Anesthesia Machine

This handout contains a written transcription of the narration in the online presentation (video). Please review the online presentation for additional material including interactive multimedia content, audio, and practice quizzes.

Case Study

During the morning meeting, Steven learns that the hospital will perform routine maintenance on the central gas supply throughout the day. The engineers don't anticipate interruptions in the gas supply but caution everyone to remain vigilant. Midway into Steven's second case, the low inspired oxygen alarm sounds. The pipeline pressure says 50 psi, the oxygen flowmeter bobbin is suspended by gas flow, and the oxygen powered pneumatic ventilator continues to function. While thinking through the differential diagnosis, the patient's SpO_2 decreases from 99% to 89%. What is the most likely cause of this situation? What corrective actions should be performed at this time?

Much of the morbidity and mortality related to the anesthesia workstation is preventable. So, it's important to have a working knowledge of the equipment in your facility to reduce the chance of patient harm. In this objective, we're going to provide a clinically oriented review of the anesthesia machine with a focus on common complications and their remedies.

Overview

The anesthesia machine performs three functions essential to the delivery of a safe anesthetic. Its primary purpose is to deliver oxygen to the patient. This is evidenced by the fact that nearly all of the safety mechanisms on the anesthesia machine are designed to ensure that the patient receives oxygen to support aerobic metabolism. Second, it provides a delivery mechanism for inhaled anesthetics, so that we can anesthetize the patient for surgical and diagnostic procedures. And finally, it allows us to deliver positive pressure ventilation as a means of promoting gas exchange, because anesthetic agents suppress the ventilatory drive and sometimes produce apnea. While not components of the anesthesia machine per se, most machines are equipped with a variety of patient monitors in compliance with the ASA and AANA monitoring standards.

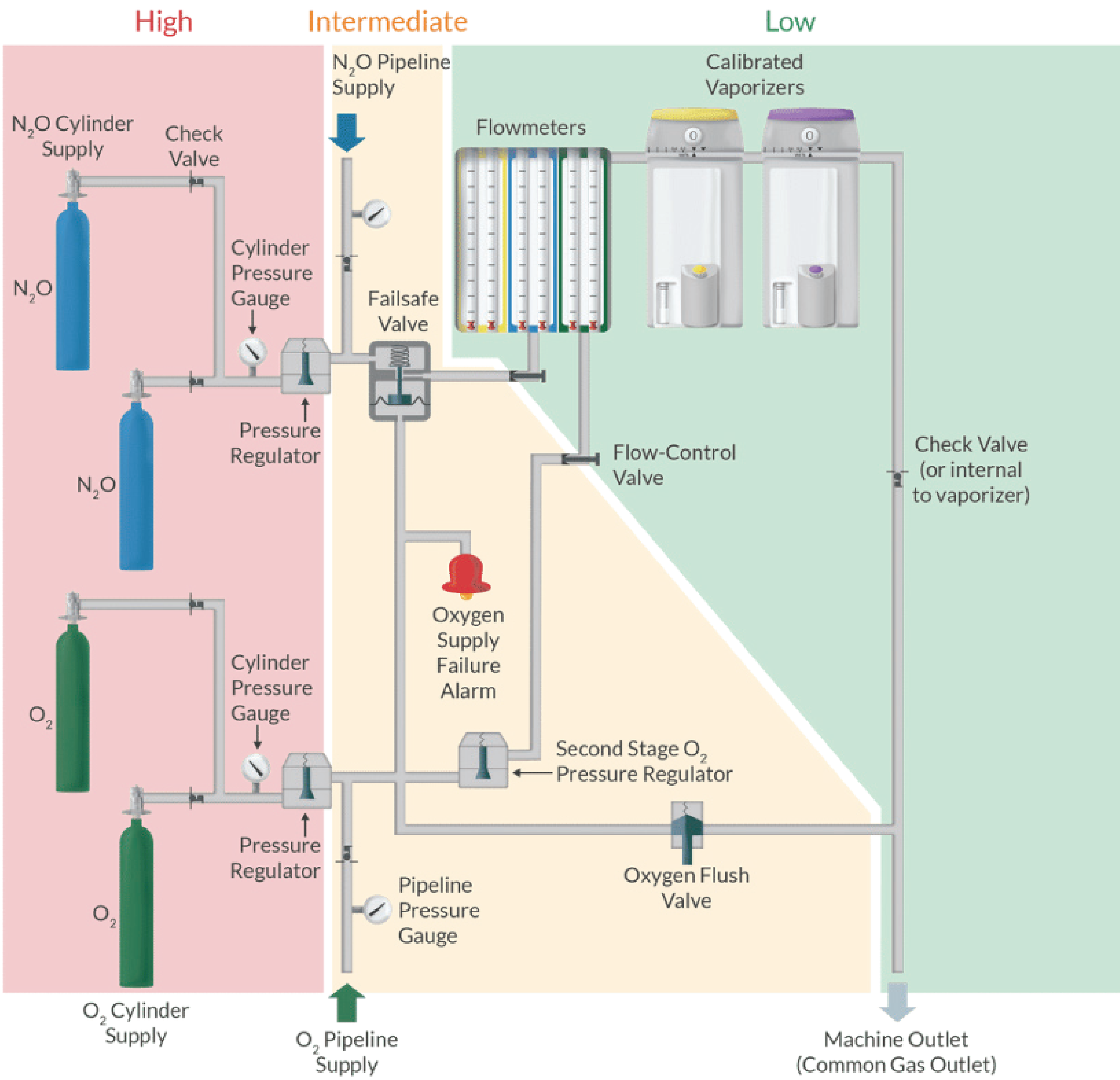
Three Pressure Systems

The anesthesia machine can be divided into three pressure systems: high, intermediate, and low. Understanding this architecture is essential to diagnosing and treating problems that arise when using the anesthesia machine.

The high-pressure system extends from each cylinder to its pressure regulator. The high-pressure system is exposed to cylinder pressure, so the pressure in this region varies as a function of cylinder contents.

The intermediate-pressure system begins at two locations — at the pipeline inlet connections and just beyond the cylinder pressure regulators. This system ends at the flow control valves as well as the oxygen flush valve. Oxygen pressure from the central pipeline enters the anesthesia machine at about 50 psi, while oxygen pressure from the cylinder supply enters the machine at 45 psi. We'll discuss the relevance of this shortly.

The low-pressure system begins at the flowmeter tubes and ends at the common gas outlet. The pressure in this region is slightly above atmospheric pressure, and it varies as a function of the fresh gas flow.



High-Pressure System

Cylinders
↓
Cylinder regulators

Pressure = Cylinder pressure

Essential components:
- Cylinders
- Hanger yolk assembly
- Cylinder pressure gauge
- Cylinder pressure regulators

Intermediate-Pressure System

Pipeline & cylinder regulators
↓
Flow control & O_2 flush valves

Pressure = 45 – 50 psi

Essential components:
- Pipeline inlets
- Pipeline pressure gauges
- Failsafe device
- 2nd stage pressure regulator (+/-)
- Flow control valves
- Oxygen flush valve
- Ventilator power inlet

Low-Pressure System

Flowmeter tubes
↓
Common gas outlet

Pressure = ~ Atmospheric

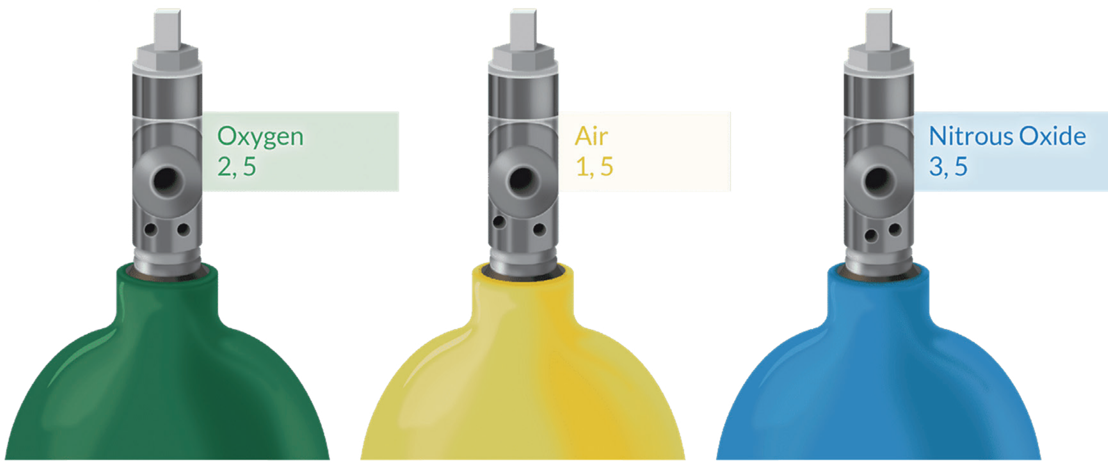
Essential components:
- Flowmeter tubes
- Common manifold
- Vaporizers
- Check valve (if present)
- Common gas outlet

Medical Gas Supply

The anesthesia machine receives medical gas from one of two locations. The primary source comes from the central supply located in the health care facility. This gas travels through pipes on its way to the operating room, and then it enters the anesthesia machine by way of color-coded hoses. This interface is called the diameter index safety system (DISS for short), where the diameter and threading of the coupling mechanism are specific for each gas. This prevents a cross-over error. Understand that there may be additional oxygen connections if the machine uses oxygen for the ventilator drive gas or has an auxiliary oxygen flowmeter. Don't confuse these with the oxygen pipeline hose.

E cylinders located on the back of the anesthesia machine serve as a secondary gas supply. They attach to the anesthesia machine at the hanger yolk assembly. The pin index safety system (PISS for short) prevents a cross-over error. Pins projecting from the hanger yolk assembly match up with holes in the body of the cylinder valve. The configuration is 1, 5 for air, 2, 5 for oxygen, and 3, 5 for nitrous oxide.

PISS configurations:



Because gas inside a cylinder is stored under enormous pressure, a pressure regulator (also known as a pressure reducing valve) reduces the pressure to about 45 psi just before it enters the intermediate-pressure system. Recall that pipeline pressure is 50 psi, so this pressure difference causes the anesthesia machine to preferentially use the pipeline supply if the oxygen cylinder is accidentally left open. Having said this, there's good reason to keep the oxygen cylinder closed when not in use. Why is this? If the pipeline experiences a loss of oxygen pressure (or a drop below 45 psi) and the oxygen cylinder is open, then the machine will consume oxygen from the cylinder. Because most anesthesia machines aren't smart enough to know where the gas is coming from, no alarm will sound. Only when the cylinder is emptied will the failsafe alarm sound! At this point, your backup supply is gone, so you'll have to scramble to oxygenate the patient.

You should know the maximum tank volumes and pressures. Oxygen can hold 660 L at a max pressure of about 2,000 psi (although some sources list between 1900 and 2,200), air can hold 625 L at a max pressure of 1900 psi, and nitrous oxide can hold 1590 L at a max pressure of 745 psi. While oxygen and air exist as gas inside their cylinders, nitrous oxide exists as a liquid. This is because nitrous oxide's critical temperature is 36 C, which is slightly above room temperature. Why does this matter? The equilibrium between the liquid and gas phase produces a partial pressure of 745 mmHg, and this partial pressure remains constant until all the liquid is gone. At this point, there's about 250 L of nitrous oxide remaining in the tank, so you'll want to exchange it for a new one. The lack of a pressure-volume relationship is also why weighing the cylinder is the only way to determine how much nitrous oxide is inside the tank. But seriously, who's going to do that?

All of this talk about cylinder volumes and pressures brings us to one of the most important equations in anesthesiology. How long will an oxygen E cylinder provide oxygen to the patient? Although there are smartphone apps to do this for you, we can do a quick calculation to figure it out. It just might come in handy on an exam…

Step 1: We need to determine how much oxygen is in the cylinder. The volume of oxygen is directly proportional to the pressure it exerts inside the cylinder, so we can set up a ratio that compares a full cylinder to our cylinder.

Tank capacity (L) / Full tank pressure (psi) x Contents remaining (L) / Gauge pressure (psi)

Step 2: Once we know how much oxygen is in the tank, we must determine how long it will last at a given flow rate.

Contents remaining (L) / FGF rate (L/min) = Minutes left before the tank expires.

Let's see an example where the pressure gauge reads 500 psi, and you're using an oxygen flow rate of 2 L/min. We know that a full E cylinder holds 660 L at a max of 2000 psi. Next, you'll need to solve for contents remaining. Finally, you'll take the volume of oxygen left in the tank and divide it by your flow rate – in this case 2 L/min. And presto! Your tank will last for 82.5 minutes. It's important to keep in mind that pressing the oxygen flush valve or using a ventilator where oxygen is the source of the ventilator drive gas will exhaust your oxygen tank faster.

Cylinder Safety

Before we finish, there are a few key points regarding cylinder safety that you should know. The cylinder valve is the most delicate component of the cylinder. If the cylinder falls and the valve breaks off, the tank can take off like a rocket or spin uncontrollably. This is why a cylinder should be stored in a secured, up-right location when it's not in use, although it's ok to temporarily lay the cylinder on its side when you're changing the tank on the back of the anesthesia machine.

When you replace a cylinder, make sure there's a washer present between the cylinder and the hanger yolk, as this will ensure an air-tight seal. You should install a new washer each time you change the tank.

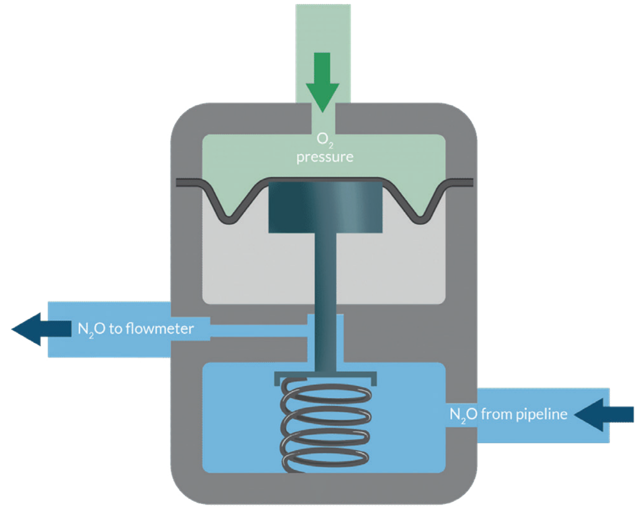
Because most cylinders are made of ferrous material, you should never take a cylinder into the MRI suite! Failure to heed this warning risks serious injury to everyone in the room. Instead, you should use a cylinder that's made of a non-ferrous material, such as aluminum. An MRI safe cylinder has two colors: most of the tank is silver but the top is colored to signify the gas it contains. Having said this, the best way to determine the cylinder contents is the read the label (not its color).

Gas cylinders can explode when they're exposed to temperatures higher than 57 C. In the event of an environmental fire, there's a safety relief device built into the cylinder that allows it to empty its contents in a slow and controlled way. Examples of safety relief devices include a fusible plug that melts at elevated temperatures. This is typically made from Wood's metal, which contains bismuth, lead, tin, and cadmium (just remember BLT w/ Cheese). Other examples include a valve that opens at elevated temperatures or a frangible disk that ruptures under pressure.

When you open a cylinder, the gas exits the cylinder through a narrow opening. This causes a sudden temperature drop, and it's called the Joule Thompson effect. It's easy to remember because Joule is cool. This can produce frost on the outside of the cylinder since it causes water in the atmosphere to freeze on the outside of the tank. There's no risk of freezing inside the cylinder because compressed medical gasses are free from water vapor. Finally, make sure there's a cylinder key on the anesthesia machine when you're doing your machine check.

Failsafe Device

The oxygen-nitrous oxide failsafe device is the first internal component of the anesthesia machine tasked with preventing the delivery of a hypoxic mixture. Oxygen entering the anesthesia machine passes directly from its source (either the pipeline or cylinder supply) to its flow control valve at the flowmeter. By contrast, nitrous oxide must pass through a failsafe device before reaching its flow control valve. This arrangement prevents the delivery of a hypoxic mixture in the setting of an inadequate oxygen pressure inside the intermediate-pressure system of the anesthesia machine.



What happens if oxygen pressure decreases? If the oxygen pressure falls below ~30 psi, the failsafe device triggers an audible alarm. If the oxygen pressure falls below ~20 psi, the failsafe device uses a pneumatic system that will (depending on the anesthesia machine) completely stop or proportionately reduce nitrous oxide flow towards its flow control valve. What are the most likely reasons the failsafe alarm sounds? If you're using pipeline oxygen, then the most likely causes include a reduction in pipeline pressure or a disconnected oxygen hose. If you're using cylinder oxygen, depletion of the oxygen tank is the most likely cause.

Is the failsafe valve really fail safe? Actually, it's not. How can this be? Let's look at two examples. First, we'll consider a pipeline crossover. This occurs when a gas other than oxygen enters the oxygen pipeline. Let's pretend that someone accidentally connects nitrous oxide to the central oxygen supply. This means that nitrous oxide would enter the anesthesia machine through the oxygen pipeline. In this situation, the failsafe device doesn't detect a problem because it senses pressure in the system. Therefore, the failsafe device allows nitrous oxide to pass through it. Remember, the failsafe device monitors gas pressure (not concentration), so it's not smart enough to know which gas is pressurizing the system.

What should you do if you suspect a pipeline crossover? First, turn on the oxygen tank. Second, you must disconnect the pipeline oxygen supply from the anesthesia machine. Why is this? Pretend you accidentally leave the oxygen tank on after doing your machine check. Adequate pressure in the oxygen pipeline closes a check valve that would otherwise prevent depletion of the oxygen tank. So, even if you open the oxygen cylinder, the pipeline pressure will prevent tank oxygen from getting to the patient. This is why you must disconnect the pipeline supply from the back of the anesthesia machine. A crack in the oxygen flowmeter is the second example where the failsafe device won't detect (or prevent) a hypoxic mixture. This is because the flowmeter resides downstream from the failsafe device.

You might be asking, does air pass through its own failsafe device? While some machines require air to pass through a failsafe device, others do not. A machine that doesn't require air to pass through a failsafe device offers an additional layer of protection because it allows the patient to be ventilated with air if the oxygen supply is not functional.

Flowmeters & Proportioning System

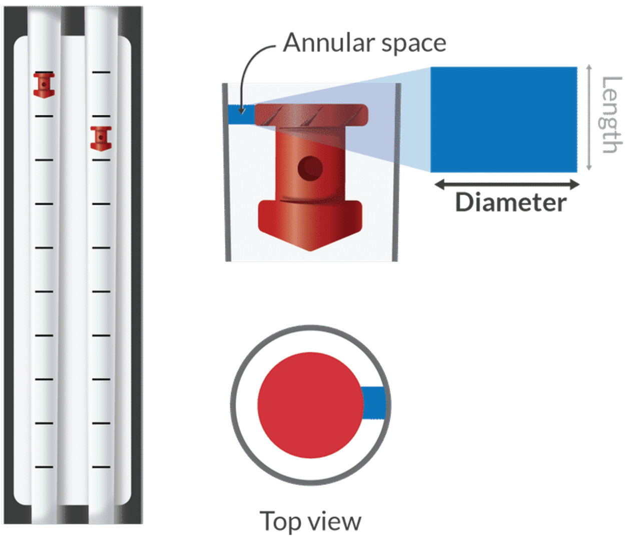
Overview

The flowmeters mark the beginning of the low-pressure system. Each flowmeter (sometimes called a rotameter or Thorpe tube) is calibrated for a specific gas, and most anesthesia machines have a flowmeter for oxygen, air, and nitrous oxide. For easy identification, the oxygen knob is the largest and has other tactile features, such as a fluted profile.

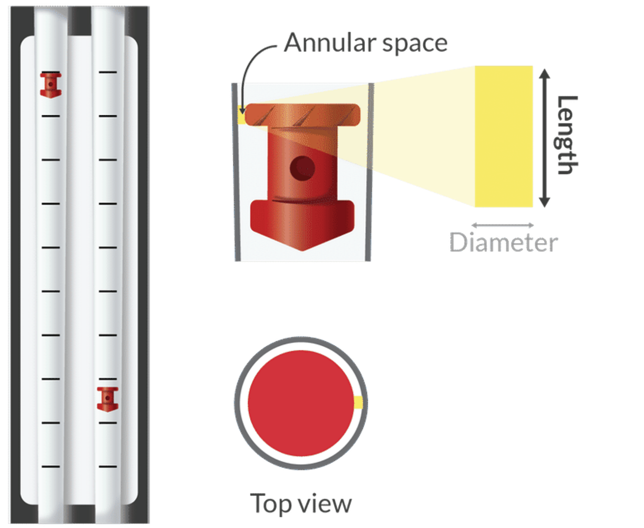
By adjusting the flow control valves (either by turning a knob or interacting with a digital interface), you can determine how much gas enters the flowmeter. Although some anesthesia machines have electronic flow control and measurement, we're going to consider the traditional flowmeter in this video. The height of the indicator is a function of the gas flow pushing the indicator up and gravity pulling it down. There are four common types of indicators (skirted, plumb bob, nonrotating, and ball). The amount of gas flowing through the flowmeter is measured at the widest part of the indicator, so all of them are measured at the top except for the ball, which is measured in the middle.

You'll commonly see flowmeters referred to as "constant pressure variable orifice," so let's take a moment to discuss what this means. The flowmeter is tapered, so it's narrow near the bottom and it progressively widens along its ascent. The annular space is the circumferential area between the indicator and the wall of the flowmeter, and this space also widens along the height of the flowmeter. At low flows, the channel between the indicator and the flowmeter wall is tubular, because the length is greater than its diameter. Therefore, gas flow is laminar and is dependent on the gas's viscosity. At higher flows, the channel between the indicator and the flowmeter wall is orifical, because the diameter is greater than its length. Therefore, gas flow in this region is turbulent and is dependent on the gas's density.

High Flow:
Gas flow is orificial and dependent on the gas's density



Low Flow:
Gas flow is laminar and dependent on the gas's viscosity



Complications

What are some complications that can arise at the flowmeter? Key examples include anything that can contribute to inaccuracy, such as debris inside the flowmeter, sticking of the indicator along the wall of the flowmeter, or vertical misalignment of the flowmeter. Other complications include the creation of a hypoxic mixture as well as a hidden indicator, and we're going to explore these two in greater detail.

Older anesthesia machines did not have a mechanism to prevent the operator from dialing in a hypoxic mixture at the flow control knobs. Fortunately, modern anesthesia machines are equipped with a proportioning system (also called the nitrous oxide ratio controller) that mechanically or pneumatically links the oxygen and nitrous oxide at the flow control valves. This system ensures that the FiO_2 dialed in at the flowmeters cannot be less than about 23 – 25%.

A leak in the flowmeter can contribute to a hypoxic mixture. Many flowmeters are made of glass. The benefit is that glass resists the build-up of static electricity, which might cause the indicator to adhere to the side of the flowmeter. The principal disadvantage of glass is that it's prone to cracks, and a crack in a flowmeter could allow oxygen to escape, ultimately resulting in a hypoxic mixture being delivered to the patient. For this reason, the oxygen flowmeter is positioned last in the sequence of flowmeters (i.e., closest to the common gas outlet and thus the patient). In the United States, this means oxygen is always furthest to the right. Understand that this arrangement minimizes the risk of a hypoxic mixture should a leak develop in any of the upstream flowmeters, but a crack in the oxygen flowmeter can still produce a hypoxic mixture.

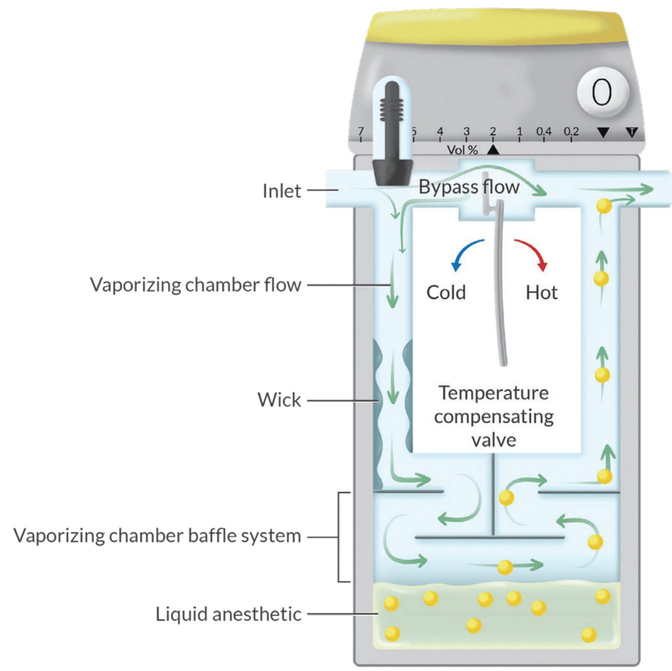
A hidden indicator can also be problematic. If the flowmeter is turned all the way up, you may not see the indicator and assume that the flowmeter is off. In an anesthesia machine that couples fresh gas flow to tidal volume, this could potentially lead to the delivery of an excessive tidal volume. Recall that in the anesthesia machine that couples fresh gas flow to tidal volume, the tidal volume delivered to the patient is the sum of the tidal volume set on the ventilator plus the volume of the fresh gas delivered during the inspiratory phase of the breath.

Variable Bypass Vaporizer: Part 1

The vaporizer lives in the low-pressure system downstream of the flowmeters and the common manifold. Although we frequently turn the dial on the vaporizer throughout each case, do we really understand what's going on underneath the hood? Let's review the essential concepts that relate to the variable bypass vaporizer.

Variable Bypass

What does "variable bypass" mean? To comprehend the concept, you must understand the splitting ratio. When fresh gas enters the vaporizer, it goes in one of two directions. Some fresh gas enters the vaporizing chamber where it becomes 100% saturated with the anesthetic agent. The rest enters the bypass chamber where it does not come into contact with the anesthetic agent. Before leaving the vaporizer, both fractions mix. This determines the final anesthetic concentration of the fresh gas leaving the vaporizer. You decide the splitting ratio when you turn the dial to your desired output. Setting a higher number on the dial directs more fresh gas through the vaporizing chamber, while setting a lower number directs more fresh gas through the bypass chamber.



Flow-Over

How does fresh gas travel through the vaporizer? Fresh gas entering the vaporizing chamber flows over a series of baffles and wicks. These structures increase surface area and turbulence, which ensures that the fresh gas inside this chamber becomes 100% saturated with the anesthetic agent. Full saturation of this gas fraction is required to guarantee a consistent vaporizer output.

Temperature Compensated

To understand temperature compensation, we need to touch on two concepts: vapor pressure and the latent heat of vaporization. Vapor pressure is the pressure exerted by a vapor in equilibrium with its liquid or solid phase inside a closed container. Vapor pressure is directly proportional to temperature, where an increased temperature increases vapor pressure and a lower temperature reduces vapor pressure. The latent heat of vaporization is the number of calories needed to convert 1 g of liquid into vapor without causing a change in temperature. Why does this matter? Vaporized molecules remove heat from the liquid anesthetic, which causes this liquid to cool. And if not compensated for, cooling would reduce vaporizer output. So, how do we solve this problem? The temperature compensating valve (either a bimetallic strip or an expansion element) adjusts the ratio of vaporizing chamber flow to bypass chamber flow. This guarantees a constant vaporizer output over a wide range of temperatures.

Out Of Circuit

Years ago, some vaporizers were incorporated into the circle system. The modern vaporizer is out of circuit, which means that it's isolated from the anesthetic breathing system. Furthermore, we can remove the vaporizer from the anesthesia machine without compromising the integrity of the breathing system.

Agent Specific

Each halogenated anesthetic has a unique vapor pressure, so a vaporizer must be calibrated for a specific agent, such as sevoflurane and isoflurane. Since desflurane's vapor pressure is very close to atmospheric pressure (it vaporizes quickly at room temperature), desflurane requires a special vaporizer design.

Variable Bypass Vaporizer: Part 2

Complications

What are some complications that can occur with the vaporizer?

Vaporizer Leak

A vaporizer leak can reduce anesthetic output. This can lead to awareness. A loose filler cap is the most common cause of a vaporizer leak, and performing the low-pressure system check will detect a vaporizer leak.

Oh No! I Used My Last Bottle Of Anesthetic Agent

Imagine you're in a long case, and you discover that your vaporizer is empty. You fill it up, but this is the last of your supply. How long will it last? Here's a useful equation to estimate how much liquid anesthetic you're using each hour.

mL of liquid anesthetic used per hour = Vol% x FGF (L/min) x 3

Filling With The Wrong Agent

Filling a vaporizer with the wrong agent can lead to a catastrophic error in vaporizer output. To guard against this, modern vaporizers have an agent-specific keyed filler device that ensures that only the right bottle can be paired with its corresponding vaporizer. Some older vaporizers don't have this safety feature, so you have to be extra careful when using one of those.

Tipping

If someone tips the vaporizer, some of the liquid anesthetic can move from the vaporizing chamber into the bypass chamber. This can increase vaporizer output and produce anesthetic overdose. Indeed, 1 mL of liquid anesthetic produces ~ 200 mL of anesthetic vapor at standard temperature and pressure. If someone tips the vaporizer, you should do two things. First, drain the vaporizer to remove the liquid anesthetic. Second, turn the dial to the highest setting and run a high fresh gas flow through it for 20 – 30 minutes or until all the liquid anesthetic has vaporized. When expired gas analysis no longer detects anesthetic agent, you can refill and reuse the vaporizer for a patient. Keep in mind, however, that manufacturers' guidelines may vary, so the best approach is to consult the product manual. Setting the dial to transport mode eliminates the worry of tipping the vaporizer during transport.

Pumping Effect

The pumping effect can increase the concentration of anesthetic leaving the vaporizer. Anything that causes gas that has already left the vaporizer to re-enter the vaporizer can create the pumping effect. This is generally due to positive pressure ventilation or use of the oxygen flush valve. A check valve placed anywhere in between the vaporizer and the common gas outlet largely eliminates this concern.

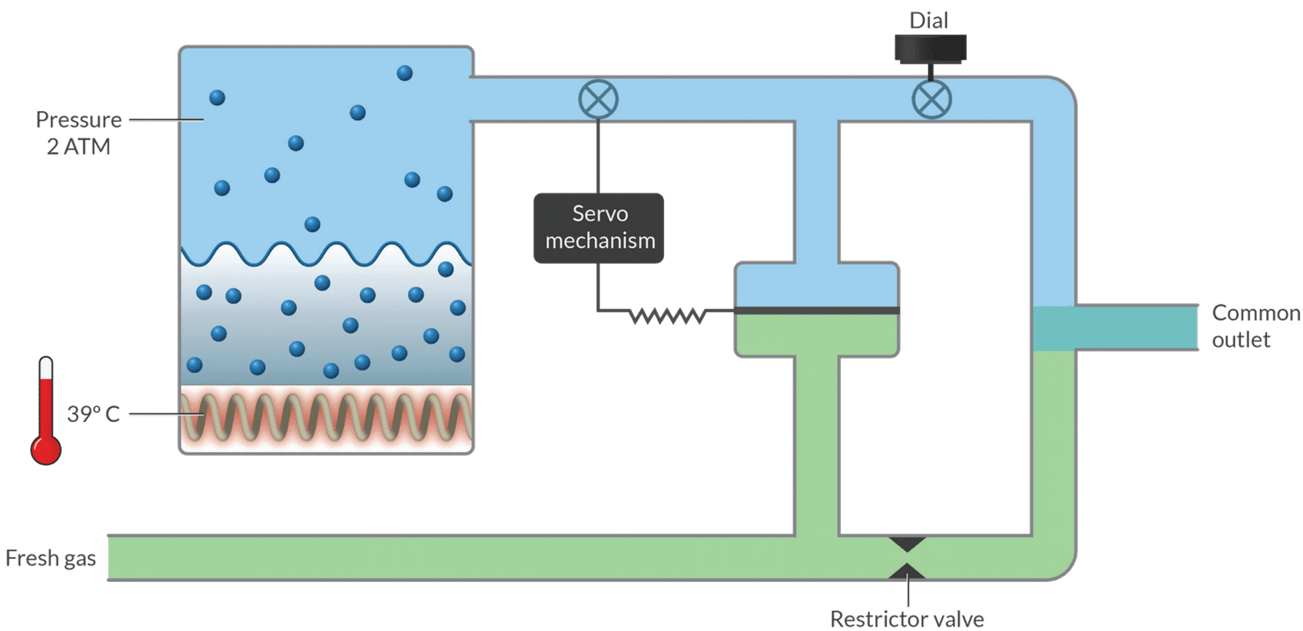
Simultaneous Administration

Volatile anesthetics are very potent, so turning more than one vaporizer on at a time can lead to an overdose. The interlock system prevents this possibility by making sure the fresh gas only travels through one vaporizer at a time.

Tec-6 Desflurane Vaporizer

Desflurane has a vapor pressure of 669 mmHg (very close to atmospheric pressure) and a boiling point of 22.8 °C (very close to room temperature). These physiochemical characteristics make desflurane very volatile (and difficult to control) at room temperature. Consequently, small fluctuations in room temperature can significantly alter vaporizer output, possibly leading to anesthetic overdose or delivery of a hypoxic mixture as a function of oxygen dilution in the final fresh gas makeup. For these reasons, desflurane is poorly suited for use in a standard variable bypass vaporizer.

Although there are several desflurane vaporizers on the market, we're going to discuss the Tec 6 vaporizer. The Tec 6 uses a parallel circuit design. In the first circuit, fresh gas enters at the inlet, passes through a restrictor valve, and exits at the outlet. The second circuit is called the vapor circuit, where desflurane resides in a reservoir that's heated to 39 °C and pressurized to 2 atmospheres (this is why the Tec 6 must be plugged into an electrical outlet). By heating desflurane well above room temperature, the Tec 6 removes the influence of room temperature on desflurane's volatility, which makes the delivery of precise concentration of desflurane achievable.



Remember how the splitting ratio on the variable bypass vaporizer diverts some of the fresh gas flow over the liquid anesthetic? The Tec 6 doesn't operate this way. Instead, the Tec 6 injects desflurane directly into the fresh gas flow. The setting on the dial determines the amount of desflurane that's injected. A series of flow resistors ensures that the final desflurane concentration is accurate over a wide range of fresh gas flow rates.

Unlike the variable bypass vaporizer that automatically adjusts anesthetic output at different atmospheric pressures, the Tec 6 delivers the volumes percent set on the dial regardless of the atmospheric pressure. Why does this matter? Recall that the depth of anesthesia is determined by the partial pressure (not the concentration) of anesthetic agent inside the brain. So, at sea level, 6% desflurane produces a partial pressure of 45.6 mmHg. Now, imagine you take your Tec 6 on a mission trip, where the operating room is located on top of a mountain where the atmospheric pressure is only 550 mmHg. In this situation, we can use Dalton's law of partial pressures to see that the same 6% setting on the dial only produces a partial pressure of 33 mmHg (this represents a 27.6% reduction in vaporizer output). As you can see, the patient will receive less anesthetic even though the setting on the dial is the same. Therefore, a lower atmospheric pressure necessitates a higher concentration set on the dial to deliver the same MAC equivalent of desflurane. The opposite is true when you're below sea level or if you're administering desflurane in a hyperbaric chamber. In these situations, you'd have to set a lower concentration on the dial to achieve the same MAC equivalent.

This is why the desflurane vaporizer must be calibrated to the atmospheric pressure where it'll be used. If your vaporizer isn't calibrated, you can use the following equation to estimate how you should set the dial to administer your desired MAC equivalent.

Required dial setting = (Normal dial setting % x 760 mmHg) / Ambient pressure mmHg

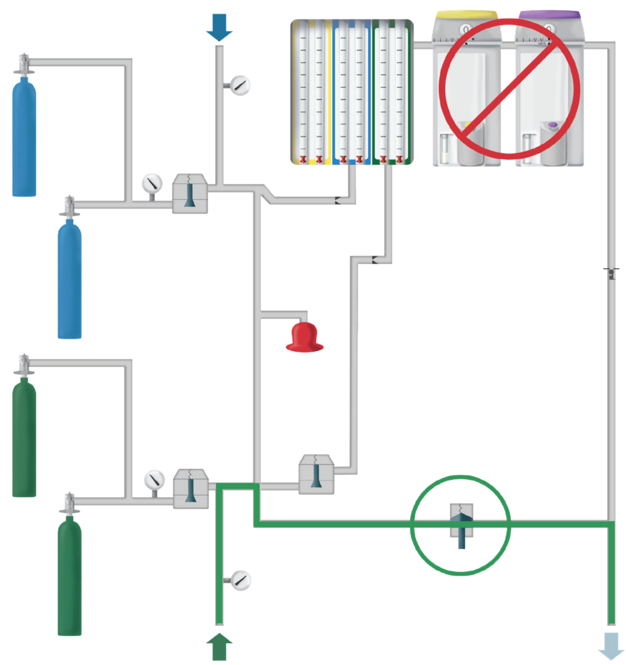
If we revisit our previous example, this equation says that you'll have to set the dial to 8.3% to administer the same MAC equivalent of 6% desflurane at sea level.

Aladin Vaporizer

The Aladin vaporizer is available on some GE anesthesia machines. It's suitable for use with sevoflurane, isoflurane, and desflurane. The Aladin vaporizer consists of two parts: a removable cassette that contains an agent-specific vaporizing chamber and a central processing unit (CPU), which is built into the anesthesia machine. Each cassette is magnetically coded so that the CPU can identify it. While it is similar in function to the traditional variable bypass vaporizer, it has electronic components that assist with record keeping as well as ensuring precise anesthetic output even when desflurane is used. Additionally, the cassette can be handled or stored in any position, which eliminates the risks associated with tipping the traditional variable bypass vaporizer.

Oxygen Flush Valve

The oxygen flush valve exposes the breathing circuit to an oxygen flow of 35 – 75 L/min at an oxygen pressure of 50 psi (the same as pipeline pressure in the intermediate-pressure system). Often, we use the oxygen flush valve to refill the breathing bag or pneumatic bellows. If the patient is on mechanical ventilation, pressing the oxygen flush valve during the inspiratory phase can result in barotrauma. Therefore, it is recommended that the valve be pressed in short bursts only during the expiratory phase. Arguably, a safer way to refill the bellows is to increase the FGF at the flowmeter. It's important to understand that the oxygen flush valve bypasses the vaporizers. Therefore, excessive use of the oxygen flush valve will dilute the concentration of anesthetic inside the breathing circuit, increasing the risk of patient awareness.



Circle System

The circle system is unique, because its unidirectional valves ensure that gas only travels in one direction and there's a carbon dioxide absorbent removes exhaled carbon dioxide. Benefits of the circle system include retained heat and humidity, recycling of anesthetic gas which reduces cost, and decreased environmental pollution. Depending on the fresh gas flow, the circle system can be configured as a semi-open circuit (FGF exceeds minute ventilation), semi-closed circuit (FGF is less than minute ventilation), or a closed circuit (FGF is just enough to support the patient's gas consumption). A closed-system technique requires meticulous attention to matching oxygen delivery to oxygen consumption as well as a comparatively longer time for FA/FI equilibration to occur.

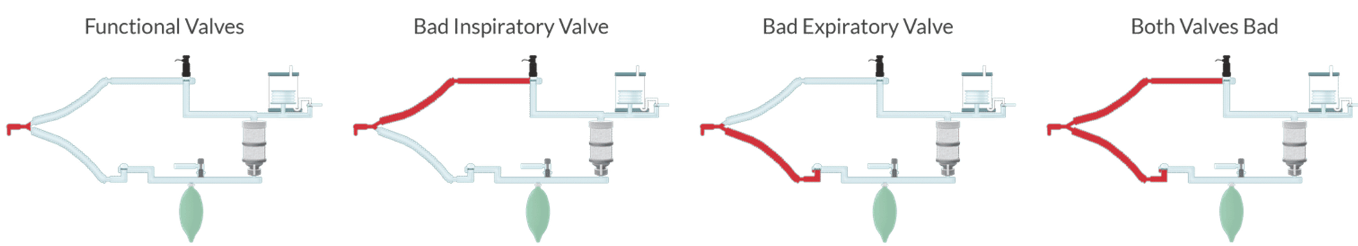
Fresh Gas Inlet

Fresh gas leaves the anesthesia machine at the common gas outlet, and it enters the circle system through the fresh gas inlet. Once inside, the fresh gas passes through the inspiratory limb of the circuit.

Unidirectional Valves

The unidirectional valves (one in the inspiratory limb and the other in the expiratory limb) ensure that fresh gas only travels in one direction. Forward flow opens the valve by pushing it upward, while backward flow closes the valve by pushing it downward. So, when the patient inhales, the valve in the inspiratory limb opens and the valve in the expiratory limb closes. The opposite occurs when the patient exhales.

A unidirectional valve can fail in one of two ways: it can get stuck in the closed position or it can get stuck in the open position. A unidirectional valve that is stuck in the closed position causes airway obstruction. If the expiratory unidirectional valve is affected in the closed position, then breath stacking and barotrauma can occur. You'll need to disconnect the circuit and ventilate by some other means. When a unidirectional valve is stuck in the open position, the entire length of the corrugated tubing between the y-piece and the affected valve becomes dead space. Inspiratory valve failure in the open position converts this inspiratory limb to dead space, expiratory valve failure in the open position converts the expiratory limb to dead space, and simultaneous valve failure converts both limbs to dead space. No matter which valve fails, the patient is at risk for hypercarbia.



How can you diagnose a unidirectional valve stuck in the open position? On the capnograph, you'll see a widened beta-angle. Depending on the fresh gas flow, the baseline may rise as well. If the unidirectional valves are visible (some machines actually conceal them), you'll likely notice that the affected disk is stuck in the open position. How should you treat this complication? Best practice is to eliminate the risk of rebreathing by converting the circle system to semi-open system.

Y-Piece

The y-piece is where the breathing circuit interfaces with the patient's airway. When the unidirectional valves are working properly, dead space begins at the y-piece and ends in the terminal bronchioles of the patent's lungs. Any device that's placed between the y-piece and the patient (such as a heat and moisture exchanger) increases dead space. It's also important to know that the y-piece is the most common site of a circuit disconnect.

Reservoir Bag

Squeezing the reservoir bag allows us to manually deliver positive pressure to the patient. It also serves as a monitor of the patient's respiratory effort during spontaneous or assisted ventilation. Three-liter bags are used for adults, and smaller bags are available for pediatrics. A safety feature of the reservoir bag is that the internal pressure won't exceed ~ 60 cm H_2O if fresh gas is flowing and the APL is completely closed. This minimizes, but does not eliminate, the risk of barotrauma.

When using a piston ventilator, you've likely noticed that (perhaps counterintuitively) the breathing bag inflates during inspiration and deflates during expiration. This is because fresh gas flow is decoupled during inspiration, and it's diverted into the breathing bag during this time. Indeed, removing the bag would cause a huge circuit leak. By contrast, the reservoir bag is functionally isolated from the breathing circuit when a bellows ventilator is used.

Airway Pressure Gauge

The airway pressure gauge monitors the pressure inside the breathing circuit. Excessive positive pressure can cause barotrauma, while excessive negative pressure can rob the circuit of oxygen as well as cause negative pressure pulmonary edema.

Equipment-related causes of excessive breathing circuit pressure include a failed positive pressure relief valve on the scavenger, a failed ventilator spill valve, failure to remove the plastic wrap from the carbon dioxide absorbent or anesthesia mask, a malfunctioning PEEP valve, or an expiratory unidirectional valve stuck in the closed position.

Equipment-related causes of low or no pressure in the breathing circuit include circuit disconnect (the most common cause), a defective carbon dioxide absorbent canister, leaks around the carbon dioxide absorbent (common after the granules have been changed), an incompetent ventilator spill valve, and leaks elsewhere in the breathing circuit or the anesthesia machine.

Equipment-related causes of negative pressure include a defective negative pressure relief valve on a piston ventilator or an active scavenger.

Selector Switch

The selector switch acts like a stopcock that diverts gas flow to the APL valve and breathing bag or the ventilator. In most machines, selecting the ventilator mode simultaneously turns on the ventilator. In other models, however, there's a separate control that performs this function. If your machine offers pressure support, it's using the ventilator circuit even if the patient is spontaneously ventilating.

APL Valve

The adjustable pressure-limiting valve (or APL) determines how much pressure can be generated inside the breathing circuit when bag mode is selected. You can think of the APL as a pop-off valve, where gas is diverted to the scavenger when the circuit pressure exceeds the value set on the valve. It's recommended that the APL be completely open during spontaneous ventilation, and it may be partially closed when providing assisted or manually controlled ventilation. Closing the APL valve during mask ventilation is useful when there's a leak around the mask. The APL valve is completely bypassed when the bag selector switch is in the ventilator position.

Oxygen Analyzer

The oxygen analyzer is the is the last line of defense against the delivery of a hypoxic mixture. Although it can be placed in either limb, it's generally best when it's placed in the inspiratory limb. In contrast to the other safety devices that monitor oxygen pressure, the oxygen analyzer monitors oxygen concentration. Consequently, it's the only device capable of detecting an oxygen pipeline crossover.

There are three types of oxygen analyzers. The galvanic fuel-cell and polarographic devices monitor an electrical current that varies as a function of the oxygen tension. They must be calibrated each day. They have consumable parts, so they tend to wear out over time. By contrast, a paramagnetic device uses a magnetic field to monitor the oxygen concentration. This design is self-calibrating, and it also has a faster response time when compared to the other types of oxygen analyzers.

Spirometer

Exhaled tidal volume is measured by a spirometer in the expiratory limb of the breathing circuit. Some machines place a spirometer in the inspiratory limb as well, which creates a feedback loop that helps the ventilator vary the fresh gas flow to ensure a consistent tidal volume.

CO_2 Absorbent

Carbon dioxide absorbents remove exhaled carbon dioxide from the breathing circuit. This allows the patient to rebreathe exhaled gas, which conserves heat and humidity. It also saves money since less anesthetic agent is diverted to the scavenger. Since soda lime is the most commonly used CO_2 absorbent, it will be the focus of this video.

How Does It Work?

Soda lime contains sodium hydroxide (a strong base) that neutralizes carbon dioxide (an acid). This reaction occurs in a three-step process. First, the carbon dioxide exhaled by the patient reacts with water on the surface of the soda lime granule, and this forms carbonic acid. Second, carbonic acid reacts with sodium hydroxide to yield sodium carbonate and water. Third, sodium carbonate reacts with calcium hydroxide to create calcium carbonate, an insoluble precipitate, and sodium hydroxide. Although some sodium hydroxide is regenerated, there is a finite quantity of CO_2 that can be neutralized. Indeed, soda lime can absorb 26 L of CO_2 per 100 g of absorbent. Since sodium hydroxide can be irritating to mucous membranes, silica is added to increase hardness and reduce dust. This reduces the risk of bronchial irritation.

Mesh Size

Does the size of the soda lime granule affect its function? The size of the granule must strike a balance between surface area (absorptive capacity) and airflow resistance (work of breathing). Small granules have a larger surface area, but they impart a higher degree of airflow resistance. Conversely, large granules have a smaller surface area, and they impart a lower degree of airflow resistance. We can pass the granules through a mesh to isolate the size we want. The best balance is achieved when 4 – 8 mesh granules are used. This means that each granule is 1/8 to 1/4 inch in diameter, and it will pass through a mesh screen with 4 – 8 holes per square inch.

Problems with Soda Lime

The problems that can occur with soda lime tend to be related to one of two issues – exhaustion or desiccation.

Remember, sodium hydroxide is a strong base. As CO_2 consumes the basic substrate, the pH of the absorbent decreases. When the pH falls below 10.3, an indicator dye such as ethyl violet changes to a blue-purple color. Why does this matter? Activation of the indicator dye tells us that the CO_2 absorbent is no longer able to neutralize carbon dioxide effectively. In other words, it's time to change the canister. Understand that, if the anesthesia machine is not in use, ethyl violet may revert to its colorless state. This does not mean that the soda lime has regenerated. If exhausted CO_2 absorbent is exposed to CO_2, it will quickly return to purple.

Imagine you're in the middle of a case and you notice the end-tidal CO_2 is 65 mmHg. The fraction of inspired CO_2 is increased, and the capnograph's baseline does not return to zero. You look at the soda lime to discover it has turned purple. Many sources recommend that you don't change the canister in the middle of a case. What should you do? Actually, let's start with what not to do. Don't be tempted to increase the patient's minute ventilation! While this will remove a greater amount of carbon dioxide from the patient, it won't remove the extra carbon dioxide from the breathing circuit. Therefore, it won't prevent rebreathing, and the patient will experience hypercarbia. Instead, the best action is to increase the fresh gas flow to 1 – 2 times the patient's minute ventilation. This converts the circle system into a semi-open system. This will prevent rebreathing, and the baseline on the capnograph should return to zero. You can change the canister after the case, but don't forget to perform a high-pressure check to make sure there aren't any leaks.

Remember, water is needed to convert CO_2 to carbonic acid. To facilitate this reaction, the soda lime granules are hydrated to 13 – 20% by weight. Desiccation occurs when there's not enough water to drive the soda lime reaction. How can you tell when the soda lime is desiccated? Unfortunately, you can't. But what about ethyl violet? Remember, the indicator dye tells you about exhaustion but not desiccation.

Carbon Monoxide

All halogenated anesthetics react with soda lime to produce carbon monoxide. Desiccated soda lime accelerates this process, and the risk is highest with desflurane, then isoflurane, and it's minimal with sevoflurane. When the patient inhales carbon monoxide, it reacts with hemoglobin to produce carboxyhemoglobin. This shifts the oxyhemoglobin dissociation curve to the left and reduces oxygen offloading at the tissue level.

How can we reduce the build-up of carbon monoxide inside the breathing circuit?

- Use a low fresh gas flow to preserve the water content of the soda lime.
- Turn off the flowmeters between cases.
- Change all the CO2 absorbent at one time (not just a single canister in a dual canister setup).
- If the flowmeter was left on overnight or over the weekend, then it's best to replace all of the CO2 absorbent.

Compound A

In the presence of sevoflurane (but not the other inhaled anesthetics), soda lime can produce compound A. The reaction is accelerated when the soda lime is desiccated. When the patient inhales compound A, there's a theoretical risk that it can produce renal dysfunction. To minimize the risk of rebreathing compound A, it's recommended that you use a minimum fresh gas flow of 1 – 2 L/min for up to 2 MAC hours and then increase to a minimum of 2 L/min after 2 MAC hours have elapsed. Fresh gas flow rates below 1 L/min are not recommended.

Several conditions increase compound A formation, and we should do our best to minimize them. Conditions that increase compound A formation include:

- A low fresh gas flow
- A high absorbent temperature
- Desiccation
- A high concentration of sevoflurane inside the breathing circuit

Alternatives

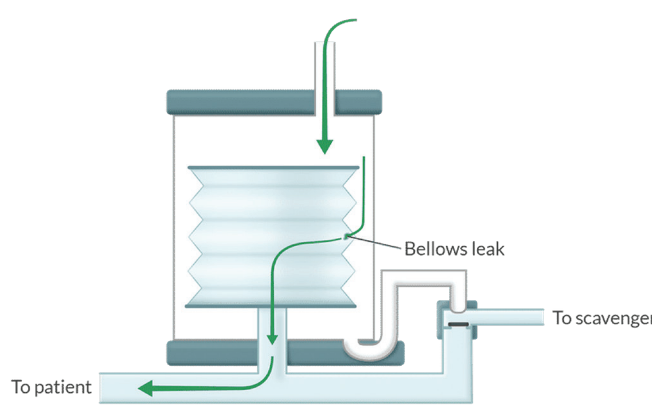
Are there alternatives to soda lime? Some formulations replace sodium hydroxide with potassium hydroxide, but this has fallen out of favor since potassium hydroxide produces more carbon monoxide and compound A when it desiccates. Amsorb replaces sodium hydroxide with calcium hydroxide (a much weaker base). The benefits are that it mitigates the concern of carbon monoxide and compound A production; however, the downsides are that it costs more, and it only has half the absorptive capacity of soda lime. Baralyme used to be another alternative, but it was removed from the market in 2005 due to an increased risk of breathing circuit fires when sevoflurane was used.

Ventilator

Let's discuss the clinically relevant aspects of the bellows ventilator and piston ventilator.

Bellows Ventilator

A pneumatic bellows uses a double circuit design, where the bellows separates the drive gas circuit from the patient breathing circuit. During inspiration, the drive gas (oxygen or air) compresses the bellows which pushes fresh gas into the patient's lungs. The drive gas also closes the ventilator spill valve. This ensures that the tidal volume goes to the patient and not to the scavenger. During exhalation, the drive gas flow stops, and the exhaled tidal volume refills the bellows. Remember that fresh gas is continuously added to the breathing circuit, so the amount of gas that refills the bellows is the sum of the exhaled tidal volume plus fresh gas flow during expiration. After the circuit pressure exceeds ~ 3 cm H_2O, the ventilator spill valve opens, and excess gas is diverted to the scavenger. This explains why pneumatic ventilators introduces intrinsic PEEP into the breathing circuit.



If your machine uses oxygen as the drive gas, it'll consume tank oxygen during pipeline failure. In this situation, it's best to conserve your oxygen supply by manually ventilating the patient. Machines that use air for the drive gas typically entrain room air, so there's no concern about premature oxygen tank depletion. A leak in the bellows allows the drive gas to mix with gas inside the patient breathing circuit. If the drive gas is composed of oxygen, you'll notice an increased inspired FiO_2. Other complications include barotrauma as well as dilution of the volatile anesthetic concentration (which can lead to awareness).

The bellows is classified as a function of the direction it moves when the patient exhales. An ascending bellows rises during expiration and falls on inspiration, and a descending bellows falls during expiration and rises during inspiration. In the event of a circuit disconnect, an ascending bellows will fail to rise, which provides an important visual cue that a disconnection has occurred. By contrast, some descending bellows (particularly on older machines) will continue to rise and fall despite the disconnect. This is dangerous because it looks like the patient is being ventilated while he's not. Newer designs incorporate safety mechanisms to alert you should this complication occur.

Most newer anesthesia machines decouple fresh gas flow from the tidal volume. This means that the tidal volume you set on the ventilator is what the patient actually receives. By contrast, older anesthesia machines couple fresh gas flow to the tidal volume set on the ventilator. This may lead to errors in predicted Vt and minute ventilation. When using a machine with fresh gas coupling, the total tidal volume delivered to the patient equals Vt set on ventilator + FGF during inspiration – Volume lost to circuit compliance. Let's look at this in context. During induction, you set the oxygen at 10 L/min. After intubation, you forget to change the fresh gas flow. You set the tidal volume to 500 mL, the respiratory rate to 10 breaths per minute, and the I:E ratio to 1:2. The fresh gas will add an extra 333 mL on top of the tidal volume set on the ventilator, so the true tidal volume is actually 833 mL minus a what is lost to circuit compliance. Imagine the implications of this when caring for neonates and small children!

Another significant consequence of fresh gas coupling is the interdependence of tidal volume and seemingly unrelated changes to the ventilator settings. For instance, you'll notice that the true tidal volume increases when you reduce the respiratory rate or increase the I:E ratio (such as going from 1:2 to 1:1). Again, this goes back to the idea that fresh gas during I-time is added to the tidal volume, so anything that increases I-time over the course of a minute will also increase the tidal volume for each breath.

Piston Ventilator

The piston ventilator uses an electric motor to compress a mechanical piston. During inspiration, the piston moves far enough to deliver the set tidal volume. This design offers greater accuracy in tidal volume delivery, which can be particularly useful in small children and patients with very poor lung compliance. Additionally, piston ventilators are uncoupled from the fresh gas flow. Since there's no drive gas, the piston ventilator won't consume tank oxygen in the event of a pipeline failure. Because the piston is quiet, some machines allow you to turn on an artificial sound that mimics the sound of a bellows ventilator. This makes it easier to detect a circuit disconnect.

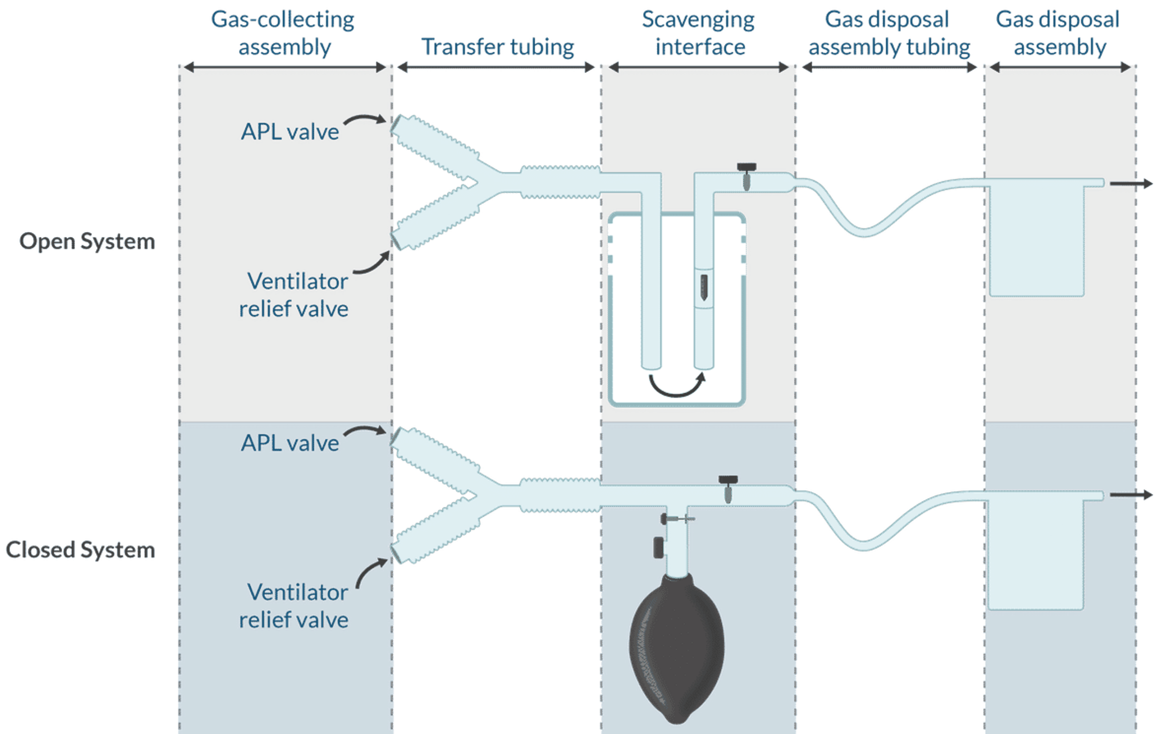
In contrast to the bellows ventilator, the piston ventilator incorporates the reservoir bag into the ventilator circuit during mechanical ventilation. Although it may seem counterintuitive, the bag inflates during inspiration (because excess fresh gas is diverted into the bag) and deflates during expiration. If the breathing bag rapidly collapses, you should rule out a circuit disconnect.

To protect against extremes in circuit pressure, there are two pressure relief valves. The positive pressure relief valve opens to the atmosphere at ~ 75 cm H_2O. This reduces (but does not eliminate) the risk of barotrauma. The negative pressure valve relief valve opens at ~ -8 cm H_2O. When this occurs, room air is entrained into the breathing circuit. This protects the patient against negative end-expiratory pressure (NEEP). In this situation, mixing of entrained room air with fresh gas will dilute the concentration of oxygen and anesthetic agent.

Scavenger

Imagine you're running a fresh gas flow at 2 L/min for a 2-hour procedure. Obviously, the patient isn't consuming all of this gas, so we need a scavenger to remove the waste gas from the breathing circuit and ultimately the operating room.

We can classify the scavenger system as active or passive. An active system relies on suction to remove the waste gas. Conversely, a passive system relies on the positive pressure of the fresh gas entering the system to push the gas through the scavenger. Let's take a look at how both of these operate.



The gas collection assembly diverts excess gas inside the patient breathing circuit to the scavenger. During spontaneous ventilation, this occurs at the APL valve, and during mechanical ventilation, this happens at the ventilator spill valve. The gas diverted into the scavenger moves toward the interface along the transfer tubing. The interface contains a reservoir for waste gas and can be classified as an open or closed system. As its name suggests, an open system communicates with the operating room environment. This design requires suction (making it an active system). A bobbin illustrates the correct amount of suction. If there's too much suction, room air is entrained into the system. If there's too little suction, the reservoir will release scavenged gas into the OR environment. This is safer for the patient because it eliminates the risk of barotrauma in the event of scavenger obstruction; however, it's not as safe for OR personnel because there's a higher risk of exposing everyone to waste gas.

As its name suggests, a closed system doesn't communicate with the OR environment, and it relies on pressure valves to protect the patient against extremes of pressure. For both active and passive systems, a positive pressure relief valve prevents barotrauma in the event of scavenger obstruction. Additionally, an active system requires a negative pressure relief valve. This protects against excessive suction, which could expose the breathing circuit to negative pressure leading to hypoxia and negative pressure pulmonary edema. Since a passive system doesn't use suction, there's no need for a negative pressure relief valve.

With any scavenger system, waste gas is either collected in a dedicated receptacle or it's released into earth's atmosphere. The halogenated anesthetics, as well as nitrous oxide, have been implicated in climate change. The Occupational Safety and Health Administration (OSHA) guidelines detail the maximum exposure to inhaled anesthetics for health care workers in the operating room. When used alone, halogenated agents should be less than or equal to 2 ppm, and when nitrous is used alone, it should be less than or equal to 25 ppm. When halogenated agents are used in conjunction with nitrous oxide, the environmental concentrations should be less than or equal to 0.5 ppm and 25 ppm, respectively.

As a reminder, improper anesthetic technique unnecessarily exposes OR personnel to anesthetic agents. A good mask fit and a properly inflated endotracheal tube or LMA can go a long way to reduce exposure to waste gases. When the patient is disconnected from the breathing circuit, it's best to reduce or (if possible) stop the flow of fresh gas. Just don't forget to turn it on when you reconnect the patient. When performing anesthesia in remote locations, be sure that the scavenger is functional and connected to a dedicated suction line (i.e., not shared with the patient's suction).

Pre-Anesthesia Checkout Procedures

Closed-claims analysis continues to implicate anesthetic equipment in morbidity and mortality, where operator error plays a key role. Indeed, the overwhelming majority of poor outcomes could've been prevented with a proper pre-operative machine checkout.

The table on this page summarizes the essential components of the pre-anesthesia checkout procedures. Although most modern anesthesia workstations automate parts of the pre-use checkout, other elements must be performed manually. Therefore, you must know the specifics about each machine that you use. Due to the variety of machine configurations on the market, it is difficult to confidently determine what is and what is not checked during the automated checkout procedure without reading the manual for your particular machine.

We'd like to highlight several things on this table. Some tasks may be completed at the beginning of each day while others must be performed before each patient. Regarding the tasks that may be performed daily, it's important to point out that these should also be performed if the anesthesia machine is moved to a new location or if a vaporizer is changed. Also, much of the checkout procedure can be performed by the anesthesia provider or an anesthesia technician.

Item	Task	Timing	Party
1	Verify auxiliary oxygen cylinder and manual ventilation device are available and functioning.	Daily*	P & T
2	Verify patient suction is adequate to clear the airway.	Before each patient	P & T
3	Turn on anesthesia delivery system and confirm that ac power is available.	Daily*	P or T
4	Verify availability of required monitors, including alarms.	Before each patient	P or T
5	Verify that pressure is adequate on the spare oxygen cylinder mounted on the anesthesia machine.	Daily*	P & T
6	Verify that piped gas pressures are $\geq$ 50 psi.	Daily*	P & T
7	Verify that vaporizers are adequately filled and, if applicable, that the filler ports are tightly closed.	Before each patient	P or T
8	Verify that there are no leaks in the gas supply lines between the flowmeters and common gas outlet.	Daily*	P or T
9	Test scavenging system function.	Daily*	P or T
10	Calibrate, or verify calibration of, the oxygen monitor and check the low oxygen alarm.	Daily*	P or T
11	Verify carbon dioxide absorbent is fresh and not exhausted.	Before each patient	P or T
12	Perform breathing system pressure and leak testing**	Before each patient	P & T
13	Verify that gas flows properly through the breathing circuit during both inspiration and exhalation.	Before each patient	P & T
14	Document completion of checkout procedures.	Before each patient	P & T
15	Confirm ventilator settings and evaluate readiness to deliver anesthesia care (anesthesia time out).	Before each patient	P only

* if anesthesia machine is moved to new location or if vaporizers are changed / ** Maximum acceptable leak is 50 mL/min at 30 cm H_2O (4) / P = provider / T = tech

Preparing the Anesthesia Machine for the MH Patient

Although the diagnosis and treatment of malignant hyperthermia is beyond the scope of this module, we want to detail how you should prepare the anesthesia machine for the patient at risk for MH. We'd like to point out that best practice is to consult the product manual for your specific machine, however we're going to reference the general guidelines from the Malignant Hyperthermia Association of the United States (MHAUS).

- Remove or disable the vaporizer by taping it in the "OFF" position.
- Do not drain the vaporizer.
- Change the carbon dioxide absorbent.
- Use a new breathing circuit and attach the reservoir bag to the y-piece. Turn on the mechanical ventilator to periodically inflate the bag.
- Newer anesthesia workstations may require a fresh gas flow of 10 L/min for up to 104 minutes.
- Older anesthesia workstations may require a fresh gas flow of 10 L/min for up to 20 minutes. Again, be sure to consult the product manual for your specific machine.

As an alternative to the purging guidelines previously noted, the MHAUS guidelines state that you may use a charcoal filter (such as the Vapor-Clean). This filter will maintain a halogenated anesthetic concentration below 5 ppm for up to 12 hours with a minimum fresh gas flow of 3 L/min. Here are the manufacture's recommendations:

- Place a Vapor-Clean filter on the inspiratory and expiratory port of the anesthesia machine.
- Flush the anesthesia machine with high fresh gas flow (greater than 10 L/min) for 90 seconds prior to using the machine on a patient.

Treatment for MH Crisis

We're going to cite the MHAUS guidelines to detail how to handle an acute MH crisis that develops during a case.

- Notify the surgeon to terminate the procedure.
- Discontinue the triggering agent.
- Maintain anesthesia with a non-triggering agent, such as an IV technique consisting of sedative/hypnotics, non-depolarizing neuromuscular blockers, and opioids.
- Call for the MH cart and additional help. You can also call the MHAUS MH hotline for further guidance.
- Hyperventilate with 100% oxygen at 10 L/min. If you have a charcoal filter (such as the Vapor-Clean), you can apply a filter to the inspiratory and expiratory port of the anesthesia machine and then apply a new breathing circuit and reservoir bag. The Vapor-Clean will need to be changed every hour.
- Administer dantrolene or Ryanodex 2.5 mg/kg IV every 3 – 5 minutes until the patient responds with a reduction in EtCO_2, heart rate, and skeletal muscle rigidity.
- If the patient's temperature is higher than 39 °C, then provide active cooling measures (such as ice packs or gastric lavage) until the core body temperature is less than 38 °C.
- Treat hyperkalemia with calcium chloride, sodium bicarbonate, and glucose and insulin. Hyperventilation will also help. Refractory hyperkalemia can be treated with albuterol, kayexalate, dialysis, or if the patient experiences cardiac arrest, then ECMO should be considered.
- Treat dysrhythmias, but do not administer a calcium channel blocker!
- Manage acidosis, and consider sodium bicarbonate if the base excess exceeds -8 mEq/L.
- Review the guidelines on the MHAUS website for further details.

(Continued on next page)

Key Points

Here are some key points for your practice.

- You can estimate how long an oxygen E cylinder will last with the following equation:
  - Step 1: [Tank capacity (L) / Full tank pressure (psi)] x [Contents remaining (L) / Gauge pressure (psi)]
  - Step 2: Contents remaining (L) / FGF rate (L/min) = Minutes left before the tank expires
- If you suspect an oxygen pipeline crossover, you must do two things. First, turn on the oxygen tank. Second, disconnect the pipeline oxygen supply from the anesthesia machine.
- The oxygen analyzer monitors oxygen concentration, while the fail-safe device monitors oxygen line pressure.
- Desiccated soda lime increases carbon monoxide production (greatest with des) and compound A (greatest with sevo).
- Understanding the implications of fresh gas flow coupling is essential to safe ventilator management, particularly in neonates, small children, and in patients with very poor lung compliance.