effects: mild (less myocardial sensitization than halothane)
- Not available in the US.

Inhalation Anesthetics: Halothane

- Good potency, low blood/gas solubility high volatility, produces anesthesia rapidly.

- Dose dependent respiratory depression.

- Myocardial muscle depression and relaxation of vascular smooth muscle.

- Sensitizes heart to catecholamines.

- Malignant hyperthermia.

Inhalation Anesthetics: Isoflurane

- Isoflurane is a stable compound which does not break down on contact with soda-lime or presence of light.

- Relatively insoluble leading to fast inductions and recoveries. It is non-flammable and has a saturated vapor pressure similar to halothane.

- It does have a fairly pungent odor and so should be introduced to the patient slowly for a mask induction.

- Isoflurane is more of a respiratory depressant than halothane, resulting in hypoventilation and hypercapnia.

Inhalation Anesthetics: Enflurane

- Discontinued in veterinary medicine due to sevoflurane and desflurane.

- Chemical isomer of Methoxyflurane.

- Cardiovascular and respiratory depression similar to Isoflurane.

- Seizure like muscle contractions with deep surgical level.

Inhalation Anesthetics: Sevoflurane

- Low solubility in blood- rapid equilibration and precise and rapid changes in depth.

- Very rapid induction and recovery and mild odor are associated with less struggling during mask induction.

- Cardiovascular and respiratory effects-similar to Isoflurane, not significantly metabolized.

- Decomposes in soda lime producing a toxic compound (olefin – compound A).

Inhalation Anesthetics: Desflurane

- High molecular stability, low toxicity
- Lowest blood/gas coefficient of all inhalant anesthetics (0.42) - fastest induction onset.
- Low boiling temperature - requires a special heated vaporizer.

Anesthetic Machines

- Can be divided into components:
    - The high pressure system
        - » Oxygen source
        - » Pressure Gauges
        - » Pressure regulators
    - The low pressure system
        - » Flowmeters
        - » Flush Valves
        - » Vaporizers

Anesthetic Machines – High Pressure

Oxygen source:

- Vital for the life of the patient and used to vaporize the volatile anesthetic agent.

- Stored in cylinders (E size, 700 liters) on the anesthetic machine itself or it can be delivered through a pipeline system from a bank of larger tanks (H size 7,000 liters).

- The pressure in oxygen cylinders is 2,200 psi. Since the oxygen is a compressed gas when the cylinder is half empty the pressure will read 1,100 psi

Anesthetic Machines – High Pressure

Pressure Gauges:

- There is one gauge, which shows the cylinder pressure, and a second gauge to show the line pressure.

- A pressure gauge is often added to the breathing circuit to show how much pressure is in the circuit, and how much pressure is applied to the patient's airway when positive pressure ventilation is performed.

Anesthetic Machines – High Pressure

Pressure Regulators (Pressure Reducing Valves)

- Used to bring the line pressure to between 40 and 50 psi.

- The reducing valves also serve to keep the pressure in the line constant since the pressure within a cylinder of oxygen will vary depending on how full the cylinder is.

Anesthetic Machines – Low Pressure

Flowmeters:

- Necessary to measure how much gas is being supplied to the breathing circuit and to the patient. There are various designs of flowmeters with different type of indicators to indicate the flow.

- Flowmeters with aluminum balls should be read from the middle of the ball whereas bobbin type indicators should be read from the top of the bobbin.

- Each flowmeter is calibrated for the particular gas it is to measure because the flow and calibration depends on the viscosity and density of the gas. Do not try to pass another gas through a flow meter designed for different gas (O_2 versus CO_2).

- Flow is measured in liters/minute.

Anesthetic Machines – Low Pressure

Flush Valves

- Oxygen flush valve delivers oxygen from the reducing valve to the breathing circuit without going through the vaporizer.

- This allows the circuit to be flushed with 100% O_2.

- An oxygen flush will deliver the gas to the patient's airway at 40-50 psi with a flow of 30 L/min, and could seriously damage the lungs.

Anesthetic Machines – Low Pressure

Vaporizers

- The fresh gas vaporizes the volatile agent used to anesthetize the patient. Specially designed vaporizers fitted to the anesthetic machine do this.

- There are two positions in which the vaporizer can be placed: either vaporizer IN Circuit (VIC) or vaporizer OUT of Circuit (VOC).

- Vaporizers are constructed of a highly conductive metal so that heat from the surrounding is transferred to the volatile agent in order to supply the latent heat of vaporization.

Anesthetic Machines – Low Pressure

Vaporizers

- Once the gas enters the chamber, it usually flows over a wick, which dips into the volatile agent, to enable the gas to be fully saturated.

- A wick keeps the surface area of the volatile agent constant and so it does not matter what level of volatile agent is present in the chamber. So long as it is not empty or overfull, the vaporizer will give the concentration indicated on the dial.

Anesthetic Machines – Low Pressure

Vaporizers

- Care should be taken not to tip the anesthetic machine over an angle of 45° or to shake it vigorously during transport. Anesthetic liquid may enter the bypass channel of variable bypass vaporizers, and potentially lethal concentrations can be delivered to the next patient.

- If the anesthetic machine has been knocked over run oxygen through the vaporizer with the control dial off for about 15 minutes (outside!) to vaporize any agent in the bypass. If the anesthetic machine is to be transported it is best to empty the vaporizer completely.

Rodent Anesthesia

- Isoflurane is the method of choice for rodent anesthesia. It is safe and very easy to use. Induction and awakening are rapid. Gas waste must be scavenged properly.

- Anesthesia Induction:

  - Place the animal in the induction chamber.

  - Adjust the flowmeter to 0.8–1.5 L/min.

  - Adjust the isoflurane vaporizer to 2%–3%.

Rodent Anesthesia

- Anesthesia maintenance:
  - Use the nosecone connected to the non-rebreathing circuit and adjust the flowmeter to 400–800 mL/min.
  - Adjust the isoflurane vaporizer to ~ 1.8%.
  - Prevent heat loss until the animal recovers.

Rodent Anesthesia - Non-rebreathing Circuit

- Fresh gases from the anesthetic machine pass into an inspiratory tube and the patient breathes from that tube. Exhaled gases pass into an expiratory tube.

- In this circuit, the pause the patient takes before inhalation is the crucial moment. During this time the fresh gas entering the circuit does not enter the patient, but enters the expiratory limb and flushes the exhaled gases further down this limb until they leave the system. When the patient takes the next breath, fresh gas is inhaled directly from the inspiratory limb and (now fresh gas in composition) from the expiratory limb.

Rodent Anesthesia - Non-rebreathing Circuit

- Thus the important point is the Total Fresh Gas Flow to the circuit from the anesthetic machine to drive the exhaled gases down the expiratory limb and `away' from the patient's next breath and also the active scavenging system used to drive the flow

- The big disadvantage is the high fresh gas flow, which can be expensive.

Rodent Anesthesia - Non-rebreathing Circuit

- The advantage is that they have little resistance and are therefore better suited for small patients, which cannot cope with high resistance circuits while under anesthesia. They can also have very little mechanical (apparatus) dead-space.

- Oxygen flush devices should not be used or barotraumas will result.