Anesthetic Equipments

Breathing circuits and scavenging system

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Introduction

- Terminology concerning anesthetic breathing circuits is very varied with no universal agreement; multiple and inconsistent definitions in North American and British literatures.
- Traditionally, the systems of terminology consist of 'closed' and 'open' themes with variations, using 'Rebreathing' as distinguishing factor, but are of little value now.
  - It is very difficult to exactly determine the degree of 'Rebreathing' by the use of such terms as 'semi-closed', 'semi-closed with absorption', 'open' etc.
  - Most workers agree that 'semi-closed' refers to 'partial rebreathing' techniques.
  - It will give the same label regardless of the degree of rebreathing; a system might have nearly complete rebreathing of the expired gases, while another may have almost no rebreathing. Clearly this nomenclature or system may allow erroneous interpretation regarding actual inspired concentration or tension of any inhalational anesthetic.
- Currently, the terminology describes the breathing systems as 'Non-rebreathing' or 'Rebreathing'.
- For majority of procedures regardless of variations of teaching, practice, and geographical location, provision of two simple pieces of information can be quite adequate for description of a breathing circuit.
  - First, the actual equipment used needs to be described (Bain etc.)
  - Second, the fresh gas flow should be stated.
  - Under certain and special circumstances, more detailed information may be provided, such as apparatus (mechanical) dead space volume, type of valves, type and location of the vaporizer (in or out of the breathing circuit) etc.
- Properties of the ideal breathing system
  - Simple and safe to use
  - Delivers the intended inspired gas mixture
  - Permits spontaneous, manual and controlled ventilation in all size groups
  - Efficient, requiring low fresh gas flow rate
  - Protects the patient from barotraumas
  - Sturdy, compact and lightweight in design
  - Permits easy removal of waste exhaled gases
  - Easy to maintain with minimal running cost
- Patient size and anesthetic breathing circuits
  - Two factors must be considered in proportion to the animal's size.
    - Apparatus (mechanical) dead space
    - Apparatus (mechanical) resistance

- Resistance is always high with turbulent flow, so narrow orifices, sharp bends, which produce this should be avoided in the apparatus.
- For the Laminar flow of a gas in a tube - the Hagen Poiseille law (see equation below) states that the pressure drop is proportional to changes in the tube length, diameter (to the power of 4), viscosity, resistance and flow rate; thus narrow tubes cause the greatest resistance, but resistance is also increased by long tube lengths and at high flow rates.

$$\text{Resistance} = \frac{Flowrate \times Length \times Vis\cos ity}{Radius^4}$$

- Modern volatile anesthetics are very potent and it is most important that the anesthetist does not come under their, acute or chronic, influence.
- The removal of waste anesthetic gases from the environment is now compulsory (Occupational Health and Safety Agency, OSHA, guideline), and installation of a scavenger with use of volatile anesthetics ensures compliance.
- Current legislation prescribes ‘maximal permissible’ concentrations of volatile anesthetic agents which are allowed to be present in the operating rooms.

Current terminology of the Anesthetic breathing circuits

Non-rebreathing circuits

- With these, the patient breathes in from the reservoir and out to atmosphere. The gases are not re-used.
- However, in practical sense, this terminology is incorrect because some rebreathing of exhaled gases occurs in most of these systems, especially with lower recommended flow rates.
- Satisfactory elimination of CO_2 is dependent on adequate gas flow, and on minimal dead space in the circuit.
- Examples: Bain, Ayre’s T piece, Magill, Lack

Rebreathing circuits

- Here the same gases are re-used, and CO_2 is removed by passage of the gas through soda lime.
- Examples: Circle, To and Fro, Universal-F.
- A circle rebreathing circuit is composed of:
  - Carbon dioxide absorbing canister
  - Y-piece
  - Inhalation and exhalation breathing tubes
  - Inhalation and exhalation unidirectional (one way) valves
  - Fresh gas inlet
  - Pressure manometer
  - pop-off valve
  - A reservoir bag

Old Terminology of the Anesthetic breathing circuits

- There are exceptions but basically all systems using non compressed gases (i.e. room air) classify as 'open' and all those using an oxygen cylinder classify as 'closed'.

Table 1. Traditional terminology of the anesthetic breathing circuits.

	RESERVOIR	REBREATHING	TYPES
1. Open. Draw over systems with non rebreathing valves.	No	No	Bag and bottle
2. Semi-open.	No	Partial (CO_2 build up)	Bag and bottle with occlusive packing
3. Semi-closed without absorption.	Yes	No	Bains, modified Jackon Rees, Ayres T piece. Lack, Magill
3. Semi-closed with absorption.	Yes	Partial	Carbon dioxide absorbers with leak (circle and to and fro)
4. Closed.	Yes	Complete	Carbon dioxide absorbers with no leaks

Open/semi-open circuits (e.g. Chloroform Mask)

- Advantages
  - Useful where complicated apparatus is not available. The patient airway remains open to room air and no tubing, valves or reservoir bag are used.
- Disadvantages
  - Difficult to obtain stable anesthesia due to unknown dilution by air.
  - Dilution depends on tidal volume and the resultant flow of gas through mask and around the sides of the mask.
  - No means of I.P.P.V.
  - Room air may not supply adequate O_2 if respiratory depression exists.
  - Agents vented to air; therefore fire and toxicity risks.

Semi-closed circuits (best considered as 'non-rebreathing' or 'rebreathing').

- Non-rebreathing (semi-closed without absorption)
  - Bain, Ayre's T-piece, Jackson Rees for animals below 6kg.
  - Mapleson classified these into A, B, C, D, E and F, but currently only A, D, E and F are commonly used during anesthesia. (see table 2 and figure 1)
- Rebreathing (semi-closed with absorption)
  - Circle (for animals weighing above 6 kg).

Mapleson non-rebreathing circuit systems

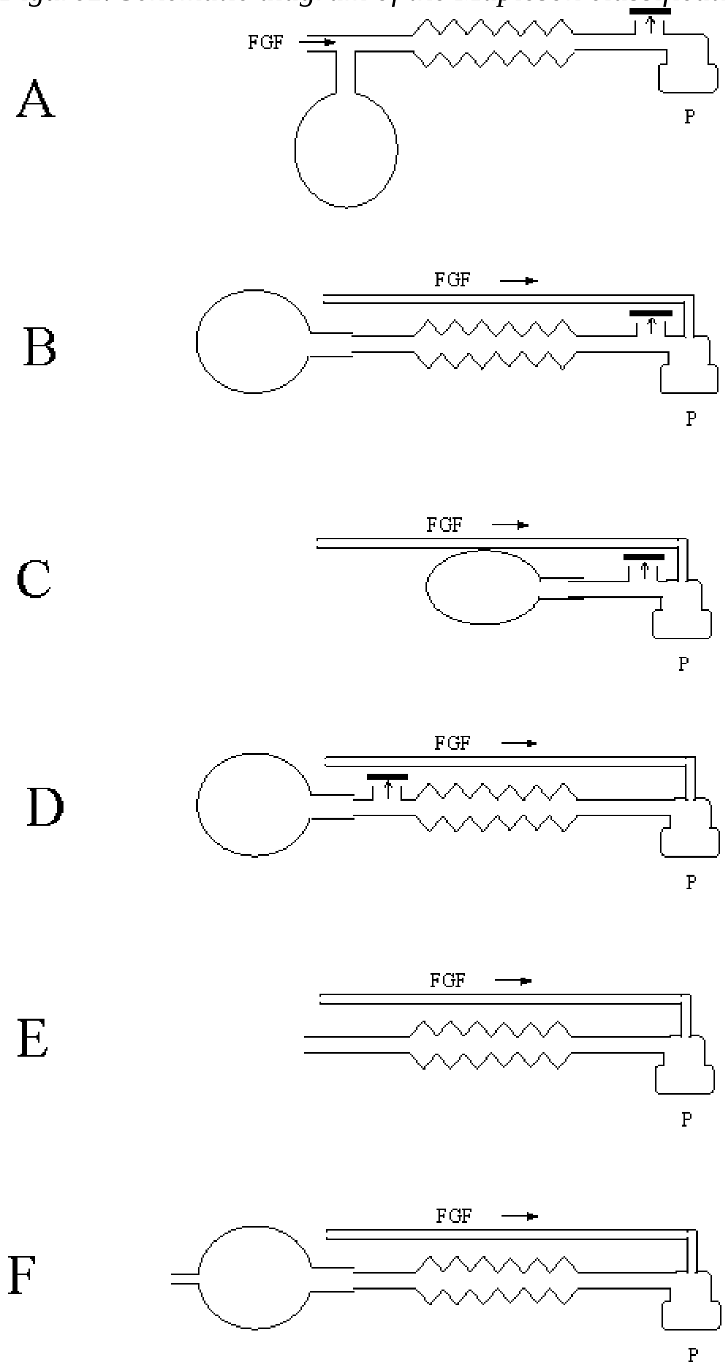
- Advantages
  - Simple, inexpensive, and rugged
  - Less resistance to breathing
  - Easy to disassemble and can be disinfected or sterilized in a variety of ways.
  - Light weight and not bulky. Less likely to cause excessive drag on the mask or tracheal tube, facial distortion or accidental extubation.
  - Reduces the time for inhalant induction for face mask induction than using a rebreathing circuit.
  - Once induced and intubated, patients larger than 6 kg can be converted to a rebreathing circuit for anesthesia maintenance.
  - Anesthesia particularly easy to keep stable as animal breathes exactly what is delivered from the machine. The fresh gas inlet in a non-rebreathing circuit is adjacent to the endotracheal tube connection, and therefore changes in vaporizer setting affect the inspired gas concentration immediately.
- Disadvantages:
  - More cold dry gases are delivered resulting in less well preserved moisture and heat within the breathing circuits, therefore danger of hypothermia.
  - More vapor use due to higher fresh gas flow requirement, so more expensive.
  - More pollution to atmosphere.
- Flow rates required.
  - Magill and Lack - 1- 1.5.X minute volume (~150 ml/kg/min)
  - Bain and T piece – 2.5 X minute volume (~250 ml/kg/min)
  - With the Magill circuit, I.P.P.V. leads to CO_2 retention.
  - I.P.P.V. can be carried out with the other circuits.
  - Ideally, a capnography is used so flow rates are adjusted as to just prevent the CO_2 rebreathing avoiding waste and expense.

Table 2. Classification of Mapleson breathing systems.

CLASS	LOCATION OF FRESH GAS INLET	VALVE LOCATION	RESERVOIR BAG	CORRUGATED TUBING	EXAMPLES AND COMMENT
A	Near the bag	Near the patient	Present	Present	Magill, Lack
B	Near to the patient	Near the patient	Present	Present	Obsolete
C	Near to the patient	Near the patient	Present	absent	Obsolete in anesthesia, still used for emergency resuscitation (Ambu-bag)
D	Near to the patient	Away from the patient	Present	Present	Bain
E	Near to the patient	Away from the patient	absent	Present	T-piece

F	Near to the patient	absent	Present	Present	Jackson Rees

Figure1. Schematic diagram of the Mapleson classification of circuits.



Rebreathing circuits

- These circuits will all contain sodalime for CO_2 absorption.
- If run on minimal gas flows with no leaks they are ‘closed circuits’.
- If run with an overflow leak of gas, they are ‘semi closed with absorption’
- Advantages

    - Economical
    - Gases warm and wet through rebreathing (disadvantage in hot weather)
- Disadvantages
    - May have high resistance due to soda lime, inhalation/exhalation valves, and pop-off valve.
    - Difficult to predict inspired anesthetic concentration because of volume buffer by breathing tubes, reservoir bag and varying degree of rebreathing.
    - Less control of anesthetic depth than non-rebreathing circuit
- Flow rates required
    - Low flow: 10 - 20 ml/kg/min of oxygen flow rate.
    - Medium flow: 20 - 40 ml/kg/min of oxygen flow rate (suitable for most clinical circumstances).
    - High flow: greater than 40 ml/kg/min of oxygen flow rate.
    - Using high flow will compensate the gas leakage better with better control of anesthetic depth than low flow, but will be less economical with more loss of heat and moisture of the patient, as well as polluting the environment more.
- Rebreathing circuits may either have the vaporizer on the anesthetic machine, therefore out of the circuit (VOC), or have the vaporizer within the rebreathing circuit (VIC).

Vaporizer out of Circuit (VOC) rebreathing circuits

- There are two methods of running VOC rebreathing circuits.
    - ‘Continuous’ and ‘intermittent’ flow
- *Continuous flow (Low flow anesthesia)*
    - This is ideal if one can replace exactly the mount of oxygen and anesthetic which is ‘used’ by the animal.
    - This is quite practical in the horse, where one will need a flow of about 2-3 liters/minute.
    - In small animals the flow required is so low that the vaporizers become inefficient, and it is often difficult to keep the animal asleep.
    - A compromise is to work with a flow of about 1 liter/minute, and to leave the expiratory valves open to allow overspill. This converts the circuit to semi-closed with absorption.
- *Intermittent flow*
    - Here, an intermittent high flow rate is used to fill the bag with oxygen and anesthetic mixture, and left off until either the bag is empty or the depth of anesthesia requires changing.
    - This system is very economical on gas, but has the disadvantage that the level of anesthetic administered is constantly being changed as dilution in the reservoir bag occurs.
    - The level of anesthesia thus oscillates and at times may be unnecessarily deep.
- There are two systems of soda lime absorption that are used for types of VOC rebreathing circuits.
    - the ‘circle system’ and the ‘to and fro system’, in which the canister may be horizontal or vertical.
- *To and fro*

- Advantages
  - Comparatively cheap , Mobile.
- Disadvantages
  - Absorption less efficient than in circle
  - Increasing dead-space as soda lime used up 'Layering', particularly when horizontal.
  - Hot dusty soda lime close to patient.
  - Weight of canister may kink endotracheal tube.

- *Circle*
  - Advantages
    - More efficient removal of carbon dioxide and use of soda lime.
  - Disadvantages:
    - Expensive to buy (now some cheap disposable circles available)
    - Can have high resistance due to length of tubing (but OK if tubes are wide)
    - Valves must be efficient, or rebreathing occurs

Circle rebreathing systems with vaporizer in circuit (VIC)

- Ohio No 8 machine, Goldman machine, Stevens machine and Kommesaroff machine.
- VIC systems are always "circle".
- In these, vaporization of the volatile agent depends on the flow through the vaporizer, which is 'pushed' through by the animal's own respiration. Thus, with every breath, more agent is vaporized.
- Advantages.
  - Very economical. O_2 requirement is that used by animal (5-10 mls/kg/min). Minimal volatile agent wasted and minimal pollution.
  - With all rebreathing circuits, retains heat and water.
- Disadvantages.
  - Cannot use N_2O in this circuit.
  - If oxygen flow is too high, difficult to get adequate concentrations of some volatile agents.
  - Cannot use safely for I.P.P.V. unless removing vaporizer.
  - Low efficiency and nonprecision
- These circuits are claimed by the manufacturers to be very safe because if animal becomes more deeply anesthetized, respiration is less, so uptake of volatile is reduced. However, this only happens at a depth of anesthesia at which (with isoflurane and sevoflurane) there is severe hypotension, and, as with any anesthetic system, it is, perfectly possible to accidentally kill patients when using these machines. The machines were originally designed to be used with ether or methoxyflurane, both of which are very much safer in this system.
- As these machines work on minimal intake of O_2 into the circuit, nitrogen will accumulate, reducing the concentration of O_2. Thus, before use the machine it is primed with 100% O_2; after about 5 minutes of anesthesia the bag is emptied, and re-primed with 100% O_2. Nitrous oxide must not be used.
- If these machines are used properly, with good monitoring, and if the animal is too deep the vaporizer setting is reduced, they can be excellent and economical for small animal anesthesia. However, if used as sometimes advertised; ie giving maximal

anesthetic agent and counting on respiratory depression to limit uptake, then with isoflurane and sevoflurane anesthesia, such depths of anesthesia will be excessive, and accompanied by severe hypotension, with subsequent morbidity.

Components of the circle system

CO_2 absorbent (Sodalime, baralyme)

- These are used to absorb the CO_2 in rebreathing circuits.
- Sodalime consists of 90% calcium hydroxide, 5% sodium hydroxide, plus 5% silicate and water to prevent powdering.
- Indicators are added to show when it is fully used (but **do not trust** them; they can get leached out by water vapor, and most change color a little too late, and also reverts to its original color when not in use).
- The absorption of CO_2 by these is exothermic (ie, the soda lime gets hot) - you can use this action to test your soda lime - if in doubt blow on some and see if its gets hot.
- The reaction of CO_2 with sodalime

$$CO_2 + H_2O \rightarrow H_2CO_3$$
$$H_2CO_3 + 2\ NaOH \rightarrow Na_2CO_3 + 2H_2O$$
$$H_2CO_3 + 2KOH \rightarrow K_2CO_3 + 2H_2O$$
$$Na_2CO_3\ (\text{or } K_2CO_3) + Ca(OH)_2 \rightarrow 2NaOH\ (\text{or } 2KOH) + CaCO_3$$

- Soft and crushable granules are converted to hard and non-crushable granules (calcium hydroxide changes to calcium carbonate - limestone) which indicates exhausted sodalime.
- Increased inspired fractional concentrations of CO_2 detected by the capnography indicates exhausted sodalime.

Y-piece

- Constructed of plastic and unites the endotracheal tube connector and the inspiratory and expiratory breathing tubes
- Contribute to the mechanical dead space, but not significantly greater than that in a non-rebreathing system
- 15 mm I.D. female port to accpept the ET tube connector

Breathing tubes

- Large bore, non-rigid breathing and usually corrugated (conducting) tubes, typically made of rubber or plastic
- Corrugations increase flexibility and resistance to kinking
- Clear plastic tubes are more lightweight, absorb less halogenated agents, have a lower compliance than rubber tubes and allow visualization of the interior of the tube.
- Act as a reservoir in certain systems.
- Provide a flexible, low resistance, light-weight connection from one part of the system to another.
- have some distensibility but not enough to prevent excessive pressures from developing

One-way (unidirectional) valves

- They direct gas flow away from the patient on expiration and toward the patient on inspiration
- Prevents the rebreathing of exhaled gases before they pass through the absorbent canister
- Gases enter a unidirectional valve from below, raise the disc, and pass under the dome to the reservoir bag, the absorbent canister or the inspiratory breathing tube
- Valve incompetence contributes to accumulation of CO_2 within the breathing circuits

Fresh gas inlet

- The location at which gases from the common gas outlet of the anesthesia machine or from the outlet of the vaporizer enter the circle system
- Placed on the absorbent canister near the inspiratory one way valve or on the inspiratory one way valve
- Entry of fresh gases on the inspiratory side of the circle
  - minimizes dilution of the gases with exhaled gases with a VOC
  - prevents absorbent dust inhalation
  - reduces loss of fresh gases through the pop-off valve

Adjustable pressure limiting valve (Pop-off valve)

- A valve which 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.
- Also called as; Pop-off valve, Exhaust valve, Scavenger valve, Relief valve, Expiratory valve, Over-spill valve etc.
- It is a one way, adjustable, spring-loaded valve.
- The spring adjusts the pressure required to open the valve.
- The patient may be exposed to excessive positive pressure if the valve is closed for prolonged period (always pay great attention to the valve closure). Some designs have a safety mechanism, allowing the relief valve open when a pressure within the breathing circuit reaches about 60 cmH_2O.

Pressure manometer

- A pressure gauge that is attached within the breathing circuits
- It is calibrated in cmH_2O, but may have a scale of mmHg or KPa (1 KPa = 7.5 mmHg)
- Typically, a pressure build-up over 20 cmH_2O for small animals and 30 for large animals is considered unsafe.

Rebreathing (Reservoir) bag

- The rebreathing (reservoir) bag is an important component of most breathing systems.
- It is made of antistatic rubber or plastic.
- Volumes of 0.5, 1, 2, 3 and 5 liters are commonly used for small animals, and 15, 20 and 30 liters are used for large animals. The typical size for a 20 kg dog is 2 liter bag, and 500 ml for small dogs and cats.

- It accommodates fresh gas flow during expiration acting as a reservoir available for use of the following inspiration.
- It acts as a monitor of the patient's ventilatory pattern, but is inaccurate for assessing the tidal volume.
- It can be used to assist or control the ventilation.
- Because of its compliance the rebreathing bag can accommodate rises in pressure in the breathing system better than other parts. When grossly over-inflated the reservoir bag can limit the pressure in the breathing system to about 40 cmH_2O. This is due to the 'law of Laplace' dictating that the pressure (P) will fall as the bag's radius (r) increases, $\text{Pressure} = \frac{tension}{radius}$
- A small bag may not be large enough to provide a sufficient reservoir for a large tidal volume.
- Too large a bag makes it difficult to act as a respiratory monitor.

Scavenging

- For halogenated hydrocarbon anesthetic agents (isoflurane, halothane, sevofurane and desflurane), 2 ppm is the allowed concentration, and 25 ppm for nitrous oxide. When the halogenated hydrocarbon anesthetic agent is used with nitrous oxide the maximum permissible concentration is reduced to 0.5 ppm.
- All 'anesthetic facilities' (including recovery rooms) must be tested for levels of escaped gases. Testing is done on an occasional basis (at the moment most vets intend to test once a year), the anesthetist wearing a 'badge' for a prescribed time which is then sent away for analysis.
- There are many scavenging devices suitable for veterinary purposes but care must be taken to ensure that their use does not have an adverse effect on the patient.
- The following reference "Commentary and recommendations on control of waste anesthetic gases in the workplace (JAVMA, 209(1), pp75-77)" describes more in detail the precautions and measures necessary to minimize the waste gas exposure.

Methods of scavenging

Passive scavenging.

- Tubes from the expiratory valve of the patient circuit lead to outside.
- Advantage
    - Cheap to install.
- Disadvantage.
    - Ineffective.
    - High expiratory resistance.
    - Can obstruct expiration.
    - Not acceptable now.

Passive with adsorption

- The tube from the expiratory valve now goes to a canister of activated carbon.
- Advantage.

- Effective adsorption of halogenated hydrocarbon anesthetics.
- Simple and portable; fills the gap when the machine is on move with the patient connected.

- Disadvantage
  - High resistance.
  - Needs frequent changing (weighed to detect when capacity full).
  - Will not adsorb N_2O

Active scavenging

- A central vacuum draws the gases away from the expiratory valve. The suction flow must be at least 30 L/min.
- Advantages.
  - Very effective. (now really the only acceptable method).
  - Minimal resistance to breathing (although need a method of also drawing in room air or else it would suck so hard that animal could not breath in!)
- Disadvantage
  - Fairly expensive to install (a reasonable system is around $3000).

Active scavenging with adsorption

- The best method of all!

Further References:

1. Veterinary Anesthesia Hall, Clarke and Trim. WB Saunders 2001
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4. Understanding Anesthesia Equipments, Dorsh and Dorsh Williams & Wilkins 1999