South Afr J Anaesth Analg. 2023;29(5 Suppl 1):S67-70
https://doi.org/10.36303/SAJAA.3028

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

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Anaesthesia breathing systems

NY Fening

Department of Anaesthesia, School of Clinical Medicine, Faculty of Health Sciences, Charlotte Maxeke Johannesburg Academic Hospital, University of the Witwatersrand, South Africa
Corresponding author, email: *nfenima@yahoo.com*

Anaesthetic breathing systems are used to provide oxygen and anaesthetic gases to a patient and to remove carbon dioxide (CO_2). Anaesthesia breathing systems are complex but important; they keep patients alive. A good understanding of their history and how they work is important for safe anaesthetic practice.

This article discusses the main components of anaesthesia breathing systems and the characteristics of an ideal breathing system. Furthermore, the various classifications of breathing systems are explored, and non-circle systems are compared to traditional circle systems.

Keywords: breathing systems, Mapleson, circle system

Anaesthesia breathing systems

Anaesthetic breathing systems are used to provide oxygen and anaesthetic gases to a patient and to remove CO_2.[2]

These are the main components of breathing systems:

1. Adjustable pressure limiting (APL) valve.
2. Reservoir bag.
3. Inspiratory and expiratory limb breathing tubes.
4. Connectors and adaptors.[1,3]

APL valve

The APL valve allows the anaesthetist to change the pressure within the breathing system. The valve is a one-way spring-loaded valve. When the valve is adjusted to a certain pressure, it allows gas to leak out of the breathing system to maintain the patient's airway pressure. The minimum pressure produced is 1 cmH_2O. A safety feature prevents pressure from exceeding 60 cmH_2O.[3]

Reservoir bag

The reservoir bag is made of antistatic rubber or plastic. Fresh gas flow (FGF) collects in this bag during expiration, reducing the amount of fresh gas required to prevent rebreathing. It can be used to monitor the patient's breathing pattern if they are breathing spontaneously. Sizes range from 0.5 to 2 L in our setting. The reservoir bag helps to limit pressure within the breathing system through the expansion of the bag to reduce pressure (Laplace's law).[1,3]

Inspiratory and expiratory limbs

The inspiratory limb supplies FGF to the patient for inspiration and the expiratory limb carries the gas flow expired by the patient back into the system. The tubing is corrugated for flexibility and increased resistance to kinking. It is usually made from clear plastic and is lightweight and with low resistance. The adult systems are approximately 22 mm and the paediatric systems are 18 mm in diameter.[1,3]

Characteristics of an ideal breathing system[1]

- Simple, safe, and inexpensive.
- Delivers intended inspired gas mixture.
- Allows for spontaneous, controlled, or assisted ventilation of all age groups.
- Efficient and allows for low FGF.
- Able to protect patients from barotrauma.
- Compact, light, and strong.
- Easily removes waste gases.
- Warms and humidifies inspired gases.
- Effectively eliminates CO_2.
- Low resistance means minimal length, maximal internal diameter, and consistent diameter.
- Minimal dead space.

Classification of breathing systems

There are many ways of classifying breathing systems.

1. The old classification:
   - Used the terms open, closed, semi-open, and semi-closed.
   - Described by Dripps (United States of America), Conway (United Kingdom), and others.[1]
   - Definitions vary and are confusing.
2. Mapleson:
   - Most well-known classification.
   - Five basic systems, A–E, with the addition of a sixth later.[1,2]

3. Miller:
    - South African-trained anaesthetist.
    - Classification based on structure and function.
        - Systems that absorb CO_2.
        - Systems that do not absorb CO_2.[4,5]

Old classification

We can look at the old way of classifying systems to understand the evolution of breathing systems.

- Open system:
    - Systems with no valves, tubing, or reservoir bag.
    - Insufflation.
    - Open drop ether.
    - The patient has access to atmospheric gases.[6]
- Semi-open system:
    - Has a reservoir like a breathing bag and there is no rebreathing.
    - Mapleson circuit.
    - Circle system at high FGF.[6]
- Semi-closed system:
    - Reservoir-like breathing bag that allows for partial rebreathing.
    - Mapleson circuit.
    - Circle system at low FGF.[6]
- Closed system:
    - A system with a reservoir such as a breathing bag allows for complete rebreathing.
    - CO_2 is absorbed.
        - Circle system with pop-off or APL valve closed and very low FGF that equals the oxygen uptake by the patient.[6]

Non-circle systems

Insufflation system

The insufflation system is unpredictable because it is an open system, which means the depth of anaesthesia is difficult to measure. Air entrainment occurs readily, and ventilation cannot be assisted. There is a high risk of fires occurring and gas toxicity within the theatre. Insufflation can be used on a spontaneously breathing patient or controlled ventilation with periods of apnoea.[6]

Examples:

- Oxygen/gases are insufflated over a child's face during induction.
- Gases are insufflated through a catheter or tube placed in the airway.

Open-drop system

Open-drop is an open system where ether or chloroform is dripped onto a mask covered with gauze (Schimmelbusch mask). As the agent vaporises, the mask temperature is lowered. There is a resultant drop in the rate of vaporisation and anaesthetic vapour pressure.[6]

Draw-over system

The draw-over system consists of a nonrebreathing valve, a self-inflating bag, and a vaporisation chamber. Room air acts as a carrier gas and supplemental oxygen is given to increase inspired oxygen (FiO_2) using a tube attached to a T-piece. They can be adjusted for intermittent positive pressure ventilation (IPPV) and continuous positive airway pressure (CPAP), as well as passive scavenging.

The draw-over system has the advantage of being portable, thus it is easily used in locations where compressed gas is not available (developing countries and battlefields).[6]

Unidirectional valve system

This valve system allows for controlled ventilation with a nonrebreathing valve. It is used with respirators or portable manual respirators (Ambu bag). Fresh gas is directed to the patient via a valve and exhaled gas is released into the atmosphere or scavenging system.[6]

Mapleson circuits

These circuits are flow-controlled or CO_2 washout circuits. They rely on FGF for washing out CO_2. The position of the basic components (face mask, fresh gas inflow, spring-loaded pop-off valve, reservoir bag) in the circuit determines the circuit's efficiency. There are six Mapleson circuit types, A–F.[1,6]

Mapleson A

The Mapleson A system is most efficient when used for a spontaneously breathing patient. It conserves exhaled dead space gas and vents exhaled alveolar gas (about FGF 70–80 mL/kg/min). It is not useful in controlled ventilation because it is inefficient (FGF > 2–3 × minute volume [MV]).[1]

As a modification, the coaxial Lack circuit was introduced in 1976. This modification to the Mapleson A circuit has a separate expiratory limb to facilitate gas scavenging and prevent operating room pollution. In this circuit, the respiratory limb runs parallel to the inspiratory limb, or in the coaxial configuration, the expiratory limb runs concentrically inside the inspiratory limb.[1,3]

Mapleson B and C

Mapleson B and C circuits are junctional reservoir systems. Mapleson B is no longer used. Mapleson C is sometimes used for resuscitation or transport along short distances. Both circuits require high gas flow to prevent rebreathing (FGF 20–25 L/min) and create a lot of theatre pollution.[1]

Mapleson D

The Mapleson D system is not efficient for spontaneously breathing patients. If FGF is not high enough, exhaled gas enters the reservoir bag together with fresh gas. It is useful for IPPV (FGF 70 mL/kg/min) as alveolar gas is vented through the expiratory valve and dead space gas is exhaled into the reservoir bag.[1]

Bain's circuit, a coaxial circuit, was created in 1972 and allows easy control of the expiratory valve and scavenging. FGF is delivered at the patient end, allowing the tubing to be longer without increasing dead space, which is useful in providing anaesthesia from a safe distance (e.g. magnetic resonance imaging). It is important to note that disconnection, kinking, and leaks of the inner tubing can lead to the breathing of exhaled gas.[1] Therefore, several checks need to be performed on Bain's circuit:[7]

- Visual inspection: For leaks or disconnection of inner tubing.
- Occlusion test: The Bain circuit is connected to a common gas outlet, flow is applied at 2 L/min, and then the inner tube is occluded with a plunger from a 2 ml syringe. If there is no leak, the bobbin of the flow meter will drop slightly due to increased back-pressure and return to its original position once the occlusion is removed.
- Ghani's test: A modification of the occlusion test, the inner tube is occluded with a 2 ml syringe and on removing the plunger tip a hissing sound should be heard for two to three seconds due to the release of pressure. If this does not occur, there is a hole.
- Pethick's oxygen flush test: The circuit is connected to a common gas outlet, the reservoir bag is filled with oxygen and the circuit is flushed with oxygen using the flush button. If there is no leak the reservoir bag collapses due to the Venturi effect.

Mapleson E

This circuit was developed in 1937. It is a low-resistance breathing system for paediatric anaesthesia (up to 30 kg). FGF of 2–3 × MV is required to prevent rebreathing. To prevent the dilution of gases with room air, the volume in the efferent reservoir limb must be greater than the tidal volume. Intermittent occlusion of the reservoir limb outlet allows for ventilation.[1,3]

Mapleson F

Mapleson F is a modification of Mapleson E (Jackson Rees 1950). It has the addition of an open-ended 500 ml bag to the expiratory limb, allowing for easy manual ventilation and monitoring of respiration by observing the movements of the bag. FGF for spontaneous ventilation is 2–3 × MV.[1]

Humphrey ADE

This circuit allows for changing between the A, D and E modes of the Mapleson circuit. It is suitable for all patient populations. The modification of the system is the addition of a soda lime canister.

Traditional circle systems

These are unidirectional breathing systems. CO_2 is absorbed and these systems allow for partial or total rebreathing of exhaled gases. FGF from the machine passes a one-way valve and is inhaled by the patient. As the patient exhales, the gases from the patient pass another one-way valve, the APL valve, and a reservoir bag, eventually passing the soda lime where CO_2 is absorbed and the gas is mixed with FGF and delivered to the patient again. This is a circle system. They can be semi-open, semi-closed, or closed.[3]

Traditional circle systems have various components:

- FGF tubing from the anaesthesia machine that does not enter the system between the expiratory valve and the patient.
- Inspiratory and expiratory valves for unidirectional flow.
- Inspiratory and expiratory corrugated tubing.
- Y-piece connector.
- Overflow/pop-off valve/APL valve located downstream of the expiratory valve.
- Reservoir bag and ventilator.
- Canister with CO_2 absorbent.[6]

Advantages of circle systems:

- Ability to maintain constant gas concentrations.
- Keeps respiratory moisture and heat within the system.
- Scavenger systems reduce theatre pollution.
- Used for closed-system anaesthesia or semi-closed with low FGF.

Disadvantages of circle systems:

- The circuit is often not checked or not checked properly.
- Lots of connections mean a high risk of disconnection, obstruction, or leaks leading to hypoventilation or barotrauma.
- Malfunction of the unidirectional valve can be deadly:
  - Rebreathing can occur if valves are stuck open.
  - Total blockage of the circuit can occur if the valves are stuck shut.
  - Breath stacking, barotrauma, or volutrauma can occur if the expiratory valve is stuck in the closed position.
- The circle system can fail:
  - A manufacturing defect, debris, patient secretions, particulate obstruction, or blocked filters can cause system failure.
  - This can cause increased airway pressure and haemodynamic instability, bilateral tension pneumothorax.
  - Loss of tidal volume from mechanical dead space.[6]

Soda lime

CO_2 is removed from these breathing systems using soda lime in a canister. Soda lime is a mixture of calcium hydroxide, sodium hydroxide (5%), potassium hydroxide (1%) silicates for binding (< 1%), pH indicator dye, and a 14–19% water content. The indicator dye contained in soda lime is ethyl violet, which turns from white to purple. Other dyes turn from pink to white.[3]

CO_2 is absorbed after a series of chemical reactions:

- $H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H + HCO_3$-
- NaOH (or KOH) + $H_2CO_3 \leftrightarrow NaHCO_3$ (or $KHCO_3$) + H_2O (+ heat) [fast]
- 2$NaHCO_3$ (or $KHCO_3$) + $Ca(OH)_2 \leftrightarrow$ 2NAOH (or KOH) + $CaCO_3$ [slow]

Soda lime granules are 4–8 mesh (this means they will fit between a mesh of 4–8 strands per inch[2]). If granules are too small dust may be inhaled, and if they are too big the efficiency of CO_2 absorption will be affected.[3]

Problems with soda lime include the production of carbon monoxide, they can absorb volatile agents and release them later leading to slower induction and emergence.[3] Additionally, soda lime produces a substance known as Compound A, a by-product of the absorption of volatiles, which is nephrotoxic in animals.

Conclusion

Anaesthesia breathing systems are complex but important, they keep patients alive. A good understanding of their complex nature and history is important for safe anaesthetic practice.

ORCID

NY Fening https://orcid.org/0000-0001-5465-3240

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