Anesthesia Machine

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Although anesthesia has been generally described as the part of the medical profession that ensures that the patient's body remains insensitive to pain and other stimuli during surgical operations, anesthesia is understood as a patient care within four different domains: sedation (reversible patient unconsciousness), relaxation (temporal reduction of the motoric functions of the patient in order to ease the surgical procedures), analgesia (insensitivity to pain), and respiration (granting the respiratory function in order to avoid permanent damage to the different tissues), which has led medical device manufacturers to develop complex machines for anesthesia delivery and patient monitoring.

Figure 1, which shows a typical setting found in many operating rooms, includes the equipment required for the delivery of vaporized and intravenous agents in order to allow the proper sedation method for each patient and surgical procedure.

The main elements of the anesthesia delivery system illustrated include the gas supply system, the gas mixing subsystem, the vaporizer for inhaled agents, the mechanical ventilator, the breathing circuit of the patient, the absorber for CO_2 removal, the infusion pumps required for intravenous anesthesia, and the monitoring subsystem for patient and equipment supervision.

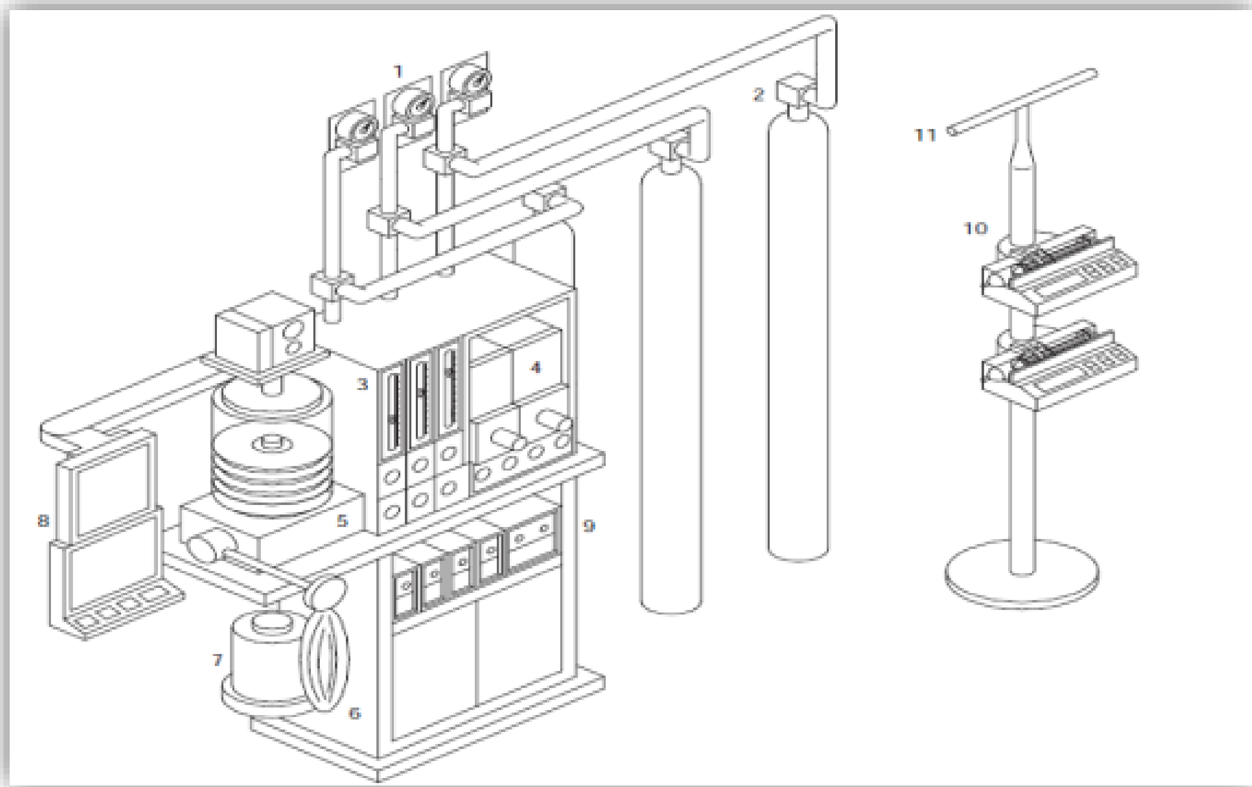

Figure 1. Simplified view of the anesthesia machines in the operating room. (1) Central gas supply (oxygen, nitrous oxide, and air), (2) high-pressure gas cylinders, (3) gas flowmeters and mixing controls, (4) anesthetic agent vaporizers, (5) mechanical ventilator, (6) breathing reservoir bag, (7) absorber for carbon dioxide removal, (8) patient and machine monitors, (9) monitoring amplifier modules, (10) infusion pumps, and (11) standing pole.

Principles of Operation

- An anesthesia machine is a device that delivers a precisely-known but variable gas mixture, including anesthetizing and life-sustaining gases. In this sense, anesthesia units dispense a mixture of gases and vapors of known concentrations in order to control the level of consciousness or analgesia of the patient undergoing surgery.
- Anesthesia is achieved by administering a mixture of O_2, the vapor of a volatile liquid halogenated hydrocarbon anesthetic, and, if necessary, N_2O and other gases. As

spontaneous breathing is often depressed by anesthetic agents and by muscle relaxants administered in conjunction with them, respiratory support is usually necessary to deliver the breathing gas to the patient.

For these purposes, the anesthesia machine must perform the following functions:

- Assuring the proper oxygen (O2) flow delivery to the patient.
- Vaporizing the volatile anesthetic agent and blending it into a gas mixture with O2, nitrous oxide (N2O), other medical gases, and air.
- Granting the ventilation of the patient by controlling spontaneous ventilation and using mechanical assistance if needed.
- Minimize the anesthesia-related risk to the patient and the clinical personnel.

- In Figure 2, the gas flow supplied by either the pipelines (2) or the security high-pressure cylinders (1) is regulated at the flow meters (5) and mixed in the common gas manifold entering the vaporizer (8), where this mixture is vaporized with the anesthetic agent used. This fresh gas flow is then sent to the patient through the breathing circuit (12), that also collects the expired gas in order to process it through the circuit selected (15). In either case, the gas will pass through the absorber (14) in order to remove carbon dioxide before returning to the inspiratory branch. If mechanical ventilation is used, the ventilator (18) sets the inspiratory and expiratory cycles according to the control adopted.

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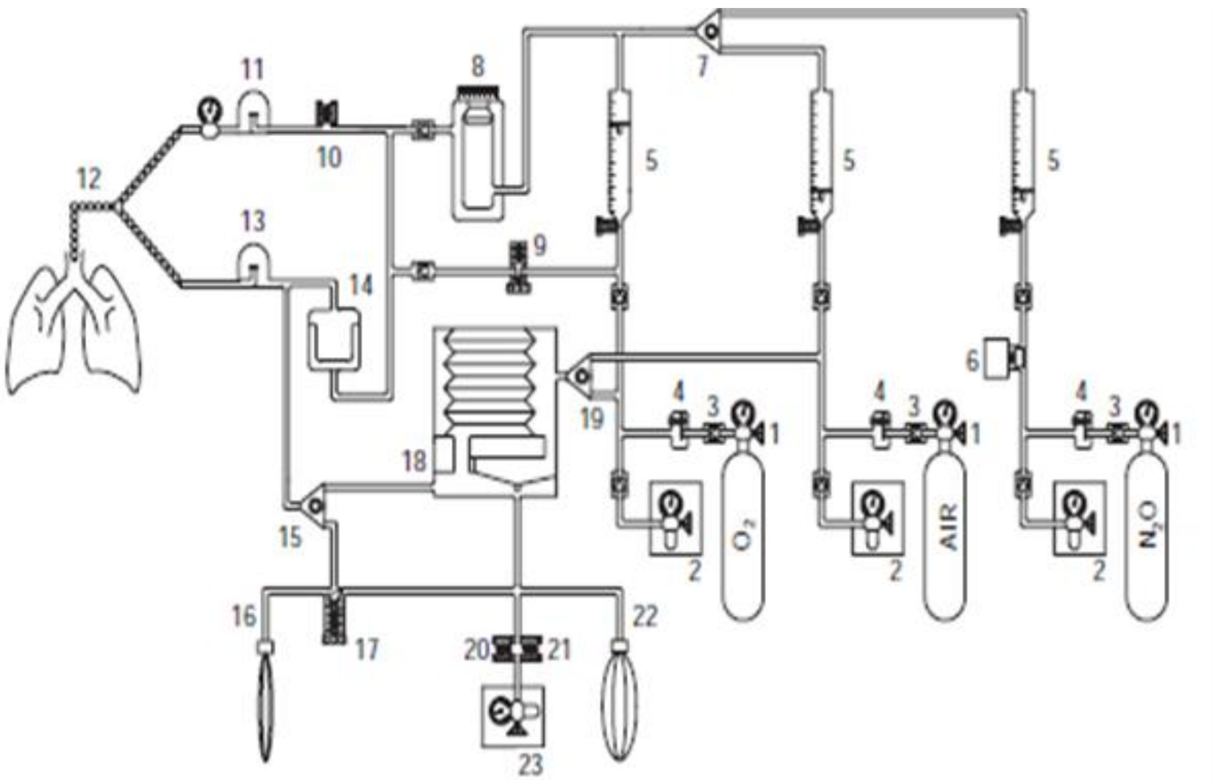

- Figure 2. Schematic diagram of an anesthesia machine for the delivery of inhaled agents.

(1)High-pressure gas cylinder, (2) central gas supply outlet, (3) unidirectional-flow valve, (4) pressure regulator, (5) gas flowmeter, (6) fail-safe device, (7) carrier gas selector, (8) vaporizer, (9) oxygen flush valve, (10) fresh gas flow positive pressure relief valve, (11) unidirectional inspiratory valve, (12) patient breathing circuit, (13) unidirectional expiratory valve, (14) carbon dioxide absorber, (15) mechanical ventilation or spontaneous breathing circuit selector, (16) breathing reservoir, (17) adjustable pressure limiting valve or pop-off valve, (18) mechanical ventilator, (19) ventilator driving gas selector, (20) scavenging gas positive pressure relief valve, (21) scavenging gas negative pressure relief valve, (22) scavenging reservoir bag, and (23) central vacuum inlet.

In the case of spontaneous ventilation, the exhaled gas is scavenged through an adjustable pressure limiting valve (APL) to the available waste gas removal system (23).

From the description related above, the anesthesia machine may be understood as the ensemble of the following subsystems:

- Gas supply
- Flow Regulators
- Vaporizer
- Breathing system
- Scavenging system

Gas Supply System

- As mentioned above, anesthesia machines do not just administer the anesthetic agents but also life-sustaining gases, such as oxygen and nitrous oxide (that may be substituted by medical air or helium, among others), so that dedicated systems have been developed for precisely supplying the proper concentration of these gases to the patient. In this sense, the gas supply system relies on three different components: **the gas source, the flow regulators, and the associated safety devices.s**

Gas Sources

- The gases commonly used in anesthesia (oxygen, nitrous oxide, and compressed air) are under high pressure and may be piped in from a central storage area or used directly from nearby compressed gas cylinders in case of central supply failure (4–9).

- ***Central Gas Supply***
- Air is produced and distributed from a compressor plant on-site. These gases are usually supplied at 345KPa (50 psi) after a two-stage regulation from the nominal pressure of the tanks.
- The wall outlets (2) are usually suited with primary and secondary check valves (that prevent reverse flow of gases from machine to pipeline or atmosphere), a pressure regulator, and a filter for the removal of the impurities.

Gas Cylinders

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- In case of central supply failure, the anesthesia machine should be fitted with a backup source of medical gases in order to grant continuous ventilation to the patient, which has become mandatory in most countries where the use of backup gas cylinders is specifically included within the regulations related to anesthesia machines. For this purpose, it is advisable to include cylinders for oxygen and nitrous oxide delivery.
- These compressed gas cylinders (which are mounted on yokes attached to the anesthesia machine) use a filter, and unidirectional flow check valve, a pressure regulator, and gauge. The pressure regulator (4) is needed to set the gas pressure below the pipeline supply pressure (310KPa for the cylinders) in order to prevent recirculation of the gas from the cylinders to the central supply system. Aside from this pressure regulator, cylinders usually include additional security features such as a safety relief device consisting of a frangible disc that bursts under extreme pressure, a fusible plug made of Wood's metal that has a low melting point, a safety relief valve that opens at extreme pressure.

- **Safety Devices**
- In order to prevent damage associated with hypoxic ventilation, several safety devices are included within the anesthesia machine. The hypoxic Guard system links the controls of O2 and N2O in order to avoid the administration of hypoxic gas mixtures (mixtures containing less than 25% oxygen). This system is complemented by means of the so-called fail-safe device (6), which shuts off the nitrous oxide supply when the oxygen pressure at the flow meter falls below a certain threshold value, which typically ranges from 69KPa (10 psi) to 138KPa (20 psi). Additionally, an oxygen flush valve (9) must be included in order to allow the rapid (35–75 L/min) washout of the breathing circuit in case of emergency, as this valve directly injects oxygen into the patient without passing through any kind of vaporizer (4–9).

- **Flow Regulators**
- Anesthesia machines have included independent flow controls for each of the medical gases used in order to cover the requirements of the anesthesiologist for precisely controlling the amount of each gas flowing into the breathing circuit attached to the patient.
- These flow meters (5) typically consist of a glass tube in which a floating conical element rotates at different heights as a function of the flow streaming out from the meter. Although

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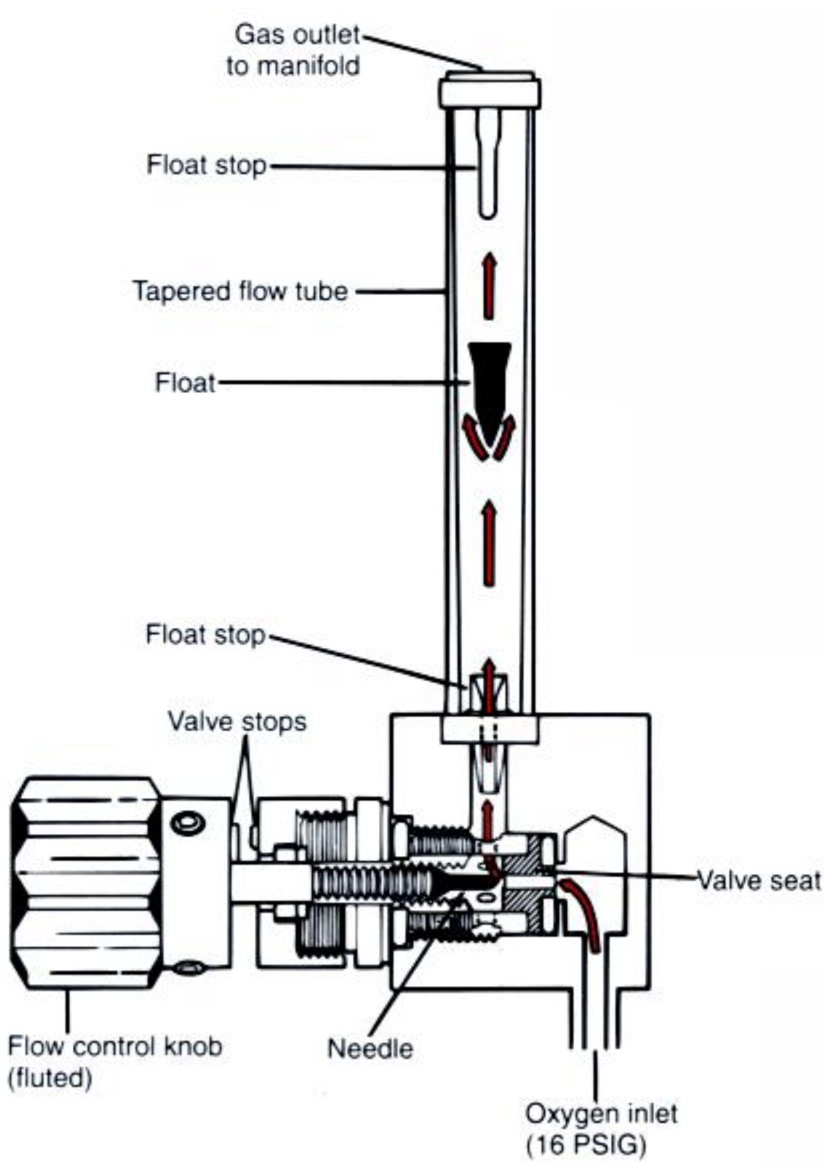
modern machines have included electronic flow meters based on different sensing principles (ultrasound Doppler, electromagnetic sensing, etc.) and digital displays, it is advisable to include at least one conventional glass flow meter in order to allow operation even when electrical power fails.



Vaporizer System

- In order to deliver most of the inhaled anesthetic agents through the breathing circuit, these liquid substances must be vaporized into the carrier gas stream. To achieve this goal, special devices have been developed and, today, are considered one of the most important elements found in anesthesia machines.
- A vaporizer enriches the carrier gas mixture with a vapor fraction of the volatile agent by means of different principles, leading to **different families of these devices such as those known as variable bypass, heated blender, measured flow, and the recently introduced injectors.** The most common are shown in Fig.1.

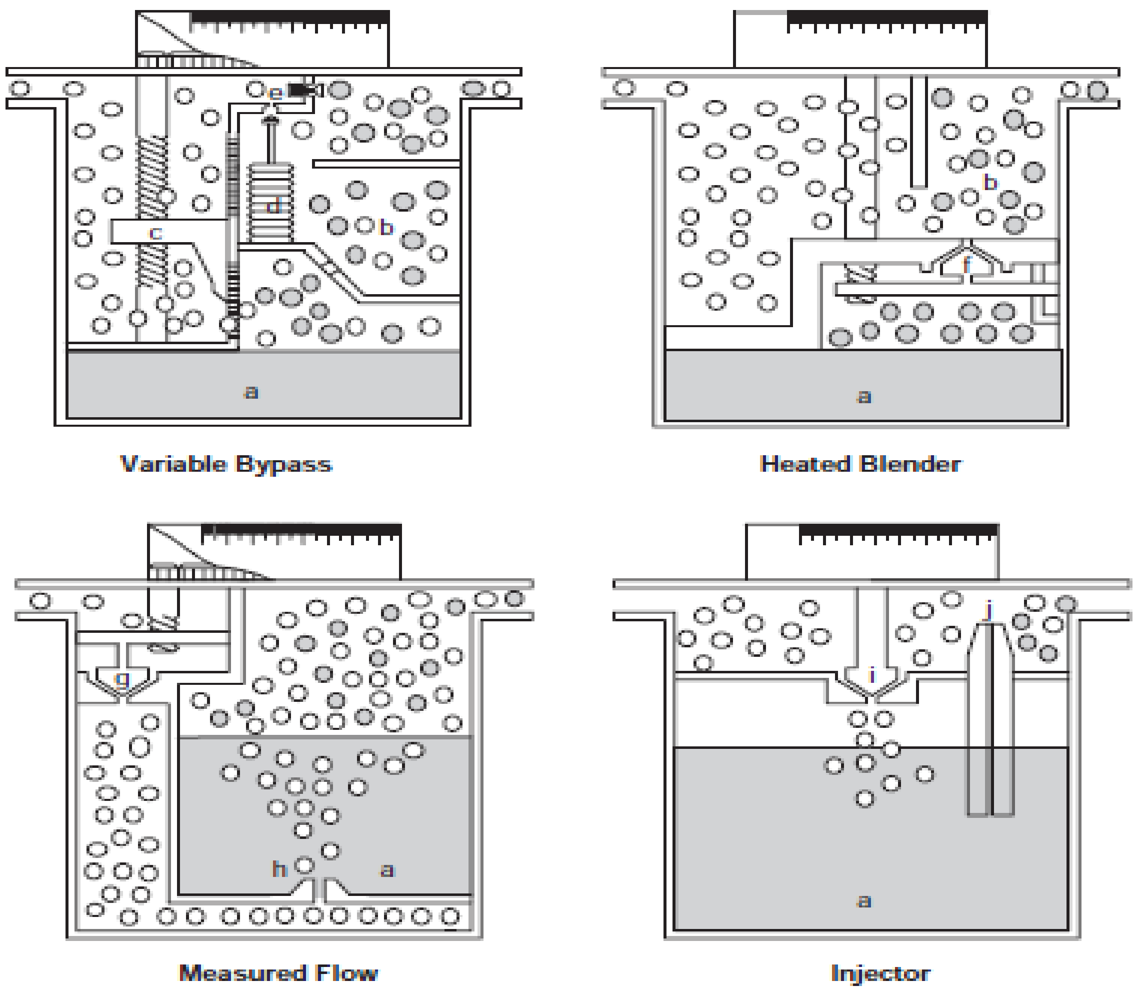


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Figure 3. Idealized views of different types of vaporizers. (a) Liquid agent, (b) mixing chamber, (c) bypass valve, (d) temperature compensation bellows, (e) pressure relief valve, (f) feedback-controlled metering valve, (g) constant flow valve, (h) gas mixture bubbler, (i) bypass valve, and (j) injector