Indian Journal of Anaesthesia
Official publication of the Indian Society of Anaesthesiologists

Indian J Anaesth. 2013 Sep-Oct; 57(5): 507–515.
doi: 10.4103/0019-5049.120148: 10.4103/0019-5049.120148

PMCID: PMC3821268
PMID: 24249884

Mapleson's Breathing Systems

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Abstract

Mapleson breathing systems are used for delivering oxygen and anaesthetic agents and to eliminate carbon dioxide during anaesthesia. They consist of different components: Fresh gas flow, reservoir bag, breathing tubes, expiratory valve, and patient connection. There are five basic types of Mapleson system: A, B, C, D and E depending upon the different arrangements of these components. Mapleson F was added later. For adults, Mapleson A is the circuit of choice for spontaneous respiration where as Mapleson D and its Bains modifications are best available circuits for controlled ventilation. For neonates and paediatric patients Mapleson E and F (Jackson Rees modification) are the best circuits. In this review article, we will discuss the structure of the circuits and functional analysis of various types of Mapleson systems and their advantages and disadvantages.

Keywords: Anaesthesia breathing systems, anaesthesia circuits, bain's circuit, magill's circuit, mapleson breathing systems, jackson-rees modification

INTRODUCTION

Breathing system is an assembly of components which connects patient's airway to anaesthesia machine through which controlled composition of gas mixture is dispensed. It delivers gas to the patient, removes expired gas and controls the temperature and humidity of the inspired mixture. It allows spontaneous, controlled, or assisted respiration. It may also provide ports for gas sampling, airway pressure, flow and volume monitoring.

Mapleson analysed five different arrangements of components of breathing system, i.e., fresh gas flow, breathing tube, mask, reservoir bag, and expiratory valve. These are known as Mapleson systems and designated A to E.[1] Mapleson system F was added later on by Wills *et al*.[2]

CHARACTERISTICS OF IDEAL BREATHING SYSTEM

1. Should be simple, safe, and inexpensive.
2. Able to deliver intended inspired gas mixture.
3. Permit spontaneous, controlled or assisted ventilation in all age groups.
4. Efficient and allow low fresh gas flow.
5. Able to protect patients from barotrauma.
6. Sturdy, compact, light weight.
7. Easily remove waste gases.
8. Warming and humidification of inspired gases.
9. Effectively eliminate CO_2.
10. Have low resistance: Should have minimal length, maximal internal diameter and be without sharp curves or sudden changes in diameter.

11. Dead space should be minimal.

COMPONENTS OF A BREATHING SYSTEM

Breathing tubes

- Large bore, usually corrugated tubes, made of rubber or plastic.
- Corrugations increase flexibility and resistance to kinking.
- Clear plastic tubes are lightweight and low resistance.
- Act as a reservoir in certain systems.
- Have some distensibility but not enough to prevent excessive pressures from developing in the circuit.[3]

Adjustable pressure limiting valve

- Also called as; pop-off valve, exhaust valve, scavenger valve, relief valve, expiratory valve, over-spill valve etc.
- This valve allows exhaled waste gases and fresh gas flows to leave the breathing system when the pressure within the breathing system exceeds the valve's opening pressure
- It is a one way, adjustable, spring-loaded valve.
- The spring adjusts the pressure required to open the valve.

Reservoir bag

- The reservoir bag is an important component of most breathing systems.
- Made of antistatic rubber or plastic. Black bags are antistatic whereas green bags are made of low charging material which will not create harmful charges but will the bag from electric fields.
- Accommodates fresh gas flow during expiration, acting as a reservoir available for use in next inspiration.
- Acts as a monitor of the patient's ventilatory pattern.
- Can be used to assist or control the ventilation
- Bag being the most distensible part of the breathing system, protects the patient from excessive pressure in the system.

Connectors and adaptors

- To connect various parts of breathing system.
- Extend the distance between patient and breathing system.
- Allow more flexibility for manoeuvring.
- They also increase dead space and resistance.
- Chances of disconnection increased.

CLASSIFICATION

Older system of classification defined breathing systems as open, closed, semiopen, semiclosed. Classifications have been described by Dripps, Echenhoff and Vandam, Collins, Conmay, Hall etc., The Mapleson system of classification is most popular.

MAPLESON SYSTEM

The Mapleson systems are the breathing circuits, also known as flow controlled breathing systems or carbon dioxide washout circuits because they depend upon fresh gas flow for washing out CO_2. Mapleson systems are classified into five basic types as Mapleson A, B, C, D, E. Later Mapleson F was also added.

MAPLESON A SYSTEM (MAGILLS CIRCUIT)

Configuration

In Mapleson A system, fresh gas enters the circuit near the reservoir bag away from the patient end [Figure 1]. A corrugated tubing connects the reservoir bag near the machine end to the adjustable pressure limiting valve at the patient end of the system. Length of tubing is 110 cm. APL valve is near the patient end for the exhaust of gases during expiration. Reservoir bag is used for monitoring respiration as well as ventilating the patient. It also acts as reservoir of gas and protects the patient from excessive pressure within the breathing system.

Modification of Mapleson

A: It is called Lack's modification.[4] Lack added separate expiratory limb which starts from the patient connection to the APL valve at the machine end of the system. It facilitates the scavenging of gas to prevent theatre pollution. The disadvantage is that it increases the work of breathing.[5]

The Lack system is available in two arrangements:

- Parallel tube.
- Coaxial configuration in which expiratory limb runs concentrically inside the outer inspiratory limb.

Technique of use

During spontaneous respiration, APL valve is kept in fully open position. Gases are vented out through the valve during expiration.

During controlled ventilation the APL valve is partially closed, so that when bag is squeezed, sufficient pressure to inflate the lungs is achieved. Intermittent positive pressure is applied to the bag for controlled ventilation. Here APL valve opens during inspiration.

Functional analysis

Spontaneous breathing: Initially when the patient inspires, the fresh gas from the machine and the reservoir bag flows to the patient [Figure 2]. During expiration the fresh gas continues to flow into the system and fill the reservoir bag. The expired gas, consisting of dead space gas and alveolar gas, pushes the fresh gas from the corrugated tube into the reservoir bag and collects inside the corrugated tube[6] [Figure 2b].

As soon as the reservoir bag is full, the expiratory valve opens and the alveolar gas is vented into the atmosphere [Figure 2c]. During expiratory pause the alveolar gas that had come into the corrugated tube is also pushed out through the valve, depending on the fresh gas flow. If fresh gas flow is equal to or more than minute ventilation (70-100 ml/kg/min) it will force the expired alveolar gas out. If flow is less than minute ventilation, some alveolar gas is retained in the system and rebreathing will occur. If fresh gas flow is very low, more alveolar gas will be retained. During the next inspiration the system is filled with only fresh gas and dead space gas when fresh gas flow is equal to the minute ventilation [Figure 2d]. The system functions at maximum efficiency, when the fresh gas flow equals the minute ventilation and the dead space gas (which has not taken part in gas exchange) is allowed to be rebreathed and utilized for minute ventilation.[7] Mapleson A is the circuit of choice for spontaneous respiration, because there is negligible rebreathing. Flow of fresh gas required is 70-85 ml/kg/min, i.e., approximately 5-6 lit./min fresh gas flow for an average adult.

Controlled ventilation To facilitate controlled ventilation the expiratory valve has to be partly closed. During inspiration the patient gets ventilated with fresh gas and part of the fresh gas is vented out through the valve [Figure 3a] after sufficient pressure has developed to open the valve.

During expiration, the fresh gas from the machine flows into the reservoir bag and all the expired gas (i.e., dead space gas and alveolar gas) flows back into the corrugated tube till the system is full [Figure 3b]. During the next inspiration the alveolar gas in the tubing flows to the patient followed by the fresh gas. When sufficient pressure is developed by squeezing the bag, part of the expired gas and part of the fresh gas escape through the valve [Figure 3c]. This leads to considerable rebreathing, as well as excessive waste of fresh gas. The composition of inspired gas mixture depends on the respiratory pattern. The system becomes more efficient as the expiratory phase is prolonged. However, it should not be used for controlled ventilation unless $EtCO_2$ is monitored.[8]

Lack's system

This system functions like Mapleson A system, both during spontaneous and controlled ventilation. The only difference is that the expired gas instead of getting vented through the valve near the patient is carried by an efferent tube placed coaxially and vented through the valve placed near the machine end [Figure 4]. This facilitates easy scavenging of expired gas. Barnes, Conway and Purcell (1980) claimed that Lack's system is less efficient than Mapleson A system. However, Nott, Walters, Norman (1977) showed that they are equally efficient. It is wiser to use fresh gas flow a little higher than Magill's circuit, i.e., more than minute ventilation.[4]

Advantages of Magills circuit

1. Best circuit for spontaneous respiration as no rebreathing occurs with adequate flows.
2. Less fresh gas flow is required during spontaneous respiration.
3. Easy scavenging of gases in Lack's system to prevent theatre pollution.

Disadvantages of Mapleson A system

1. Wastage of gases.
2. Theatre pollution by Magill circuit.
3. Mechanical ventilator should not be used with this circuit because the entire system becomes dead space.
4. Incorrect manufacturing or assembling of Lack's circuit. Like fresh gas inlet mounted adjacent to the APL valve rather than the reservoir bag. This would result in increase in dead space.[9]

CHECKING OF THE CIRCUIT BEFORE USE

Mapleson A is tested for leaks by occluding the patient end, closing the APL valve and pressurising the system. APL valve functioning should be checked by opening and closing it. In addition checking is done by breathing through it.

Lack system requires additional testing to confirm the integrity of the inner tube.

- Attach a tracheal tube to the inner tubing at patient end. Blow down the tube with the APL valve closed. There will be movement of the bag if there is leak between the two tubes.
- Occlude both the limbs at patient connection with the valve open and then squeeze the bag. If there is leak in the inner limb, gas will escape through the valve and bag will collapse.[10]

MAPLESON B AND C

They are similar in construction, with the fresh gas flow entry and the expiratory valves located at the patient end of the circuit and reservoir bag is at the machine end of the circuit, except that corrugated tubing is omitted in Mapleson C as shown in [Figure 1]. They are not commonly used in anaesthetic practice although C system may be used for emergency resuscitation. High flow of gases is needed to prevent rebreathing of CO_2 and theatre pollution is maximum. Fresh gas flow required is equal to peak inspiratory flow rate (20-25 lit/min) to prevent rebreathing.[1] So there is lot of wastage of fresh gases.

MAPLESON D

The Mapleson D, E, F systems have T piece near the patient [Figure 1]. Mapleson D is the most efficient system during controlled ventilation.

CONFIGURATION

Classic form of Mapleson D has a 6 mm tube that supplies the fresh gas from the machine. It connects to the T piece at the patient end and other limb of the T is attached to a wide bore corrugated tube to which the reservoir bag is attached and the expiratory valve is positioned near the bag.[3,11]

BAIN'S MODIFICATION

In principal it is modification of the system used by Macintosh and Pask during Second World War to administer anaesthesia. It was introduced by Bain and Spoerel in 1972 [Figure 5].

In this circuit the fresh gas supply tube runs coaxially inside the corrugated tubing. The diameter of the outer tubing is 22 mm and inner tube is 7 mm. Length of the circuit is 1.8 metre. Outer tube is transparent so that inner tube can be seen for any disconnection or kinking. Length of the circuit can be increased to modify it for use at remote locations. Various studies have been done to analyse its efficiency after increasing its length. It is seen that as the length increases, the resistance increases during spontaneous breathing.[12,13] Also ventilator settings should be adjusted to deliver set tidal volume with long Bains circuit as there is reduction in peak inspiratory pressure and tidal volume with increased length of the circuit.[8]

TECHNIQUE OF USE

During spontaneous respiration APL valve is fully opened. Patient inspires fresh gas from the circuit and excess gases are vented out through the APL valve during expiration. In controlled ventilation the APL valve is kept partially closed and patient is ventilated by squeezing the reservoir bag. Here excess gases are vented out during inspiration.

Ventilation can also be instituted by connecting hose of a mechanical ventilator to the circuit in place of reservoir bag and valve. The length of the corrugated tubing between ventilator and Bains circuit should be one metre to prevent air dilution of the gases delivered. Tidal volume is set on the ventilator and fresh gas flow should be kept at 1.5 to 2 times the minute ventilation. Ventilator should need only air to work.[14] On modern work stations mechanical ventilation is done with closed circuits

FUNCTIONAL ANALYSIS

Spontaneous respiration

When the patient inspires, the fresh gas goes to the patient [Figure 6a]. During expiration, the expired gas gets continuously mixed with the fresh gas and flows back into the corrugated tube and the reservoir bag [Figure 6b]. When the bag is full, APL valve opens and excess gas is vented to the atmosphere through this valve. During the expiratory pause the fresh gas continues to flow and fills the proximal portion of the corrugated tube [Figure 6c]. During the next inspiration, the patient breathes fresh gas as well as the mixed gas from the corrugated tube [Figure 6d]. Many factors influence the composition of the inspired mixture. They are fresh gas flow, respiratory rate, expiratory pause, and tidal volume. If the fresh gas flow is high (1.5-2 times minute volume), patient will inhale only fresh gas from the corrugated tubing and if the fresh gas flow is low (less than 1.5 times minute volume), some expired gas containing CO_2 will be inhaled along with the fresh gas causing rise in end tidal CO_2.

Fresh gas flow should be at least 1.5 to 2 times the patient's minute ventilation in order to minimize rebreathing to acceptable levels. Based on body weight, recommendations for fresh gas flow are 150-200 ml/kg/min to prevent rebreathing during spontaneous respiration.[3,8]

Controlled ventilation

To facilitate intermittent positive pressure ventilation, the expiratory valve has to be partly closed. When the system is filled with fresh gas, the patient gets ventilated with the fresh gas from the corrugated tube [Figure 7a]. During expiration, the expired gas flows down the corrugated tubing. It gets mixed with the fresh gas that is continuously flowing into the tubing. During the expiratory pause the fresh gas continues to enter the tubing and pushes the mixed gas toward the reservoir bag [Figure 7b]. As the bag is squeezed to ventilate, pressure in the system increases, the expiratory valve opens and the contents of the reservoir bag are discharged into the atmosphere. It contains dead space gas, some of the alveolar gas, and fresh gas. During the next inspiration, the patient gets ventilated with the fresh gas and gas in the corrugated tube i.e., a mixture of fresh gas, alveolar gas [Figure 7c] depending upon the fresh gas flow. If the fresh gas flow is low, patient will inhale some exhaled gas also. Rebreathing can be avoided by keeping the fresh gas flow high, i.e., 1.5-2 times minute ventilation or by increasing the expiratory pause so that fresh gas can push exhaled gases down the tubing toward the reservoir bag to be vented out.[3,8] Other factors that influence the composition of gas mixture with which the patient gets ventilated are the same as for spontaneous respiration namely fresh gas flow, respiratory rate, tidal volume and pattern of ventilation. But these parameters can be controlled by the anaesthesiologist to maintain normocarbia.

Fresh gas flow recommended is 1.5-2.0 times minute ventilation. Bain, Spoerel and Aitken recommended fresh gas flow 70-100 ml/kg/min with guidelines of ventilating with tidal volume of 10 ml/kg and frequency between 12 and 14/min.

ADVANTAGES OF BAIN'S SYSTEM

1. Light weight.
2. Minimal drag on ETT as compared to Magill's circuit.
3. Low resistance.
4. As the outer tube is transparent, it is easy to detect any kinking or disconnection of the inner fresh gas flow tube.
5. It can be used both during spontaneous and controlled ventilation and change over is easier.
6. It is useful where patient is not accessible as in MRI suites.
7. Exhaled gases do not accumulate near surgical field, so risk of flash fires is abolished.
8. Easy for scavenging of gases as scavenging valve is at machine end of the circuit.
9. Easy to connect to ventilator.
10. There is some warming of the inspired fresh gas by the exhaled gas present in outer tubing.

DISADVANTAGES OF BAIN'S SYSTEM

1. Due to multiple connections in the circuit there is a risk of disconnections.[15,16]
2. Wrong assembling of the parts can lead to malfunction of the circuit.
3. Theatre pollution occurs due to high fresh gas flow. However, it can be prevented by using scavenging system.
4. Increases the cost due to high fresh gas flows.
5. There can be kinking of the fresh gas supply inner tube blocking the fresh gas supply leading to hypoxia[15]
6. There can be crack in the inner tube causing leakage[17]
7. Case report available about the defect in metal head so that fresh gas and exhaled gas mix and entire limb becomes dead space[18]
8. It cannot be used in paediatric patients with weight less than 20 kg.

CHECKING OF THE CIRCUIT

- Mapleson D system is checked for leaks by occluding the patient end, closing the APL valve and pressurizing the system. The APL valve is then opened. The bag should deflate easily if the valve is working properly. Outer tube integrity should also be checked by following the simplest innovative method. Wet the hands with spirit. Blow air through the tube. Wipe the tube with wet hands. Leak will produce chillness in the hands.
- For checking integrity of inner tube of Bains system, a test is performed by setting a low flow on the oxygen flowmeter and occluding the inner tube with a finger or barrel of a small syringe at the patient end while observing the flow meter indicator. If the inner tube is intact and correctly connected, the indicator will fall.
- Pethicks test – To check the integrity of the inner tube, activate the oxygen flush and observe the bag. Due to venturi effect the high flow from the inner tube at the patient end will create a negative pressure in the outer exhalation tubing and this will suck gas from the bag and bag will deflate. If the inner tube is not intact, this maneuver will cause the bag to inflate slightly.[19,20]

MAPLESON E SYSTEM

Ayre's T-piece was invented by Phillip Ayer in 1937. This consists of a light metal tube 1 cm in diameter, 5 cm in length with a side arm [Figure 8]. Used as such, it functions as a non-rebreathing system. Fresh gas enters the system through the side arm and the expired gas is vented into the atmosphere and there is no rebreathing.

Use of this system has decreased in anaesthesia because it is difficult to scavenge excess gases and high fresh gas flows, i.e., peak expiratory flow rate are required.

Mapleson E system is derived from Ayre's T piece configuration by adding tubing to the expiratory part of the circuit.[21] It acts as a fresh gas reservoir during inspiration. Its capacity should be more than the expected tidal volume. It is mainly used in neonates, infants and paediatric patients which are less than 20 kg in weight or less than 5 years of age.

Technique of use

For spontaneous ventilation, the expiratory limb is open to atmosphere. Controlled ventilation can be performed by intermittently occluding the expiratory limb and allowing the fresh gas to inflate the lungs.

FUNCTIONAL ANALYSIS

Mapleson E functions on the same principles as Mapleson D. During inspiration, the patient inspires fresh gas from the fresh gas inlet as well as reservoir tube. During expiration, the patient expires into the reservoir tube and expired to the atmosphere along with some fresh gas which is continuously flowing into the reservoir tube. During expiratory pause, the expired gas is vented out and the fresh gas is filled in expiratory tube for next respiration. Rebreathing and air dilution can occur with this system. It depends on the fresh gas flow, the patient's minute volume, the volume of the expiratory limb, and type of ventilation whether spontaneous or controlled. Fresh gas flow required is 2.5 to 3 times the minute volume during spontaneous ventilation and 1.5 to 2 times the minute volume during controlled ventilation. Air dilution can be prevented by keeping the volume of the expiratory limb greater than patient's tidal volume.[8,22,23]

MAPLESON F SYSTEM

It is a modification of Mapleson E by Jackson Rees and is known as Jackson Rees modification. It has a 500 ml bag attached to the expiratory limb. This bag helps in respiratory monitoring or assisting the respiration. It also helps in venting out excess gases. The bag has a hole in the tail of the bag that is occluded by using a finger to provide pressure.[3,23] The bags with valve are also available. It is used in neonates, infants, and paediatric patients less than 20 kg in weight or less than 5 years of age.

Technique of use

For spontaneous respiration. The relief mechanism of the bag is left fully open. For controlled respiration the hole in the bag can be occluded by the user during inspiration and ventilation is done by squeezing the bag.

Functional analysis

It also functions like Mapleson D system. The flows required to prevent rebreathing are 2.5-3.0 times minute volume during spontaneous ventilation and 1.5 to 2 times the minute volume during controlled ventilation. In this system, during expiration fresh gas and exhaled gas will collect and mix in the bag. The next inspiration results in patient inhaling fresh gas both direct from inlet and from expiratory part of the circuit as in Mapleson E. During expiratory pause the expired gases are replaced by fresh gas in the expiratory limb. Observation of bag movements helps in assessing respiration during spontaneous breathing. It also allows controlled ventilation by squeezing the bag. Heat and moisture exchanger should not be used with Mapleson E and F during spontaneous respiration as it increases resistance. So most of the fresh gas will enter expiratory limb leading to wastage of fresh gases and delaying induction by inhalation agents.[24,25,26]

ADVANTAGES OF MAPLESON E AND F

- Easy assembly.
- Inexpensive.
- Low resistance system due to the absence of valves.

DISADVANTAGES OF MAPLESON E AND F

- Barotrauma can occur during controlled ventilation in Mapleson E, due to overinflation. This is because anaesthetist does not have the feel of the bag during inflation. Pressure buffering effect of the bag is absent. This problem is not seen with Mapleson F as there is a bag in the system.
- High fresh gas flows are required.
- Humidification of gases does not occur as in coaxial circuits.
- Atmospheric pollution.

ADVANTAGES OF THE MAPLESON SYSTEM

1. They are simple and less costly.
2. Components are easy to disassemble and can be disinfected or sterilized.[27]
3. They are light weight. So they do not cause drag on tracheal tube.
4. The length of the Mapleson D can be increased. So, they are suitable for use in remote locations like MRI suit.[28]
5. Humidification of the gases occurs in coaxial systems (Lack and Bains).
6. Resistance of these systems is low. So they are good for spontaneous respiration. But if the APL valve is not opened properly, it can add to resistance.[29,30,31]
7. There is no risk of toxic products production such as compound A as with circle system due to CO_2 absorbent.

DISADVANTAGES OF THE MAPLESON SYSTEMS

1. The fresh gas flow required for these circuits is high which increases the cost.
2. There is more theatre pollution due to high gas flows required.
3. Due to high fresh gas flow, inspired heat and humidity tend to be less. So, humidification of the gases is required separately.[32]
4. The optimum fresh gas flow is difficult to ascertain. If it is lowered by any cause it can result in rebreathing.

5. In Mapleson A, B and C systems, APL valve is close to the patient. So, scavenging is difficult.
6. In Mapleson E, air dilution can occur.
7. They are not suitable for patients with malignant hyperthermia because very high fresh gas flow is required to washout excess CO_2 load.[33]

SUMMARY

Mapleson A for spontaneous respiration has the best efficiency of the six systems since fresh gas flow required to prevent rebreathing is equal to minute ventilation. For controlled ventilation it is the worst system because very high fresh gas flows are required to prevent rebreathing. Mapleson D or Bain's circuit is best for controlled ventilation. Mapleson B and C are rarely used today. Mapleson D, E, F require higher fresh gas flow to prevent rebreathing. They are next in order of preference list for spontaneous respiration. But they are better than Mapleson A for controlled ventilation.

Footnotes

Source of Support: Nil

Conflict of Interest: None declared

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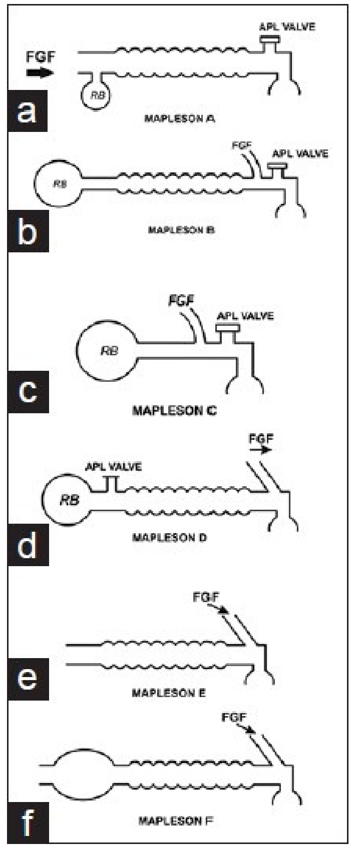
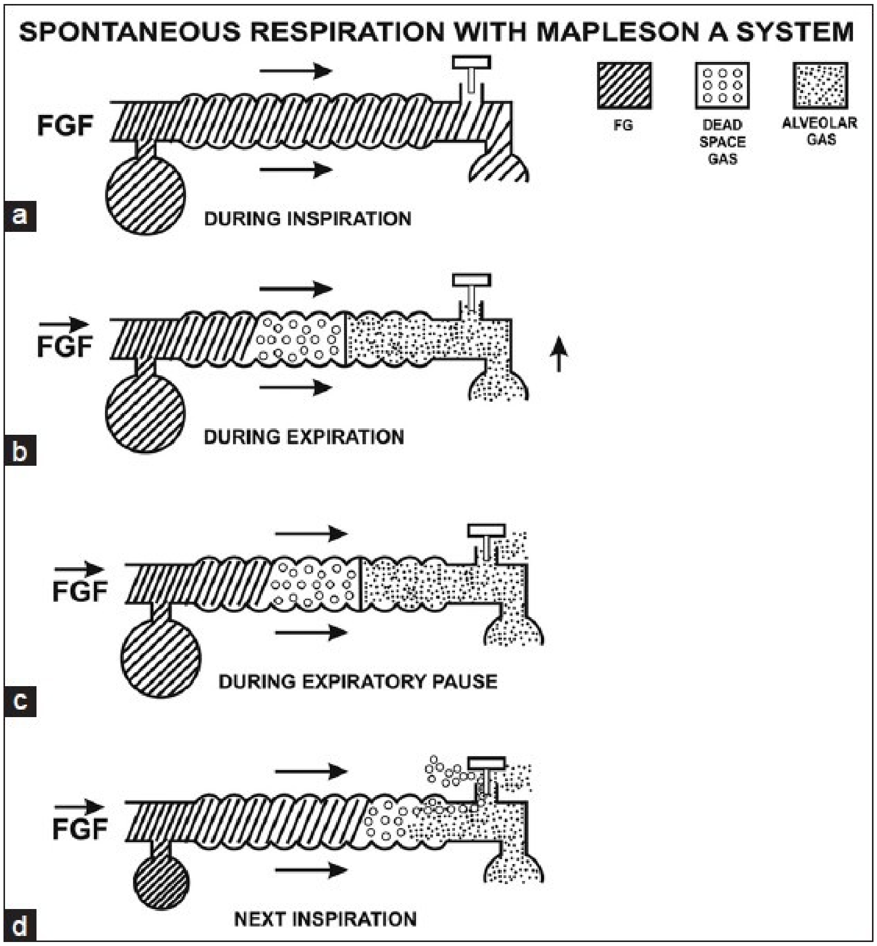
Figures and Tables

Figure 1



Classification of Mapleson system (a to f)

Figure 2



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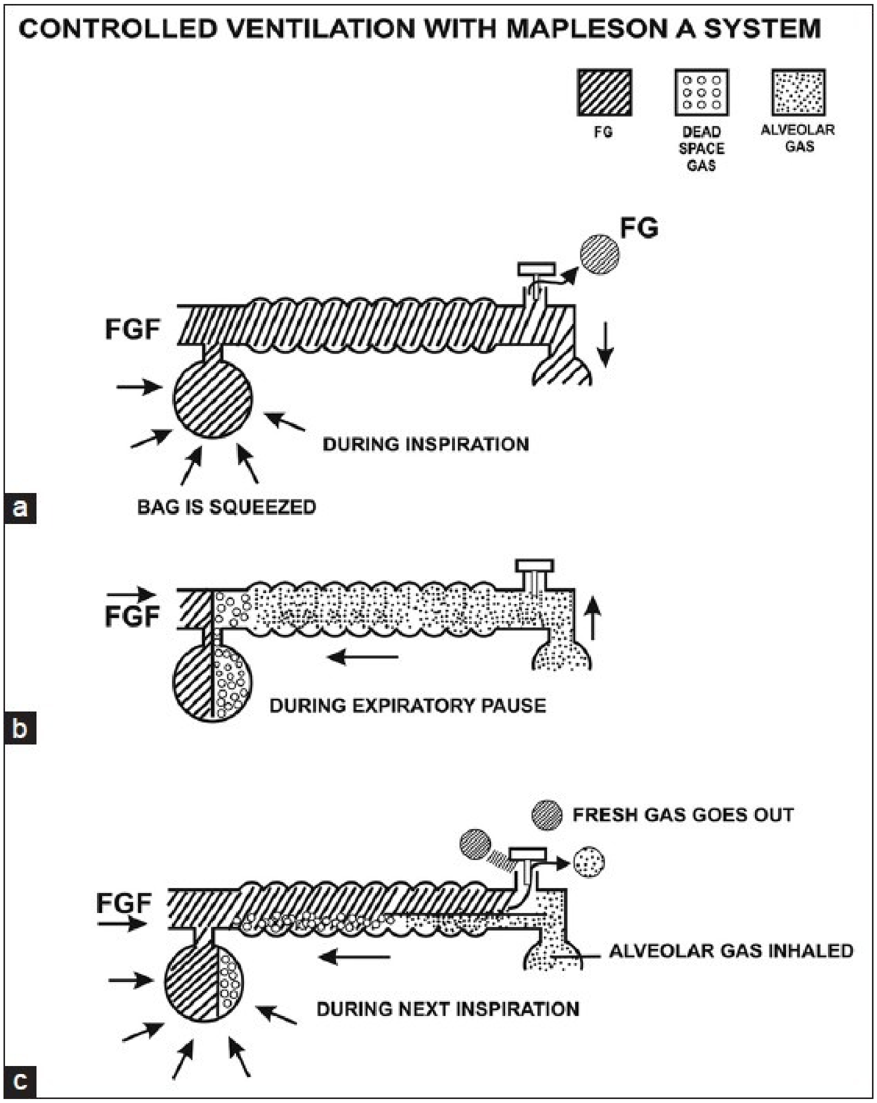
Functional analysis of Mapleson A system during spontaneous respiration

Figure 3



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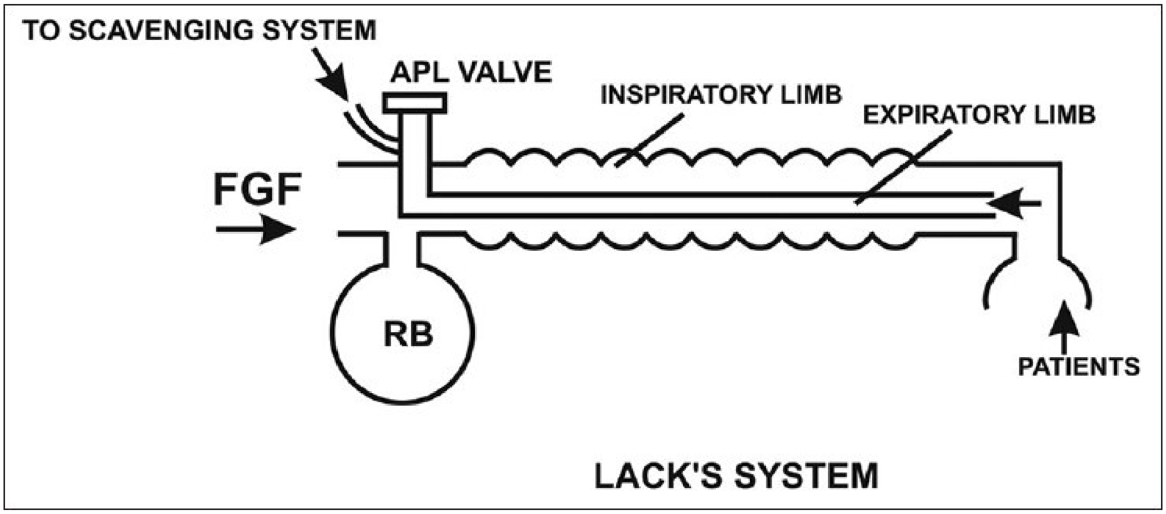
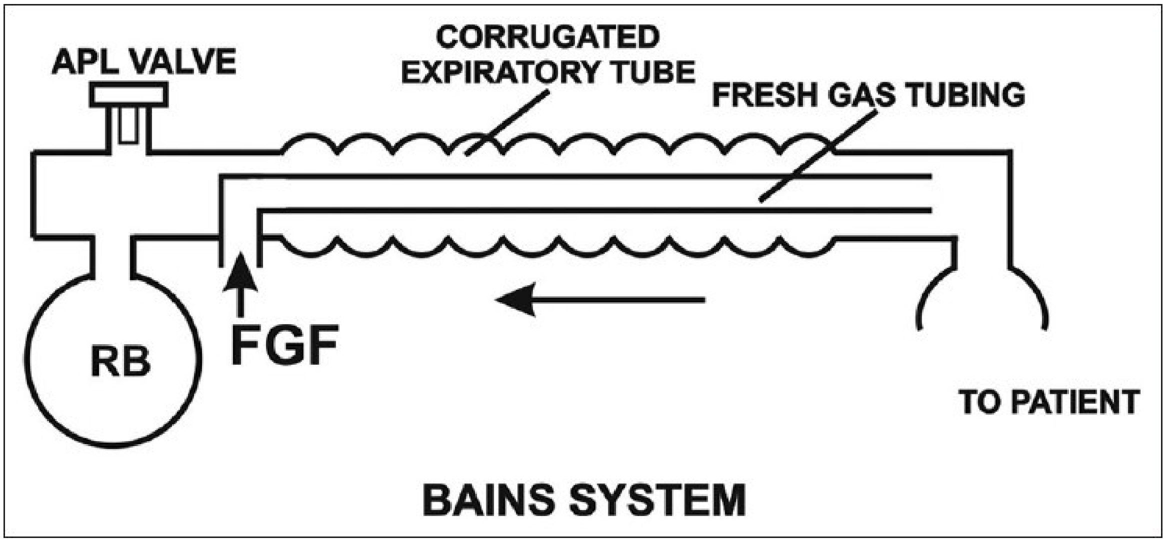
Functional analysis of Mapleson A system during controlled ventilation

Figure 4



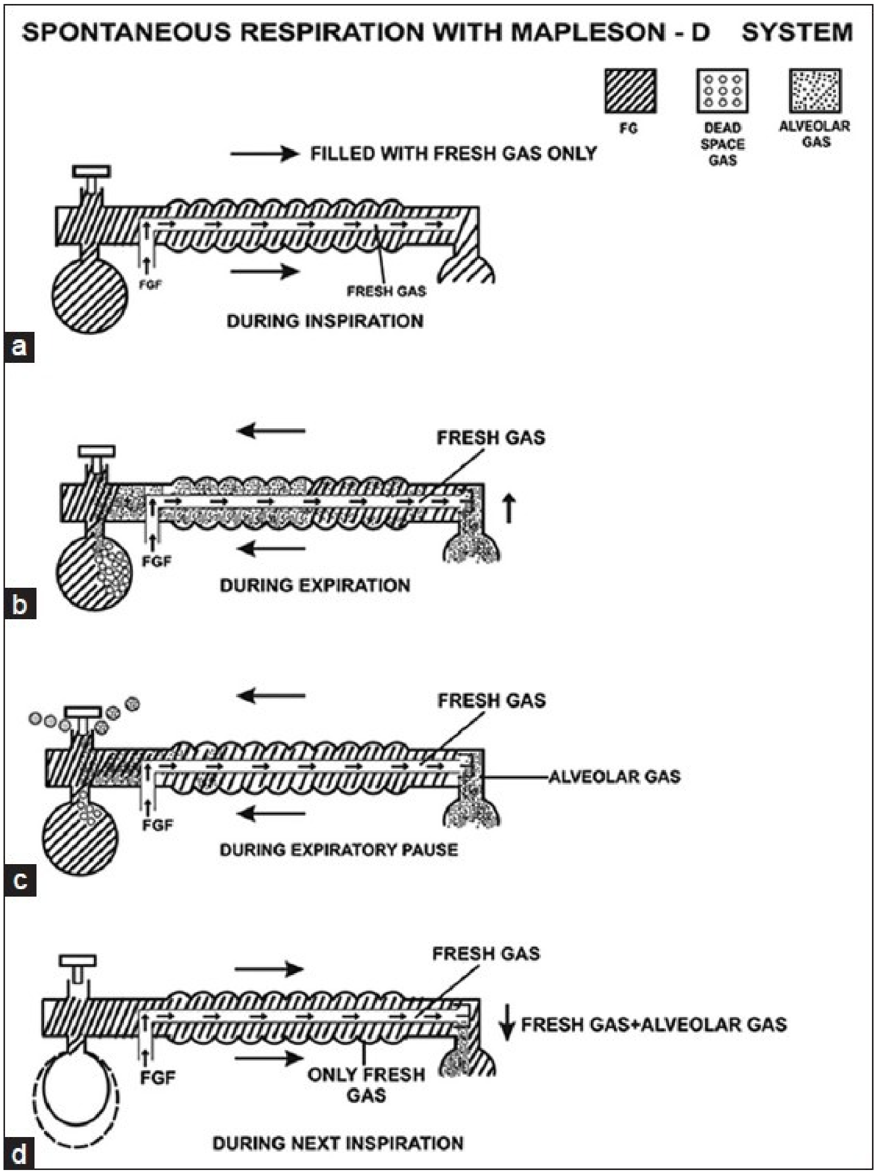
Lack's modification of Mapleson A system

Figure 5



Bain's modification of Mapleson D system

Figure 6



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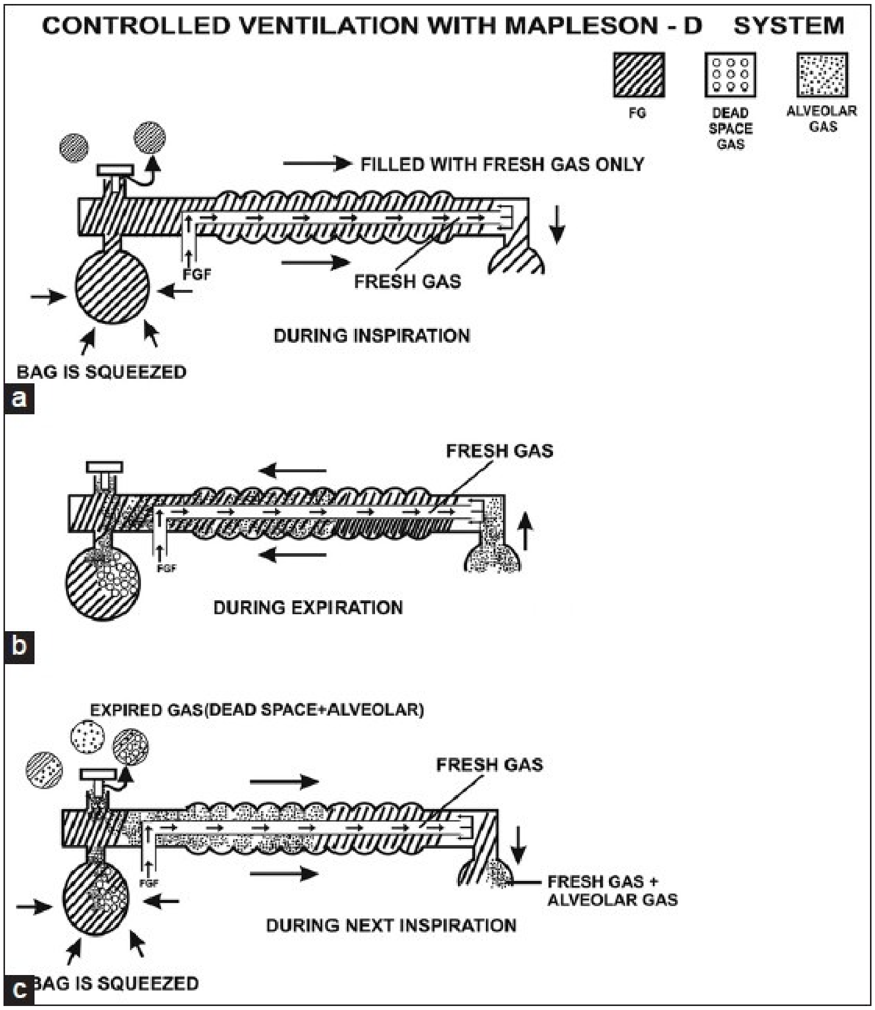
Functional analysis of Mapleson D system during spontaneous respiration

Figure 7



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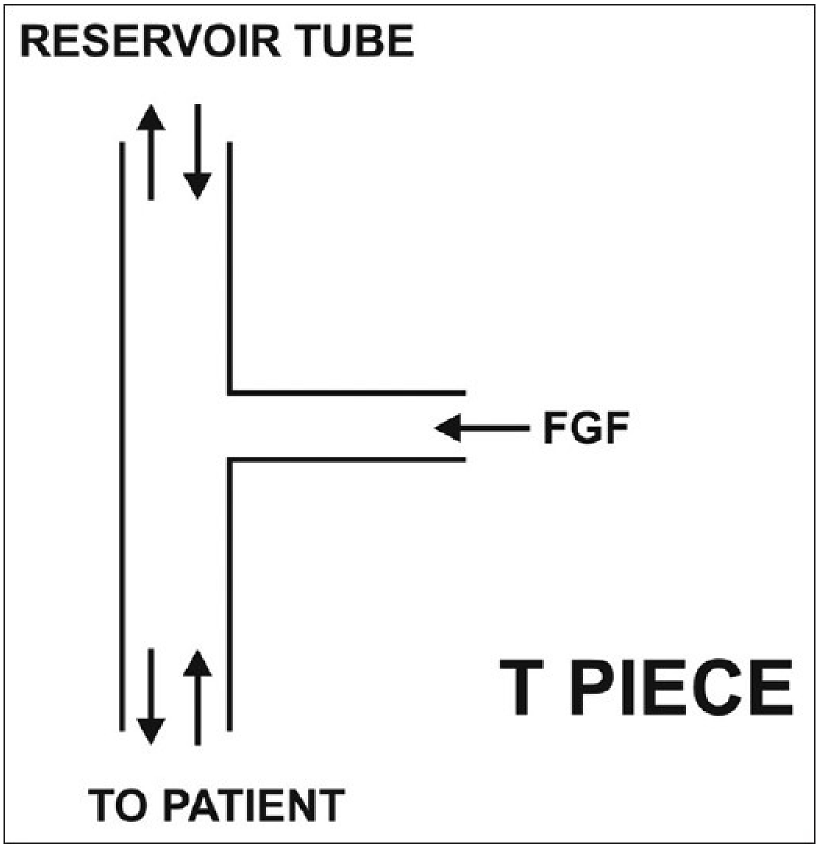
Functional analysis of Mapleson D system during controlled ventilation

Figure 8



Ayer's T- Piece