Anesthetic Equipment
(เครื่องให้ยาดมสลบ)

Anesthetic Machines

An anesthetic machine is used to deliver an anesthetic gas mixture to the patient via an appropriate breathing circuit. The basic anesthetic machine used in veterinary practice can be divided into components serving a special function:

The High Pressure System

1) The Fresh Gas Source

Oxygen is used for two reasons: Firstly, it is vital for the life of the patient and secondly it is used to vaporize the volatile anesthetic agent and deliver it to the patient. Oxygen can be stored in cylinders (E size, 700 litres) on the anesthetic machine itself or it can be delivered through a pipeline system from a bank of larger H size tanks (7,000 litres) somewhere else in the building.

Hospitals with a larger demand for oxygen will have it delivered and stored as a liquid. The pressure in oxygen cylinders is 2,200 psi. (There is a move now towards measuring pressures in SI units: kPa [1 kPa = 7.5 mmHg]). Since the oxygen is a compressed gas when the cylinder is half empty the pressure will read 1,100 psi.

Nitrous Oxide is often used in anesthesia and is 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 vapour 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. The E-cylinder can contain 1,600 L, and an H-tank contains 16,000 L. It is more expensive than oxygen. Cyclopropane and Carbon Dioxide cylinders may be found on old human hospital machines. These gases are of very little use in veterinary practice. Cylinders are fitted with a number of safety features because of the dangerously high pressures they hold, and to avoid the wrong cylinder being fitted to the yoke of the anesthetic machine.
a) Service Pressure. This is the limit to which the tanks can be filled. Markings are stamped on the top of the cylinder indicating the service pressure, type of steel, serial number, manufacture and testing dates.

b) Colour of Cylinder. Should follow international standards, but not all countries comply. e.g.:

- Oxygen: Canada: green and white, or green, or white
- U.S.A.: green
- U.K.: black and white. (This is the International System).

- Nitrous Oxide: blue
- Cyclopropane: orange
- Carbon Dioxide: grey.

c) Label on cylinder. Warns of principle hazards. There is a danger of fire with oxygen and the risk of explosions if oxygen comes into contact with grease. Only silicon or Teflon lubricants can be used on anesthetic machines. NEVER use grease. (Nitrous oxide also can support combustion but does not spontaneously ignite).

d) Tag Label indicates whether the cylinder is full, part full or empty.

e) The valve unit of the cylinder has a safety release valve to let the gases escape under control if the ambient temperature rises too high as in a fire. If the oxygen cylinder were to crack at full pressure it has enough force to drive it through a concrete wall.

f) Brass valve which controls flow of gas under normal conditions. Know which part of the cylinder should be opened with a wrench.

g) Pin Index Safety System is used in small E-cylinders. The receiving yoke of the anesthetic machine should have the same configuration of pins as the cylinder has holes so that the correct cylinder is attached to the correct yoke. Large cylinders have different thread patterns to prevent improper connections. Cylinders should be properly secured at all times and the valve should never be opened unless the cylinder is secured within the yoke of the anesthetic machine.

2) Pressure Gauges

There are several types of pressure gauge found on gas cylinders and on anesthetic machines. With a two-stage pressure reducing valve (see below) there is one gauge which shows the cylinder pressure and a second gauge to show the line pressure. With the one-stage valve the anesthetic machine has a gauge to show the pressure within the cylinder. There is no need for a gauge to show the line pressure since this is fixed.
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).

3) Pressure Regulators (Pressure Reducing Valves)

The high pressure of the cylinders must be brought down to a lower pressure for the flow meters and vaporizer. The high pressure system must have strong metal gas piping, but this is not necessary once the pressure has been lowered. Large tanks have two-stage reducing valves to bring the pressure down to required level, usually around 40 psi for an anesthetic machine. The cylinders on the anesthetic machine are fitted with one stage reducing valves to bring the line pressure to between 40 and 50 psi. On pipeline supplies the reducing valves are placed by the bank of cylinders so that the pressure delivered by the wall outlet is already at a pressure of 50 psi. At the WCVM the line pressure is set at 60 psi so that the large animal ventilator can be driven.

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 it is.

**The Low Pressure System**

1) Flowmeters (Rotameters)

The fresh gas passes from the cylinder via the high pressure tubing to the reducing valve. From here, the low pressure tubing carries the gas to the specific flowmeter for that gas. The flowmeter is 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. Flow is measured in liters/minute. Flowmeter knobs are colour coded for the gas they measure: green for oxygen (white in the U.K.), and blue for nitrous oxide.

2) Flush Valves

Most anesthetic machines are fitted with an oxygen flush valve which delivers oxygen from the reducing valve to the breathing circuit without going through the vaporizer. This allows the circuit to be flushed with 100% oxygen. It should only be used with a circle system. Make sure that any Bain circuits (see
(later) are correctly attached as an oxygen flush will deliver the gas to the patient's airway at 40-60 psi with a flow of 30 L/min, and could seriously damage the lungs.

3) Nitrous Oxide Cut-off Valve.

If oxygen runs out while the nitrous oxide is still flowing the patient will eventually become extremely cyanotic without any warning signs of an empty rebreathing bag or even dyspnea. For this reason there should be a safety device which will cut off the flow of nitrous oxide if oxygen is depleted or becomes disconnected. Some anesthetic machines have a whistle which will sound if oxygen does not flow.

4) Vaporizers

The fresh gas has to vaporize the volatile agent used to anesthetize the patient. Specially designed vaporizers fitted to the anesthetic machine do this. There are many different designs depending on which type of agent is to be vaporized, and where in the circuit the vaporizer is positioned. There are two positions in which the vaporizer can be placed: either vaporizer IN Circuit (VIC) or vaporizer OUT of Circuit (VOC). Note that the `C' stands for (breathing) CIRCUIT not circle. Either the vaporizer is placed in the patient's breathing circuit ([VIC], usually a circle rebreathing circuit, hence the confusion) or before the point at which the breathing circuit is attached ([VOC], any circuit can be used with these). Vaporizers All of the commonly used, potent general anesthetics are volatile liquids at room temperature and atmospheric pressure. These agents must be transformed into the vapour phase for clinical use. The molecules in a liquid anesthetic must overcome forces keeping them in the liquid phase and energy must be supplied to the molecules for vaporization to occur. As a result, the temperature of the liquid falls and in a closed container the vaporization will cease when an equilibrium is reached between the liquid and vapour phases. The molecules colliding with the walls of the container create a pressure: The Saturated Vapour pressure. Each agent varies in how readily it evaporates. Listed below are the saturated vapour pressures (mmHg) at 20°C and 760 mmHg for the three commonly used volatile anesthetic agents.

- Halothane 243 mmHg 32%
- Isoflurane 239 mmHg 31%
- Methoxyflurane 23 mmHg 3%

This means that at room temperature halothane will vaporize to about 32% (243/760) and is a fairly volatile agent whereas methoxyflurane vaporizes to a maximum of only 3%. The MAC value (a measure of potency: see 'Inhalation Anesthesia') of halothane is about 0.8% and so it can be seen that 32% halothane will be lethal
in a short period of time. Therefore the fairly volatile, potent anesthetic agents should be administered using a vaporizer which can accurately control the amount of agent vaporized. Simple plenum vaporizers These are simple containers such as glass jars, which allow a certain amount of fresh gas (oxygen +/- nitrous oxide) through the space above the liquid anesthetic agent. They do not compensate for the drop in temperature seen during vaporization nor do they compensate for the surface area of anesthetic agent presented to the fresh gas, both of which affect the final output concentration. These vaporizers often do not have the capability of compensating for ambient temperatures. They have low resistance to gas flow and can be found within breathing circuits in the VIC position e.g. Ohio anesthetic machine and Stephen's anesthetic machine. The gradations on the vaporizer do not indicate the actual vapour concentration unlike the more elaborate (and expensive) precision vaporizers.

**Precision vaporizers**

These vaporizers have adaptations to allow them to compensate for ambient temperatures and the drop in temperature seen during vaporization. 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. Temperature compensation occurs with thermostats composed of bimetal strips which regulate the amount of gas diverted into the vaporizing chamber where the volatile agent is situated. There are two ways in which the oxygen flow is diverted into the chamber, either by the measured flow technique (Copper Kettle vaporizer, not often seen in veterinary medicine) or the variable bypass (Fluotec, Pentec, Fortec. Manufactured by Cyprane). With the measured flow there are separate flowmeters one of which sends all of its flow into the vaporizer. This becomes fully saturated with the volatile agent. This gas flow then joins the fresh gas flow (FGF) from other flowmeters not containing any volatile agent. Depending on the FGF into the vaporizer and the FGF of the other flowmeters the final concentration can be calculated. With the variable bypass vaporizers a certain amount of FGF is diverted into the chamber depending on temperature and the position of the control dial. Once the FGF 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. Precision vaporizers are...
calibrated for one agent only and several safety mechanisms are included on newer vaporizers to stop the wrong volatile anesthetic agent being placed in the vaporizer. If halothane is placed in a vaporizer designed for methoxyflurane, disaster would result! These vaporizers generally have a high resistance to gas flow and are therefore placed out of the breathing circuit (VOC). They are positioned between the flowmeters and the breathing circuit where the flow from the flowmeters can 'cope' with this degree of resistance. Some older vaporizers tend to be inaccurate at low flows (e.g. Fluotec 2 at < 250 mL/min) and can produce a higher concentration than indicated on the control dial. The older halothane vaporizers may also suffer from sticky dials due to the preservative thymol in halothane, unless vaporizers are regularly cleaned. The newer vaporizers have working parts covered with Teflon. Precision vaporizers should be regularly cleaned and serviced by the dealer / manufacturer. Care should be taken not to tip the anesthetic machine over 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 to be anesthetized. 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.

**Breathing Circuits/Systems**

A description of breathing circuits and an explanation of the use of different flow rates in systems is available from Alan Klide at the School of Veterinary Medicine, University of Pennsylvania. This is a well designed site with good information.

**General Principles**

The breathing circuit is the system through which the patient breathes and which carries the volatile anesthetic from the anesthetic machine to the patient. There are four principle concerns with all breathing circuits.

1) Resistance

Anesthetic gases flow from the anesthetic machine to the patient in response to a pressure gradient that exists between the gas pressure regulators or reducing valves at the machine (about 40 psi) and the patient (atmospheric pressure). This pressure gradient is regulated by the flowmeters and by the resistance to the flow of gas through the tubes. Resistance to gas flow depends on whether it is laminar in nature or turbulent. Resistance will increase with turbulent flow.
a) Laminar flow is smooth and orderly and the lines of flow are parallel to the walls of the tube. Flow is fastest in the centre of the tube where there is least friction. When flow is laminar the Hagen-Poiseuille Law applies. This states that the change in pressure (or resistance) is directly proportional to the flow rate, viscosity of the gas and the length of the tube, but is inversely proportional to the fourth power of the radius. Therefore a critical determinant of resistance is the radius of the tube (this also applies to flow through i/v catheters and endotracheal tubes. See later).

b) Turbulent flow follows disorderly paths and some eddies flow against the general direction the gas is traveling. Irregularities in the tube lumen (narrowing, sharp turns, valves) will cause turbulent flow and the resistance now varies as the square of the flow rate. To overcome the increased resistance the spontaneously breathing patient must generate a greater pressure gradient which translates to a greater work of breathing (something a patient who already has depression of the respiratory centre through anesthetic drugs will find difficult to do).

For minimal resistance the gas conducting pathways of a circuit should be of minimum length, maximum internal diameter without sudden narrowing and without sharp bends. However, the resistance offered by the breathing circuit is usually small compared to that of endotracheal tubes and their connections.

2) Rebreathing

To rebreathe means to inhale gas which has already been previously exhaled and from which carbon dioxide may or may not have been removed. If expired carbon dioxide is not removed, the arterial carbon dioxide level will increase as a result of rebreathing. Breathing circuits that are designed to 're-use' the expired oxygen and anesthetic gases (cheaper to run) must have facilities to remove the carbon dioxide (discussed later). The amount of rebreathing will depend on three factors:

a) Fresh Gas Flow. If the total volume of gas supplied in a minute is less than the minute volume of the patient a certain amount of the exhaled gas will have to be rebreathed to make up the shortfall.

b) Mechanical (Apparatus) Dead Space. This is the space in the breathing circuit which is rebreathed without any change in composition and may contain carbon dioxide depending on whether it contains anatomical dead space gas, mixed expired gas or alveolar gas. This area should be minimized as much as possible (especially with very small patients).

c) Design of Circuit. This will be discussed later. The breathing circuits used are broadly classified into Non Rebreathing or Rebreathing Circuits.

3) Inspired Concentration
Several factors may modify the gas mixture which is delivered from the anesthetic machine so that what the patient inspires is considerably different from the gas mixture delivered to the circuit.

a) Rebreathing. See discussion under Circle Systems. By definition rebreathing does not occur in non-rebreathing circuits such as the Bain circuit.

b) Air Dilution. With an inspiratory limb open to atmosphere and the patient able to breathe in room air (very short Bain or Ayre's T-piece Circuit) because the patient's tidal volume is greater than the volume of the circuit.

c) Leaks. The composition and amount of gas lost (or gained) depends on where the leak is and the pressure within the system. Anesthetic circuits must be checked for leaks before they are used or patients may not stay anesthetised.

d) Uptake and Release of Anesthetic Agent by the System. Uptake of lipid soluble anesthetic agents into rubber, plastic and carbon dioxide absorbent can produce a lower inspired concentration at the beginning of the anesthetic period or a higher one during recovery (circle system).

4) Heat and Humidity

Medical gases contain no water (or oil, remember oxygen + grease = explosion hazard) to prevent clogging of regulators and valves. The inspired gases are therefore heated and humidified at the expense of the patient's body heat. A number of clinical effects may result from the use of dry anesthetic gases including impairment of ciliary function, loss of body heat and water, decreased water content of mucus and the accumulation of a more viscid secretion. Rebreathing systems conserve body heat and water and this is to the patient's advantage. Incidentally, if oxygen is to be administered to critical care patients over a period of many hours, the oxygen should be bubbled through distilled water (preferably sterile) to humidify it.

The Components of Breathing Circuits

1) Connectors and Adaptors
These are found where two parts of the circuit are to be joined e.g. endotracheal tube to breathing circuit hose. The fittings should be of standardized sizes 22 mm female and 15 mm male openings.

2) Reservoir (Rebreathing) Bag
The bag is made of rubber or neoprene so that it has a high compliance for safety. If the pressure builds up to excessive amounts in the circuit. It is not fail-safe, so make sure excessive pressures do not occur. The commonest problem is a closed exhaust valve. The size of the bag should be greater than the patient's vital
capacity and it has been suggested that it should be at least six times the patient's tidal volume. This is so there would be sufficient gas in the bag to cope with the demand of increased ventilation if the patient suddenly becomes too 'light' (when talking about depth of anesthesia). The bag should be about three-quarters full of anesthetic gases for optimum conditions. The patient will find it difficult to breathe from an empty bag and impossible to exhale into a bag which is overfull. The bag has the following functions:

   a) It allows accumulation of gas during exhalation so that a reservoir of anesthetic gas is available, and it prevents dilution with room air in non-rebreathing systems.

   b) It provides a means of assisting or controlling the ventilation of the patient.

   c) It allows visual observation of patient ventilation.

   d) It acts as a safety factor, protecting the patient from excessive pressure in the breathing system...up to a point!

   e) It provides a reservoir of gases to meet the flow rate generated by the act of inspiration (higher than the flow of gases entering the circuit).

3) Breathing Tubes/Hoses

   These are made of corrugated plastic or rubber to avoid the risk of kinking when the hoses are bent. They have two functions:

   a) To act as a reservoir in certain circuits.

   b) To provide a flexible, low-resistance and lightweight connection from one part of the system to another. The tubing can be seen to bulge on inspiration during intermittent positive pressure ventilation. This means that some of the energy used to ventilate the patient is wasted in expanding the hoses. This is not a big problem with modern plastic hoses. The plastic hoses are often translucent and are one-use only in human anesthesia, but are re-used after cleaning in veterinary practice. Rubber hoses are still found in older circuits and are often black because of the carbon used in them to make them conductive and prevent the build up of static electricity (important because ether was often used).

4) Valves

   Most circuits (except Ayre's T-piece and similar) have exhaust valves (relief valves or 'pop-off' valves) to allow excess pressure to be vented to atmosphere, and to conduct away waste gases. There are
several types, but most operate on a loaded spring mechanism. Modern valve assemblies have scavenging outlets which allow the attachment of hoses to carry the waste gases outside the room in which the anesthetic machine is being used. This prevents the build-up of anesthetic gases in the workplace which is of concern with occupational health authorities. Some people feel tired and complain of headaches if they spend a large part of their working day in an operating room with poor or non-existent scavenging. See 'Inhalational Anesthesia' The exhaust valves should be left open when the patient is breathing spontaneously so there is very little resistance to the exhaled gases. During assisted or controlled ventilation the valve will have to be closed so that gases are directed into the patient and not to atmosphere. Remember to open the valve if the circuit pressure builds up! Careful and periodic adjustments of the valve setting may be necessary to achieve the desired level of ventilation and maintain adequate filling of the bag. Another valve found in circle rebreathing circuits is the unidirectional valve which will be discussed under circle systems.

5) Pressure Gauges

These are not always present in a circuit, but when they are they are useful indicators of in-circuit pressure. This is important when intermittent positive pressure ventilation is being used so an idea of the airway pressures developed can be gained. Cats and dogs should be ventilated to pressures of 10-15 cm H2O. Horses are ventilated to a pressure between 20 - 25 cmH2O. When checking the circuit for leaks squeeze the reservoir bag with the patient end of the hose closed and exhaust valve closed and see if a pressure of 30-40 mmHg can be developed. If not, there is a leak which must be found before the circuit is used. There is considerable confusion over terminology for describing anesthetic circuits, particularly since many circuits which are defined as semi-closed by the British system are defined as semi-open in the North American system. In veterinary anesthesia we usually call circuits that do not have a means of absorbing carbon dioxide non-rebreathing systems, although that is not technically accurate. The best way to describe an anesthetic system is to name it and record the fresh gas flow through the system. Such descriptions as semi-open and semi-closed then become superfluous. Here, the circuits are going to be divided into two basic systems and then the commonly used circuits will be discussed:

1) Non-rebreathing Circuits

2) Rebreathing Circuits

**Non-Rebreathing Circuits**
Fresh gases from the anesthetic machine (with anesthetic vapour) pass into a reservoir and the patient breathes from that reservoir. Exhaled gases pass into the atmosphere, either directly or through an exhaust valve. The most basic of these systems is the Ayre's T-piece and the most commonly used system today is the Bain circuit and modifications. In these circuits, 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. 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. Their big disadvantage is the high fresh gas flow which can be expensive so these circuits are usually used on patients less than 10 kg. 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 with non-rebreathing circuits or barotrauma will result.

A) Ayre's T-Piece

This simple non-rebreathing system has no valves and so has very little resistance which makes it useful for very small patients. It also has very little dead-space. The expiratory limb should be greater in volume than the patient's tidal volume or room air will be inhaled as the end of this limb is open. The circuit can be fitted with a reservoir bag with a hole in the distal end. To ventilate the patient the hole should be closed off with the finger and thumb and the bag gently squeezed with the rest of the hand, in between breaths the hole should be opened. The bag itself looks flat compared to other circuits, but respiratory movements can be easily seen. This circuit is not common in N. America. (Gas flows should be 2-3 times minute volume, the circuit works very similarly to the Bain.)

B) Bain Circuit

Also known as a co-axial system because the fresh gas flows down the centre tube (inspiratory) and expired gases flow along the outer tube (expiratory). This circuit does not have to have a reservoir bag attached to the end of the expiratory limb, but one can be added and it makes observation of patient breathing easier and provides a method of ventilation if necessary. [Bain attachments or modified Bain circuits are often used where there is a reservoir bag and exhaust valve added to the expiratory limb.] They are sold as one-use units, but in veterinary medicine they are cleaned and re-used
(and in human medicine also). They can be used on any size of animal, but economics preclude their use in very large patients (a horse would require a flow of 60 litres/min!) These circuits do not have any mixing of exhaled gases with inhaled gases and so you know definitely that providing there is no rebreathing i.e. with correct gas flows, what is set on the anesthetic machine (O2 : N2O ratio and vaporizer concentration) is what the patient is inhaling. They are efficient at CO2 removal if used at the correct gas flow for IPPV unlike some other non-rebreathing circuits. With the earlier units there was a danger of disconnection or kinking of the inner tube. Present units are better constructed. Check the circuit beforehand. Flow Rates for Bain Circuits: The TOTAL FRESH GAS FLOW should be set to prevent rebreathing of CO2. The final fresh gas flow should be 100-120 mL/kg/min to prevent rebreathing (see O2 only flow rate).

1) Oxygen only .......... 100-120 mL/kg/min.

2) Oxygen and Nitrous Oxide:
   Oxygen .................. 40-60 mL/kg/min.
   Nitrous Oxide .......... Double the oxygen flow rate:

   The patient is then breathing 33% O2 and 66% N2O.

C) Magill Circuit and Lack Co-Axial Circuits

Not common in N. America, used in the U.K. Both these circuits work in a similar way and require fresh gas flows 1-1½ times the minute volume of the patient. These circuits tend to allow the accumulation of carbon dioxide to occur within the circuit during intermittent positive pressure ventilation and patients can eventually become hypercarbic. The Lack circuit looks like a Bain, but the fresh gas flows down the outer tube and the exhaled gas flows up the inner tube. The reservoir bag is on the inspiratory limb like the Magill and unlike the Bain. The Modified Lack is gaining in popularity in the U.K., The Mapleson Classification (For Non Rebreathing Circuits)

Mapleson A ............. The Magill Circuit and Lack Circuit.

Mapleson B and C ...... Not used in vet. practice.

Mapleson D and E ...... Bain and Ayre's T-Piece Circuit.

**Rebreathing Circuits**

In these systems the exhaled gases are re-used and the exhaled carbon dioxide is removed by chemical means, with soda-lime or bara-lyme. They have the advantages of conserving water and heat and being cheap
to run. They are more expensive to buy, soda-lime dust may be inhaled and there may be more resistance to breathing.

A) The Circle System

The components of the circle system are as follows: CO2 absorber, two unidirectional valves, pressure gauge (optional), fresh gas inlet, exhaust (pollution control) valve, breathing tubes, Y-piece and rebreathing bag.

a) CO2 Absorber

The two commonly used absorbent materials are soda-lime (‘SodaSorb’) and Baralyme. Soda-lime which is more commonly used is composed of 94% calcium hydroxide, 5% sodium hydroxide and 1% potassium hydroxide as its dry weight, but is sold ‘wet' with 14-19% water. It has a dye indicator to provide information on its pH and this is used as an indicator of soda-lime exhaustion. The chemical reaction is as follows:

\[
\text{H}_2\text{O} + \text{CO}_2 \rightleftharpoons \text{H}_2\text{CO}_3 \\
2 \text{NaOH} + \text{Ca(OH)}_2 + 2 \text{H}_2\text{CO}_3 \rightleftharpoons \text{CaCO}_3 + \text{Na}_2\text{CO}_3 + 4 \text{H}_2\text{O} + \text{heat energy}
\]

Note that this reaction is exothermic and that calcium carbonate is formed which makes the granules hard. Baralyme is a mixture of hydrated barium hydroxide and calcium hydroxide which reacts along similar lines to soda-lime. Soda-lime is more dense than Baralyme (104 g compared to 86 g/100 mL) and 15% more efficient in that 100 g of dry soda-lime will absorb 23 litres of CO2 while Baralyme can absorb 18 litres CO2. The absorber canister itself should be large enough to hold the tidal volume of the patient in the spaces between the granules (45-70% of absorbent volume is air space) and the shape of the canister should produce as little resistance to gas flow as possible (squat and wide rather than tall and narrow). When the canister is being filled the sides should be tapped to make the soda-lime settle and to remove dust. Air flow will favour the path with least resistance and CO2 absorption may not take place efficiently (channeling), this normally occurs to a certain degree down the walls of the canister. The exothermic nature of the reaction is of considerable use in gauging the activity of the absorbent. In the patient, a rising blood pressure, increased heart rate, increased ventilation, more capillary oozing, sweating and brick red mucous membranes can indicate hypercarbia and poor absorbent function (some ex-hospital anesthetic machines have soda-lime canister bypass switches and these can inadvertently be turned on).

b) Fresh Gas Inlet
The fresh gas inlet is the point at which gas from the anesthesia machine enters the breathing circuit. It is usually connected by a flexible rubber tubing to the common gas outlet on the anesthetic machine. It may be attached in several positions, but in most cases it is attached to the absorber in the circle system.

c) Unidirectional Valves

These consist of a disc covered with a clear plastic dome which allows visual inspection of the valve. The disc should sit horizontally on an annular seat. As gas enters the base and flows through the centre tube of the valve unit it raises the disc from its seat. The gas then passes under the plastic dome and on into the breathing system. Reversing the gas flow will cause the disc to contact the seat and stop retrograde flow, in this way, the valves keep the gases flowing one way around the circuit in a circle. These two valves are a major cause of resistance in circle systems although modern valves are lighter to operate. The main problems with these valves are either becoming stuck in the open mode, or jamming shut and blocking gas flow. Another problem can be the loss of a disc during cleaning, and subsequent failure to notice this before use of the circuit. Always look at the discs during the pre-anesthetic check of the machine.

d) Y-Piece

The Y-piece is used to join the inspiratory and expiratory tubes to the mask or endotracheal tube. All Y-pieces designed for human or small animal use have two 22 mm male connectors for attachment of breathing tubes and the patient connection port has a 15 mm female connector or mask adaptor. The breathing tubes, pressure gauges and exhaust valve have been discussed before.

Desirable Objectives of Design of the Circle System

a) Minimal consumption of absorbent. For this, the gas vented through the exhaust valve should have the highest possible concentration of CO2. This will occur when the exhaled gas has not passed through the absorber before being vented. When the exhaled gas is diluted as little as possible by fresh gas or previously exhaled gas and when the vented gas is that exhaled late in expiration (contains higher CO2) the absorbent will last longer.

b) Minimal Dead Space. The mechanical dead space extends into the Y-piece as far as the partition. Using a Y-piece with a septum should decrease the dead space.

c) Low Resistance to Ventilation. The most important components in the circle influencing the resistance are the exhaust valve, unidirectional valves and the soda-lime canister. Resistance will depend on among other things, the fresh gas flow (influences through the exhaust valve) and the pattern of ventilation (influences the flow rate through the canister and valves).

d) Maximal humidification of inspired gases.
e) Convenience. Bulkiness of circuit, expense etc.

f) Avoidance of hazards. Correctly fitting unidirectional valves, see-through plastic domes for these valves, easy to set up and lack of leaks etc.

Inspired and Delivered Concentrations The inspired gas concentration differs from that delivered to the circle system by the anesthetic machine (the setting on the vaporizer). Principal reasons for this include:

a) Rebreathing: During induction, there is rapid uptake of anesthetic from the alveoli. The exhaled gas therefore has a lower anesthetic concentration than the inhaled gas. If the fresh gas flow is low, the concentration will be lowered by mixing with the exhaled, recycled, gas. The inspired concentration will therefore be lower than the delivered concentration (the vaporizer setting). Induction is therefore slowed (this is overcome by running high fresh gas flows and turning up the vaporizer output setting). During recovery the alveolar anesthetic tension exceeds that of the delivered gases (zero - because the vaporizer is off) and so recovery will be slowed if the exhaled gases are rebreathed. (We can eliminate the exhaled gases by periodically 'dumping' the bag through the exhaust valve and running in high flows of fresh oxygen).

b) Position of Vaporizer. Either in (VIC) or out (VOC) of circuit. See the attached chart of differences between circuits due to position of vaporizer. Also note the different methods used to alter depth of anesthesia depending on placement of vaporizer. This is very important.

c) Nitrogen. Patients just connected to an anesthetic breathing circuit are in equilibrium with air (79% N2 compared to 0% N2 in fresh gas from the anesthetic machine). The patient inspires the fresh gas from the circuit and this washes nitrogen out of the patients lungs and dilutes the gases in the circuit. High gas flows for a few minutes allow more of the expired (nitrogen rich) gas to be vented from the machine and speeds the process of 'denitrogenization' (see 'Inhalation Anesthesia'). Gas flows of around 2-3 litres/minute provide satisfactory denitrogenization in approximately 3 to 5 minutes in small animals. Higher flows do not speed up denitrogenization significantly. Data is not available for horses, but initial flows of 10 litres/minute are commonly used at the beginning of an anesthetic period for about ten minutes or so.

d) Carbon Dioxide. In a system with absorbent, the inspired carbon dioxide concentration should approach zero. Accumulation of carbon dioxide may arise from failure of unidirectional valves or exhausted soda-lime as well as depression of ventilation under anesthesia. Fresh gas flow should have no effect on inspired CO2 concentration in a properly set up system.

e) Oxygen. O2 enters the system with the fresh gas and leaves through patient uptake, the exhaust valve and leaks. O2 inhaled is from the fresh gas and rebreathed gas that has been through the soda-lime.
Uptake and elimination of other gases will affect the inspired O2 concentration (especially N2O where the second gas effect is significant initially and its use also reduces the inspired concentration of O2, ) See 'Inhalation Anesthesia'. The position of the fresh gas entry and unidirectional valves can influence the relative proportions of expired and fresh gases in the inspired mixture. The uptake of oxygen by the animal affects the expired component of the inspired mixture as does the fresh gas composition and flow rate. This is a circuit that should be understood since it is commonly used in veterinary practice for small animal patients greater than 10 kg and in nearly all large animal anesthetic machines. This circuit is used in some anesthetic machines with the vaporizer in circuit e.g. Ohio and Stephen's. Recommended flow rates depend on whether oxygen is being used on its own or whether N2O is also being used. There is still controversy over the O2 and N2O flow rates, but for now, the recommendations are:

Oxygen only........5-8 mL/kg/min. (supplying metabolic oxygen requirement + safety factor)

Oxygen and Nitrous Oxide

Oxygen ...............30 mL/kg/min (as above + safety factor)

Nitrous Oxide ........30-60 mL/kg/min. (Inspired N2O about 50-70%)

If nitrous oxide is used care must be taken in monitoring patient and anesthetic machine to avoid hypoxic mixtures developing in the circuit.

**Low Flow - Closed Circuit - Anesthesia**

With modern monitoring equipment such as inspiratory gas monitors (Oxygen, Nitrous Oxide, Anesthetic gas concentration), capnographs and pulse oximeters it is now possible to use closed circuit (circle system) anesthesia safely. With closed circuit anesthesia enough oxygen is delivered to supply the metabolic needs of the patient. (The pop-off, pollution control, valve is often closed but this is not essential to the definition of a closed circuit). If nitrous oxide is not used then it is possible with good patient monitoring to safely run closed circuit anesthesia without all the monitors. It is necessary to use a higher vaporizer setting than with a high flow anesthesia protocol.

See "Vet Clinics North America, March 1992, P381 et seq." There are significant savings to be made by using either closed circuit or low flow anesthesia (Up to $10.00 per hour compared with high flow anesthesia in dogs).

B) The Water's To and Fro System
This system was first developed by Waters in 1923. The patient breathes back and forth through a soda-lime canister. Inspired gas comes from the fresh gas flow and the rebreathing bag. The fresh gas is introduced as close to the patient as possible although there has been some work done on placing it distal to the soda-lime canister. There are no unidirectional valves, it is simple in design, sturdy, easy to clean and assemble, not bulky and conserves moisture and body heat. It does, however, have its problems in that the soda-lime canister is so close to the patient that soda-lime dust can be breathed in and the canister may become hot causing patient hyperthermia. Since the soda-lime nearest the patient becomes exhausted first this can effectively increase circuit dead-space and if it goes unnoticed may cause hypercarbia. This type of circuit is very common in veterinary practices in the U.K. because it is much cheaper than circle systems. Pediatric sizes are also available and these are used on small patients such as cats and small dogs (< 10kg). Also available in the U.K. are commercial large animal to and fro circuits portable enough to be transported to a farm. Not common in North America.

**Flow rates are as for the circle system.**

Clinical Use of Anesthetic Machines and Circuits After induction of anesthesia, usually with an injectable anesthetic, the animal is intubated. The patient is positioned in lateral recumbency and the endotracheal tube is connected to the Y-piece of the anesthetic machine [See section on Apnea in Anesthetic Complications]. The endotracheal tube is usually tied in place with the adapter between the canine teeth. The endotracheal tube cuff is inflated and checked for leaks by compressing the reservoir bag to produce an in-circle pressure of 15 to 20 cm H2O. The cuff must not be over-inflated (see section on endotracheal intubation). The patient is placed in the required position for surgery and monitoring devices are attached as needed.

**Induction and Maintenance of Inhalation Anesthesia** There should be a responsible person monitoring the patient during the anesthetic period and maintaining an accurate anesthetic record. Each animal will respond in an individual manner to the anesthetic. The following are guidelines for the use of our two standard anesthetic machine set ups with circle systems and VIC and VOC and also the set up with a Bain circuit.

A. Machines with an in-circle methoxyflurane vaporizer Due to the very slow induction and recovery times methoxyflurane is not used for anesthetizing Large Animal patients. For Small Animals, the reservoir (rebreathing) bag on the machine is filled with oxygen and the Y-piece connected to the endotracheal tube. The oxygen flow rate on the flow meter should be set above the anticipated oxygen consumption of the animal (Small Animals: 5-8 mL/kg/min.). For example, a 10 kg dog would probably have an oxygen consumption of...
50 to 80 mL/min and the oxygen flow meter should probably be set about 300 mL/min. The excess gases in the circuit would be vented through the pop-off valve by gentle pressure on the reservoir bag. Every two or three breaths the vaporizer setting in increased gradually (one or two increments at a time). Starting with the vaporizer full on may cause temporary breath-holding due to the pungent nature of the methoxyflurane. At the end of about 3 minutes, the reservoir bag should be emptied (through the pop-off valve) by gentle pressure. The reservoir bag should be refilled with oxygen. This procedure should be repeated at about seven minutes. This is designed to remove nitrogen from the circuit. The flow meter may then be turned down so that sufficient oxygen is entering the circuit to keep the re-breathing bag approximately three-quarters full i.e. sufficient oxygen to supply the patients metabolic needs. Note: - this is an in-circle vaporizer and with a high setting on the vaporizer, all or the majority of gases in the circuit are passed through the vaporizer. Therefore, filling the re-breathing bag with oxygen without turning off the vaporizer does not lighten anesthesia as the oxygen will pass through the vaporizer before reaching the patient. If the vaporizer is turned down and the oxygen flow increased, then anesthesia will lighten slowly as methoxyflurane is absorbed into the body from the system. It is generally advisable to run the machine with the vaporizer setting at full open for 15 to 20 minutes in order to achieve stable anesthesia. Methoxyflurane is a very soluble drug which is rapidly distributed in the body and absorbed into the fat. If the concentration is turned down too soon the animal will lighten from anesthesia. After this time, the vaporizer setting may be turned down to the region of 5 to 6. Depending on the nature of the operation and the expected operating time and the patient response, the vaporizer may be set to 2 or 3 after a further period of 10 to 20 minutes. Remember that the "glass jar" vaporizers that are in-circuit are not precision vaporizers. The numbers on the vaporizers show the proportion of gas passing through the vaporizing chamber and not the actual percentage of methoxyflurane delivered to the system. With low flows of oxygen into the circle there will be a gradually increasing concentration of anesthetic in the circle (VIC) if the vaporizer setting is not changed and the reservoir bag is not flushed. Flush the circle every twenty minutes if using low flows. Should anesthesia continue for more than 1.5 hours then it is possible about 20 to 30 min before the anticipated end of surgery for the vaporizer to be turned off completely, the machine flushed with oxygen and the rebreathing bag filled with pure oxygen. Animals are quite slow in recovering from methoxyflurane anesthesia and this procedure will permit the animal to be lightening at the end of surgery. Repeated flushing with oxygen will speed recovery slightly. For a routine
laparotomy, one could switch off the vaporizer and flush the circuit at about the time that the surgeon is completing closure of the muscle layers.

It must be emphasized that these settings, flow rates and times are all guidelines only. The animal must be monitored very carefully for anesthetic depth in order to ascertain that the correct settings are being used. Methoxyflurane is noted as being a respiratory depressant and respiratory acidosis is very common in procedures taking any length of time. For these reasons, it is advisable to use intermittent positive pressure ventilation (IPPV). This means that every minute or so the anesthetist should close the pop-off valve and expand the animal's lungs once or twice. It is advisable to try to time the expansion of the animal's lungs with spontaneous ventilation. This helps to expand unopened areas of the lung and to flush out any accumulated CO2. This procedure should not be carried on too vigorously or for too long due to the possibility of mechanical damage to the lungs by too much pressure or producing apnea by hyperventilation, or by interfering with blood flow through the lungs and causing hypotension. For this procedure it is not necessary to alter the vaporizer setting. Continuous IPPV will vaporize more methoxyflurane due to increased flow through the vaporizer. Inspiratory pressure above atmospheric also increases the gradient between inspired methoxyflurane and the blood. Hyperventilation increases the tidal volume and increases the uptake of anesthetic agent. For these reasons, if the animal is to be ventilated continuously for such procedures as open chest surgery, the vaporizer should be turned down to a low setting and the circuit flushed occasionally. It is difficult to vary the depth of anesthesia rapidly with methoxyflurane due to the high solubility of the drug. Therefore, it is important to know the surgical procedure and to be able to anticipate varying requirements for anesthetic depth. B. Anesthetic machine with an out-of-circle Halothane or Isoflurane Vaporizer The reservoir bag on the anesthetic machine is filled with 1.5% or 2% anesthetic vapor using a high flow of oxygen through the flow meter. Do not use the oxygen flush valve to fill the reservoir bag as this bypasses the vaporizer and results in the bag being filled with pure oxygen. The anesthetic concentration may be varied slightly if the animal is particularly deeply or lightly anesthetized with the induction agent. The Y-piece is connected to the endotracheal tube. The flow of oxygen should be set at 1 - 2 L/min for the first ten to fifteen minutes for small animals and up to 10 - 12 L/min for an adult horse. The pop-off valve should be open. This high flow is required so that the anesthetic concentration
in the circle more closely approximates the setting on the vaporizer. Excess gases escape through the open pop-off (exhaust, pollution control) valve and carry nitrogen with them, thus aiding in denitrogenization of the system. Care must be taken to ensure that the reservoir bag does not become over-inflated, as once it reaches its stated capacity, pressure in the system begins to rise rapidly. Such a rising pressure interferes with the animal's respiratory movements and may also compress the lung capillaries leading to a reduction in cardiac output causing hypotension. If the bag is full it should be squeezed gently to empty it through the pop-off valve. Compression should be timed with the animal's own inspiration to avoid interference with the normal respiratory pattern. Gently expanding the lungs will aid in the elimination of carbon dioxide.

The patient is to be monitored carefully for anesthetic depth and the concentration of halothane reduced as a plane of surgical anesthesia is reached. A smooth transition should occur from the induction agent anesthetic to the inhalation anesthetic. When equilibrium is established, the flow of oxygen through the flowmeter may be reduced. If the fresh gas flow is set at a minimum, at the patient's metabolic needs, the vaporizer will have to be set at a slightly higher concentration than would be necessary with a higher flow. This is because the inspired concentration is always lower than the delivered concentration with an out-of-circle vaporizer as the patient is continuously absorbing anesthetic from the system. Usually the flow is set to a minimum of 500 mL/min to allow for fluctuations in flow through the flowmeter and to ensure correct output from the vaporizer. This flow rate is above the metabolic needs (O₂ - 5 - 8 mL/kg/min.) of all but the largest dog. Horses require a metabolic oxygen flow of about 3 mL/kg/min. (1.5 L/min for a 500 kg horse) and the flow is usually set at 2 - 4 L/min when stable anesthesia has been achieved. With an out-of-circle vaporizer more stable anesthesia is obtained with these higher flow rates. With halothane or isoflurane machines fitted with nitrous oxide, the carrier gas used may consist of two parts nitrous oxide: one part oxygen with the proviso that the oxygen flow should always be at least three times the minimum metabolic needs of the patient (i.e. use 30 mL/kg/min.) if the system is not going to be flushed regularly and there is no method of monitoring the inspired oxygen concentration. The use of nitrous oxide will give good analgesia, decrease the concentration of halothane or isoflurane required and give a more rapid induction and recovery. Thus a 20 kg dog would require an oxygen flow of 600 mL and a nitrous oxide flow of 1200 mL. We would generally use O2 1L /min and N2O 2L /min. Nitrous oxide is rarely used in large animal anesthesia due to the accumulation of gas in the intestinal tract. See: Nitrous Oxide.
Recovery from halothane anesthesia is much more rapid than from methoxyflurane; isoflurane is even quicker, and care must be taken not to turn the anesthetic off too soon. As skin closure is being completed, the vaporizer should be switched off, also nitrous oxide if it is being used, and the oxygen flow increased to about 3 L/min for dogs, 10 - 12 L/min for adult horses and cattle. About five minutes on pure oxygen is generally adequate before disconnecting the machine. Horses are generally maintained on oxygen with a Hudson Demand Valve until they are ready to be extubated.

C. Anesthetic machine with an out-of-circle methoxyflurane vaporizer

The procedure is very similar to that for halothane except that the vaporizer is initially set to maximum. After about 5 minutes it is turned down to 2.5% then over the next 20 min. to 1.0 to 0.5%. Stable surgical anesthesia will generally be obtained with a vaporizer setting between 0.5 and 1.0% for the first hour and lower thereafter as the concentration in the body rises.

D. Non-Rebreath: - Bain Circuit.

With a Bain circuit the fresh gas flow should be 100 - 120 mL/kg/min to prevent rebreathing of expired gases (CO2). Note this is the total fresh gas flow regardless of whether it is a mixture of nitrous oxygen and oxygen or oxygen alone. This is far above the metabolic needs of any anesthetised animal (3 - 10 mL/kg/min depending on species). Thus a 100 kg foal would require a fresh gas flow of 12 L/min and a 500 kg horse would require 50 L/min!!

Endotracheal Intubation

Endotracheal intubation is the placement of a tube in the trachea to provide an airway. It is a valuable technique that enables us to attach an animal to a breathing circuit or, just as importantly, to secure an airway during an emergency such as respiratory or cardiac arrest. It is important that time be taken to learn the anatomy of the laryngeal area and the skill of intubation so that intubation may be performed quickly and with little chance of misplacement. Indications and Advantages.

1. Maintenance of a patent airway - preventing obstruction, aspiration, and laryngospasm.
2. Prevents aspiration pneumonia if an inflated cuff is used.
3. Allows controlled ventilation (minimizing atelectasis, permitting intra-thoracic surgery.)
4. Correct size tube minimizes dead space.
5. Economy of gases with inhalation anesthesia.

Possible Unfavourable Complications:
1. Laryngitis, tracheitis (trauma).
2. Laryngeal edema (trauma).
3. Increased resistance to ventilation (too narrow a tube).
4. Obstruction of tube (bending of tube, occlusion by biting).
5. Intubation of esophagus.
7. Dislodgment of tube (improperly fastened).
8. Laryngospasm. Particularly likely to occur in lightly anesthetized cat - remove tube while anesthesia still moderately deep. Other species remove tube after swallowing reflex returns.
9. Over-inflation of cuff leading to damage to the tracheal mucosa.
10. Lack of sterility.
11. Contamination with disinfectants leading to a chemical tracheitis.

**Endotracheal Tubes**

There are many endotracheal tube types, and they basically consist of a tube, generally curved except for Large Animal tubes, with a bevelled end and an adapter for attachment to the anesthetic circuit.

1. **Diameter.** Tube diameter is used to indicate size. The modern standard diameter gives the internal diameter (ID) in millimeters. Other methods include French units (external diameter in millimeters multiplied by 3) which approximates the external tube circumference. The ID method does not give any indication of external diameter which varies with the tube type. Allowance must be made for the wall thickness. The larger the internal diameter the lower the resistance to breathing. This is critical in very small sizes used in cats, puppies and rodents. One should use the largest tube that can be placed through the larynx without force.

2. **Length.** Avoid the use of excessively long tubes, especially in very small animals, as they will increase resistance and may increase apparatus dead space if the tube is allowed to protrude out of the mouth. Tubes for human use have external length markings to assist placement. A tube which is too long may accidentally enter one bronchus, allowing ventilation of only one lung.

3. **Curvature.** Based on use in man, the tubes have 14 cm radius of curvature for oral insertion with a 20 cm curvature in nasal tubes. Some larger small animal tubes (size 11 or greater) or large animal tubes made for veterinary use have no
4. Bevel Angle. Most tubes are bevelled to facilitate slipping the tube between the vocal folds. Some armoured tubes do not have any bevel.

5. Murphy Eye. A hole through the tube wall near the bevel end on the opposite side to the bevel. The purpose of the eye is to allow passage of gas if the bevel is tight against the tracheal wall or otherwise occluded.

6. Construction Material. This covers a wide gamut from metal, synthetic and natural rubber, polyethylene, polyvinyl chloride, silicone, and the other plastics. The material is tested for inertness and safety -- indicated by markings on tube wall "IT" (implant tested) or "Z-79" (Committee Z-79 of the USA Standards Institute).

7. Wall Reinforcement. Some tubes have their walls reinforced with coiled wire or heavy nylon thread to prevent collapse or kinking. These often have no bevel and may be quite flexible, mandating the use of a stylet for placement.

8. Cuff. Tubes may be cuffed or uncuffed. The cuff is inflated with air to create a seal against the underlying tracheal mucosa. This seal facilitates positive pressure ventilation and prevents pulmonary aspiration. Cuffs are classified as high pressure, low residual volume or low pressure, high residual volume. Low volume cuffs must be inflated to high intraluminal cuff pressures (180 - 250 mm Hg) before they expand enough to create a seal. This high cuff pressure is partially transmitted to the underlying tracheal mucosa. Ischemia may occur wherever the pressure on the tracheal mucosa exceeds capillary arteriolar pressure (about 32 mm Hg). High volume, low pressure cuffs inflate symmetrically adapting to the contour of the tracheal wall with low intraluminal cuff pressure (15 - 30 mm Hg). These cuffs decrease but do not prevent tracheal injury at the cuff site.

9. Adapters. Connect the tube (patient) to the breathing circuit. 15 mm outer diameter at the machine end. These should be tightly attached to the endotracheal tube, and secured to the jaw by a length of gauze bandage.

10. Special Designs. There are many of these but some that veterinarians are more likely to encounter are:

   a. Cole Tubes. These tubes are uncuffed and the distal end is tapered. The smaller portion is inserted into the trachea and the larger portion wedged against the arytenoid cartilages to form a seal.
b. Endobronchial Tubes. Designed to allow differential ventilation of the lungs by intubating each bronchus.

**Care of Tubes**

a. Mechanical cleaning both internally and externally to remove mucus and saliva.

b. Sterilization (autoclave, chemical, or ethylene oxide).

c. Storage (packaged, labeled, and dust-free).

d. b & c are not commonly carried out in veterinary practices. Beware of chemical contamination of rubber tubes.

**Laryngoscopes**

The laryngoscope is useful in providing a direct light source to visualize the laryngeal structures. Many veterinarians do not use laryngoscopes, but those that do are able to intubate animals with less trauma, greater ease, and more assurance of correct placement. The laryngoscope consists of a battery powered handle and a blade or spatula with a light source attached. There is a wide variety of blade types, usually designed for use with human patients. There are two principle designs:

1. Curved blade (Macintosh), which is used to exert pressure on the base of the tongue in front of the larynx. It does not touch the epiglottis, but if used correctly will displace the epiglottis ventrally to allow visualization of the arytenoid cartilages, vocal folds, and rima glottides.

2. Straight blade (Miller). Most blades have a side flange on the back part of the blade that serves as a tongue deflector for use in the human patient in dorsal recumbency. Since dogs and cats are commonly intubated in sternal recumbency, the flanges tend to be in the way and some people will purchase blades (such as a Michael's blade) which have no flange. Care of laryngoscopes consists of cleaning the blades, keeping charged batteries, and having a spare light bulb available.

**Stylets**

Special flexible guides are available to increase endotracheal rigidity to facilitate intubation. When used they introduce an additional risk of trauma and may be difficult to withdraw. They should not protrude beyond the patient end of the endotracheal tube.

**Anatomy**
Knowledge of the anatomy of the structures surrounding the laryngeal opening will make intubation much easier. (The following structures can and should be visualized in your lab dogs during intubation, in the third year labs.)

- Soft Palate
- Epiglottis
- Glottis
- Vocals folds
- Rima glottides
- Lateral ventricles

Cuneiform and corniculate processes of the arytenoid cartilages

1. Note the position of the larynx and cranial trachea in relation to the esophagus. The larynx is ventral to the esophagus, thus extending the head and neck will facilitate intubation.

2. The cuneiform and corniculate processes project out cranially on both sides of the laryngeal opening and the endotracheal tube will often "hang up" on these structures.

3. Note the position of the soft palate in relation to the epiglottis in the resting animal. The most caudal end of the soft palate usually lies ventral to the tip of the epiglottis and must be displace dorsally during intubation.

4. The vocal folds are pulled laterally during inspiration, making intubation easier at this time, particularly in cats and horses. Horses which are "roarers" may be more difficult to intubate and require a smaller size tube than would normally be required.

**Preoperative Evaluation**

Prior to anesthetizing an animal, the preoperative exam should include an assessment of the animal's mouth and airway.

1. Can the mouth be opened wide enough to allow intubation? Certain conditions such as tumours or diseases of the temporomandibular joint or myositis may prevent the animal or you from opening its mouth. These conditions may be so severe that even under anesthesia the mouth cannot be opened wide enough to permit intubation, and an alternative must be found (e.g. nasotracheal intubation or a tracheotomy).

2. Are there any fractures of the head or neck region of which you need to be careful during intubation?
3. Is the animal's airway normal e.g. hypoplastic trachea, elongated soft palate, roarsers, oral or laryngeal tumours, etc.?

4. Is the animal likely to vomit or regurgitate during intubation? Animals with a megaesophagus should have the esophagus suctioned out prior to intubation.

**Method of Intubation**

1. Patient state of mouth and ability to open patent nares palpate trachea
2. Select tube size type test cuff measure length against outside of patient.
3. Other equipment ready laryngoscope lubricant (sterile) mouth gag. The necessity of a mouth gag and the style of gag will depend on the species and the individual animal. gauze bandage to tie in the endotracheal tube. air syringe to inflate the cuff. emergency equipment (suction, relaxant) stylet
4. Prepare patient wash mouth in horses preoxygenate if necessary.
5. Intubate inflate cuff secure tube observe reservoir bag and or check lung sounds do not use external thoracic compression as a routine check for tube placement.
6. Maintenance check position and patency check cuff "pressure" periodically
7. Extubation suction pharynx if necessary cuff deflated - only partially if foreign material in pharynx remove tube KY Jelly or lidocaine ointment is used to lubricate the tube but it should not be allowed to dry out on the tube.

Secure the tube so it does not move during anesthesia as this increases trauma. Usually the tube is secured to the maxilla in dogs and the mandible in horses. In cats, the gauze is tied around the head behind the ears. Be careful to avoid contaminating the endotracheal tube (e.g. don't put it on the table beside the animal). Inflate the cuff after closing the pop-off valve and while squeezing the reservoir bag. Fill the cuff just to the point that air ceases to escape as evidenced by cessation of sound at the mouth. Do not forget to reopen the pop-off. The cuff volume/pressure will increase as the gases warm up and nitrous oxide diffuses into the air filled cuff. Readjust cuff inflation after 15-30 minutes. Pilot balloon inflation may be a guide when over inflation occurs.

**Causes for failure at intubation include**

1. insufficient depth of anesthesia
2. inexperience
3. trauma, neoplasia, or inflammation of the laryngopharyngeal region
4. inability to open the mouth or extend the head
5. inappropriate choice of tube size. It is essential that, in the face of failure, one neither forces the tube nor traumatizes the oral cavity. Instead, consider nasotracheal intubation, tracheostomy or wake up the patient or choose a method for the conduct of anesthesia.

Intubation for Individual Species

Canine
Dogs are the easiest species to intubate. After induction of anesthesia, the patient is positioned in either sternal or lateral recumbency. The head is extended and the mouth opened and the tongue brought forward. The laryngoscope is used to obtain a good view of the vocal folds and the laryngeal opening. The laryngoscope or the tip of the endotracheal tube can be used to dislodge the epiglottis from the soft palate. The bevel of the E/T tube is then gently slipped between the vocal folds. Occasionally the tube will "catch" on the processes of the arytenoid cartilage on a vocal fold. Do not force the tube to advance. Retract the tube slightly and rotate the position of the tube so the bevelled end slips between the folds easily. It is wise to learn to intubate without putting your fingers into the dog's mouth. This avoids the risk of injury. One-person intubation is possible in a deeply anesthetized dog; preferably using a mouth gag then passing the tube.

Feline
Cats are difficult to intubate because of the deep position of the larynx in the neck and the propensity of cats to have laryngospasms. The use of local anesthetic sprays help by decreasing the tactile perception to start spasm. Intubation is easiest with the cat in sternal recumbency and with the assistant holding the head and neck up by grasping the cat's zygomatic arches. Then open the mouth and pull the tongue forward. Use a small laryngoscope blade to visualize the larynx and slowly and gently pass a tube between the arytenoids when they are open. The tube must not be forced through nor allowed to touch the larynx prior to intubation. Inhalation anesthesia makes intubation easier compared to light thiobarbiturate anesthesia which seems to increase spasm. Ketamine, either as a premedication or induction agent, makes intubation easier despite the fact that laryngeal reflexes are supposed to remain intact. Laryngeal spasm does not occur during deep general anesthesia. However, very deep anesthesia is not recommended as a routine procedure for intubation. Should several attempts at intubation fail, the anesthetized cat may be paralyzed by the administration of a relaxant drug such as succinylcholine after it has inhaled 100% oxygen for 1 to 2 min. to prevent hypoxia during the subsequent intubation. The cat must be ventilated until spontaneous respiration returns.
Equine

The primary problems are an inability to visualize the larynx and the high seating of the epiglottis. Oral (or nasal) intubation is done blindly with repeated but gentle passes at the larynx. Position the horse in lateral recumbency with the head extended. The mouth is opened and a gag or block inserted. The tongue is held down and to the side to allow tube to pass over the dorsum of the tongue and engage the larynx. If the tube has much of a curve, another technique is to turn the concave side towards the hard palate until the tip pushes up the soft palate and is over the epiglottis. Then by rotating the tube 180 degrees pass it into the larynx. When the tube passes into the trachea it should meet no resistance. If it does it is either in the esophagus or "caught" on the arytenoids or vocal folds. The tube is withdrawn 2-6 cm, rotated slightly and passed forward again. Nasal intubation is fairly easy in horses but requires a tube one to two sizes smaller than for oral intubation.

Bovine

Except for small cows or calves, laryngeal visualization is not possible. Intubation is carried out blindly or by manual guidance. The technique of blind intubation is not easy and has the animal at increased risk of aspiration. The more common method is to put in a strong and secure mouth gag (Hauptner or Bayer's) and use one arm to enter the pharynx and identify the laryngeal glottis. The tube is passes up beside or under the arm and guided into the trachea. It is a tight fit for both arm and the tube and it is important to avoid tearing the cuff on the teeth. A variation of the manual method is to place a 3-5 mm polypropylene or nylon guide into the trachea and then to pass the tube over the guide. The guide must be at least three times longer than the endotracheal tube or it will be lost inside the tube. If regurgitation occurs during intubation, an E/T tube should be put quickly into the esophagus, inflating the cuff, and guiding rumenal contents out of the mouth via the tube.

Ovine & Caprine

In sheep and goats (and calves) endotracheal intubation is best performed by blind intubation which is simpler with these animals than with adult cattle. Sometimes the tube needs to be stiffened with a stylet and given a good curve to get over the back of the tongue. Intubation is also possible under direct vision with the aid of a laryngoscope.

Porcine
Pigs are probably the hardest domestic species to intubate. The rima glottis is small and the larynx is set at an angle to the trachea, making it difficult to pass a tube beyond the cricoid ring. A curved tube tends to get lodged into the ventral diverticulum of the larynx. Intubation is made easier with a small diameter long tube that has been straightened with a stylet. Use a laryngoscope if possible and rotate the tube 180 degrees as it passes through the larynx.

Avian

Intubation is very easy in birds with the larynx visible in the base of the tongue when the mouth opens. The main danger is over inflation of the cuff and tracheal damage. The trachea of birds is not flexible due to complete tracheal rings in most species.

Lagomorphs & Rodents

These are difficult species in which to visualize the very small larynx. Intubate rabbits blindly. Once anesthetized, position the animal in sternal recumbency and extend the head in a vertical position as much as possible and pass the tube down to the larynx. (Do not pull the tongue out). Listen for respiratory sounds through the tube and gently rotate until the tube passes into the trachea. Guinea pigs and hamsters are even more difficult with the additional problem of food pouches. Use an otoscope or small laryngoscope blade to try and visualize the larynx.

Llamas

Llamas have a very deep-seated larynx and a very narrow jaw (somewhat similar to rabbits). They are extremely difficult to intubate. A further complication is their tendency to regurgitate if the larynx is stimulated under light anesthesia. Make sure that anesthesia is adequate and keep the llama in sternal recumbency until an endotracheal tube has been correctly placed and the cuff inflated. The head should be extended vertically on the neck. Blind intubation may be accomplished (similar to the rabbit) or a long-bladed laryngoscope may be used to visualise the larynx. Direct intubation may be possible or a long stylet passed into the trachea and the endotracheal tube passed over it. Complications of Endotracheal IntubationLaryngoscopy and Intubation trauma hypertension and tachycardia dysrythmias aspiration trauma to handlers aggravation of spinal injuries Tube in place misplacement (endobronchial or esophageal) obstruction (foreign body, kink, cuff, bevel) accidental extubation aspiration bronchospasm tracheal epithelial ischemia aspiration of tube Immediate and delayed complications following extubation laryngospasm aspiration laryngeal edema or ulceration tracheitis introduction or bacteria or foreign matter into lung vocal cord damage webs or stenosis secondary to tracheitis MANUFACTURERS AND SUPPLIERS
Rusch Inc., New York, NY Suggested Tube Sizes

<table>
<thead>
<tr>
<th>Animal</th>
<th>Weight Range</th>
<th>Tube Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-4 kg</td>
<td>4-5 mm</td>
</tr>
<tr>
<td></td>
<td>7 kg</td>
<td>6.0 mm</td>
</tr>
<tr>
<td></td>
<td>9 kg</td>
<td>7.0 mm</td>
</tr>
<tr>
<td></td>
<td>12-14 kg</td>
<td>9-10 mm</td>
</tr>
<tr>
<td></td>
<td>16-18 kg</td>
<td>11-12 mm</td>
</tr>
<tr>
<td></td>
<td>20-25 kg</td>
<td>12-14 mm</td>
</tr>
<tr>
<td>Feline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>kittens</td>
<td>2-3 mm</td>
<td>Cole or uncuffed</td>
</tr>
<tr>
<td>adults</td>
<td>3 - 4.5 mm</td>
<td>Cuffed</td>
</tr>
<tr>
<td>Equine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foals</td>
<td>9 - 14 mm</td>
<td></td>
</tr>
<tr>
<td>Small Ponies</td>
<td>14 - 16 mm</td>
<td></td>
</tr>
<tr>
<td>Thoroughbreds</td>
<td>26 - 30 mm</td>
<td></td>
</tr>
<tr>
<td>Draft Horses</td>
<td>30 - 36 mm</td>
<td></td>
</tr>
<tr>
<td>Bovine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calves 3 months</td>
<td>9 - 12 mm</td>
<td></td>
</tr>
<tr>
<td>Calves 6 months</td>
<td>14 - 18 mm</td>
<td></td>
</tr>
<tr>
<td>Yearling cows</td>
<td>22 mm</td>
<td></td>
</tr>
<tr>
<td>Mature cows</td>
<td>26 mm</td>
<td></td>
</tr>
<tr>
<td>Large Bulls</td>
<td>30 mm</td>
<td></td>
</tr>
<tr>
<td>Caprine &amp; Ovine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>7 - 9 mm</td>
<td></td>
</tr>
</tbody>
</table>
Porcine
25 kg  6 mm
50 kg  9 mm
Large sows and boars  10 - 14 mm

Rodents & Lagomorphs
Rabbits  2 - 4 mm
Guinea Pigs  2 - 3 mm

Anesthetic Drug Check List

The following are the major groups of anesthetic agents used in the Veterinary Teaching Hospital and the names of some examples of individual agents.

1. Tranquilizer/Sedatives
   a. Phenothiazines. e.g. Acepromazine.
   b. Butyrophenones. e.g. Azaperone.
   c. Benzodiazepines. e.g. Diazepam.

2. Sedative/Hypnotics
   a. Alpha-2 Agonists. e.g. Xylazine.
   b. Chloral Hydrate.

3. Opioid Analgesics
   a. Morphine Sulfate
   b. Meperidine HCl.
   c. Fentanyl Citrate
   d. Oxymorphone
   e. Sufentanil
   f. Butorphanol

4. Commercial Neuroleptanalgesics
   a. Innovar-Vet (Droperidol/fentanyl)

5. Anticholinergics
   a. Atropine
   b. Glycopyrrolate
6. Peripheral Muscle Relaxants
   a. Succinylcholine
   b. Pancuronium
   c. Atracurium
   d. Vecuronium

7. Centrally Acting Muscle Relaxants.
   a. Guaifenesin.
   b. Benzodiazepines

8. Inhalation Agents
   a. Ether (Not used clinically due to its explosive nature)
   b. Halothane
   c. Methoxyflurane
   d. Isoflurane
   e. Nitrous Oxide

9. Injectable Agents
   a. Barbiturates. e.g. Thiamylal, thiopental
   b. Cyclohexamines. e.g. Ketamine
   c. Steroid Anesthetics. e.g. Saffan
   d. Alkyl Phenol derivatives e.g. Propofol
   e. Imidazoles. e.g. Etomidate.