Anesthesia Machine

Variable Bypass

- The variable bypass vaporizer is the most commonly used in today's machines for the vaporization of many agents such as enflurane, isoflurane, halothane, and sevoflurane. This type of vaporizer receives this name because a variable shunt valve (c in Fig. 3) regulates the proportion of gas flowing into the vaporization chamber and into the mixing chamber (b).
- As the gas flowing out of the vaporizer chamber is mixed with the bypassed gas stream, the concentration of the agent in the gas mixture is directly related to the splitting ratio of the valve. Temperature compensation bellows (d) are included in order to compensate for the effect of temperature changes that affect the equilibrium vapor pressure above the agent. As this kind of vaporizer is able to deliver accurate concentrations of the anesthetic agent, specific designs and calibration methods are used for each type of liquid agent.

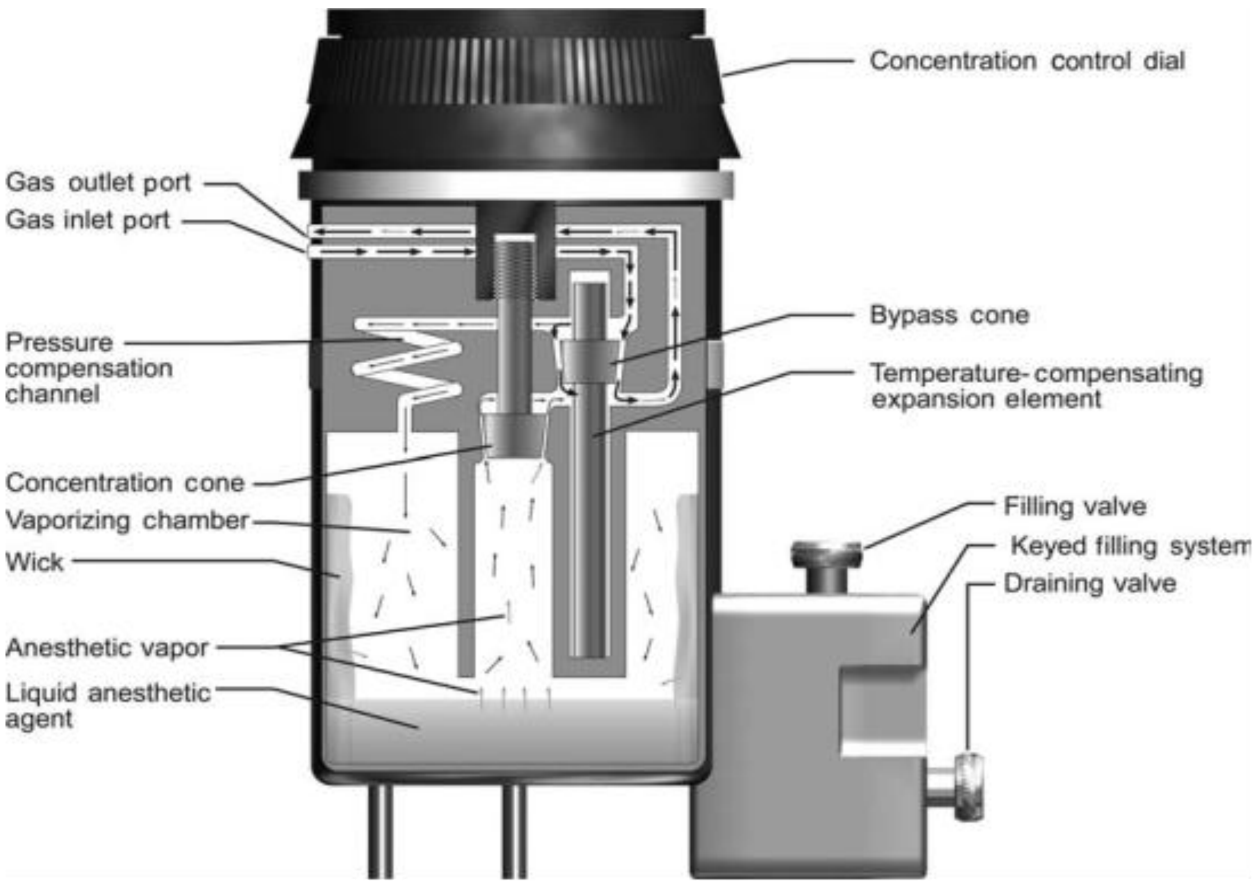

Figure 2. Schematic of a variable-bypass vaporizer. Arrows indicate direction of gas flow; heavier arrows indicate larger flow rates. Gas enters the Inlet Port and is split at the Bypass Cone into two streams. One stream is directed through a bypass channel and the rest enters the Vaporizing Chamber. Gas entering the Vaporizing Chamber equilibrates with Liquid Anesthetic Agent to become saturated with Anesthetic Vapor. This concentrated anesthetic mixture exits the chamber to join, and be diluted by, gas that traversed the bypass channel. The Concentration Control Dial is attached to the Concentration Cone, which regulates resistance to flow exiting the Vaporizing Chamber and thus controls the anesthetic concentration dispensed from the Outlet Port.

Heated Blender

- Initially introduced for use with desflurane, the liquid agent is heated within a chamber before entering the mixing chamber through an adjustable feedback-controlled metering valve (f) that regulates the vapor stream flow.

Measured Flow

- These devices are not able to deliver accurate concentrations of the liquid agent because they are not calibrated, which is because of the vaporization control implemented, which is based on a constant flow of carrier gas (g) bubbling up (h) through the liquid agent.

Injector

- This recently introduced system uses a valve (i) to regulate the amount of fresh gas flowing into a pressurized chamber where the liquid agent is stored. As the pressure of this chamber increases, the agent is forced up through the injector nozzle (j) where it is atomized within the fresh gas flow. As no vaporization occurs, (just atomization of the liquid agent), temperature compensation is not required.

- **Breathing System**
- Once the anesthetic agent is vaporized at the desired concentration, the gas mixture has to be administered to the patient in order to get the desired therapeutic effect and the proper ventilation. For this purpose, anesthesia machines are connected to the patient by the so-called breathing circuits.
- Breathing circuits are often classified either as open systems or closed systems. In open systems, the fresh gas flow is administered to the patient before being scavenged, whereas in closed systems, the exhaled gases are processed in order to recycle them, reducing the total amount of agent required (in order to reduce anesthesia costs and staff exposure to the agents.

- **Circle System**
- The breathing circuit receives the vapor-enriched gas mixture from the vaporizer outlet and sends it to the patient circuit (12) through the unidirectional inspiratory valve (11), installed to prevent rebreathing from the patient to this branch of the circuit. The inspired branch is completed with a security overpressure valve (10) installed in order to release the gas out

of the circuit in case the pressure of the gas mixture going into the patient circuit exceeds the threshold of 12.5 kPa (125 cm H2O) established by the regulating authorities.

- The exhaled gases return through the unidirectional expiratory valve (13) flowing into the absorber (14), which is installed to remove carbon dioxide in order to recycle the breathing gas. In the function of the circuit selected (15), part of the exhaled gases will cycle through the ventilator (18) or the spontaneous breathing circuit formed by the breathing reservoir bag (16) and the adjustable pressure limiting valve (APL) (17) before returning to the absorber inlet.

Carbon Dioxide Absorber

- Circle systems require the use of chemical elements for carbon dioxide removal from the exhaled gases before recycling them back to the inspiratory limb of the breathing circuit. These absorbers present in the form of a canister containing pellets of the absorbing compound (soda lime), which is placed within a shell connected inline with the circle system.

- **Ventilation**
- Ventilation of the patient should be granted for the supply of the life sustaining gases and the vaporized anesthetic agent, which is usually done in two ways, depending on the ventilator assistance strategy adopted. If the patient presents a healthy condition and the surgical procedure does not interfere with the function of the respiratory system, the anesthesiologist in charge of the sedation may decide for keeping spontaneous ventilation throughout the procedure instead of mechanical ventilation.
- If the first strategy is adopted, the patient will breathe spontaneously inhaling the gas mixture through the inspiratory limb of the circuit before exhaling the mixture to the expiratory one. As the gas is expired, it enters into the reservoir bag (16) connected to the pop-off or adjustable pressure limiting valve (17), which is sensitive to the pressure of the exhaled stream. In case this pressure exceeded the preset level, the APL valve will open, sending a fraction of the exhaled gases directly to the scavenging system. If mechanical ventilation is used, a similar valve located at the ventilator will release the excess pressure to the scavenging system, assuring the proper operation of the machine.

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Scavenging System

- Once the gas mixture has been released by the ventilation circuit, it must be properly disposed in order to avoid the risks associated with the contamination of the operating room's atmosphere. For this purpose, most of the hospitals count on central scavenging systems based on vacuum pipelines.
- In order to guard the patient airway from possible suction by the scavenging system, modern systems include pressure relief valves. If the suction pressure was greater than the pressure of the exhaled gas stream, the negative pressure relief valve will open, letting the air from the operating room flow into the scavenging system until the pressure of the line reaches the preset value of the valve.
- In the opposite case, when the suction pressure was not enough to assure the disposal of the exhaled gases, a positive pressure relief valve will open, ejecting the exhaled gas mixture into the atmosphere of the operating room.
- This system, based around valves between the anesthesia machine and the scavenging system, is known as a closed system since the introduction of the first open systems in recent years. In these other systems, which have become popular, the exhaled gases are scavenged from a dedicated reservoir bag without requiring pressure relief valves.

Monitoring

- In addition to the main components described above (gas delivery, vaporizer, ventilator, and breathing circuit), anesthesia machines usually include a monitoring subsystem specifically designed for the supervision of the state of the patient and the proper function of the whole system in order to:
- 1. Improve the security of the patient as a whole by preventing potentially harmful physiological conditions and detecting malfunctions in the normal operation of the anesthesia delivery unit.
- 2. Collect several physiological measures, which are considered to be interesting by the specialist in charge of the anesthetic procedure.

- 3. Check the integrity of the different components involved in anesthesia administration and taking corrective actions in response to system malfunctions.
- 4. Study the degree of change on a certain indicator in order to analyze trends and provide data required for the forecast of the patient evaluation during the surgical procedure.
- 5. Validate the impact of a specific therapy on the physiological state of the patient in order to give personalized anesthetic care.

Anesthesia Delivery System Supervision

- System failures or malfunctions (such as hypoxic gas mixture administration, poor ventilation of the lungs because of low-volume gas mixture supply, or misconnections in the administration piping, overdosing, etc.). Seriously endanger patients undergoing the anesthetic procedure. In order to avoid the undesired effects of these failures, granting the proper operation of the anesthesia delivery unit, several variables should be monitored, such as:
- Inspired oxygen concentration.
- Anesthetic vapor concentration.
- Carbon dioxide concentration.
- Air pressure.
- Exhaled gas volume.
- Manually operated valves and regulators set-points.

Gaseous Concentrations

- Oxygen concentration has to be continuously monitored in order to reduce the risk of administration of hypoxic or hyper oxygenated gas mixtures. Delivery of inappropriate gas mixtures should trigger the proper alarming mechanism. Although most of the devices limit the minimum rate of oxygen to a minimum of a 25%, inspired oxygen concentration has to be sensed at the inhalatory branch of the breathing circuit by means of transducers.

Patient Monitoring

- As happens in most of the medical procedures, anesthesia should minimize the patient's perception of pain while preserving the normal functionality of all of the body systems. In order to grant the integrity of the patient, certain physiological parameters should be monitored to correct possible alterations before they lead to permanent cellular damage. In this sense, monitoring the oxygenation using pulse oximeter, ventilation, circulation, temperature, blood pressure, ECG, and neurological function of the patient using EEG is mandatory when performing anesthetic procedures. Among others, typical anesthetic protocols include the acquisition of hemodynamic, respiratory, and neurological variables.

Monitoring the Depth of Anesthesia

- Brain stem auditory evoked responses have become the closest to depth of anesthesia monitoring, but it is difficult to perform ,is expensive, and is not possible to perform during many types of surgery. A promising new technology, called bi-spectral index (BIS monitoring) is purported to measure the level of patient awareness through multiple analysis of a single channel of the EEG.