Anesthetic Machines

Lyon Lee DVM PhD DACVA

Introduction

- Various equipments are used to deliver volatile anesthetics and carrier gas (eg, oxygen).
- Relatively sophisticated, expensive, and yet cumbersome equipments are used for administering volatile anesthetics.
- Most anesthetic delivery systems contain the same components. They reduce the high pressure of compressed gases and allow precise mixing with potent inhalant anesthetics for safe delivery to the patient through breathing circuits.
- Primary requirements to deliver volatile anesthetics to a patient are;
    - Carrier gas - cylinders of oxygen, atmospheric air
    - Pressure regulator
    - Flowmeter
    - Vaporizer
    - Patient breathing circuit
    - Mask or endotracheal tube
- An anesthetic machine can be functionally subdivided into the following four components
    1) High pressure system – where the pipeline and cylinder gas supplies are attached
    2) Low pressure system – where O_2 and volatile anesthetics are mixed
    3) Breathing system – where the anesthetic gas mixture is delivered to the patient
    4) Scavenging system – where excess gas from the breathing system is collected and diverted into the waste gas evacuation system
- Figure 1 depicts an anesthetic machine and its parts.

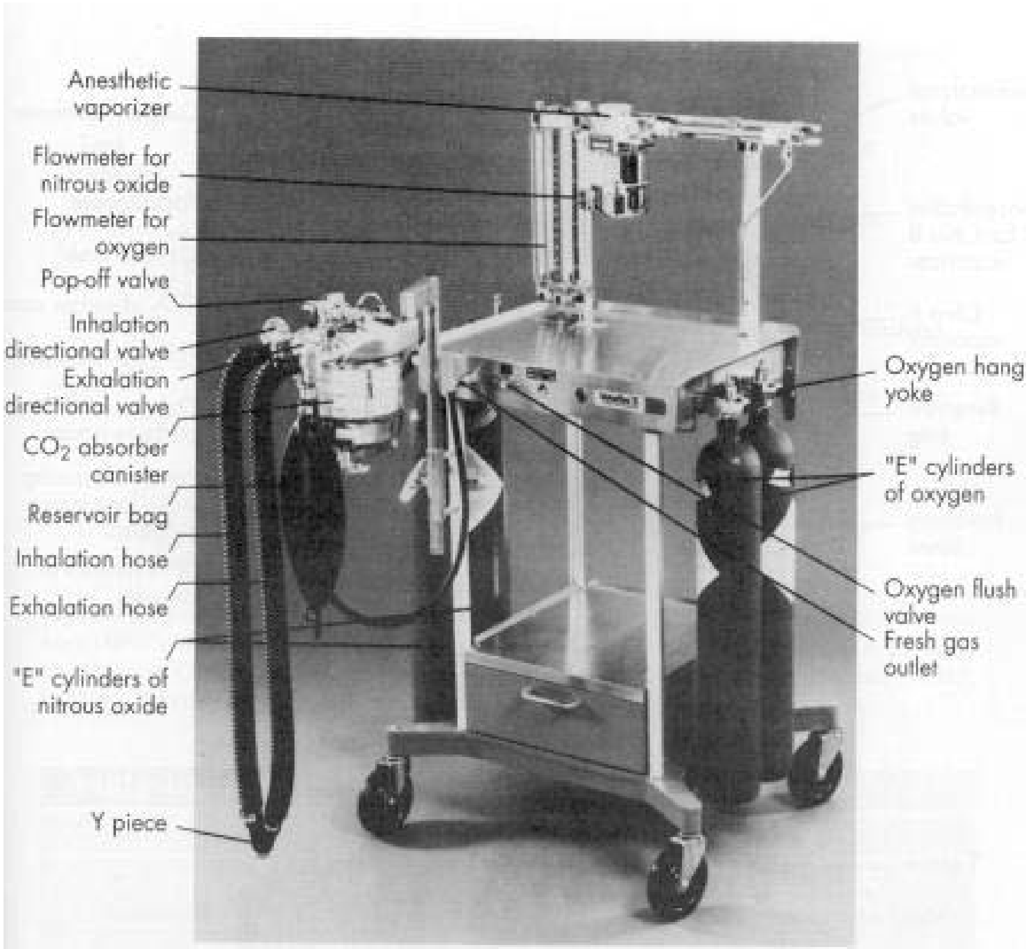

Figure 1. Anesthetic machine and its parts

Carrier gases

- The carrier gases are used to supply a minimum of 20% oxygen, and to vaporize volatile anesthetics, and to dilute them.
- They come in color-coded compressed cylinders (see table 1)

Table 1: Color coding of medical gas cylinders and their pressure when full

AGENT	FORMULA	UNITED STATES	INTERNATIONAL	STATE IN CYLINDER	FILLING PRESSURE (P.S.I.)
Oxygen	O_2	Green	White	Gas	2,200
Nitrous oxide	N_2O	Blue	Blue	Gas + Liquid	750
Carbon dioxide	CO_2	Gray	Gray	Gas + Liquid	800
Helium	He	Brown	Brown	Gas	1,650
Air		Yellow	White & Black	Gas	1,900

- Cylinder sizes are letter-coded, with A being the smallest. Size E is the cylinder most commonly used attached on anesthesia machine.
- E cylinders are readily portable but the large G or H cylinders are cumbersome to move around yet contain considerably more gas and are typically less expensive to use. H tanks are commonly used in veterinary practice usually staying in the operating room. A full H tank contains approximately 6,600 liters of oxygen with filling pressure of 2,200 psi.

- For central pipeline gas delivery, G or H tanks may be arranged in series or banks and used away from the operating room.
- A full E size oxygen cylinder contains approximately 660 L volume of oxygen at 2,200 psi (pound per square inch). The pressure gauge reading can be used to estimate remaining amount of oxygen as the tank depletes by multiplying a fudge factor of '0.3'. For example, if pressure gauge reads 1000 psi, then the oxygen in the cylinder is estimated to contain 300 L (0.3 x 1100), and at the oxygen flow rate of 3 L/min, it should last approximately 100 minutes before running out of oxygen. The fudge factor becomes '3' for size H tank for estimation of the gas amount, which is calculated in the same manner.
- Nitrous oxide is present within the cylinder as a liquid and a gas and its pressure is constant at 750 psi until all the liquid is depleted and remaining gas is used, which then falls. The only way to estimate the amount of gas within a nitrous oxide cylinder is to weigh the full tank and subtract the weight of the tank in question. In general, if the pressure starts to fall, 25% of the gas remains in the cylinder. An E size full nitrous oxide cylinder contains 1,600 liters of the gas.
- Cylinders should be handled with care and are subject to regulatory control over its use.
- If a cylinder is dropped it may explode because of its high pressure.
- Most machines have a hanger yoke for attaching one or more cylinders, which are key-coded to prevent accidental misuse of a carrier gas. Pin-indexed safety system (PISS) is common for cylinder attachment, but diameter-indexed safety system (DISS) is used for centralized pipeline attachment.
- For firm attachment of a cylinder to the anesthesia machine in a 'hanger yoke over a pin' configuration, a 'Bodock seal' (small washer) is needed around the inlet on the yoke.
- The machine should have some form of warning device (eg., whistling) to alert to oxygen failure (oxygen "fail-safe" system), and where N_2O is included, an N_2O cut-off device (as O_2 fails) should also be included.

Pressure regulator (Pressure reducing valves)

- Pressure reducing valves are built into most anesthetic machines.
- High-pressure gas within the cylinder is a danger to the patient and the pressure regulator reduces it to working level of 45 psi
- This ensures that high pressure gas does not enter to the flowmeter.
- It maintains constant flow in response to changes of pressure in a cylinder.
- It allows a wide range of flowmeter settings.
- The difference in pressure (pipeline gas at 50 psi; cylinder gas at 45 psi) forces the anesthetic machine preferentially use gas supply from the pipe line gas when both sources are attached to the anesthetic machine.

Flowmeters

- Flowmeters control the flow rate at which a specific gas passes through them.
- They are individually calibrated for each gas.
- For flow rates above 1 liter per minute the units are L/min, and flow rates below 1 liter per minute the units are 100 ml/min.

- The most common gas flowmeter is rotameter; it contains a ball or bobbin that rises within a glass tube to a height proportional to the flow of gas passing through the tube; the gas flow rate is read at the widest diameter of the ball or bobbin.
- Individual gas flows are combined downstream from the flowmeters; from here gases move to an out-of-circuit vaporizer or directly to the anesthetic circuit.
- A crack in the flowmeter may result in hypoxic mixture and the oxygen flowmeter should be the last in a series of flowmeter to avoid this.

Oxygen flush valve

- It allows the gas bypass the vaporizer and deliver directly to the anesthetic circuit via the common gas outlet
- It delivers oxygen flow between 35 to 75 L/min. Beware as this large amount of gas delivery can over-pressurize small-sized lungs, particularly in a non-rebreathing circuit, resulting in a pneumothorax.
- It dilutes the anesthetic concentration in the breathing circuit.
- It is best to fill the breathing circuit using flow control valve (flowmeter).

Common gas outlet

- The exit from the anesthetic machine for blended gas mixtures of carrier gas and volatile anesthetics.
- Most machine outlets have a 15 mm inner diameter slip-joint connection (that will accept a tracheal tube connector), with a 22 mm connection for outer diameter.
- It is a frequent source of gas leaks, so some machines come with a retaining device at the connection to make it harder to disengage.

Vaporizers

- An ideal vaporizer is one which will always give accurately known concentrations of anesthetic vapor at all flows and temperatures.
- Such does not exist, but modern expensive ones, such as the Fluotec Mark III or later, do so over the usual working range (eg, above 12 ºC).
- Points to consider
  - Temperature sensitivity
    - Non compensated e.g. Boyle bottle.
    - Temperature buffered e.g. Copper kettle.
    - Temperature compensated, e.g. Tech series vaporizer, Vapor 19.1, Ohio calibrated vaporizer, Penlon PPV sigma vaporizer
  - Flow sensitivity
    - This is difficult to predict. The Fluotec Mark III and similar models are compensated for flow changes down to approximately 500 ml/min.
  - Efficiency
    - This is increased by increasing the gas-liquid interface area available for vaporization, e.g. by bubbling through a Boyle bottle, or by adding wicks.
    - A high efficiency is not always an advantage.
  - Resistance

- If the gas is powered through the vaporizer by the compressed cylinder gases, the resistance is not critical but where the power comes from the patient's breathing (i.e. the vaporizer is in the breathing circuit), a specially designed low resistance draw-over vaporizer (e.g, the Ohio No. 8, Komasarof, Goldman) must be used.

- Many types of vaporizers are available and simple classification is not possible. Table 2 summarizes the classification of vaporizers.

Table 2. Classification of vaporizers

CHARACTERISTICS & CLASSIFICATION	TYPES
Precision of control of the output concentration	1. Precision 2. Non-precision
Method of regulating output concentration	1. Concentration calibrated or variable bypass 2. Measured-flow or Kettle type
Method of vaporization	1. Flow over 2. Bubble through 3. Injection
Temperature compensation	3. Thermoconcentration 4. Supplied heat
Location	1. In the circuit 2. Out of the circuit
Specificity	1. Agent specific 2. Multiple agent
Resistance	1. Plenum 2. Low resistance

- Commonly accepted simplified classification of vaporizers are 'precision' and 'non-precision' ones.
- The precision vaporizers are more widely used both in human and veterinary medicine.
- They have two chambers; vaporizer and bypass. A portion of oxygen flow passes through the vaporizer chamber and another portion bypasses. The gases rejoin exiting the vaporizer providing intended concentration as set on the dial of the vaporizer. Figure 2 depicts the anatomy of a precision vaporizer.
- Characteristics of a precision vaporizer are
    - concentration calibrated or variable bypass
    - flow over
    - thermocompensated
    - agent specific
    - high resistance

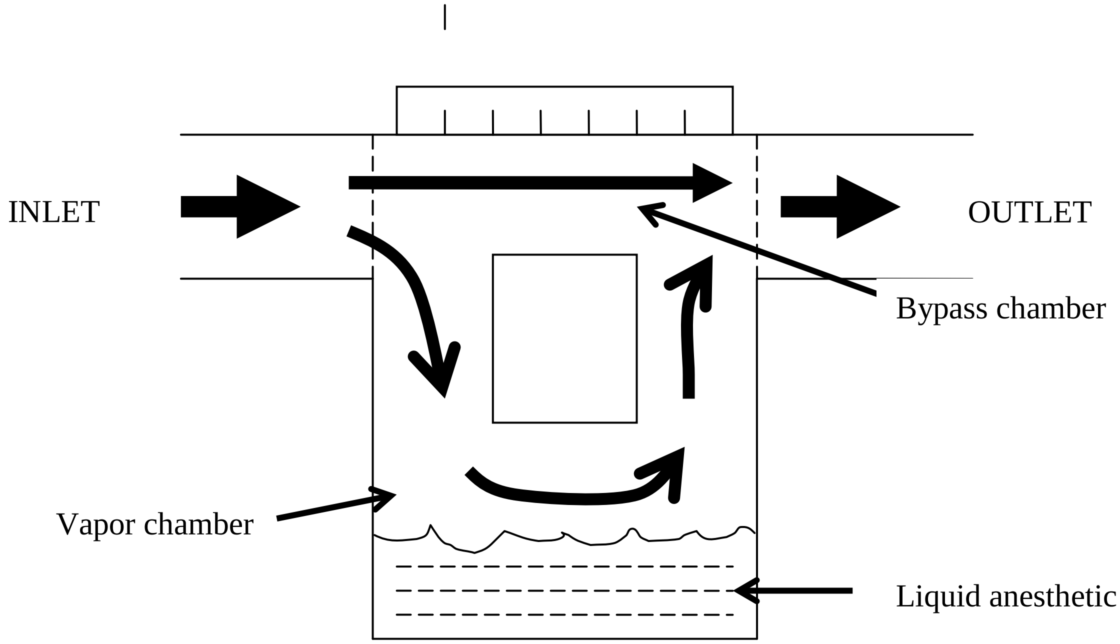

Figure 2. Schematic diagram of a precision vaporizer

Monitoring the anesthetic machine

- In modem human anesthesia a large variety of monitors of the anesthetic machine function are considered essential, and are set to "fail safe" (i.e. the machine cannot be used at all if the monitor is not functioning).
- Examples of monitors are;
  - oxygen pressure warning alarms and nitrous oxide cut off devices (both of which should also be used on veterinary machines)
  - inspired and expired pressure measurements (to detect if tubing is blocked)
  - inspired oxygen concentration
  - inspired and expired carbon dioxide concentrations
  - volatile anesthetic concentrations
  - disconnection alarms

Further References:

1. Veterinary Anesthesia Hall, Clarke and Trim. WB Saunders 2001
2. Veterinary Anesthesia Thurmon, Tranquilli and Benson. Williams & Wilkins 1996
3. Handbook of Veterinary Anesthesia Muir, Skarda, Hubbel. Mosby 2000