REVIEW ARTICLE

Anaesthetic Circuits–Review Study

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Introduction

The modern anaesthesia machine is usually equipped with calibrated retamoter and accurate vapourisers in order to supply known volume and concentration of Oxygen and inhalational anaesthetic agents. This concentration of agents may be attended or modified by type of circuit they are passed through, from the machine to the patient. Any rise in carbon dioxide (CO_2) level in the circuit results in fall of inspired oxygen concentration.

So the anaesthetic circuits should be and have been made to maintain correct concentration of different anaesthetic agents used and oxygen. But many times it is found that valves and conducting rubber tubings are arranged to anaesthetist's convenience rather than functional reasons. Whatever may be the cause of such arrangements, breathing (anaesthetic) circuits have been classified by many authors in their own way as according to Dorsch and Dorsch "A favourite past time among anaesthesiologists has been classification of breathing system and the result has been hopelessly confused terminology".

Classifications and their descriptions

Most of the anaesthesiologists in their classification of breathing anaesthetic circuits have used the terms **open, semiopen, semiclosed** and **closed** and yet the same terms have been defined very differently by different anaesthetists.

But then all of circuits are prepared, giving economy of anaesthetic gas and minimum rebreathing the highest priority.

Here how I would like to present some existing classifications of breathing circuits by different authors (anaesthesiologists)

A) Dripps, Vandam & Echnehoff in their classification of anaesthetic circuits have categorised them in five different types depending on presence or absence of

1. Reservoir bag in the breathing circuit
2. Rebreathing of exhaled gas
3. Carbon dioxide absorber
4. Directional valve in the circuits.

According to these authors, following are the types of anaesthetic circuits

1. **Insufflation** In this system oxygen and anaesthetic gases are supplied directly to patient's mouth This system has no reservoir bag or absorber.
2. **Open** - In this type circuit oxygen and anaesthetic gases are supplied by an anaesthetic machine (including intermittent type) with non-rebreathing valve (which direct the exhaled gas to atmosphere). Reservoir bag may or may not be present and has no CO_2 absorber.
3. **Semiopen** In this system exhaled gas partially escapes to atmosphere and partially enters into the inspiratory tube which may be re breathed. There is no CO_2 absorber rebreathing depends on flow of fresh gas. Reservoir bag and valve may or may not be present e. g open drop, Magill Ayre's 'T' piece.
4. **Semiclosed** - In this system CO_2 absorber is used. Reservoir bag and valve are present. Exhaled gas is partly lost into atmosphere and partly mixes up with fresh gas
5. **Closed** Here a CO_2 absorber is used. Exhaled gas is fully rebreathed reservoir bag and valves are used, e. g. To-&-fro circle.

The whole thing can be charted as follows

Types of Circuit	Reservoir Bag	Rebreathing	CO_2 absorber	Directional valve
1. Insufflation	No	Least	No	No
2. Open Demand	No	Minimal	No	Two
Non-rebreathing	Yes	Minimal	No	Two
3. Semiopen				
Opendrop	No	Partial	No	More
T piece	No	Partial	No	More
Magill	Yes	Partial	Yes	Two
4. Semiclosed	Yes	Partial	Yes	Two
5. Closed				
To & fro	Yes	Complete	Yes	None
Circle	Yes	Complete	Yes	Two

B) After Dripps and Vandam's we can take a look at J. Moyer's "Classification of circuits" which has divided it into four varieties depending on presence or absence of reservoir bag and rebreathing. Following chart shows Moyer's classification.

Circuits	Reservoir	Rebreathing
Open	No	No
Semi-open	Yes	No
Semi-closed	Yes	Yes, partial
Closed	Yes	Yes, complete

C) V. J. Collins, in his classification has shown four types of classification. In his classification he defined

1. **Open circuit**- As circuit where anasthetic vapour is given to patient with the help of atmospheric air. The respiratory passage has access to atmosphere during inspiration and expiration. There is no reservoir bag and no rebreathing as wall.
2. **Semiopen**- In this, patient's respiratory system is open to atmosphere both during inspiration and expiration. The reservoir is also open to atmosphere and technically there is no rebreathing. Anaesthetic gas or vapour is carried by atmospheric air.
3. **Semiclosed**- As a circuit in which patient's respiratory tract is closed to atmosphere during inspiration but open to atmosphere during expiration. Reservoir bag is present and it does not communicate with atmosphere.
4. **Closed**- In this system there is no escape of anaesthetic vopours or gases to atmosphere. Respiratory tract is not open to atmosphere either on inspiration or on expiration. Reservoir bag is present and there is full rebreathing.

Collin's classification is shown in brief in following chart.

Circuits	Reser-voir	Rebrea-thing	Insp-iration	Expira tion
Open	No	No	Yes	Yes
Semiopen	Yes	No	Yes	Yes
Semiclosed	Yes	No	No	Yes
Closed	Yes	Yes full	No	No

D) Adriane has similarly divided breathing circuits into -

Open Vapourisation
Insufflation
Semiclosed — Rebreathing / Non-rebreathing

E) Hall, in Wright's veterinary anaesthesia has described the anaesthetic circuits as shown in following chart.

Circuits	Reservoir Bag	Rebreathing
Open	No	No
Semi Open	No	Partial
Semi-Closed		
a. Without CO_2 absorber	Yes	Partial
b. With CO_2 *absorber*	Yes	Partial
Closed	Yes	Complete

F) Mc Mohan in 1951 in Journal of American Assoc. Nurse Anaesthetist classified anaesthetic circuits as

Circuits	No rebreathing
Open	No rebreathing
Semiclosed	Partial rebreathing
Closed	*Total rebreathing*

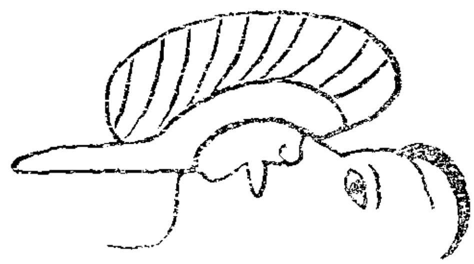
G) C. M. Conway's classification-

Conway also used the terms open, semiopen, semiclosed and closed in his classification of circuits. This classification is accepted most widely by anaesthesiologists for purpose of description and teaching till date.

Conways classification allows rigid definition under any given condition though behaviour of many circuits can be altered by small change in circuit arrangement or fresh gas flow His circuits are -

1. **Open**- Open circuit has been described as a circuit with infinite boundaries with no restriction or control over fresh gas supply. So there is no control over concentration of inspired anaesthetic gas or vapour. There is no rebreathing and inspired gas contains the administered anaesthetic vapour and atmospheric air. So the inspired concentration of anaesthetics is not amenable to simple mathematical analysis. Examples of this being - a) when volatile liquids are administered in an open drop fashion on a mask held inches away from patient's face or b) anaesthetic gases being delivered from mask or tube which are held quite away from patient's face.

Open



Semi-open

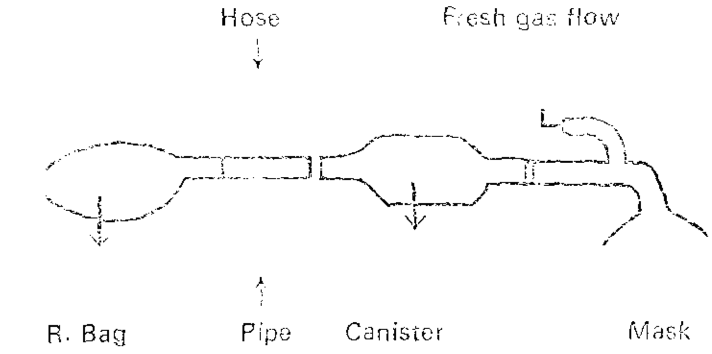
2. **Semi-open** This is partially bounded circuit with some restriction or control over fresh gas supply. The simplest example of this circuit being gauge covered Schimmelbusch mask closely applied to patient's face (amount of rebreathing in this circuit depends on thickness of material used on mask). As air is the vapourising gas in this circuit, high concentration of Ether (this is commonest agent used) may be achieved under mask and a reduction of inspired Oxygen may also occur. The hypoxia which may thus be produced can be reduced by administration of a stream of oxygen through a nasal catheter passed beneath the mask. This besides enriching inspired oxygen will also mask and reduce rebreathing.
3. **Closed** - This is a fully bounded circuit without any provision of gas overflow. There is complete rebreathing in this type of circuit. Though this circuit had been in use since middle of nineteenth century but its safe, controlled and regular use become possible only after introduction of CO_2 absorber (i. e.- in 1915 by Jackson & in 1923 by Waters).

There are two basic types of closed circuits with CO_2 absorber in it.

i. To & fro system

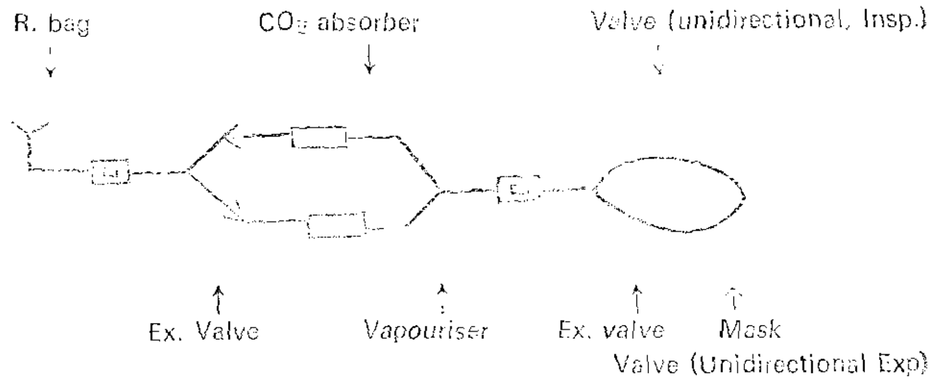
ii. Circle system

To & fro system of Conway's closed circuit was introduced by Waters & there is no unidirectional valve in this. The patient breaths to &-fro from a reservoir bag & through a circuit containing CO_2 absorber. Fresh gas is supplied near patient's mouth. The reservoir bag is kept away from absorber by using a small hose pipe but the absorber has to be nearer to patient.



To & fro system (From Sc. of foundation of Anaesthesia 1974)

The circle system was first introdued by Sword (1926). In this circle the direction of gas flow is controlled by two unidirectional valves, so that the expired gas passes through absorber to reservoir bag and then to the patient. There are various arrangements of circle system depending on site of fresh gas flow, unidirectional valve, expiratory valves, reservoir bag and CO_2 absorber, this arrangement is of more importance when this circuit may have to be used as semiclosed one, but in fully closed circuit with basal fresh gas flow it is not very significant.



Circle system (from Scientific Foundation of Anaesthesia- 1974)

Another important factor in closed circuit is position of vapourisers used. The main reasons for use of this circuit were economy of fresh gas, conservation of water vapour and limitation of fire hazard are out of which economy of fresh gas being the most important one.

The basic principle of closed circuit of anaesthesia is that at equilibrium (between) there is no net exchange of anaesthetic agent between the patient and ambient atmosphere. Thus after reaching a state of equillibrium anaesthesia can theoretically be maintained for indefinite period by simply providing a supply of oxygen to meet patient's basal requirement and efficient absorption of carbon dioxide. Under this condition no additional anaesthetic agent has to be added to fresh gas supply.

But in practice even with the most insoluble anaes thetic vapour i) it takes few hours to reach a state of equillibrium between inspired and alveolar concentration ii) even after attainment of equillibrium alveolar concentration can be attended with the change of respiratory patterns and with small change in proportion of gases which may be added to the circuit iii) the uptake or excretion of any component of mixture of gases from the circuit will alter the whole thing again.

Thus though the fully closed circuit is supposed to require. Only basal oxygen flow, it is not possible to maintain, but yet this circuit needs very low gas flow and minimal volatile anaesthetic agents, hence this circuit is believed to be the most economical one.

For these reasons circle system and to & fro system are commonly used as semiclosed system rather than fully closed one and in this semiclosed system it requires fresh gas flow more than basal and minimum amount of anaesthetic agent or agents

4. **Semiclosed**- M. Conway's semiclosed circuit is of three types.

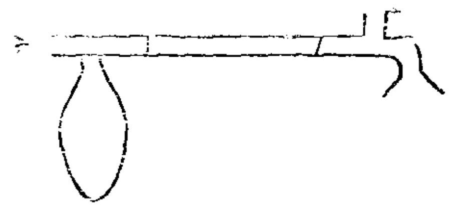
   i) Re-breathing
   ii) Semiclosed with CO_2 absorber
   iii) Non rebreathing

i) Semiclosed rebreathing is divided by Mapelson as A, B, C, D, E etc. This has been very widely accepted.

The Magills (or Mapelson's A) -

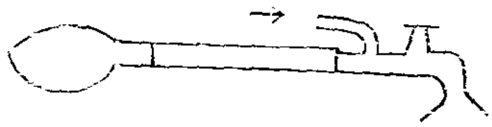
During spontaneous ventilation rebreathing in this can be prevented by relatively smaller amount of fresh gas. According to Mapelson amount of fresh gas equal to that of alveolar ventilation should be enough to prevent rebreathing however in practice he advised a fresh gas flow equal to the minute volume of patient, but again Kain & Nun (1968) show that 71% total minute volume is enough to prevent rebreathing.

Fresh Gas Flow



Mapelson- A
Sp. Vent - 1 X MV
Asst. T - 2-2.5 X MV

Fresh Gas Flow



Mapelson- B
Sp. V -- X MV
Asst. V -- X MV

During controlled ventilation the Mepelson A show a different pattern. In order to ventiilate a patient, expiratory valve opening pressure has to be increased and the venting of gas occurs during inspiration, during expiration alveolar gas is retained in the tubes and this alveolar gas is the first component of gas delivered to patient during inspiration, when the pressure during manual or mechanical ventilation is raised high enough to open the valve a mixture of expired (Dead space + alveolar gases) and fresh gas goes out. So there is marked- rebreathing. And this can be reduced only by increasing Tidal volume or by increasing fresh gas flow nearly 2 25 times the normal minute volume.

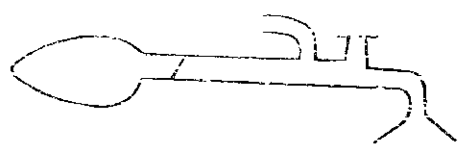
In circuit B, C, D fresh gas is supplied close to the patient's mouth which looks quite beneficial but are not as good as Mapelson A when the patient is on spontaneous ventilation.

In 'B' there is a closed limb unflushed by fresh, the tube can also be or act as a part reservoir. During expiration fresh and expired gas flow into reservoir and a mixture of fresh gas and alveolar gas goes out when the valve is opened. During inspiration the patient receives fresh gas from machine and mixture of fresh gas + alveolar gas from reservoir bag. To prevent this rebreathing fresh gas flow greater than twice the minute volume is required.

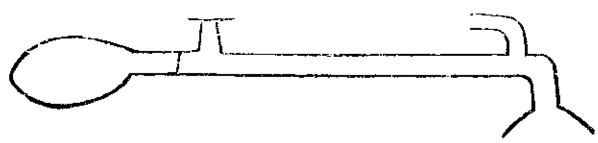
In 'C' the tube length is reduced to Zero thus the volume of reservoir is reduced and the fresh gas mixed throughly with expired gas. So when rebreathing occurs CO_2 build up is at slower rate than in B.

In 'D' both the fresh gas and expired gas flow back along the tubing in the bag then out through the valve during expiration. During inspiration the patient therefore receives fresh gas from the machine and alveolar and fresh mixed gas from tubing. This rebreathing can be prevented by administering fresh gas twice the minute volume of patient.

During controlled ventilation B & C behaves in same way as in spontaneous. Rebreathing is slightly reduced as fresh gas accumulates near patient-end during expiratory pause. But this less marked due to absence of rubber tubing in 'C'.



Mepelson - C
Sp. V -- 2-3 MV
Asst. V - 2-3 X MV



Mapelson - D
Sp. V - 1-5-2 MV
Asst. V - 70ml -100ml/kg
minute vol.

In D during controlled ventilation all the fresh gas input is supplied to patient there is much less rebreathing than in B & C. Fresh gas flow requirement is also very low, i. e. 70-100 ml/kg is said to enough t maintain a PCO_2 between 40 & 36.

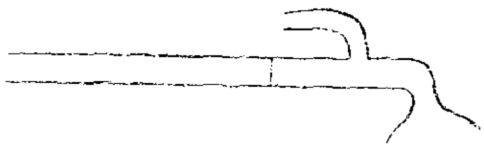
In order of merit the circuit are but as shown below durin spontaneous and assisted ventilation.

Spontaneous vent.	*Assisted vent.*
A	D
D	B
C	C
B	A

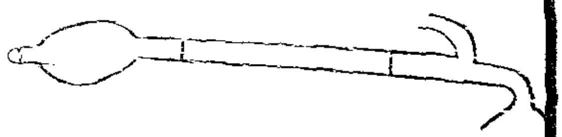
In Mapelson's E circuit, he used a valveless *Ayres (Phillips Ayr* in 1973) 'T' piece. During expiration fresh gas and expired gas from patien flow down to expiratory limb. During expiratory pause fresh gas accumulates a *patient's end of 'T' piece. During inspiration gas is drawn from fresh ga* supply and also from expiratory limb.

Now if fresh gas flow is more than peak inspiratory flow rate the *only all included gas will* be fresh gas. So according to *Mapelson fresh ga* flow of three times the minute volume is required to inhibit gas from expirator limb to be rebreathed but in practice 2-25 times is usually sufficient to preven *rebreathing.*

Controlled ventilation in circuit is produced by intermitten occulsion of expiratory limb. As there is no reservoir bag and minute volum should be related to fresh gas flow and inspiratory expiratory ratio.



Mapelson- E



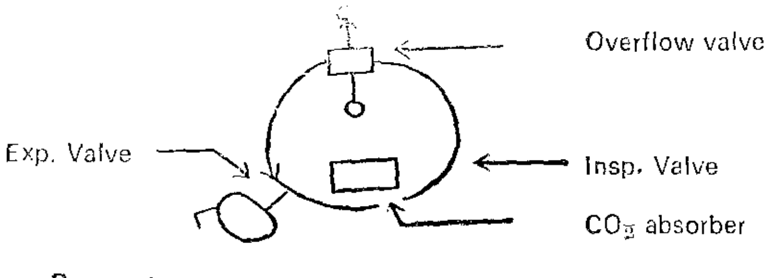
Jackson-Ree's Modification of M-E

Modification of Mapelson's E has been done by Jackson-Ree by adding a open tailed *reservoir bag to expiratory limb. The function* reamains unaltered provided the length of tube is more than tidal volume patient. This is sometimes called Mapelson F.

ii) *Semiclosed circuit with CO_2 absorber-*

Increasing fresh gas flow to a closed circuit above basal level and letting out the alveolar air from it converts a closed circuit into semiclosed circuit with absorber.

In this circuit for inspired atmosphere to be similar to fresh gas flow, it is preferrable that all the alveolar air be vented out from the circuit under these condition use of sodalime will be minimal. This occurs if the overflow valve is kept, close to patient and fresh, gas entry should be between inspiratory unidirectional valve and absorber, and reservoir bag between absorber and expiratory unidirectional valve.



(From Sc. Foundation of Anaesthesia 1974)

iii) Semiclosed non-rebreathing- These circuits contain some form of non-rebreathing valves close to patient. These valves can be used in any of Mapelson ABC circuits by replacing the expiratory valve.

In ideal condition a non-rebreathing circuit will have full control over the inspired gas when it is equal to minute volume.

During spontaneous ventilation with non-rebreathing circuit serious dysfunction can occur even if there is small discrepency between fresh gas flow and patients minute volume. If FGF is inadequate there will be depletion of inspiratory reservoir which may finally prevent inspiration similarly excess of FGF will raise pressure in inspiratory reservoir causing the unidirectional valve to gain in inspiratory position of prevent expiration.

So one has to be very careful in using these non-rebreathing or unidirectional valve. If they have to be used at all slight excss of FGF should be given with one overflow valve in inspiratory limb which will vent out excess gas and prevent the rise of pressure inspiratruory reseruoir.

Besides all these circuits there are a) Bain's circuit-which is a modification of Mapelson D where fresh gas tubing runs inside the expiratory limb. These two tubes are made of two different colour, usually the outer one is white PVC and the inner one is blue. This to recognise any damage in the inner tube.

Functionally its similar to Mapelson D circuit, dysfunction can occur only if inner tube is broken or damaged This was invented by Bain and Spoerel (1972). This light handy and lengthy enough to keep anaesthetist away from operating field and make the operating field less clumsy as there is no seperate fresh gas tube.

Another is Lake's which is similar to Mapelson 'A' where expiratory tube is inside and inspiratory tube is outside. There is difficulty in assisted ventilation of patients with this circuit. Functionally its similar to Mapelson A.

These two are also known as "Co axial circuits".

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