Breathing Systems

Prepared by : Dr. Azad J. Ali
Senior Anesthesiologist
November -2022
Part-I

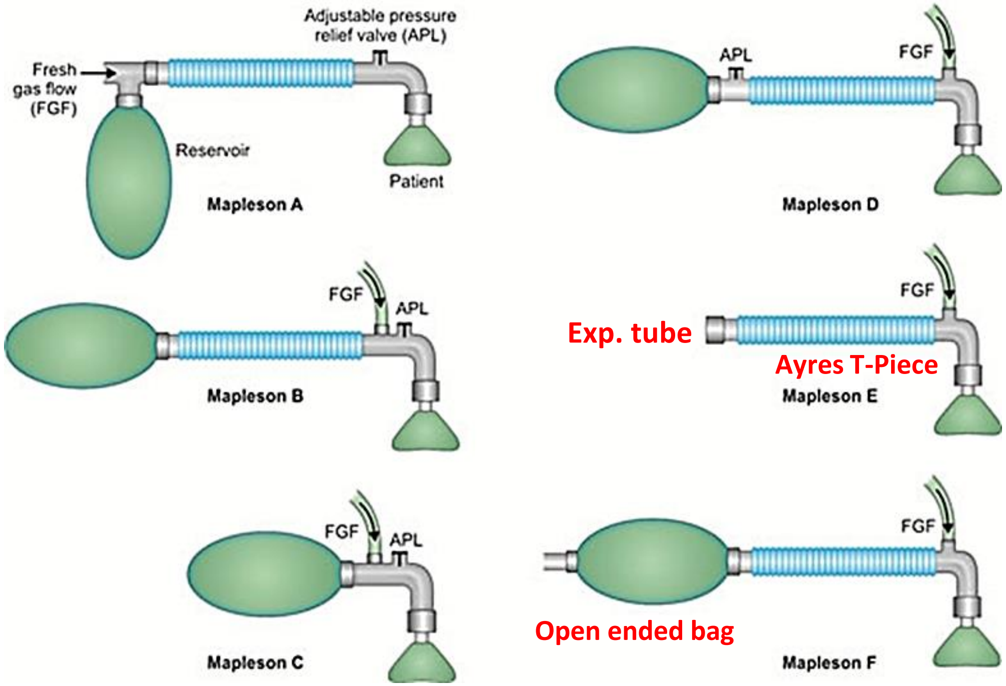

Objectives

1. ***Delivery of oxygen.***
2. ***Removal of CO_2 from the patient.***
3. ***Delivery of anesthetic agents which are inhaled by the lungs and eliminated from the lung .***

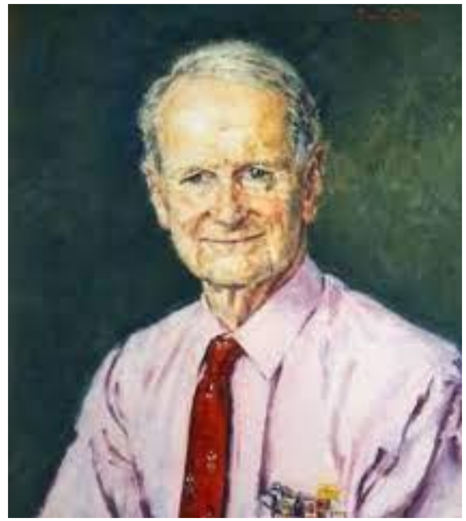
Classification

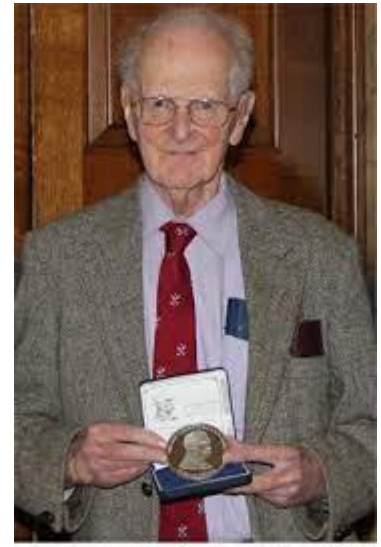
- *There are several breathing systems used in anesthetic machine.*
- *Mapleson classified them into A ,B ,C, D & E.*
- *Mapleson F was added later by Jackson-Rees known as Rees' modification of Mapleson E system by adding an open ended bag to open expiratory tube of the Ayres T-Piece .*

Gordon Jackson Rees

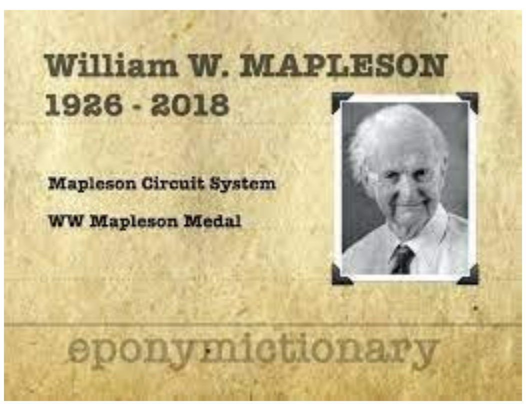


Mapleson ,the giant of anesthesia





Photograph by: Dr Subrahmanyan Radhakrishna



Dr. Gordon Jackson Rees



Currently only A,D,E& F and their modifications are commonly used during anesthesia.

B&C are used during recovery and transport and emergency situations.

Properties of the ideal breathing system

1. *Simple and safe to use.*
2. *Delivers the intended inspired gas mixture.*
3. *Permits spontaneous , manual and controlled ventilation in all age groups.*
4. *Efficient (requires low flow FGF rates).*
5. *Protects the patient from barotrauma.*
6. *Sturdy ,compact and light weight in design.*
7. *Permits the easy removal of waste exhaled gases.*
8. *Easy to maintain with minimal running cost.*

Efficiency of breathing system

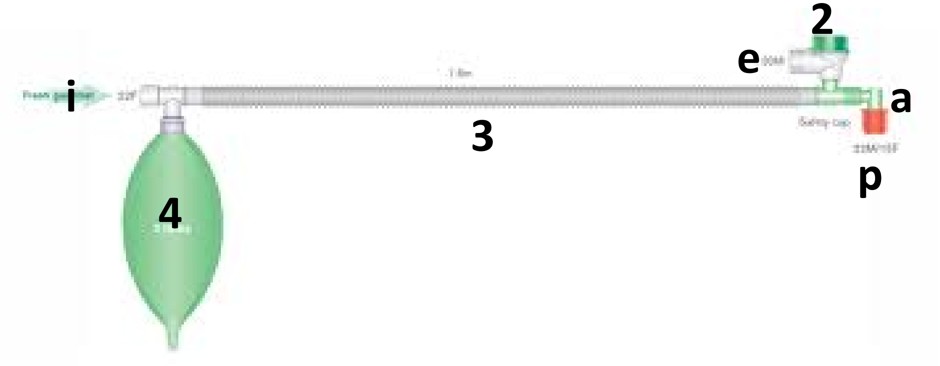
Is measured by the FGF rate required to prevent rebreathing of patient's own alveolar gas . The lower FGF rate required the more efficient is the breathing system.

Components of the breathing system

1. *Three ports :the inlet (i) ,the patient(p) and the exhaust(e) ports. Exhaust port can be open to the atmosphere or connected to the scavenging system.*
2. *Adjustable Pressure Limiting (APL)valve.*
3. *Corrugated Hose or hoses.*
4. *Reservoir or rebreathing bag.*
5. *Angle piece (a)with or without gas sampling port.*
6. *Bacteria virus filter with or without gas sampling port.*

Components of the breathing system

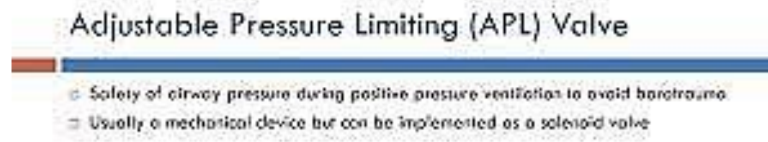
- *Some designs serve as:*
- *Angle piece.*
- *Bacteria and virus filter*
- *Humidifier , at the same time.*

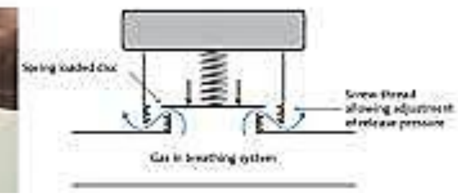


APL valve

- ***Allows exhaled and excess FGF to leave the breathing system.***
- ***It does not allow room air to enter the breathing system.***
- ***Synonymous terms:***

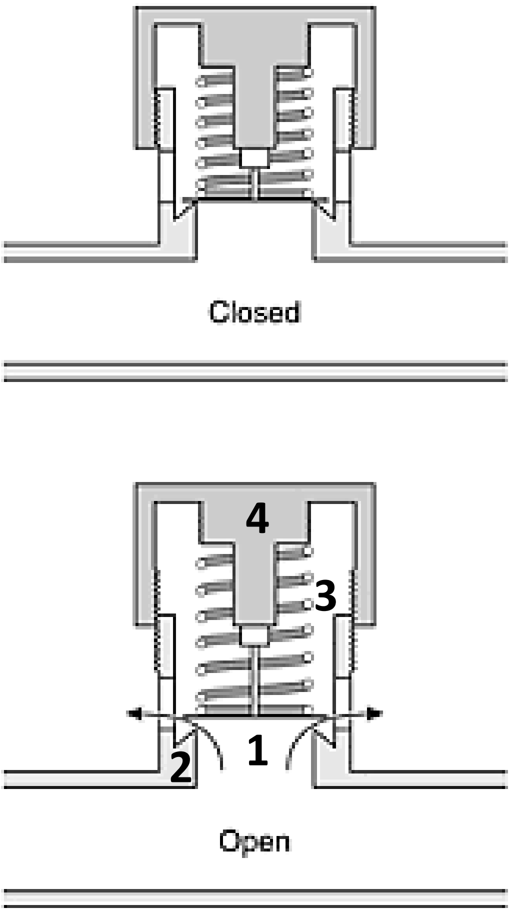
Expiratory valve, pop-off valve ,spill valve ,relief valve.





Components of the APL valve

1. A *light weight disc* .
2. A *knife-edge seating* on which the disc is positioned.
3. A *tension spring* that holds the disc onto the seating.
4. A *valve dial* that controls the tension in the spring and thus opening of the valve .



Mechanism of action

<u>During spontaneous ventilation</u>: the APL is put in open position:

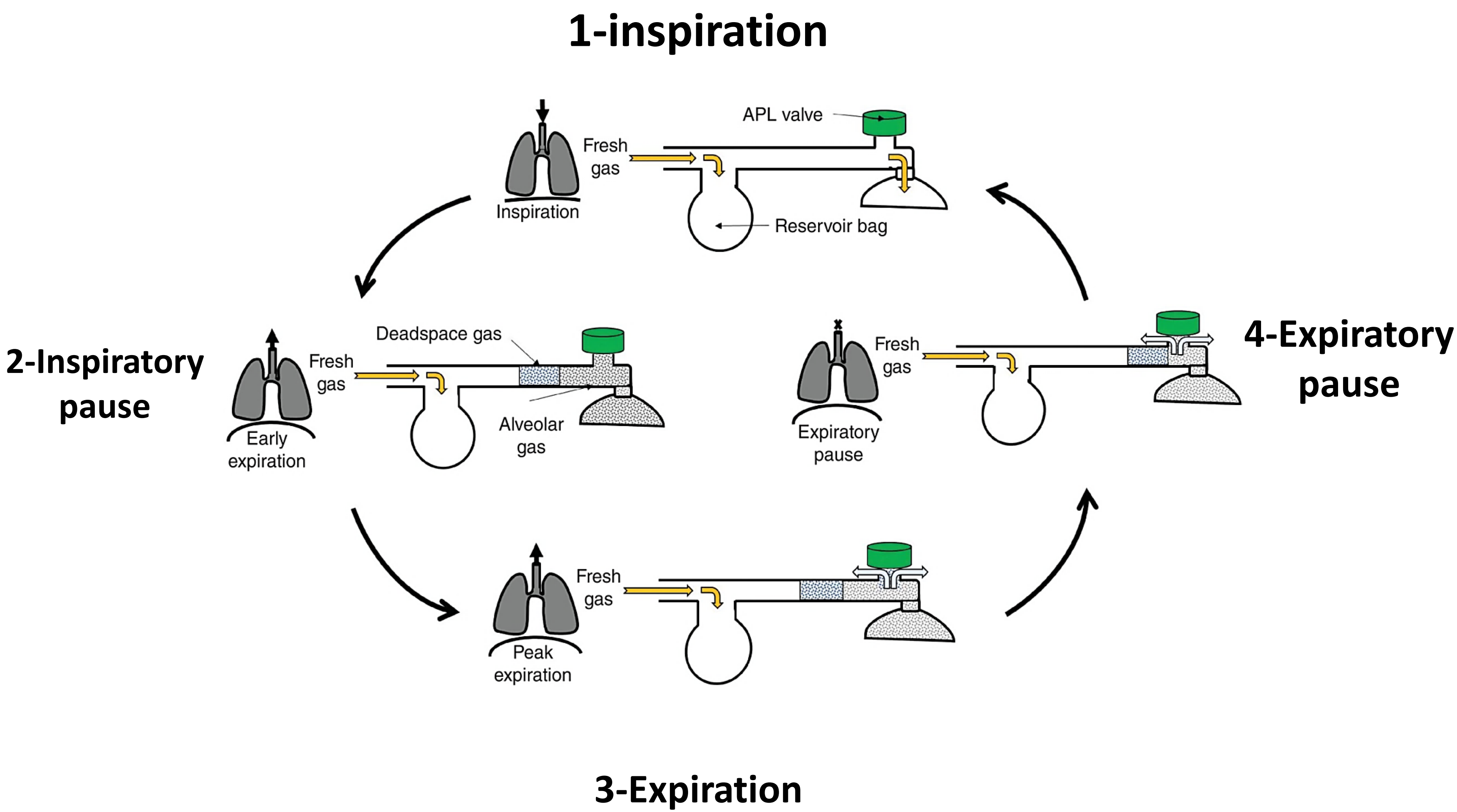
1. ***<u>During inspiration</u> this one way adjustable ,spring-loaded valve closes by the effect of the spring and gravity , and as the patient creates a negative pressure , then the FGF passes to the patients.***
2. ***<u>During expiration</u> the valve opens as the patient creates a positive pressure expelling the exhaled and excess FGF out of the system , less than 1cm H_2O <u>(0.1 kPa)</u> is needed when the valve is fully open .***

Mechanism of action

<u>During Manual controlled ventilation</u> the APL is adjusted to a desired controlled leak position .

1. ***<u>During inspiration</u>: the anesthetist creates a positive pressure by actively pressing the bag and pushing FGF into the patients lungs.***
2. ***<u>During expiration:</u> the patient expels the exhaled and excess FGF passively(no force by the anesthetist or the patient is needed) .***

Phases of respiratory cycle



Problems in practice and safety measures

1. ***Condensed water vapor causes sticking of the disc to the seating and failure of the APL valve to open during expiration resulting in barotrauma to the patients lungs this is minimized by:***

a) ***Knife edge reduces surface area of contact with the disc.***

b) ***Using hydrophobic materials in manufacturing of the disc.***

c) ***A pressure-relief safety valve opens at 60cm H_2O is installed in some designs .***

Reservoir Bag

- *Its an important part of most breathing systems.*
- *Its made of antistatic rubber or plastic .latex free versions exist now.*
- *Ellipsoid in shape.*
- *Volume from (0.5-6) available .the 0.5L is usually used for pediatric patients and large sizes are used for inhalational induction in adults with sevoflurane.*

Importance of reservoir bag:

1. ***Accommodates the FGF during expiration acting as a reservoir to be used in the next inspiration .***
2. ***It makes the breathing system economic (less FGF is needed to prevent rebreathing of exhaled gases***
3. ***Acts as a monitor for spontaneous breathing but its a very inaccurate guide to the patients tidal volume.***
4. ***It can be used to assist or control ventilation.***
5. ***In Mapleson F system the open ended bag serves as an expiratory port.***

Problems in practice and safety features

1. *It is distensible therefore it prevents pressure build-up within the system and the patients lungs ,this property is a safety measure*
2. *Too small bag for a patient can not provide enough reservoir FGF , and too large bag makes monitoring of ventilation difficult*

Tubing

- ***They connect the parts on the breathing system to each other.***
- ***They act as a reservoir of FGF in certain systems.***
- ***Manufactured from disposable plastic or reusable silicone rubber or silver impregnated bactericidal plastic.***
- ***The lengths are variable according to the breathing system***
- ***The diameter is 22mm for adults and 15mm for pediatric age groups.***
- ***Their corrugated surfaces make them flexible or***
- ***(non-kinking) but promote more turbulent flow.***

Terminology

Respiratory cycle:

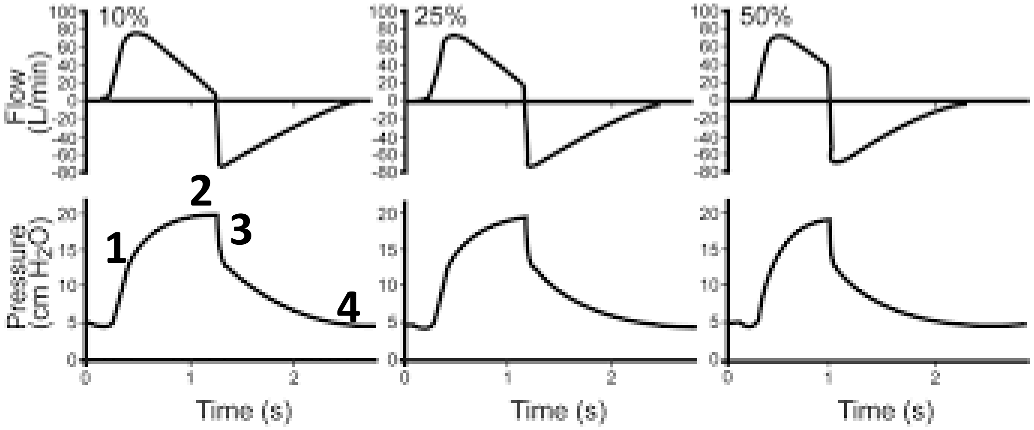
is divided into 4 stages

1- inspiration.

2- inspiratory pause.

3-expiration.

4- expiratory pause.



Terminology

<u>Normocapnea</u>: CO_2 is at the normal physiological level in the exhaled gases .This is achieved by normal ventilation without rebreathing of alveolar air.

<u>Hypocapnea:</u> CO_2 is lower than normal physiological level in the exhaled gases .This results when the patient is hyperventilated and excess CO_2 is washed out from the lung.

<u>Hypercapnea:</u> CO_2 is higher than normal physiological level in the exhaled gases. This results when the patient is hypoventilated and excess CO_2 accumulates in the lungs or (CO_2 retention) occurs.

Breathing systems

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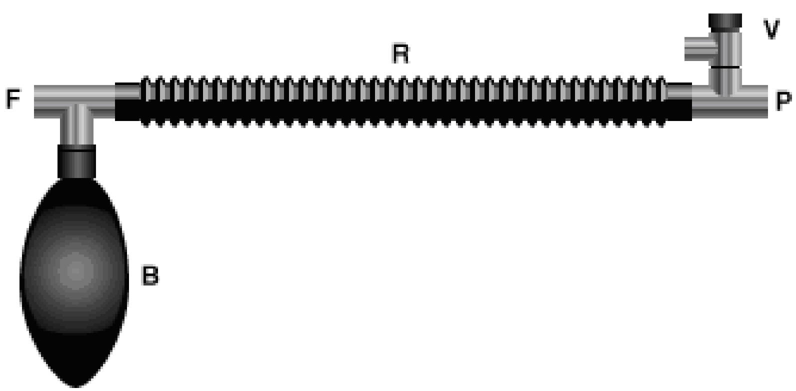
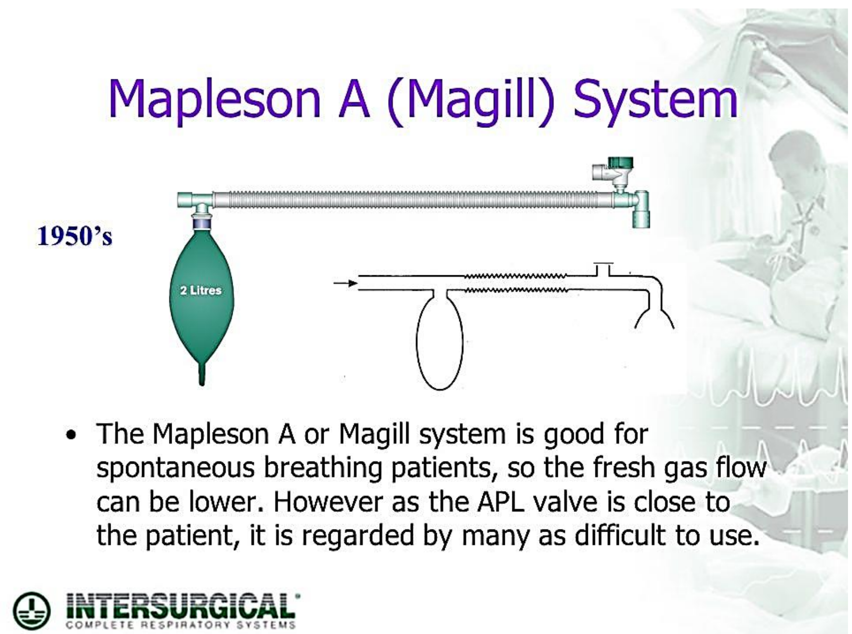
Part-II

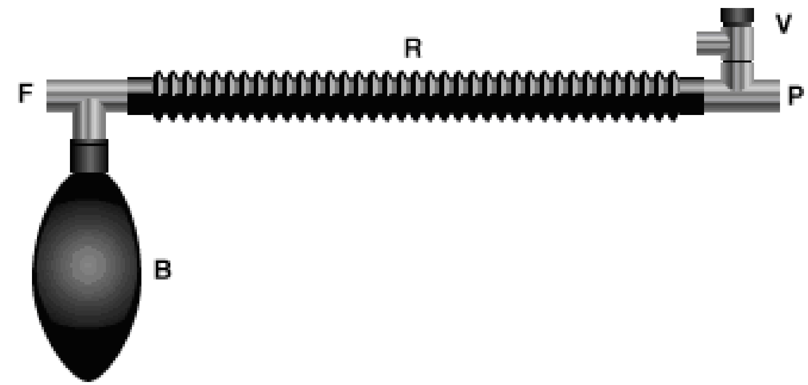
Magill system(Mapleson A)

This breathing system is popular and widely used in the UK.





Magill system(Mapleson A)



Components:

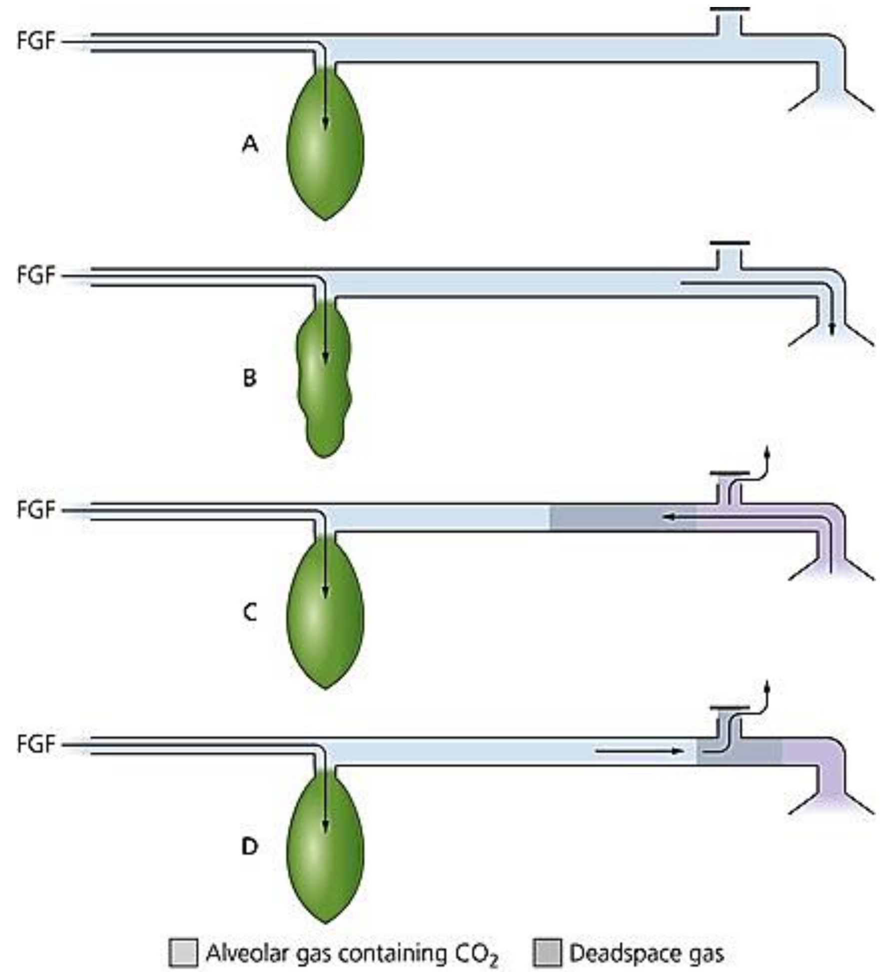
1- corrugated rubber or plastic tubing (R)which is (110-180 cm) length & at least(550ml)internal vol.

2- A reservoir bag (B) at the machine end .

3-APL valve (V) at the patient end.

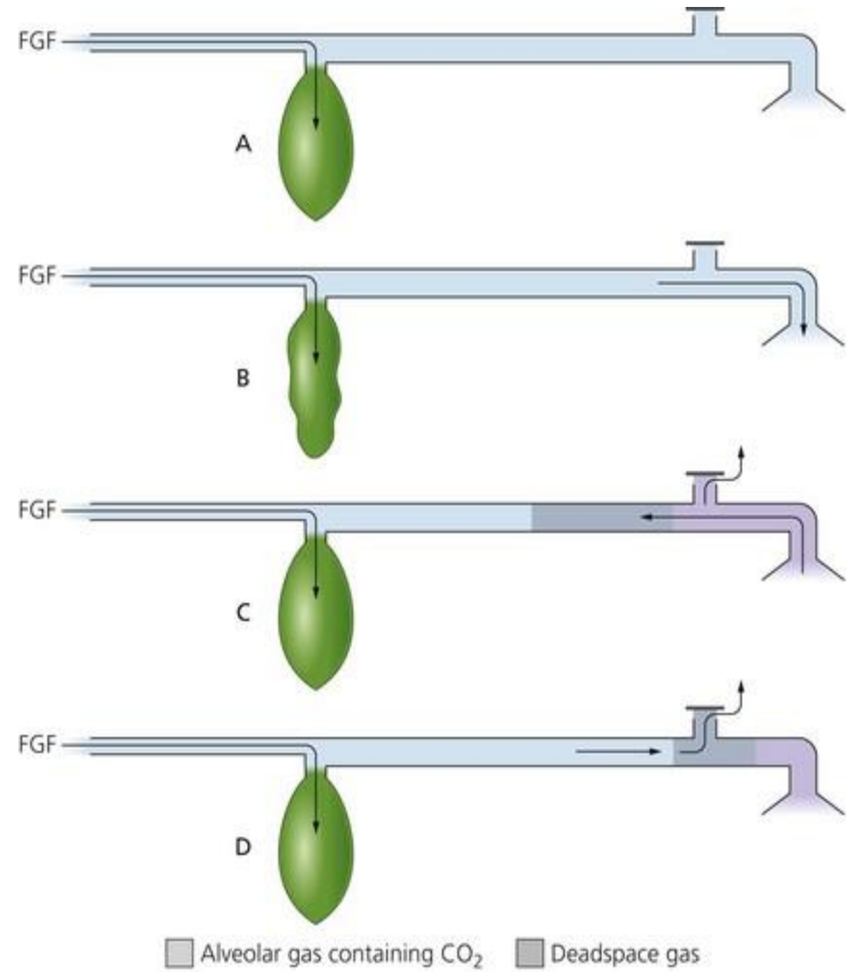
Mechanism of action

1- During inspiration, all the gases are fresh & consist of O_2 & anesthetic gases & Vapor from the anesthetic machine.



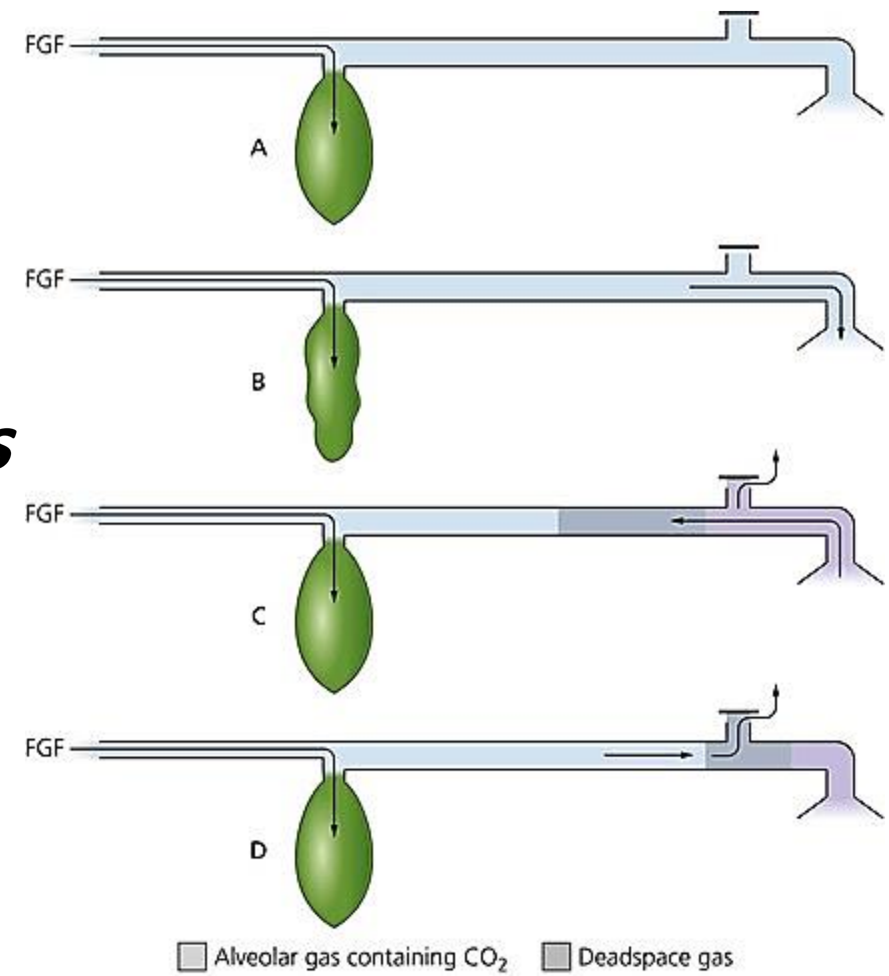
Mechanism of action

2- During expiration (C)the patient exhales the gases coming from the anatomical dead space 1st that have not undergone any exchange so contains no CO_2 and moves towards the bag which is filled continuously with FGF .



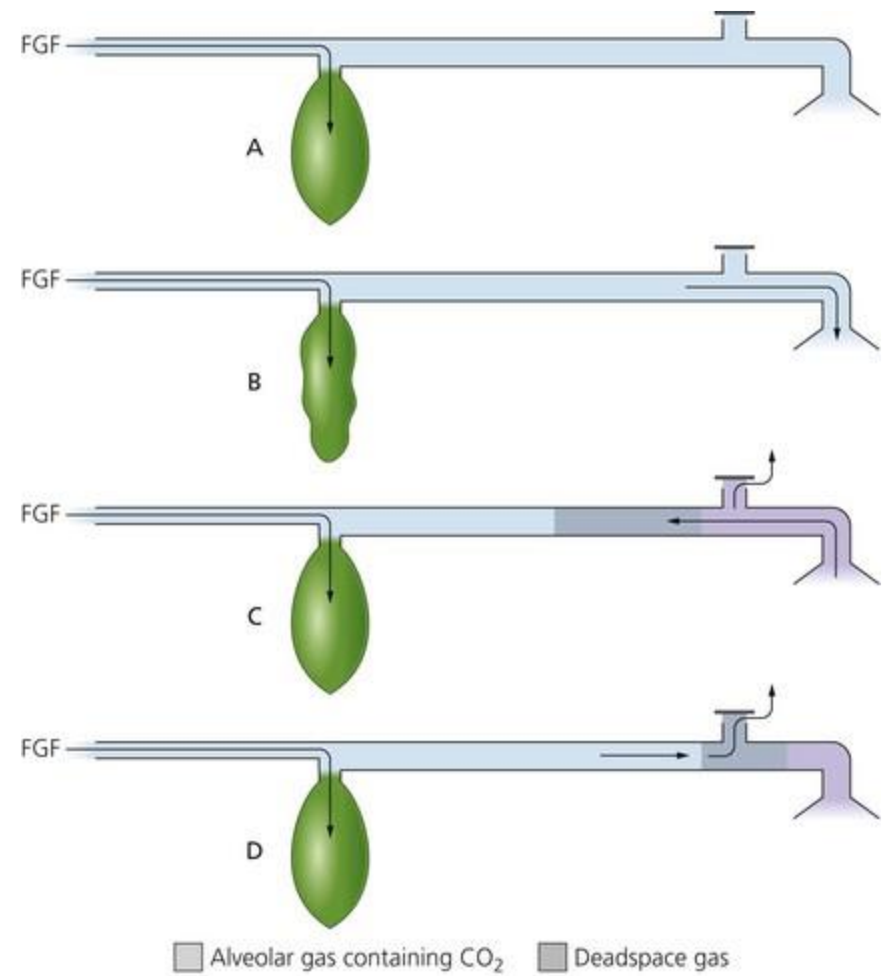
Mechanism of action

3- During expiratory pause pressure built-up within the system allows the FGF to expel the alveolar gas first out through the APL valve (D).



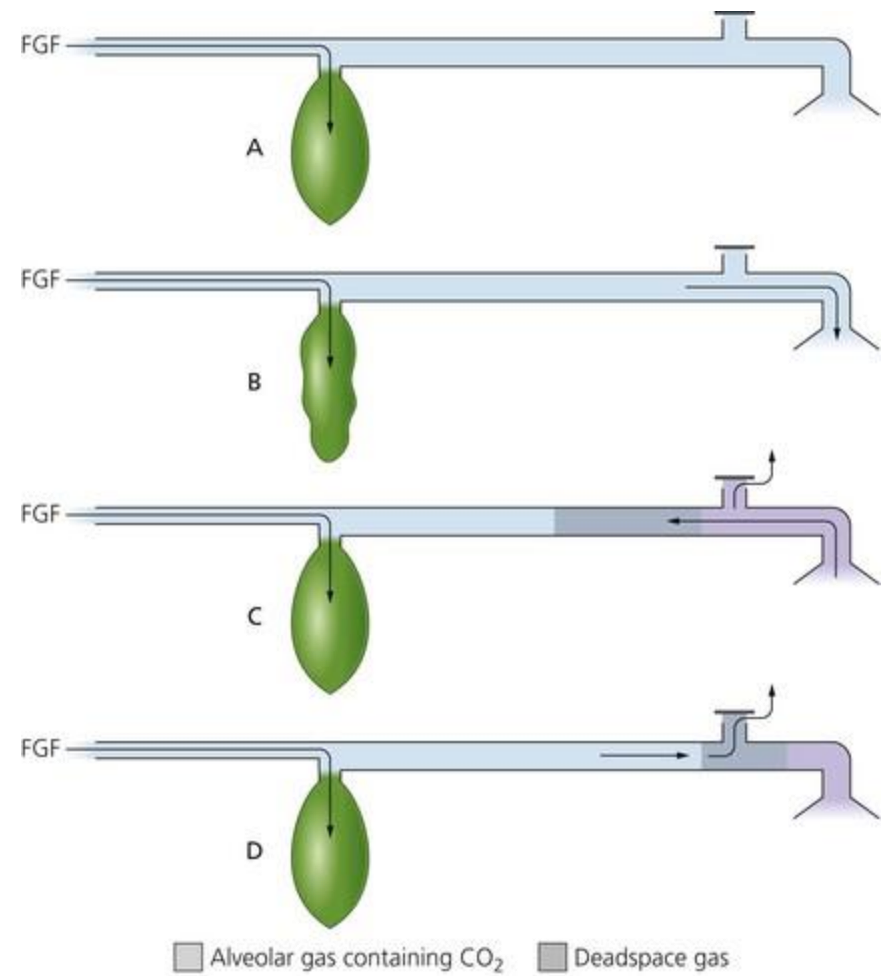
Mechanism of action

4-By that time the patient inspires again & inhales a mixture of FGF & the rebreathed anatomical dead space gases.



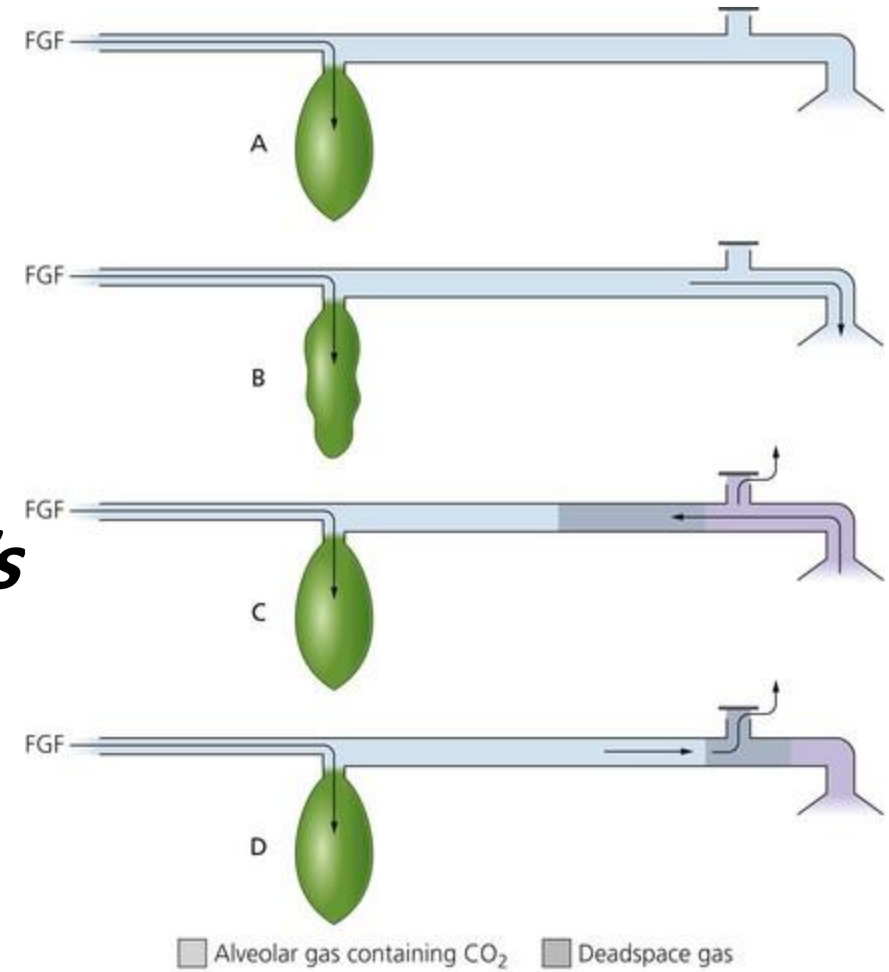
Mechanism of action

5- it's a very efficient system for <u>spontaneous breathing</u>, since it requires FGF equal to the patient's alveolar Minutes Volume (70ml /Kg/min) to prevent rebreathing of the alveolar gas.



Mechanism of action

6- it's not an efficient system for <u>controlled ventilation</u>, since it FGF Three times the patient's alveolar MV to prevent rebreathing.



Problems in practice and safety features

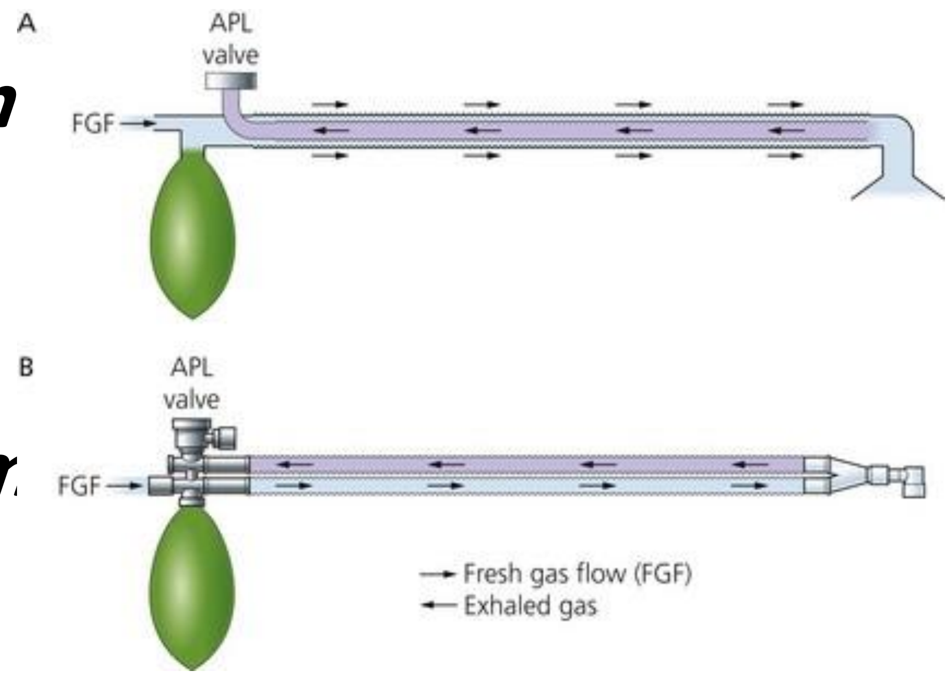
- ***Its not suitable for use in children or body weight less than 25-30 kg because of relatively large dead space specially by the angle piece and face mask.***
- ***Heavy weight APL at the patient end (specially if scavenging system is connected) makes disconnection or Endotracheal tube dislodgement more likely.***
- ***Position of the APL near the patient makes it not suitable for use in head and neck surgery.***

Lack System (Mapleson A)

This is a co-axial or parallel modification of Magill system.

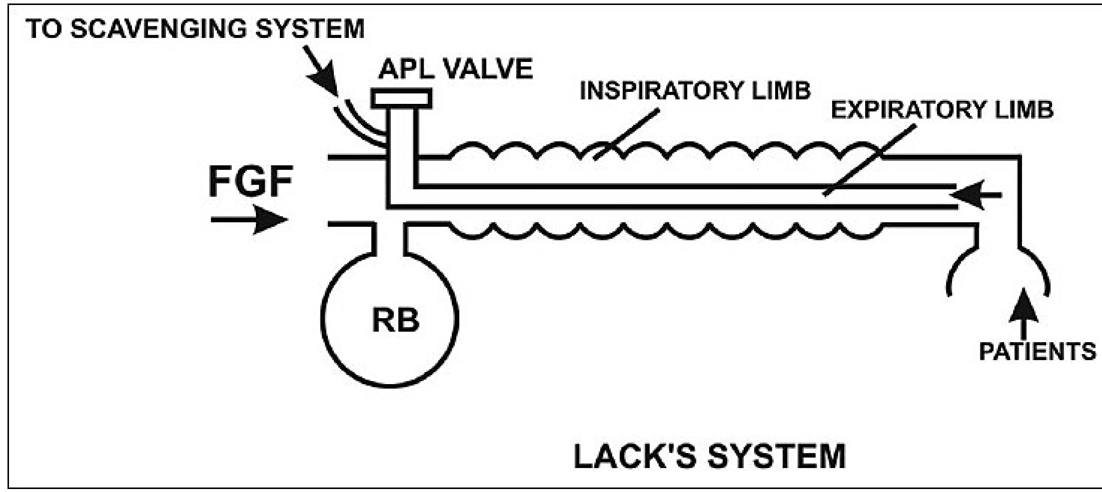
A-Coaxial lack system

B-Parallel Lack system



Components

1. A 1.8 meter co-axial (tube inside tube).
The outer tube is inspiratory limb for FGF.
2. The inner tube is the expiratory limb which is relatively wide to reduce resistance to expiration (14mm diameter).



3. The reservoir bag at the machine end.
4. The APL (unlike Magill system)is positioned at the machine end ,thus reduces chance of disconnection or dislodgement of the ETT.
5- A parallel tubing version is available with the same flow characteristics, one limb is inspiratory and the other is expiratory.

Mechanism of Action

1. ***Similar to Magill system except that inspiration and expiration is through separate tubing (co-axial or parallel).***
2. ***Efficient for spontaneous breathing (70ml/Kg/min) is required to prevent rebreathing.***
3. ***Not efficient for controlled ventilation.***

Mapleson B & C systems

1. ***FGF is added just proximal to the APL.***
2. ***APL is at the patient end.***
3. ***Both systems are not efficient during spontaneous and controlled ventilation***

(1.5-2) times FGF is required to prevent rebreathing.

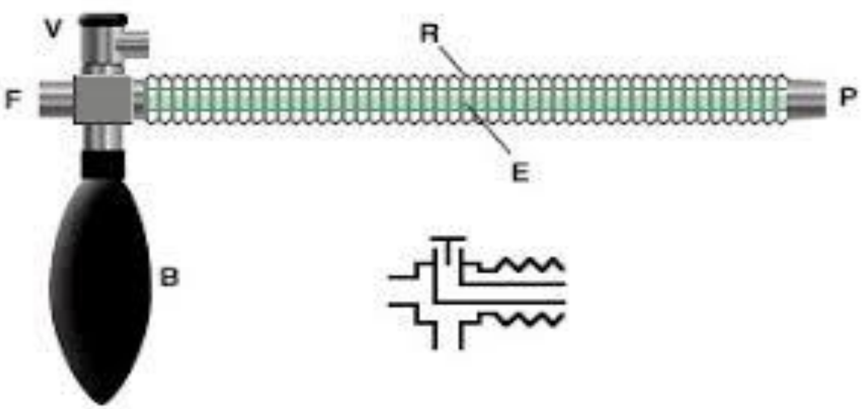
4. ***B is better than A during controlled ventilation.***
5. ***4. They are mainly used during transport of patients.***

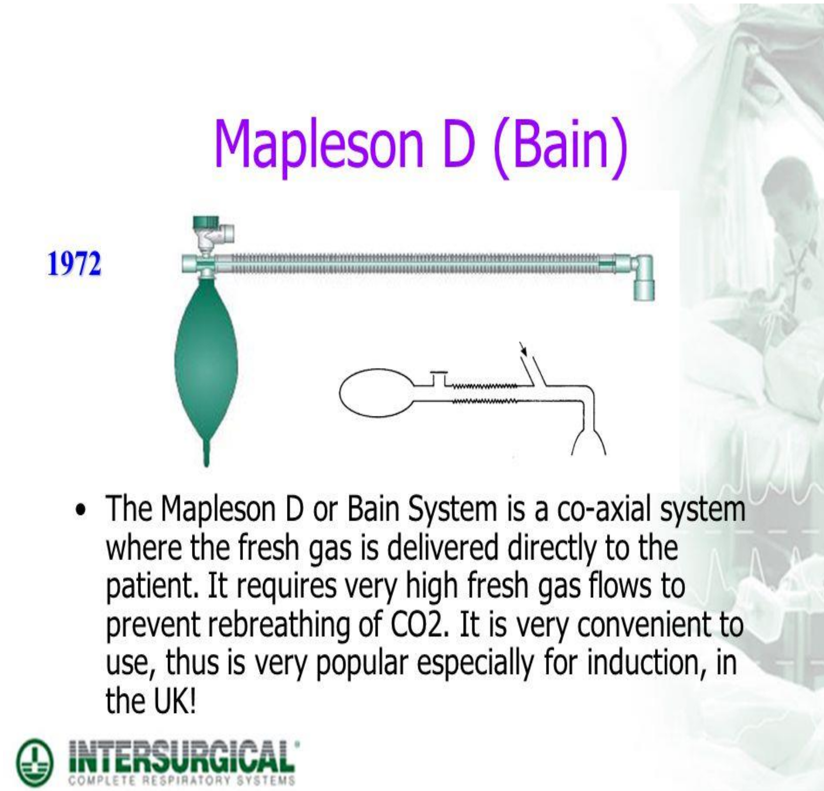
Bain (Mapleson D) System

-It's a co-axial version of Mapleson D system.

-Its light weight and compact at the patient end.

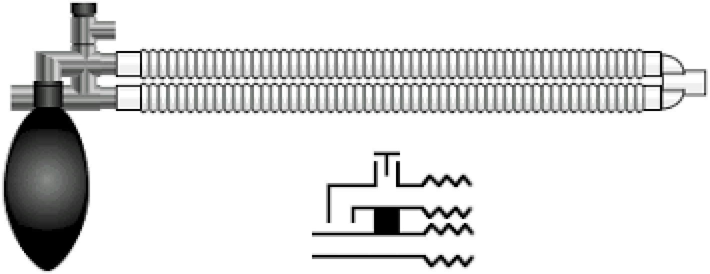
-Useful during head and neck surgery.





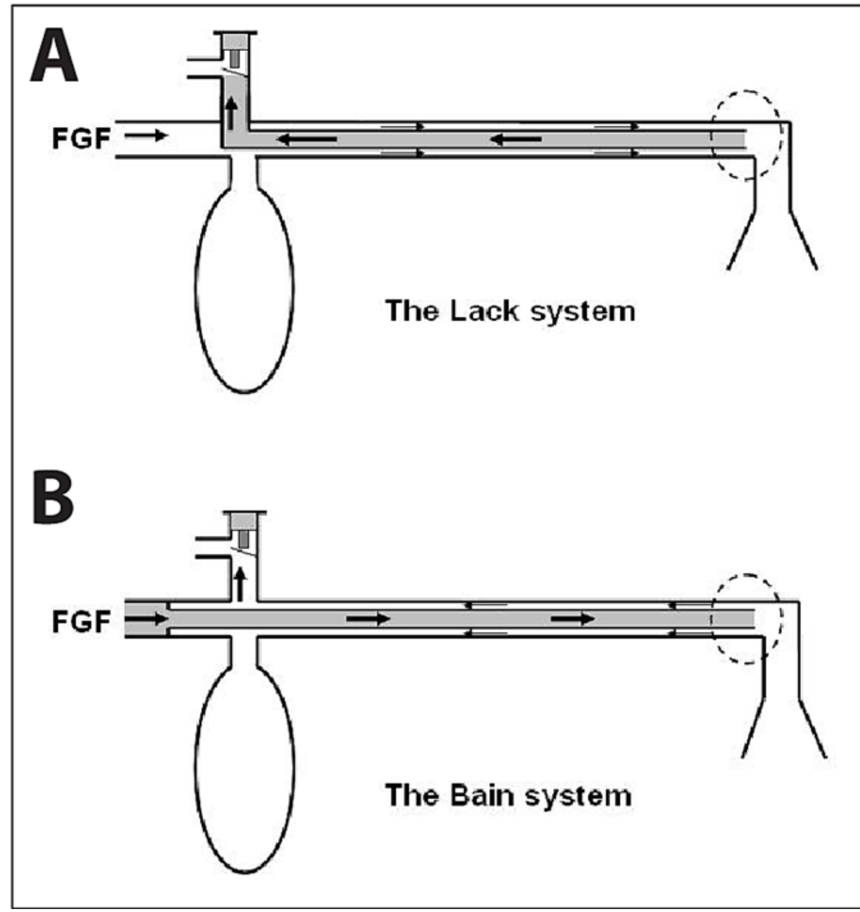
Bain (Mapleson D) System

- A non-coaxial (parallel)version is available in Manley ventilator when its switched to spontaneous ventilation mode.



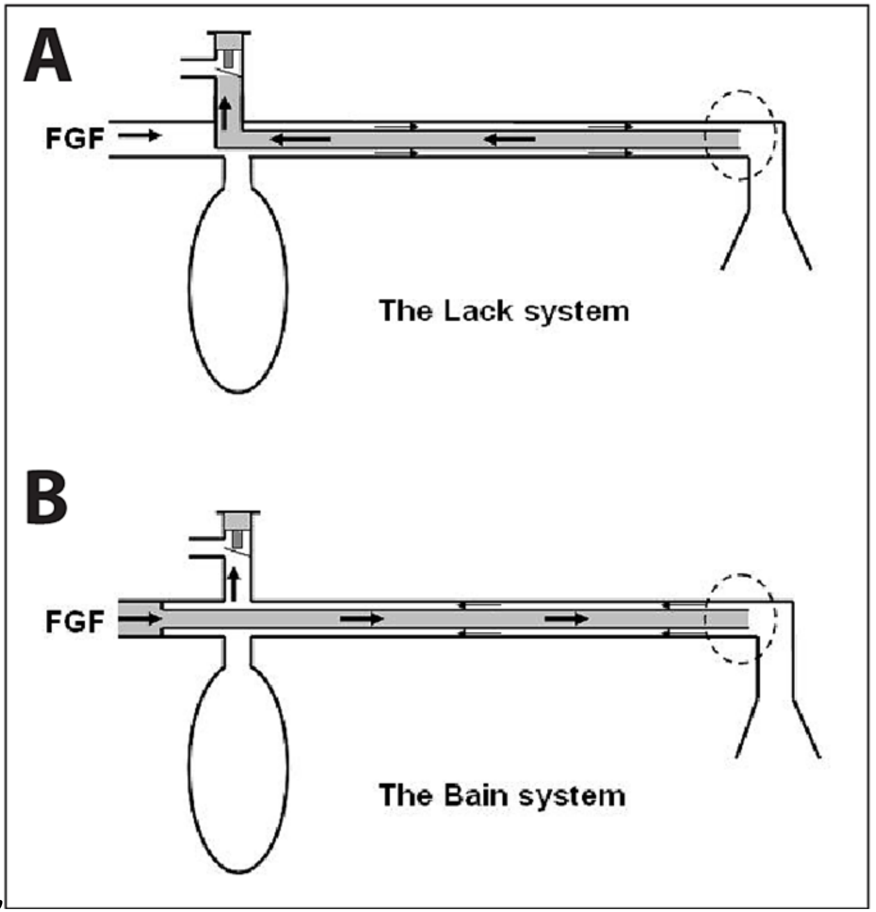
Components

1. *The usual length of the co-axial tubing is (180cm), but it can be supplied at (270cm)for dental or ophthalmic surgery and (540cm) for Magnetic Resonance Imaging(MRI)scan where the anesthetic machine needs to be kept outside the scanners magnetic field. Increasing the length <u>Does not</u> affect the physical properties of the system.*



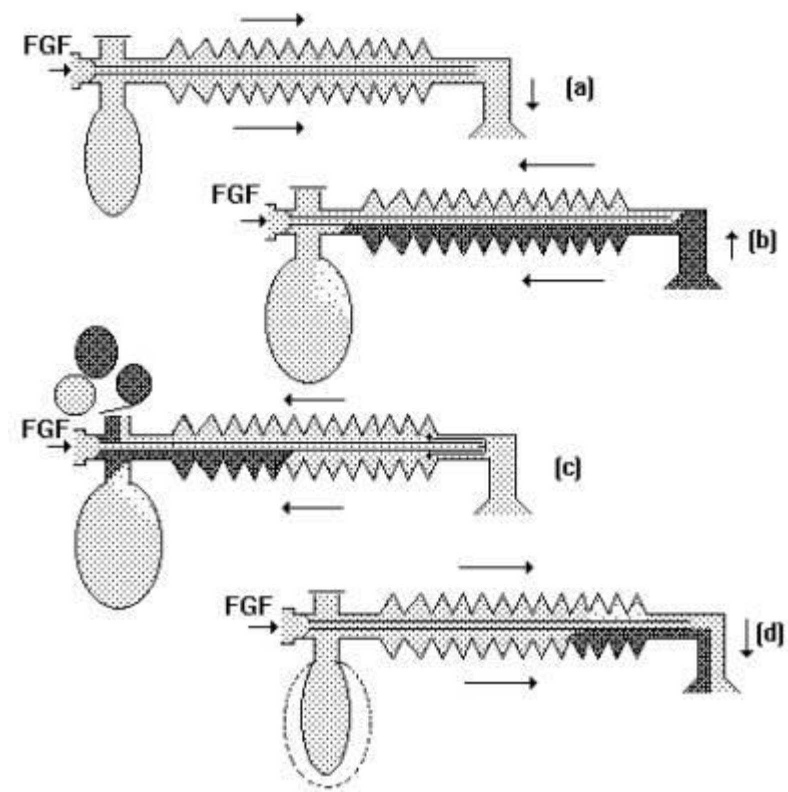
Components

2- The inner tube is inspiratory carries FGF. while the Outer tube is expiratory carries exhaled gases.
3- The reservoir bag is at the machine end.
4- The APL valve is at the Machine end .
Both of them are attached to the Outer(Expiratory tube).



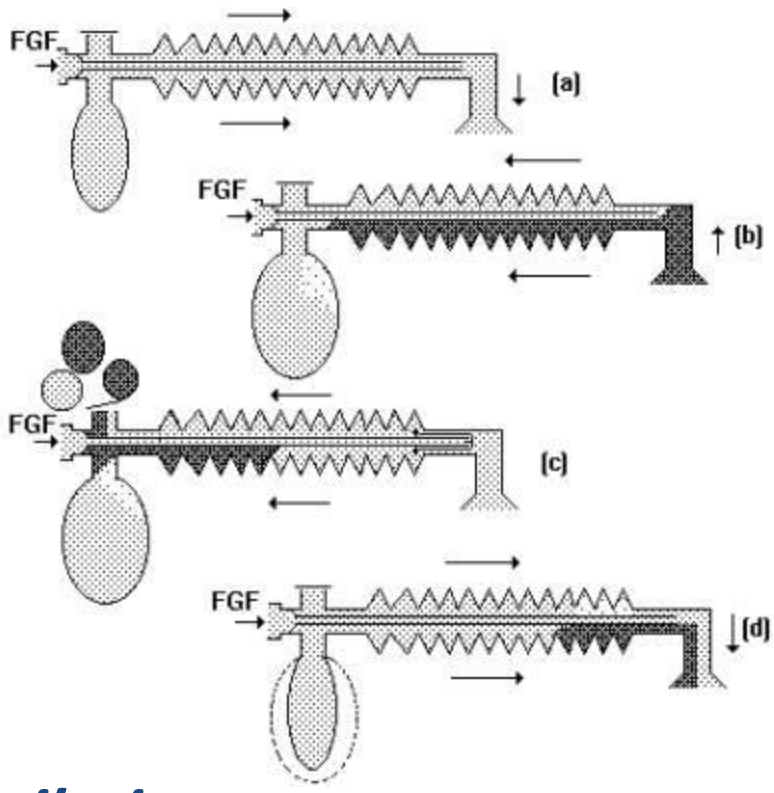
Mechanism of action

1. ***During <u>spontaneous Ventilation</u> ,the patients exhaled gases are pushed via the outer(expiratory tube) to the reservoir bag which become mixed with FG. And as pressure is built-up within the system by continuous FGF, the APL opens venting a mixed exhaled and FG out.***



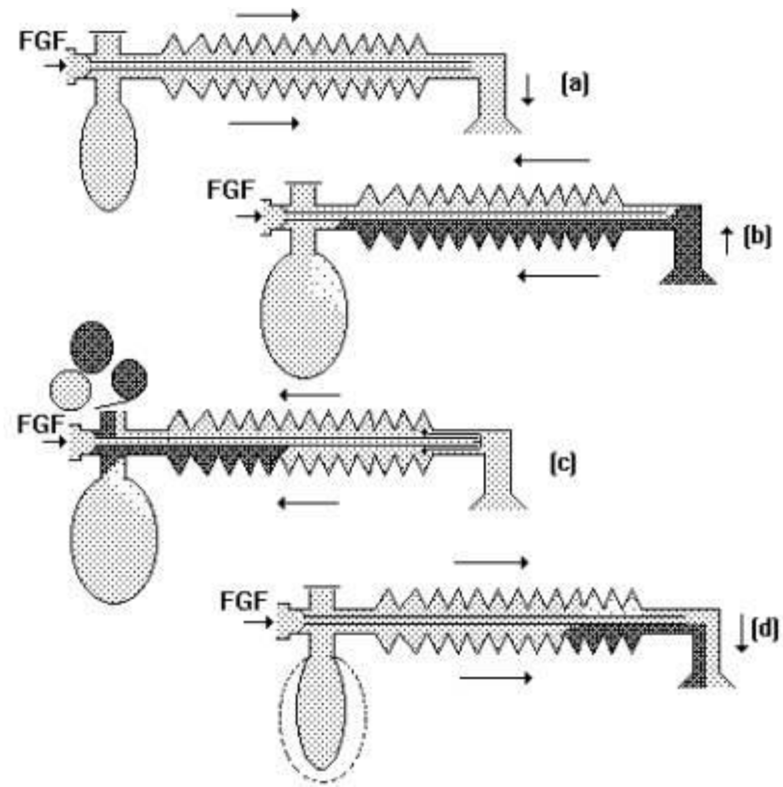
Mechanism of action

2- The FGF required to prevent rebreathing during spontaneous ventilation is about 1.5-2 times alveolar minute volume.
A flow rate of 150-200 ml/Kg/min is required.
Thus this system is an inefficient and uneconomical system during spontaneous ventilation.



Mechanism of action

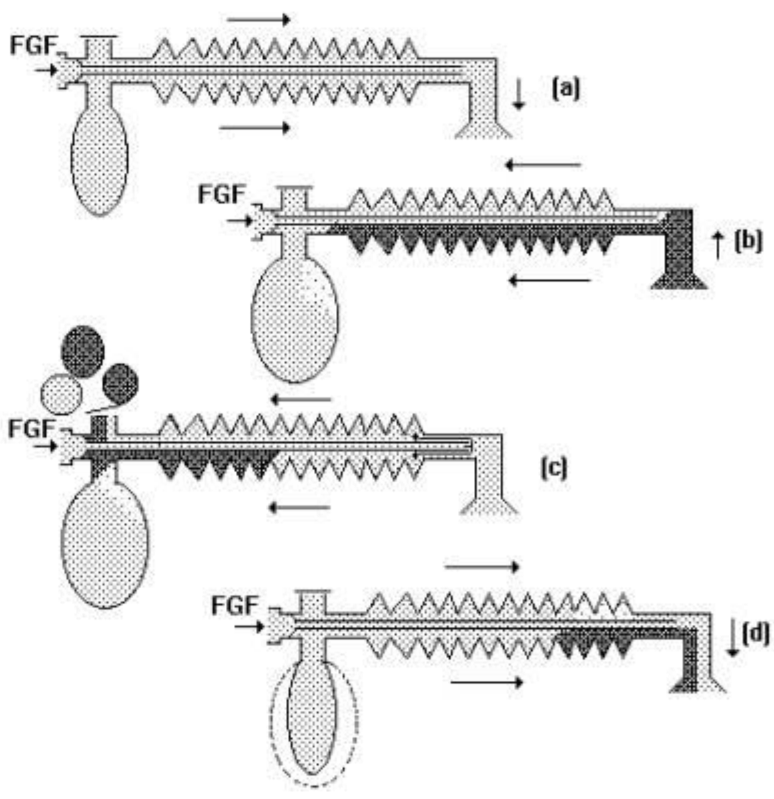
3- It is more efficient during controlled Ventilation . A flow rate of 70-100ml will maintain normocapnea. A flow of 100 ml will cause moderate hypocapnea during controlled ventilation.



Mechanism of action

4- Connection to a ventilator Is possible .By removing the bag a ventilator of Penlon-Nuffield 200 version can be connected to the bag mount using a one meter corrugated tube.The APL valve must be fully closed.

5- A parallel version of Mapleson D system is available.



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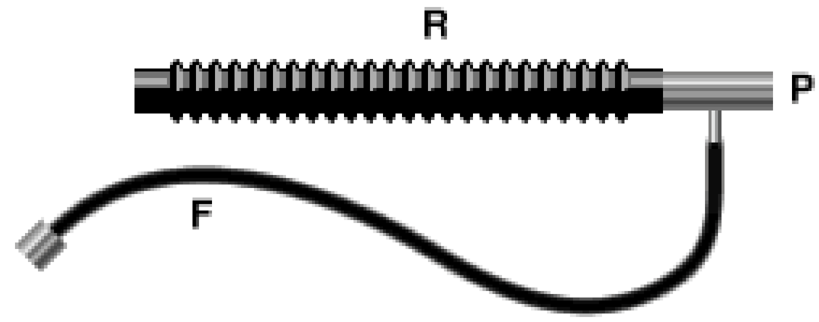
Part-III

Problems in practice and safety features

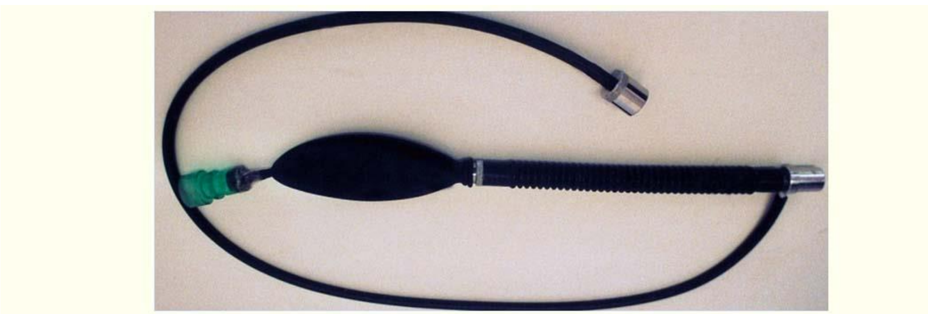
1. *The internal tube may be kinked and prevent FG delivery to the patient ,thus a swivel mount is installed at the patient end.*
2. *The inner tube may be disconnected at the machine end ,increasing the dead space and resulting in hypoxia and hypercapnea. Thus movement of the reservoir bag during spontaneous breathing does not mean that FG is delivered to the patient.*

T-piece system
(Mapleson E and F)

- *Valveless system.*



- *Used in anesthesia for children up to25-30 Kg.*



- *Suitable for spontaneous and controlled ventilation.*

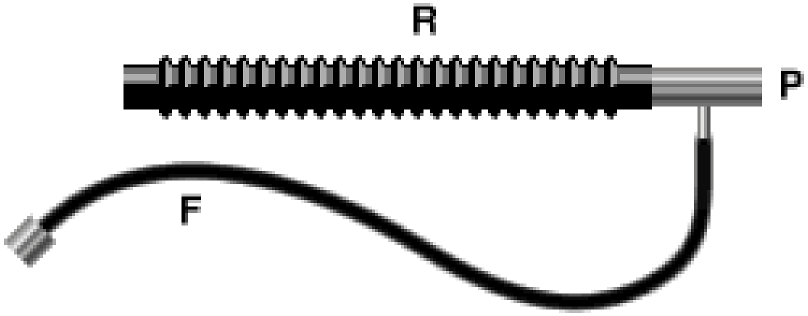
Components

1. *T-shaped tubing with 3 open ports(Mapleson E).*

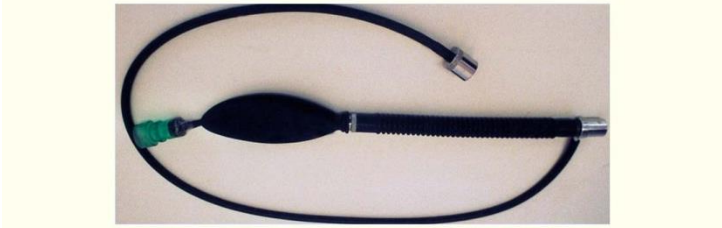
F= FGF from the machine

P= patient's mask or tube.

R= reservoir tubing.



Jackson Rees added a double ended bag to the reservoir tubing making it (Mapleson F)



Components

-A recent modification exists. An APL valve is added before a closed ended 0.5 L reservoir bag .

-A pressure relief safety mechanism in the APL is actuated at a pressure of 30 cm H_2O.

-It allows effective scavenging.

Mechanism of Action

1. ***Requires (2.5- 3) patients MV to prevent rebreathing (with a minimum flow rate of 4L /min).***

2.The double-ended bag acts as;

a- visual monitor for spontaneous breathing.

b-used for assisted or controlled ventilation.

c- provide a degree of continuous positive airway pressure(CPAP) during spont. Breathing.

Mechanism of Action

3. Controlled ventilation in Mapleson E system can be conducted by intermittent thumb occlusion of the reservoir tubing or connecting it to a special ventilator like Penlon Nuffield ventilator .

In Mapleson F it is conducted by manual intermittent squeezing of the double ended bag.

4- the volume of the reservoir tube determines the degree of rebreathing, thus it should approximate the patients tidal volume.

***Too large* causes *rebreathing*.**

Too small* causes *entrainment of ambient air.

Problems in practice and safety features

1. ***There is a problem of scavenging since traditionally there is no APL valve.***
2. ***Addition of the double ended bag added the advantage of CPAP.***

Hamphrey ADE breathing system

- *Very versatile system.*
- *Combine advantages of Mapleson A,D & E.*
- *Can be used efficiently for spont. & controlled ventilation in both adults & children.*
- *The mode is determined by the position of a lever mounted on the Hamphrey Block*
- *Both parallel and coaxial versions exist.*

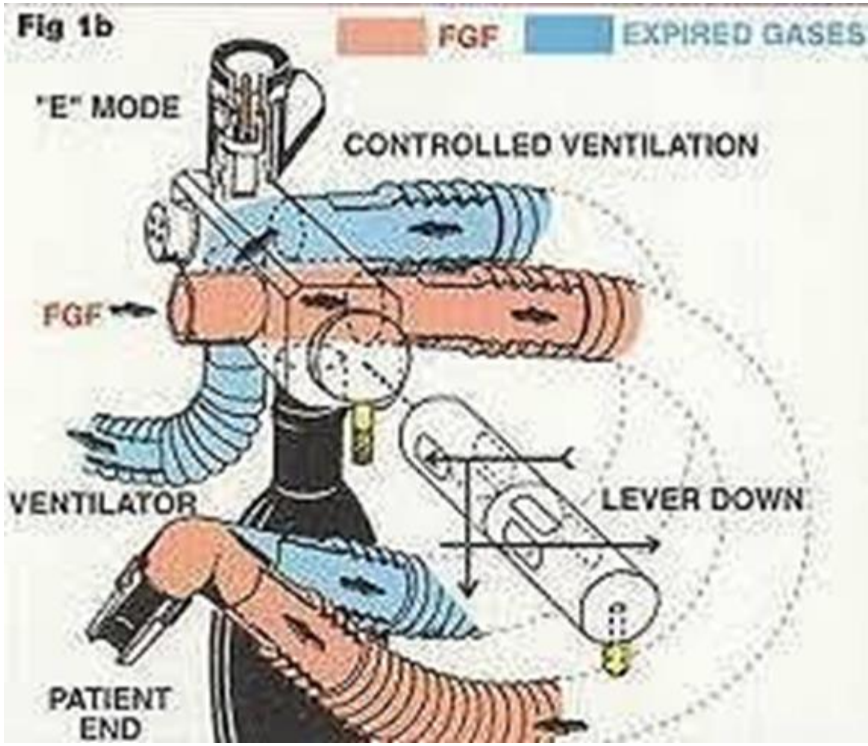
Components

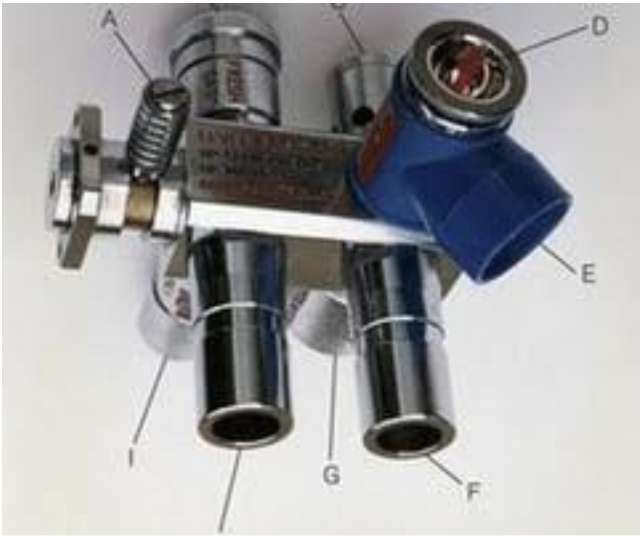
1. Two 15mm smooth tubes with appropriate lengths. One delivers FGF to the patient and the other carries exhaled gas away from the patient. Distally they are connected by a Y-connection and proximally connected to the inspiratory and expiratory ports on the Hamphrey block .

Components

2- the Hamphrey block is at the machine end & consists of:

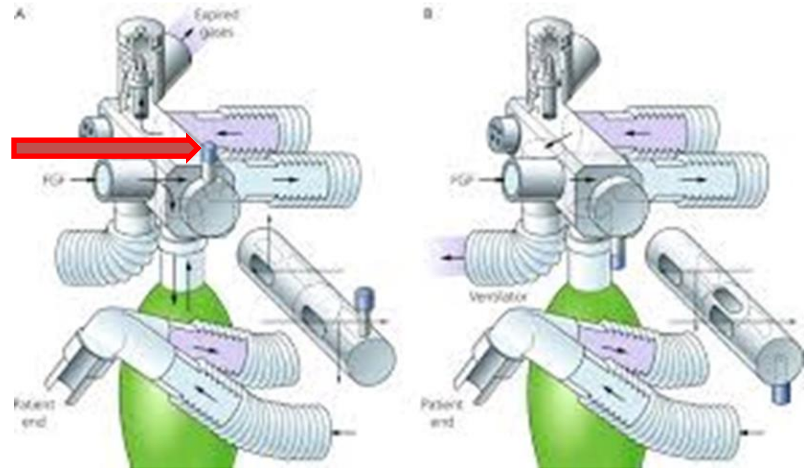
a) APL valve featuring visible indicator of valve performance.
b) A 2L reservoir bag.
c) A lever to select spontaneous or controlled ventilation.
d) A safety pressure relief valve that opens at 60cm H_2O.
e) Soda lime canister in new designs.

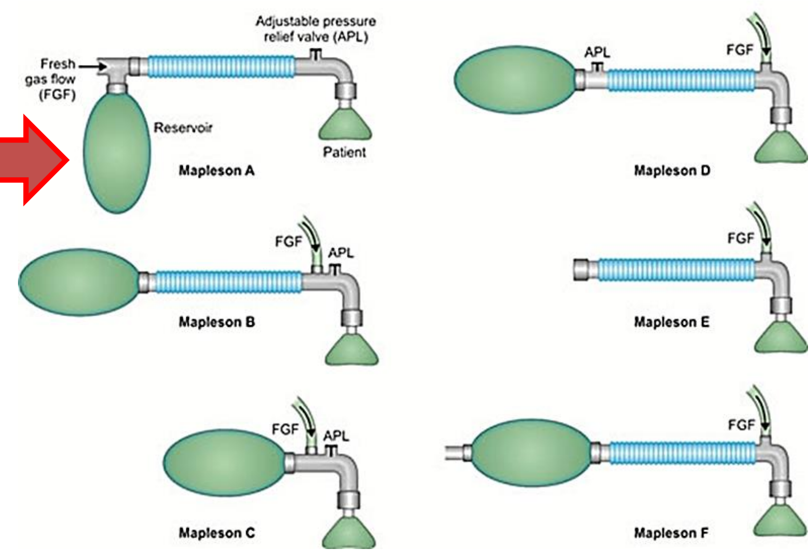



A
D
E
I
G
F


Mechanism of action

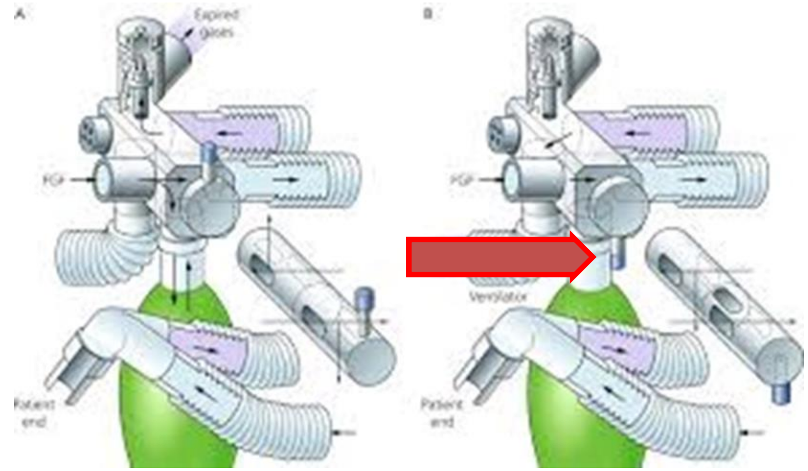
1. ***With the lever up in the spont. mode, the reservoir bag & the APL are connected to the breathing system as in Magill system (Mapleson A)***

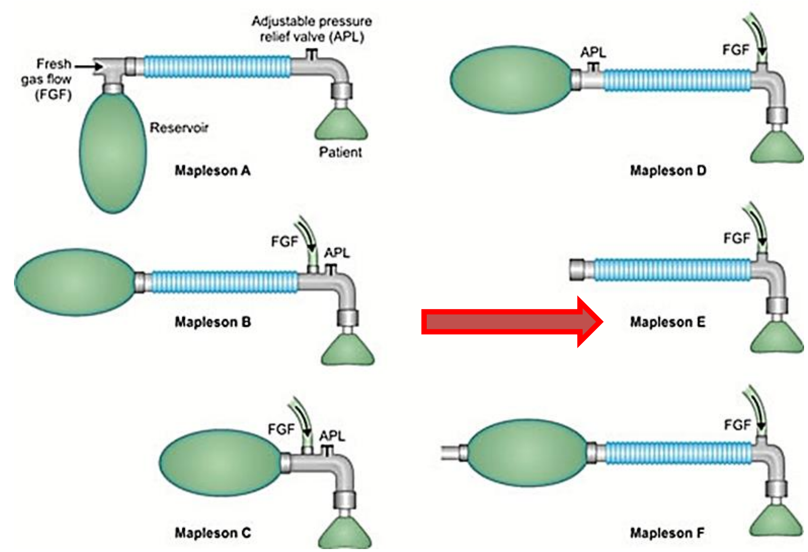




Mechanism of action

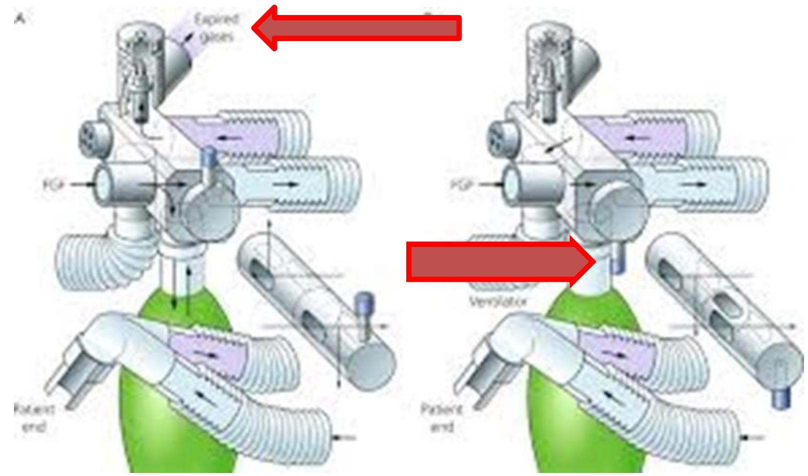
2. ***With the lever down in the ventilator mode, the reservoir bag & the APL are isolated from the breathing system as in (Mapleson E)***

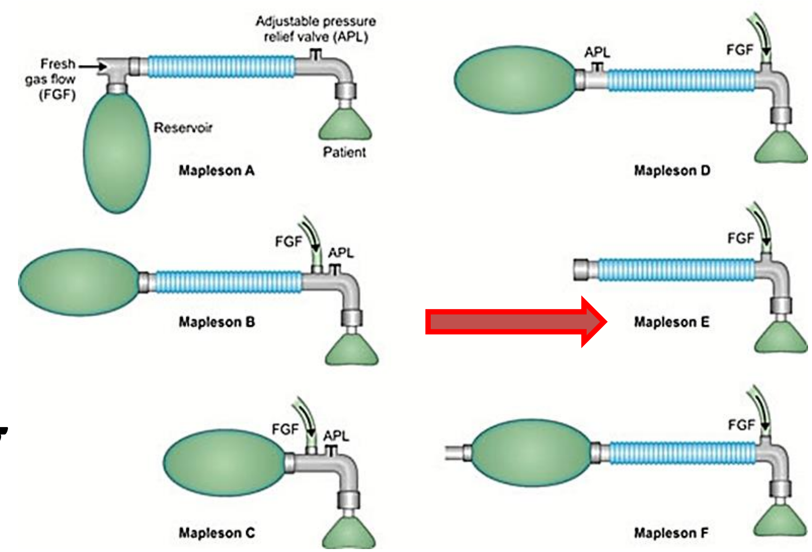




Mechanism of action

2. *With the lever down in the ventilator mode, the reservoir bag & the APL are isolated from the breathing system as in (Mapleson E) The exhaled gas is expelled through the expiratory limb of the ventilator to the scavenging system.*





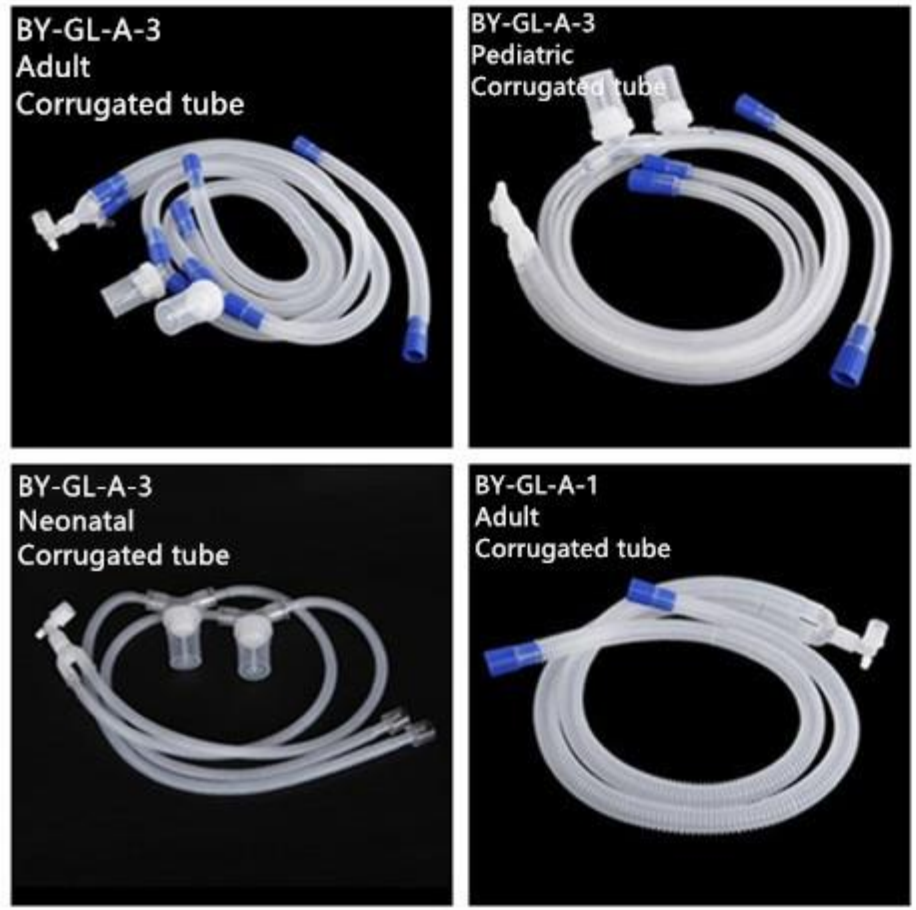
Mechanism of action

3. The system is suitable For pediatric & adult use. The tubing are narrower (15 mm diameter) with a smooth inside & smaller internal volume for pediatric use ,thus :

-There is minimal resistance to flow compared to (22mm) corrugated adult tubing.

-Small tidal volumes are Possible during controlled Ventilation.

-Less energy is required during spontaneous breathing.



Mechanism of action

4- Presence of APL valve offers a physiological advantage in pediatric anesthesia as it offers a small amount of PEEP (1cm H_2O).

5- During spontaneous ventilation:

a) FGF of 50-60 ml/Kg/min. is needed in adults.

b) Recommended initial FGF for children weighing less than 25Kg 3L/min this offers a considerable safety.

Mechanism of action

During controlled ventilation:

a) An FGF of 70ml/Kg/min is needed in adults .

b) The recommended initial FGF for children less than 25 Kg is 3L/min.

However adjustment may be necessary to maintain normocarbia.

Soda lime and the circle breathing system

->80% of the anesthetic gases are wasted when FGF of 5.0L/min.is used.

-Typically reduction of FGF from 3L/min.to 1L/min. saves about 50% of the total consumption of any volatile anesthetic agent.

Soda lime and the circle breathing system

In this breathing system:
-Soda lime is used to absorb the patients exhaled CO_2.
-FGF requirements are low, making the circle system very efficient with minimal pollution, thus interest in low flow anesthesia has been renewed due to the cost of new, expensive inhalational agents.

Breathing systems

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November -2022
Part-IV

Types of anesthesia according to FGF

1. *Closed circle anesthesia.*
2. *Low flow anesthesia.*
3. *Minimal flow anesthesia.*

1-Closed circle anesthesia

1. ***The FGF is just sufficient to replace the volume of gas and vapors consumed by the patient.***
2. ***No gas leaves the APL valve, and the exhaled gases are rebreathed by the patient after the Co2 is reabsorbed .***
3. ***Significant leaks from the breathing system are eliminated and this is possible by returning the gases sampled by the gas analyzer back to the breathing system.***

2- low flow anesthesia

1. *the FGF used is less than the patients alveolar MV. (Usually below 1.5 L/min.)*
2. *Excess gases leave the system via the APL valve.*

3- Minimal flow anesthesia

The FGF used is reduced to 0.5L/min.

Components

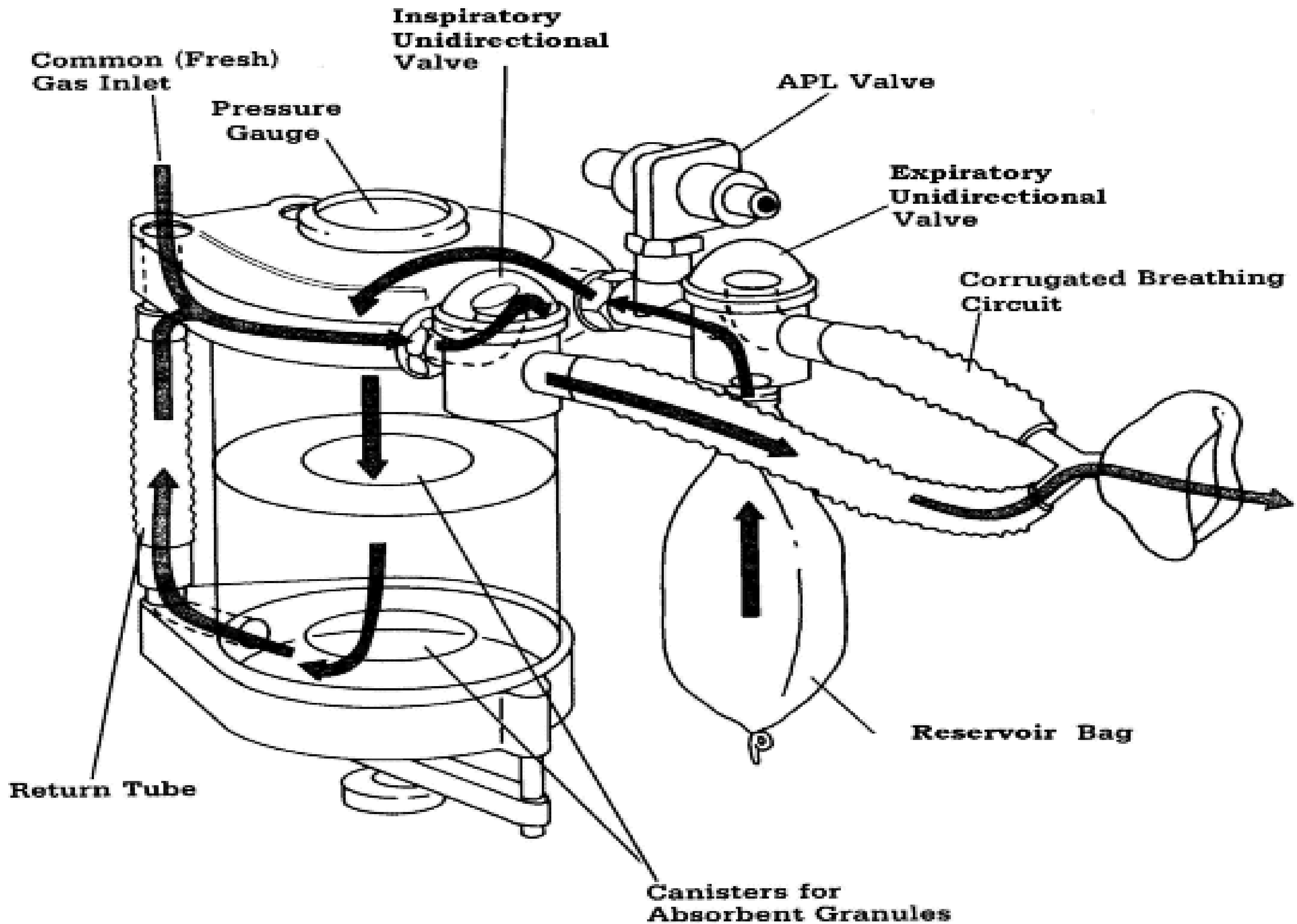
1- A vertically positioned canister containing soda lime with 2 ports: one to receive exhaled gas from the patient and the other to deliver inspired air to the patient.

2-inspiratory and expiratory tubing (limbs) connected to the canister.

Each port incorporates a unidirectional valve.

3- FGF from the anesthetic machine is positioned distal to the canister but proximal to the inspiratory valve.

Components



Inspiratory Unidirectional Valve
Common (Fresh) Gas Inlet
APL Valve
Pressure Gauge
Expiratory Unidirectional Valve
Corrugated Breathing Circuit
Reservoir Bag
Return Tube
Canisters for Absorbent Granules

Components

4- An APL valve is positioned between the expiratory valve and the canister and connected to the reservoir bag.

5- A vaporizer mounted on the back bar (VOC) or on the expiratory limb (VIC).

6- Soda lime consists of :

- *$Ca(OH)_2$ 94%.*
- *NaOH 5%*
- *KOH <1%*

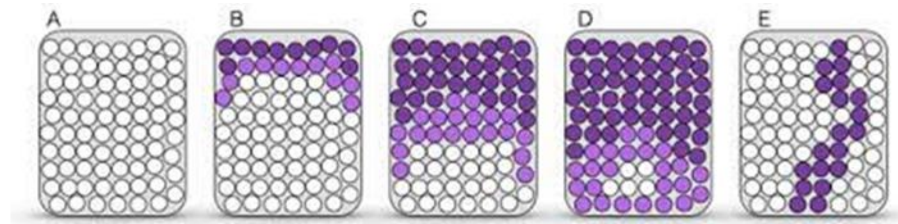
Components

***Soda lime:* has moisture (14-19)% & PH of (13.5).**

-Silica (2%) is added to keep soda lime in a granule form and avoid disintegration into powder (specially during transport) which results in high resistance to flow of gases through it.


Components

-A color indicator is added to change the granules' color from:
-pink to white,
-white to violet/purple
-green to violet, when soda lime is exhausted and PH is below 10.



Newer types add small amount of zeolite to maintain PH and moisture for a longer time thus improving (CO_2) absorption and reducing (CO) and compound A formation.

Components

7- Recently Size of soda lime granules 3-4 mm spheres resulting in a larger surface area of absorption , longer life with lower dust content, more even flow of gases with lower resistance to flow : 1 Kg can absorb >120 L of CO_2.

Barylime:** **is widely used in USA .consists of:

Barium hydroxide 80%

Calcium hydroxide 20%

Mechanism of Action

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

Important points regarding closed breathing system and CO_2 absorption

1-denitrogenation of the circle system:

-High FGF for up to 15 min is needed for the initial period to avoid build up of unacceptable levels of nitrogen in the system and 6 min in low-flow ,later reduced to (0.5-1)L/min if N_2O is used.

-its not necessary to denitrogenate if N_2O is not used, only short period of high flow is needed to prime the system .

Important points regarding closed breathing system and CO_2 absorption

2- the heat and water produced by the reaction between the CO_2 and soda lime makes the returning gas mixture warm and humidified before joining the FGF to be delivered to the patient again.

Important points regarding closed breathing system and CO_2 absorption

3- Presence of unidirectional (inspiratory & expiratory) valves in the system ,controls the direction of gas flow in one direction and prevents mixing of inspired and expired gases thus prevent rebreathing. These valves are mounted in see-through plastic domes so that they can be seen functioning properly.

Important points regarding closed breathing system and CO_2 absorption

4- the canister is positioned vertically to prevent exhaled gas channeling through unfilled portion.

-Large canisters are more efficient.

-double absorber with 2 canisters mounted over each other are more efficient than single canister.

Important points regarding closed breathing system and CO_2 absorption

5-the lower the FGF rate the more rapidly soda lime is exhausted , because less exhaled gas being discarded.

e.g. for a 70-80 kg adult, V_T=500ml, RR=12/min

CO_2 production 250ml/min ,

Soda lime will be exhausted :

After 5-7h if FGF 1L/min .

After 6-8h if FGF =3L/min.

Problems in practice and safety features

1- Adequate monitoring of FiO_2, $EtCO_2$,AA (inhalational anesthetic agent) concentration is essential.

2-Unidirectional valves may stick (due to water vapor condensation) or fail to close .this leads to increase in dead space.

3-Increased resistance to breathing during spontaneous ventilation because of unidirectional valves sticking or soda lime dust formation which in addition may lead to channeling and less efficient CO_2 absorption .

Problems in practice and safety features

4-Compound A which is nephrotoxic ,is formed when Sevoflurane is used in conjunction with soda lime.

The factors that increase the production of compound A are:

A-high temperature.

B-high sevoflurane concentration.

C-use of Barylime rather soda lime.

D- low FGF.

E-newer designs of soda lime(low KOH and very low NaOH claim less or no compound A formation.

Problems in practice and safety features

5- carbon monoxide(CO) production when the CO_2 absorber is dry and left unused for an overnight or at weekends specially in smokers and with low flow leading to the formation of harmful carboxyhemoglobin .

O_2 flushes every hour will prevent this.

6-uneven filling of the canister with soda lime will lead to channeling of gases and decreased efficiency.

Problems in practice and safety features

7- the circle system is bulkier, heavier and more difficult to clean.

8- soda lime is corrosive, thus eyes/face and skin protection is necessary.

9-leaks or even disconnection are potentially risky because of numerous connection sites in circle system.