Breathing Systems

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Key Points
- Ideal features for a breathing system include reliable delivery of various concentrations of oxygen, effective removal of carbon dioxide, low resistance to breathing with minimal dead space, efficient use of gases, and conservation of heat and humidity in the airways.
- Mapleson circuits have the advantage of being able to provide positive pressure ventilation with a relatively simple and portable design. The disadvantages of Mapleson circuits include poor conservation of gases, heat, and humidity.
- The circle system improves the shortcomings of the Mapleson system with significant improvements in the ability to conserve gases, heat, and humidity. This comes at the expense of making a significantly more complex system that is not portable.
- The carbon dioxide absorber converts carbon dioxide into calcium carbonate. This allows the rebreathing of gases in the circle system.
- Compound A is produced when the strong base in the carbon dioxide absorber removes hydrogen fluoride from sevoflurane. It is a nephrotoxin in rats and has unclear clinical significance in humans.
- Carbon monoxide is produced by desiccated carbon dioxide absorbers. The risk is greatest with desflurane and first-start cases Monday morning. This occurs since the anesthesia machine is less likely to be used during the weekend and the carbon dioxide absorber can dry out when not in use.

34

34.1 Introduction

One of the first breathing systems was developed by Barth in 1907 for the use of nitrous oxide to provide anesthesia. It consisted of a nitrous oxide cylinder, a valve, and a reservoir bag. The valve could be adjusted to allow complete rebreathing from the reservoir bag to breathing completely from the atmosphere, or somewhere in between. This system allowed some degree of control of the amount of nitrous oxide and oxygen delivered to the patient. The next step in the development of breathing systems occurred when Magill and Rowbothom designed a single lumen endotracheal tube. This led to the development of the "Magill's circuit" (Mapelson A circuit). Additional breathing systems were developed with the goal of designing one that was reliable and efficient for both spontaneous and controlled ventilation.

Requirements for breathing systems:
- Delivery of oxygen can be reliably delivered to the patient at the desired concentration and easily adjusted
- Effectively removes carbon dioxide
- Low resistance to breathing
- Minimal amount of dead space

Desirable features:
- Efficient use of gases
- Humidification of gases
- Conservation of heat
- Portable
- Simple, sturdy and compact design that allows easy testing and troubleshooting of the components
- Ability to remove waste anesthesia gases to prevent pollution of the operating room

Even with today's modern anesthesia machine, no breathing system is able to achieve all of the desirable features listed above and for this reason different breathing systems are used for different settings.

34.2 Classification of Breathing Systems

As more breathing systems were designed, multiple authors tried to develop classification systems based on the amount of rebreathing, presence of a carbon dioxide absorber, and the presence or absence of unidirectional valves. A common and relatively simple classification system is shown in Table 34.1.

Table 34.1 Classification of breathing systems

	Reservoir	Rebreathing	Example
Open	No	No	Open Drop
Semi-Open	Yes	No	Non-rebreather circuit
Semi-Closed	Yes	Partial	Circle system with flows of 2 L/min
Closed	Yes	Complete	Circle system with flows just sufficient to replace uptake of oxygen

34.3 Non-rebreathing Systems

34.3.1 Insufflation

The term insufflation refers to a breathing system that is not in contact with the patient but instead blows oxygen and the anesthesia gases across a patient's face. There are 2 common methods where insufflation is used in modern practice. The first is in pediatric patients who will not allow the placement of an intravenous line or the application of an oxygen face mask to their face. In this case the oxygen mask is held near the patient's face and when they breath in, they inhale the oxygen and the anesthesia gases that are supplied by the mask. The other example of insufflation is during cataract surgery and procedures performed typically under conscious sedation or monitored anesthesia care (MAC) when the patient's face is fully covered with the surgical drapes. Frequently oxygen tubing is then placed under the drapes to blow oxygen at high flows near the patient's face to minimize the rebreathing of carbon dioxide. The disadvantage of insufflation is positive pressure ventilation cannot be done and the concentration of oxygen delivered is variable even at high flow rates.

34.3.2 Open-Drop Anesthesia Systems

In modern medicine, open-drop anesthesia systems are no longer in use, but since they were one of the earliest methods for providing anesthesia, they deserve a brief description. These were the primary methods for administering ether or chloroform anesthesia to patients. They consisted of a face mask with a gauze-covered opening where a highly volatile anesthetic was then dripped onto the gauze. When the patient inhaled, the flow of air through the gauze caused the liquid volatile anesthetic to become a gas. The depth of anesthesia was controlled by the amount of volatile anesthetic liquid applied to the gauze. The major disadvantage of this system is the patient had to be breathing spontaneously and there was no way to monitor the concentration of volatile anesthetic the patient was inspiring.

34.3.3 Mapleson Circuits

The development of the Mapleson circuits attempted to overcome the major shortcomings of the insufflation and open-drop systems. Compared to previous breathing systems, the Mapleson circuits had the following advantages:

- Ability to deliver a reliable concentration of oxygen and volatile anesthetics
- Provide positive pressure ventilation
- Ability to scavenge waste gases
- Portable and relatively simple design

Since there are no unidirectional valves or CO_2 absorbers, the CO_2 is eliminated by fresh gas flows that flush the CO_2 into the atmosphere or scavenger via the pop-off valve. The Mapleson circuits are classified based on the location of the following parts as seen in Fig. 34.1:

- **Fresh gas inlet** – Supplies oxygen, air, and volatile anesthetics to the system
- **Reservoir bag** – Acts as a reservoir for the gases and a method for creating positive pressure
- **Pop-off valve/Adjustable pressure relief valve** – Allows the release of excess gases from the system. Closing of the valve allows increasing levels of pressure to be achieved
- **Face mask**

Although the Mapleson circuits all have the same components, the comparison of the circuits and the amount of CO_2 rebreathing that occurs can be complex. Rebreathing that occurs for each circuit is affected by the position of the pop-off valve in relationship to the fresh gas input and the reservoir tubing and bag. Each type of Mapleson system has different levels of fresh gas flows required to prevent rebreathing. In addition, each class of circuit responds differently to spontaneous versus controlled ventilation in relation to the fresh gas flows required to prevent rebreathing.

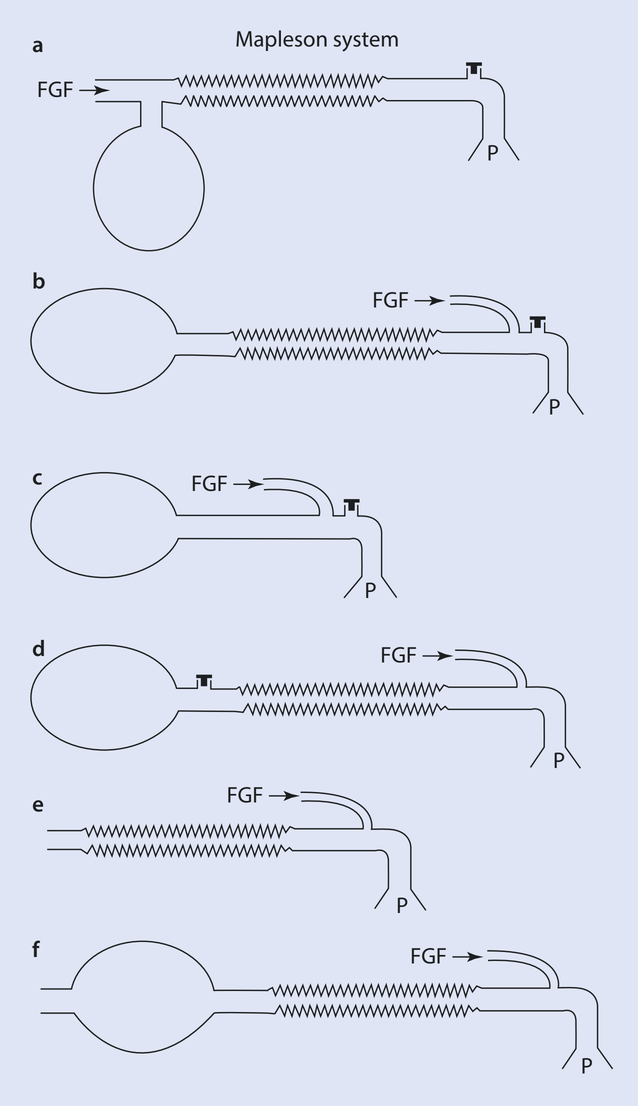
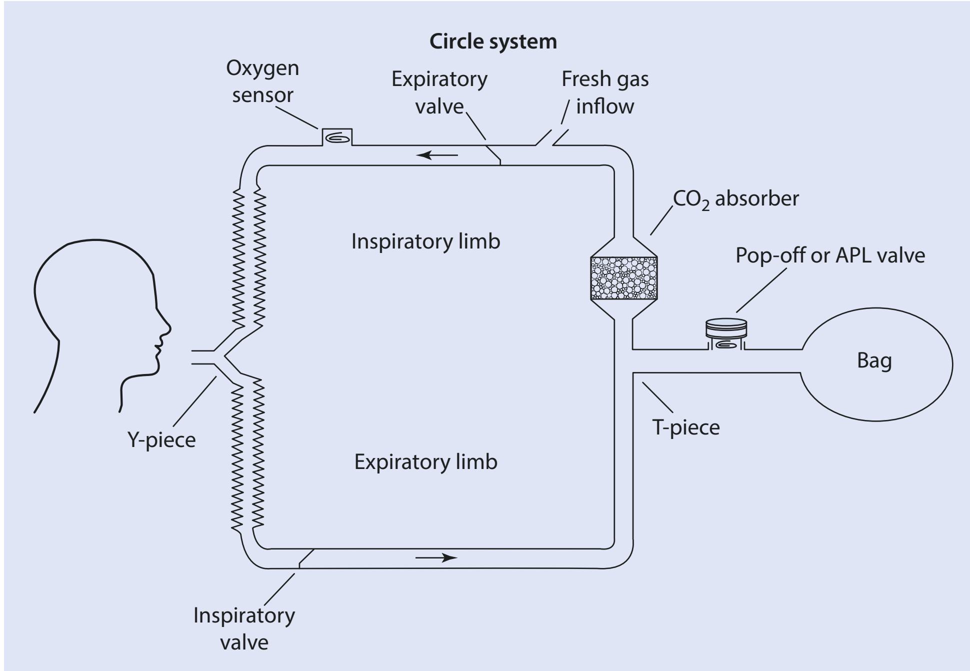


Fig. 34.1 **a-f** Mapleson system. *FGF* fresh gas flow, *P* patient

Mapleson A (see Fig. 34.1) is considered the most efficient circuit for spontaneous ventilation but is not recommended for controlled ventilation due to the need for unpredictably high fresh gas flows required to prevent rebreathing. By changing the position of the pop-off valve and the fresh gas inlet the system becomes a Mapleson D (see Fig. 34.1), which is significantly more efficient for controlled ventilation. This is because the fresh gas flushes the exhaled gases away from the patient and toward the pop-off valve. The Bain circuit is a modified Mapleson D system that incorporates the fresh gas inlet tubing inside the larger

Fig. 34.2 Circle system



corrugated breathing tube. This decreases the size of the system and allows warming of the inspired gases by the exhaled gases. A major disadvantage of Bain circuit is if the fresh gas inlet tubing is disconnected or kinked, this will lead to significant rebreathing of exhaled gases.

Efficiency of Mapleson Circuits

Spontaneous Ventilation A > DFE > CB

Controlled Ventilation DFE > BC > A

(Refer to Fig. 34.1 for the different Mapleson circuits by letter.)

While the Mapleson systems were a significant improvement from previous breathing systems, the major disadvantage remained to be poor conservation of heat and humidity. In addition, the minimum flows required to prevent rebreathing are typically 5–10 L/min for an adult.

34.3.4 The Circle System

The circle system was designed to overcome some of the limitations of the Mapleson circuits. Through the rebreathing of exhaled gases humidity and heat are maintained. Since the exhaled gases are rebreathed, this leads to a conservation of volatile anesthetics, oxygen, and air. These advantages have resulted in the circle system being the ventilation system used in all modern anesthesia machines. While the oxygen, nitrogen, and the volatile anesthetics are rebreathed, CO_2 absorbers chemically neutralize the CO_2 so there is no rebreathing of CO_2. However, to achieve these results the complexity of the breathing system was substantially increased. As shown in Fig. 34.2 the necessary components of a circle system include:

1. CO_2 absorber
2. Unidirectional valves
3. Fresh gas inlet
4. Y-connector
5. Adjustable pressure relief valve ("pop-off valve")

Carbon Dioxide Absorber

To prevent rebreathing of carbon dioxide, a carbon dioxide absorber is an essential part of any circle system. The absorber is able to convert carbon dioxide gas to calcium carbonate. In addition, the reaction leads to the production of heat and water:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O + Heat$$

$$Na_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2NaOH$$

Soda lime is the most commonly used agent to absorb carbon dioxide. It is capable of absorbing 23 L of CO_2 per 100 g of soda lime. It is important to note that for the reaction to occur water is necessary to begin the reaction, but as the reaction continues each molecule of CO_2 leads to the net production of 1 molecule of H_2O. Since the carbon dioxide absorber requires water to start the reaction, they are packaged by the manufacturer with 14–19% water content.

As the absorber is exhausted, hydrogen ions accumulate. To monitor the pH an indicator dye (ethyl violet) is added to the absorber granules, which causes the white absorber granules to turn purple as they are exhausted. If an exhausted carbon dioxide absorber is not used for a time, the granules may return to the original white color. However, the absorber is still exhausted and cannot absorb additional carbon dioxide. All modern anesthesia machines monitor the inspired and expired carbon dioxide. With a properly functioning carbon dioxide absorber, inspired carbon dioxide should be zero and the absorber should be changed once the inspired carbon dioxide is present. If it is not possible to replace the carbon dioxide absorber, high flows (>5 L/min) can effectively wash out the carbon dioxide from the system.

The absorber granules are capable of absorbing and releasing volatile anesthetic gases. This is clinically relevant when the absorber canisters are changed during a surgical case. When this occurs, the new absorber canister will absorb the volatile anesthetic in the anesthesia machine and the depth of anesthesia will decrease temporarily. The other clinically significant scenario is in patients at risk of malignant hyperthermia. In these patients if an anesthesia machine is used that had previously been used with volatile anesthetics, then the patient may be exposed to volatile anesthetics. Since this could trigger an episode of malignant hyperthermia, a new carbon dioxide absorber should be used.

Unidirectional Valves

In a circle system, unidirectional valves are essential to maintain the flow of gases in the correct direction. This is important to prevent rebreathing of the expired gases with carbon dioxide present. There are 2 valves in the system. During inspiration the inspiratory valve opens and the expiratory valve closes. During expiration the expiratory valve opens and the inspiratory valve closes. The most common malfunction of the unidirectional valves is incomplete closure—usually due to a warped valve. If this occurs, then rebreathing of carbon dioxide is possible and hypercapnia can result.

Fresh Gas Inlet

One of the advantages of the circle system is the rebreathing of oxygen and volatile anesthetic gases. However, due to the uptake of oxygen and volatile gases by the patient there must be continuous addition of oxygen and volatile gases to the circle system. This occurs via the fresh gas inlet. When adding gases to the system, it is important to remember that gases from the fresh gas inlet will be diluted by the gases already in the circuit. For example, a typical circle system in a modern anesthesia machine will have a volume of 7 L. If the fresh gas inlet is at low flows (<1 L/min), there can be a significant difference between the concentration of volatile gases coming from the vaporizer via the fresh gas inlet and the concentration delivered to the patient. This is most apparent during induction and emergence from anesthesia. To compensate for the dilution effect, a high flow rate (>5 L/min) can be used.

Adjustable Pressure Relief Valve ("Pop-Off Valve")

As previously mentioned, higher fresh gas flows can be used to speed changes in the concentration of volatile anesthetics in the circuit. The adjustable pressure relief valve will vent off the excess gases from the circle system to maintain a set volume. The adjustable pressure relief valve is also used to adjust the pressure in the system during positive pressure ventilation. During spontaneous ventilation, the adjustable pressure relief valve should be fully open to minimize the pressure to which the patient is exposed.

Order of Components in the Circle System

To optimize the efficiency of the circle system, the components of the circle system are arranged in the following order, starting from the patient during expiration:

- Expiratory limb of circuit going to the expiratory unidirectional valve.
- After the expiratory unidirectional valve, the adjustable pressure relief valve is next and it is positioned before the carbon dioxide absorber. The result is the excess exhaled gas is vented away before it goes through the absorber. This conserves the absorber since the excess gas does not need to have the carbon dioxide removed.
- After the carbon dioxide absorber is the fresh gas inlet. This positioning allows the newly supplied gas to bypass the adjustable pressure relief valve and the carbon dioxide absorber. Therefore, all of the new gases are directly supplied to the patient.
- The inspiratory unidirectional valve is next, and then gas moves through the inspiratory limb of the circuit where it delivers gases to the patient.

Dead Space

Dead space is defined as ventilation that does not reach the alveoli and therefore is not effective in exchanging oxygen and carbon dioxide. As the dead space increases, the tidal volumes must increase to maintain a given carbon dioxide. Due to the unidirectional valves in the circle system, the dead space begins at the Y-piece where the inspiratory limb joins with the expiratory limb. Therefore, increasing the length of the circle system does not increase the amount of dead space.

Disadvantages of the Circle System

While the circle system has many advantages compared to the Mapleson breathing system, there are a few disadvantages:

- **Complexity** – The circle system is more complicated and it requires frequent maintenance and daily machine checks to ensure the essential components are functioning properly.
- **Size** – The circle system is significantly larger and less portable.
- **Breathing Resistance** – Due to the unidirectional valves and the carbon dioxide absorber, there is more resistance. However, even in a premature infant a circle system can be used.

Circle System with High vs. Low Flows

One of the significant advantages of the circle system is the ability to run low fresh gas flows due to the rebreathing of exhaled gases. The rebreathing of exhaled gases can lead to significant differences in the concentration of volatile anesthetic between the fresh gas inlet and the gas delivered to the patient. One example where this is clinically significant is during induction of anesthesia. During this time there is rapid uptake of volatile anesthetics and the expired gases have minimal amounts of volatile anesthetics. If low fresh gas flows are used, then even if high concentrations of volatile gases are delivered via the fresh gas inlet the gases will be significantly diluted by the larger volume of exhaled gases from the patient. This will result in a delay in induction of anesthesia. The same is true during emergence from anesthesia. If low flows are used, then the expired volatile anesthetics will continue to circulate in the breathing system even if volatile anesthetics are no longer being delivered via the fresh gas inlet. Therefore, to speed induction and emergence from anesthesia high flows (>5 L/min) are typically used.

With low fresh gas flows it is also essential to monitor the concentration of the inspired oxygen concentration that is delivered to the patient. This is because with low flows the majority of the gases will be rebreathed. During ventilation the oxygen is absorbed while the nitrogen is not. With time the concentration of nitrogen will increase and potentially a hypoxic mixture of gases can be delivered to the patient. With higher flows this does not occur because the excess volume of gas is vented from the system via the pop-off valve and the concentration of the inspired gases more closely matches the gases from the fresh gas inlet. This also applies to nitrous oxide. Initially during induction the nitrous oxide is absorbed and the concentration of oxygen is maintained. However, as the absorption of nitrous oxide slows, the nitrous oxide will accumulate in low fresh gas flows and a hypoxic mixture can also be delivered. For these reasons it is essential to monitor the concentration of oxygen and anesthetics that are being delivered to the patient with a gas analyzer when using a circle system.

34

34.3.5 Closed Circle System

In a closed circle system the fresh gas flows of oxygen are matched with the uptake of oxygen by the patient. If done correctly, then no excess gases are vented via the pop-off valve. A closed circle system maximizes the advantages of the circle system, which include conservation of gases, humidity, and heat. However, a closed circle system exacerbates the problems listed previously for low fresh gas flows. Delivery of volatile anesthetics is particularly difficult with a closed circle system due to the changing uptake of the volatile anesthetics as the patient progresses from induction to maintenance of anesthesia. Due to the extremely low fresh gas flows (0.2–0.3 L/min) it is difficult to rapidly change the concentration of oxygen or volatile anesthetics in the breathing circuit. For these reasons, closed circle systems are not frequently used in clinical practice.

34.3.6 Use of Circle Systems in Neonates

Several adaptations have been made to the circle system to decrease the work of breathing for neonates. For adult circuits the dead space begins at the y-piece, which joins the inspiratory and expiratory limbs of the circuit. The dead space consists of the Y-piece, the endotracheal tube, and the airways down to the level of the alveoli. In an adult, the total amount of dead space represents only a small amount of the total tidal volume. However, in pediatrics, and especially neonates, the dead space can represent a significant portion of the tidal volume. To minimize the dead space a septum can be added to the y-piece and then the volume of the y-piece is no longer part of the dead space. The pediatric circuit also consists of narrower and more rigid corrugated tubing to minimize the compliance of the system.

34.3.7 Potential Complications with the Circle System

Compound A

The carbon dioxide absorber consists of a strong base that can lead to the removal of hydrogen fluoride from the volatile anesthetics. With sevoflurane this can lead to the production of compound A. In rats it has been shown to be a nephrotoxin, but in humans it has an unclear significance. After a prolonged exposure of high levels of compound A in otherwise healthy volunteers, there is a transient albuminuria. To minimize exposure to compound A, it is recommended to use a minimum fresh gas flow of 2 L/min. This will allow a continuous washout of compound A from the circle system.

Production of Carbon Monoxide

The use of desiccated soda lime in the carbon dioxide absorber can lead to the production of significant quantities of carbon monoxide. The risk of carbon monoxide production varies for the different agents:

desflurane > isoflurane >> sevoflurane

Since this only occurs with desiccated soda lime, there is a higher incidence of carbon monoxide production with the use of old soda lime during the first case of the day. As the soda lime is used to remove carbon dioxide, water is produced by the reaction. This rehydrates the desiccated soda lime and subsequent surgical cases have a lower incidence of carbon monoxide exposure. The highest risk is on Monday morning after the anesthesia machines were not used over the weekend. For the same reason, anesthesia machines at offsite locations where the anesthesia machines are only used infrequently also have a high risk of exposure to carbon monoxide. Any time the fresh gas flows are left on at high flows and the machine is not connected to a patient, there is a risk of drying out the soda lime. If the fresh gas flows are left on overnight when the anesthesia machine was not in use, the soda lime should be replaced. If carbon monoxide is produced, then the use of low fresh gas flows will lead to an accumulation of carbon dioxide in the system. The risk of carbon monoxide production with new soda lime is low because it arrives pre-hydrated from the manufacturer.

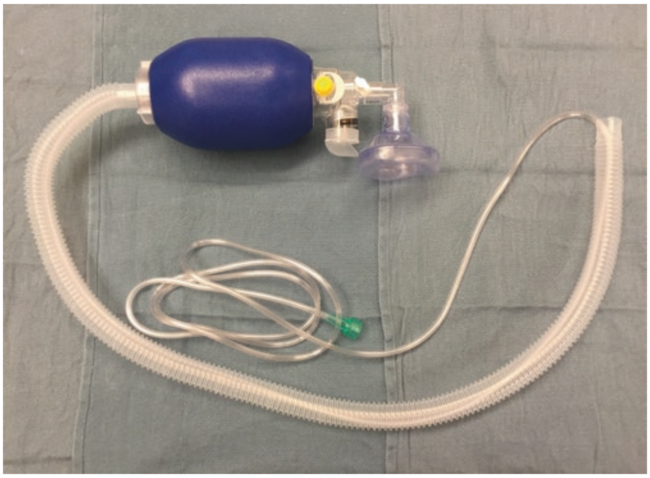


Fig. 34.3 Ambu bag

Malfunction of Unidirectional Valves

The valves consist of a horizontal ceramic disc that rests on the valve seat. As gas flows through, the disc is lifted up. When the flow reverses, the disk is pushed down and it seals the valve and prevents reversal of flow. The most common malfunction of the valve is due to warping of the disc or improper seating of the disc. When this happens to either valve, the result is rebreathing of exhaled gases and potentially hypercapnia. The expiratory valve is exposed to the moisture in the exhaled gases and is the most common valve to malfunction.

34.3.8 Manual Resuscitator Bag "Ambu Bag"

Common uses for the Ambu bag, which is shown in Fig. 34.3, include transport of patients and emergency ventilation when a ventilator is not available or is not functioning properly. The advantages include a small and easily portable ventilation system. It has few moving parts and is extremely reliable. Components of an Ambu bag include a self-expanding bag, reservoir tubing, oxygen source, and a non-rebreather valve.

The Ambu bag can be either connected to an endotracheal tube or used with a face mask to provide positive pressure ventilation. The self-expanding bag is used to create positive pressure. Since it is a self-expanding bag it can be used without an oxygen source, unlike the Mapleson circuits that require compressed gas to expand the reservoir bag. With the use of high flow oxygen (>8 L/min) close to 100% oxygen can be delivered to the patient. Unlike the circle system, there is no rebreathing of gases and therefore it has similar disadvantages to the Mapleson circuits.

34.4 Conclusion

Breathing systems have come a long way since the creation of open-drop anesthesia. An optimal breathing system would include a simple, reliable, portable system that can also make efficient use of the gases with conservation of heat and moisture. So far no current breathing systems have been able to achieve all the desired characteristics. The Mapleson systems are primarily used where a portable breathing system is required or in locations where a circle system is not available. A circle system is typically the optimum system, assuming portability is not needed. However, with all the advantages of the circle system comes a significant increase in complexity. This leads to the need for more frequent maintenance and constant monitoring of the inspired gases to ensure a safe delivery of the desired gases to the patient.

34.5 Questions and Answers

Questions (Choose the Most Appropriate Answer)

1. The following are all characteristics of Mapleson circuits EXCEPT:
   - A. Ability to provide positive pressure ventilation
   - B. Ability to scavenge waste gases
   - C. Portable
   - D. Contains a carbon dioxide absorber
2. A disadvantage of the Mapleson system is:
   - A. Complex design
   - B. Poor conservation of heat
   - C. High level of resistance during expiration
   - D. Unable to provide high concentrations of oxygen
3. All are necessary components of a circle system except:
   - A. Carbon dioxide absorber
   - B. Self-inflating reservoir bag
   - C. Unidirectional valves
   - D. Adjustable pressure relief valve
4. For the carbon dioxide absorber to work, the following are necessary:
   - A. Water
   - B. Heat
   - C. Hydrochloric acid
   - D. Sodium hydroxide
5. The following can occur after the carbon dioxide absorber is changed:
   - A. Increase in concentration of carbon dioxide
   - B. Decrease in concentration of oxygen
   - C. Decrease in concentration of volatile anesthetics
   - D. Decrease in concentration of water content
6. If the unidirectional valves malfunction in the circle system the following can occur:
   - A. Hypercapnia
   - B. Hypocapnia
   - C. Hypoxia
   - D. Increased concentration of volatile agents
7. Increasing the length of the circuit tubing in a circuit system will increase the amount of dead space
   - A. True
   - B. False

8. Which of the following are NOT TRUE about compound A?
   A. Produced by the removal of hydrogen fluoride from sevoflurane
   B. Is a nephrotoxin in rats
   C. With sevoflurane fresh gas flows of at least 1 L/min are recommended
   D. Prolonged exposure in humans leads to transient albuminuria
9. The following is true about the production of carbon monoxide by the soda lime carbon dioxide absorber:
   A. Sevoflurane is more likely to produce carbon monoxide compared to desflurane.
   B. It is most likely to occur during surgeries lasting greater than 6 h.
   C. It occurs when the soda lime is exhausted and cannot absorb additional carbon dioxide .
   D. It is most likely to occur during the first case of the day.
10. All of the following breathing circuits require compressed gas (typically oxygen) to function properly except:
   A. Ambu bag
   B. Circle system
   C. Mapleson circuit
   D. Insufflation

34

Answers

1. **D.** The essential components of a Mapleson circuit include a fresh gas inlet, reservoir bag, pop-off valve, and a face mask. This provides the ability to provide positive pressure ventilation. The pop-off valve is where the exhaled gases are vented and this allows a scavenger system to be connected to the circuit. This is done if the Mapleson circuit is used with volatile anesthetics to prevent the contamination of the patient care area. Since the Mapleson system consists of only a few lightweight components it is highly portable. A carbon dioxide absorber is not included in the components of a Mapleson system but is instead found in the circle system.
2. **B.** The advantages of the Mapleson system include a relatively simple and portable design. Compared to other ventilation systems, including the circle system, a Mapleson system has very low resistance during exhalation. If pure oxygen is supplied to the system in adequate flows (>5 L/min), then the patient will receive close to 100% oxygen. Since the Mapleson system does not recirculate the exhaled gases as occurs in the circle system, this leads to a loss of heat and moisture.
3. **B.** The following are all necessary components of a circle system including: carbon dioxide absorber, unidirectional valves, fresh gas inlet, reservoir bag, and adjustable pressure relief valves. In the circle system the reservoir bag is soft plastic and only expands if the pressure relief valve is closed and gas fills the bag. An example of a self-inflating reservoir bag occurs in an Ambu bag.
4. **A.** For absorption to take place the following reaction occurs:

$$CO_2 + H_2O \rightarrow H_2CO_3$$
$$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 + 2H_2O + Heat$$
$$Na_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2NaOH$$

   The first step in the reaction is the combination of carbon dioxide with water. For this reason when the carbon dioxide absorber is packaged by the manufacturer, it includes 14–19% water. This allows the absorber to immediately start working once it is placed in the circle system. Once the reaction is underway, for every molecule of carbon dioxide that combines with a molecule of water, the end result is the production of 2 molecules of water. This allows water to be available for the next reaction to occur. The most likely reason that water is not present is if the fresh gas flows were left on overnight when a patient is not connected to the circle system. The fresh gas flows have no water present, and if exposed to the absorber for several hours, this can lead to the depletion of water. If this occurs, then the absorber should be replaced.
5. **C.** When the carbon dioxide absorber is replaced, it begins working immediately so the concentration of carbon dioxide will be either unchanged or it will begin to decrease if the previous absorber was exhausted. The absorber does not absorb oxygen so the oxygen concentration will be unchanged. Since the absorber is saturated with water from the manufacturer, the water content in the circuit will likely be unchanged or increase slightly. When the absorber is replaced, it will absorb the volatile anesthetics if present and the depth of anesthesia for the patient will decrease temporarily. The absorber quickly becomes saturated with volatile anesthetics and then the depth of anesthetics will remain constant.
6. **A.** The purpose of the unidirectional valves is to ensure that the gases move through the circuit in only 1 direction. When there is a malfunction in 1 of the valves, it allows the gases to move in both directions. This will lead to rebreathing of the exhaled gases and hypercapnia will develop. Hypoxia would be unlikely because the exhaled gases still have oxygen present and even with rebreathing the patient will still receive sufficient oxygen. Malfunctioning valves will have no impact on the concentration of the volatile agents.
7. **B.** False. Due to the unidirectional valves in the circle system, the gases are only able to move in 1 direction. Therefore, no matter how long the circuit is, the dead space begins at the y-piece that joins the expiratory limb and the inspiratory limb with the endotracheal tube.

8. **C**. Compound A is produced by the removal of hydrogen fluoride from sevoflurane by the carbon dioxide absorber. Rats exposed to compound A show signs of renal injury and healthy humans develop a transient albuminuria. Due to the potential for renal injury in humans, it is recommended to run fresh gas flows of at least 2 L/min to minimize the buildup of compound A in the circle system.
9. **D**. The production of carbon monoxide is greatest with desflurane than isoflurane and sevoflurane has the lowest risk. It occurs when the soda lime is desiccated. As soda lime removes carbon dioxide, it leads to the production of water. So longer surgeries have a lower risk of carbon monoxide production. An exhausted absorber does not produce carbon monoxide. The first case of the day has the highest risk of having desiccated soda lime, especially if the fresh gas flows were left on when the anesthesia machine was not in use. This leads to the first case of the day having the highest risk of carbon dioxide production.
10. **A**. The circle system and the Mapleson circuit both require a compressed gas source to fill the reservoir bag since the bag is not self-expanding. For insufflation there is nothing in contact with the patient, but it works by blowing oxygen toward the patient's face. The Ambu bag is the only system with a self-inflating reservoir bag; this allows it to be used with or without a compressed gas source.

Suggested Reading

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