2.17 Anesthesia Machines

2.17.1 Clinical Use and Principles of Operation

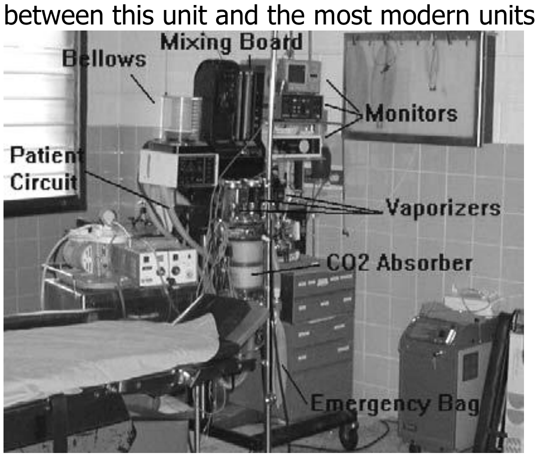
Anesthesia is defined as the loss of feeling or sensation. During most surgical procedures, some form of anesthesia is used. There are at least four different types of anesthesia that are encountered in the developing world.

General anesthesia is a state of unconsciousness, with an absence of pain sensation over the entire body, produced by anesthetic agents, often with muscle relaxants. General anesthesia is administered by inhalation, intravenously, intramuscularly, rectally or via the stomach. Local anesthesia is where a specific area is "numbed" such as in a dentist's office. The patient is awake and may feel some limited pain. Saddle block anesthesia is where the patient is conscious and the area of the body that would touch a saddle is affected. This is accomplished by injecting an anesthetic agent low in the dural sac and is common for childbirth. Spinal anesthesia is where an anesthetic agent is injected beneath the membrane of the spinal cord. There is no sensation below that point until the agent wears off.

General Anesthesia unit, inhalation

The anesthesia machine, sometimes called a Boyle machine, works by mixing selected concentrations of gases and drugs that the patient inhales. Consciousness is regained relatively quickly after the procedure terminates.

This anesthesia machine in Togo shows all the basic components. There is little difference between this unit and the most modern units seen in the US.



Anesthesia machines are generally large, on wheels, and contain one or more vaporizers, flow tubes, attachments for compressed gas cylinders, a ventilator, ports for obtaining compressed gases from wall connections, a carbon dioxide absorber other gas traps (or scrubbers) and various monitoring devices either built in or attached to the unit. These machines can cost over $60,000.00 to purchase and require regular maintenance. Some of the maintenance requires specialized testing equipment that may not be available in a developing world hospital, including devices for the measurement of the concentration of gases, flow rates and pressures. Additional training is typical in western hospitals before attempting any calibration or repair of the gas delivery system. However, in the developing world, repair, calibration and maintenance are often done by whoever is available.

The flow of gases can be traced from the source to the patient. Typically, compressed gases such as air, oxygen, and nitrous oxide are supplied from gas cylinders or from wall outlets. By passing through a pressure regulator, gas in a cylinder is reduced from thousands of psi to a typical delivery pressure between 20 and 50 psi (regulators and cylinders are covered elsewhere is this book). From the regulator, gas in the line will often pass through an O2 failure detector. Next the gases enter the mixing board which contains rotameters for measuring gas flow. From there, the gases move through vaporizers where a volatile agent such as halothane will be added to the mixture. Delivery of the final gaseous product to the patient is achieved with a series of tubes, valves and a mask that is referred to as the anesthesia circuit.

Vaporizers

Vaporizers are used to convert a liquid anesthetic agent into a vapor. Because they are designed to function under continuous pressure and flow environment, they are sometimes called plenum vaporizers. As air enters the vaporizer, it is directed into either the vaporizing chambers or a bypass chamber. The anesthesiologist will control the bypass valve to allow more or less of the incoming gases to flow through the vaporizing chamber usually via a large knob on fob of the vaporizer. The liquid anesthetic agent resides in the lower part of the unit. As the gas moves across the top of the liquid, the anesthetic agent vaporizes and is carried by the gas towards the outlet, where it is blended with the gas that had bypassed the chamber.

Two vaporizers (for two different anesthetics) sit to the right of the mixing board and a large manometer.

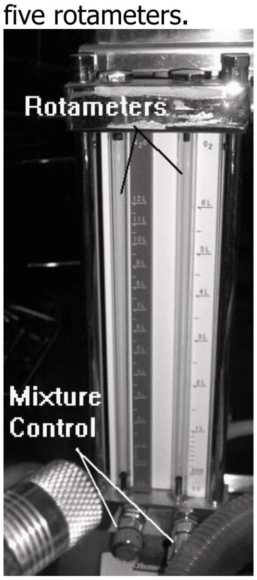
Since vapor pressure is affected by temperature, a warm environment would normally encourage more of the anesthetic agent to vaporize and a cold environment less. Furthermore, the process of vaporization itself removes heat from the vaporizer and the anesthetic agent. In order to compensate for temperature effects, a bi-metallic valve is added to the by-pass system. The bi-metallic valve physically distorts to adjust for temperature changes. It is possible to compensate for temperature variations by warming the fluid to a fixed temperature, but this approach is less common.

The vaporizer should be maintained level as operation out of level can affect the calibration. Also, when working with a vaporizer, care should be exercised not to tip vaporizer as this can cause a hazardous spill. Should a spill occur, water can be used to clean up the anesthetic agent and doors should be opened to clear the vapors. Vaporizers should generally be calibrated every six months; however, in the developing world this is rarely undertaken. Vaporizers are very reliable, but if the vaporizer does break, it must be sent back to the factory or other qualified repair service. There is little a field engineer can do to repair a broken vaporizer.

Rotameters

A mixing board on the anesthesia machine will allow the anesthetist to mix oxygen, anesthetic gases and the patients expired air to the desired ratios for delivery to the patient. The ratio of the fresh gasses is continuously measured by their flow rates. A typical mixing board will contain several rotameters for measuring gas flow. Rotameters are made from either glass or plastic tubes containing a metal or ceramic ball that serves as a float. The walls of the rotameters are slightly "V" shaped so that as the ball rises, more of the gas is diverted around the ball lowering the force upwards on the ball. When the force of gravity is just balanced by the force upwards of the gas, the ball will stop moving. As the flow rate increases, the ball moves up and as the flow rate decreases, the ball moves down. However, as the ball moves up, the force of the gas on the ball drops because more of the gas is diverted around the ball. Thus, the height of the ball can be used to determine the flow rate of the gas in the rotameter.

A small mixing board with only two rotameters. In some anesthesia machines there can be four or five rotameters.



Rotameters are calibrated in cubic centimeters (cc) or milliliters (ml) of gas per minute. The amount of each gas entering the mixing board is controlled by needle valves at the base of each rotameter.

Gas Handling

Anesthesia gases are supplied from tanks that are mounted on the anesthesia cart or from a central source in the hospital. In the latter case, there will be wall mounts in the room with specialized fittings so that hoses are not misconnected. As a safety feature, gas tanks may have what is called a pin index connection that allows only specific yokes to be connected to the tank. The tank is attached to a yoke that has pins sticking out that match the holes in the neck of the tank. During every inspection of the anesthesia unit, the pins on each yoke should be verified that they are present and in the correct positions for the designated tank. However, in the developing world as donations may come from many sources, the pin indexes may be missing, tampered with or ignored. A backup to the pin index is the color-coding of the paint on the tanks. In the US, oxygen tanks are painted green (blue in some other countries) while nitrous oxide tanks are blue and air tanks are yellow. Similarly, the connection hoses for the centralized gas system should be color coded to match the gas tank. Europe has a different color-coding scheme, and in the developing world, there may be no system to the color of the tanks or hoses.

Faced with unmarked tanks, connectors and hoses, the engineer should first thoroughly discuss the system, and label it, before attempting service.

The modern anesthesia machine will contain a purge button which serves as a bypass button, bypassing the mixing board, vaporizers and rotameters. This button allows for 100% oxygen to flow to the patient connection. It is used before a surgical case begins to clear out any residual gases from the patient connection. Additionally, it is used to provide a quick burst of oxygen to the waking patient (and reduce the level of anesthesia to the patient) as the case terminates.

Since the expired gases of the patient contain anesthetic agents, they must not be allowed to enter the operating room. In addition to potentially placing the operating staff under the anesthetics effects, certain agents are flammable, and chronic exposure can cause high fevers and severe liver damage. To remove this danger, anesthesia machines will contain a scavenger (or scrubber or trap) before venting the expired gas into the room. In the developing world, the activated carbon may not be changed –or even available– forcing the staff to vent the expired gas outside.

In the expired air is to be rebreathed - that is, returned to the patient - then a CO_2 absorber is used. A CO_2 absorber contains a soda-lime filter that strips the expired gases of CO_2.

This scavenging system shows the CO_2 absorbing material (white material in glass container behind cage in lower left). Two valves are shown under the glass domes in the middle right.

Self-inflating bags or bellows are purely mechanical devices that allow the anesthetist to measure the patient's ventilation. By its movement in a calibrated chamber, a bellows indicates the volume of air that the patient is breathing. The bellows will rise when the patient exhales and will fall when the patient inhales.

The bellows may be connected to a ventilator that controls the patient's ventilation. The ventilator forces air into the patient's lungs at a prescribed rate and volume. Ventilators are covered elsewhere in this text. When intermittent ventilation is required, the doctor can use a bag (emergency bag), or reservoir bag. The bag allows the doctor to manually push air into the patient's lungs. This bag is also used to give the anesthetist a sense of the patient's lung compliance and resistance, which can be used to indicate that more or less anesthetic agents are needed or that the physiology of the lungs is changing.

The Circuit

The circuit contains tubing and valves required for the operation of the anesthesia machine. Both the bellows and self-inflating bag are filled through a non-return valve that ensures that the proper gases are always delivered to the patient. The circuit will also contain a non-rebreathing expiratory valve at the patient end that diverts inspired and expired gases through two different pathways. Often, these non-rebreathing valves are part of the circuit. The circuit includes the connection to the patient, the mask, endotracheal tube and other components.

While considered a disposable item, in the developing world, the circuit may not be replaced after every patient. Even in the developed world, there may be connections to and from the absorber that, while part of the circuit, are not replaced with each use. If the circuit is to be reused, after patient use, it is best to hang the tubing vertically to dry in a storage area.

Monitoring

The anesthesia machine may also have a monitor for the patient's ECG, invasive or non-invasive blood pressure, and pulse oximetry. More details about these monitors are available in their respective chapters.

Drawover Anesthesia

A drawover anesthesia system provides anesthesia without necessitating a supply of compressed gases. Drawover anesthesia systems have the added advantages of being (1) inexpensive to purchase, (2) easy to maintain, and (3) compact and portable. In using a drawover system, atmospheric air serves as the primary carrier gas and is drawn through the vaporizer by the patient's inspiratory effort. Whether a patient is being artificially ventilated or breathing spontaneously, the patient will draw air through the vaporizer. Therefore the vaporizer must have a low resistance to the intermittent gas flow. Once in the vaporizer, the atmospheric air mixes with the anesthetic agent which is typically ether or halothane. The patient now inhales this air via a non-rebreathing valve. Low-flow oxygen, such as from an oxygen concentrator, may be added to the drawover system by using a T-connector

General Anesthesia, Injectables

Injectable anesthesias are cheaper and therefore more common in the developing world than in the US. They are more dangerous as an overdose cannot be as easily reversed. These agents are combined with muscle relaxants and should be used only for short-term procedures. Ketamine is a very common general anesthetic agent, and lidocaine is a popular local anesthetic. No additional equipment is required to use these agents.

2.17.2 Common Problems

As with other pieces of medical equipment, power supply and user error problems account for most of the problems in anesthesia machines. Injectable anesthetics are not generally referred to the technician when there is a problem. Drawover machines have fewer problems than other anesthesia machines, but all machines suffer from with leaks and sticky valves.

Leaks

Tubes tend to deteriorate in hot and humid environments. Also, reusing disposable materials tends to favor deterioration. An expiration-side leak occurring before the scavenger is most critical to check, but also the easiest because anesthetic gases have a distinctive smell which is easily detected. If a leak occurs in the OR, doors to the room should be opened to allow air to flow through the room (consult with the staff before doing so). Moreover, a second danger with gas leaks is that some anesthetic gases are flammable. Halothane and ether are two explosive anesthetic gases.

The tubing most often develops leaks in between the corrugations. You can check for leaks by placing the tubing in a bucket of water, blocking one end, blowing in the other, and looking for bubbles to escape. Repair tubing leaks with epoxy or a silicon sealant. However, this is a temporary repair. It is better to replace the tubing. In some cases, the tubing can be shortened to remove the leaking section. Consult with the anesthetist before shortening a section of the circuit.

Other problems

The monitoring devices are covered in other sections of this book.

The needle valves controlling the flow into the rotameters can be sticky or blocked. Also, the floats in a rotameter can be stuck. Rotameters and needle valves can be dismounted and flushed alcohol. Make sure they are completely dry before using again. When taking apart multiple rotameters, floats and needle valves, be sure to put them back together in a set. The float from one gas may not work in the glass tube from another. One simple solution is to disassemble only one rotameter at a time.

If there are valves which appear to be sticky in the circuit, the circuit needs to be replaced. Other sticky valves may be cleaned with water and dried thoroughly before reuse.

If the problem is in the ventilator, CO_2 absorber or vaporizer, and the problem is not a leak, the problem is typically very difficult to repair in the field. It is generally necessary to replace the entire subunit with one from another anesthesia machine.

2.17.3 Suggested Minimal Testing

If the device has been removed from the operating room due a problem that you have now fixed, you should test it before returning it to use. However, most often you will not have the equipment required to test the function of a vaporizer, CO_2 absorber or ventilator. As the surgical schedules may be severely affected or even halted until the anesthesia machine is working, it may not be in the hospitals patient population's best interests to wait until you have the proper testing equipment to release the anesthesia machine for use. If a repair resulted in a replacement of the vaporizer, absorber or ventilator, you will need to consult with the anesthetist on what testing will be required before use.

If the repair required the fixing of a leak, it is sufficient to retest the tubing to insure that the leak is repaired.

If the repair involved the rotameters, they should be checked before use, even if the problem was just a sticky valve or float. A simple way to check flow rates is to flow the gas into a calibrated balloon for 60 seconds. The volume can be approximated by connecting a balloon to the patient tubing. You must calibrate the balloon to volume before you begin. The easiest way to do this is to fill the balloon with a known volume of water. Make two marks on the balloon a fixed distance apart, indicating the volume next to the mark. Repeat this procedure for several volumes. Now, when the balloon expands to the indicated volume, the marks should be your set distance apart.