Anaesthetic Circuits

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Key Words:
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An anaesthetic circuit or system can be defined as that part of anaesthetic apparatus which is used to connect the patient to the anaesthetic machine deployed to deliver predetermined volumes and concentration of oxygen, anaesthetic gases and volatile agents. This can easily be achieved by using a length of tubing, supplying the anaesthetic mixture from the machine to the patient. But it is highly desirable to have a proper circuit or system between the patient and the anaesthetic machine due to the following reasons:

(a) The patient is to be provided with a desired, balanced and congenial breathing atmosphere. Some anaesthetic circuits may tend to modify the concentration of gases and vapours which are actually delivered to the patient.
(b) The re-breathing of exhaled anaesthetic mixture requires to be prevented or minimised. Accumulation of CO_2 due to re-breathing also reduces the inspired concentration of O_2 and anaesthetic mixture in use.
(c) The mixing of inspired gases with room air as well as the pollution of theatre atmosphere from expired gases has to be prevented.
(d) The resistance to expiration needs to be minimised.

An anaesthetic circuit should, therefore, achieve the functional objectives as stated above and have the following characteristics:

(i) Simple:— should not complicate the overall function of an anaesthetic machine.
(ii) Light weight:— because a heavy circuit will cause dragging on the endotracheal tube or mask.
(iii) Versatile:— which can be used for all age groups as well as with spontaneous, controlled or assisted breathing.

Furthermore, this circuit should be easily sterilized. A large number of circuits or systems have been designed but, considering all the functional objectives one has in mind, none can be described as perfect. For descriptive purposes, however, Conway (1970) [1] has classified anaesthetic circuits into the following four groups:—

1. Open circuits.
2. Semi-open circuits.
3. Closed circuits.
4. Semi-closed circuits.

His classification allows a rigid definition of any system under any condition of use. The purpose of this article is to describe these circuits and to discuss new developments which have taken place since then.

1. Open Circuits

These circuits are those which have indefinite boundaries and no restriction upon the entry of anaesthetic mixture, e.g. open drop method. They offer little control over inspired concentration of gases. Anaesthetic mixture usually mixes with atmospheric air and for this reason, open circuits are nowadays rarely used. No re-breathing occurs in this system.

2. Semi-open Circuits

This type of circuit is partially bounded with some restrictions on fresh gas entry, e.g. gauze-covered Schimmelbusch mask. Depending on its volume, the mask applied to the face increases the patient's dead-space, causing re-breathing, the degree of which is dependent on the mask volume and the thickness of material around it. A reduction in inspired oxygen concentration usually occurs in this system. Supplying a stream of oxygen beneath the mask reduces the

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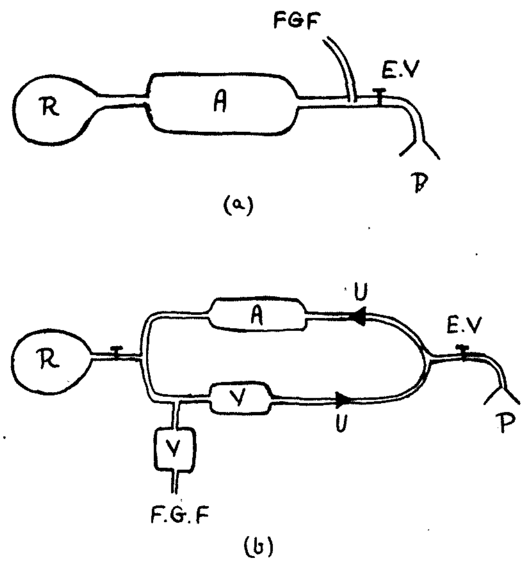

Fig. 1
CLOSED CIRCUITS
(a) To and Fro system.
(b) Circle system.
A = Absorber
E.V. = Expiratory valve.
I.V. = Inspiratory valve.
FGF = Fresh gas flow.
P = Patient end (mask).
R = Reservoir bag.
U = Unidirectional valve.
V = Vaporiser.

danger of hypoxaemia, flushes the mask and reduces re-breathing.

3. Closed Circuits

These are fully bounded circuits with no provision for any gas overflow. In this sort of apparatus total or partial re-breathing is intended because a facility for CO_2 absorption exist within the system. However, fresh gas flow (FGF) is necessary to allow for O_2 utilization and a certain degree of leakage which is unavoidable. They have two basic types:—

(*a*) *Water's To and Fro system*

The patient breathes to and fro from a re-breathing bag and through a carbon-dioxide absorber. Fresh gas is introduced into the circuit near the patient's mouth. There are no uni-directional valves, (Fig. 1).

(*b*) *Sword's Circle system*

The direction of gas flow is controlled by two uni-directional valves. Expired gas is allowed to pass into the CO_2 absorber through an uni-directional valve and then to a re-breathing bag, the reservoir. The bag also receives fresh gas flow which is directed to the patient through another uni-directional valve. Numerous variations of this arrangement can be made and are available depending on the site of fresh gas entry, relative positions of valves, reservoir bag and CO_2 absorber. However, the position of any vaporiser used and its efficiency is of greater importance than arrangements of components in closed circuits.

The principal reasons for the introduction and early popularity of both these closed-circuit systems were their economy in the use of gases and anaesthetic vapours, the conservation of heat and water vapour, less risk of explosion and minimum pollution of theatre atmosphere. Nevertheless, both systems suffer considerable disadvantages. The to and fro system, although simple and less cumbersome, has more inherited deficiencies than the circle system. Prediction regarding the concentration of gases within the circuit is impossible due to varying degree of anaesthetic uptake, efficiency of CO_2 absorption, and the difficulty in estimating basal O_2 requirements. Resistance to breathing is greater in to and fro system. Apart from this it has a relatively large dead-space. There exists also the danger of inhalation of irritant alkaline dust.

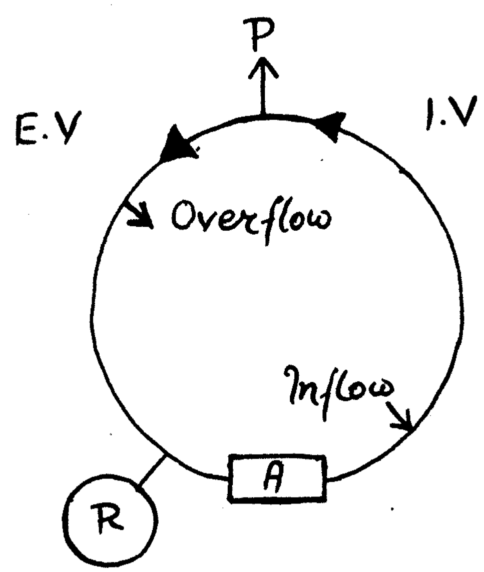

Fig. 2
SEMI-CLOSED ABSORPTION CIRCUIT
Overflow and unidirectional valves are placed close to the patient.

4. Semi-closed Circuits

These are fully bounded circuits having provision for venting of excess gas. They are the result of development carried out over the years on the previously stated systems. They can be described as absorption, re-breathing or non-rebreathing circuits.

(*a*) *Absorption Circuits*

A closed absorption circuit can be converted into a semi-closed system by increasing fresh gas flow (FGF) above the basal level. Thus, the inspired gas mixture is controlled at the expense of fresh gas supply. Besides wastage the efficiency of the system is dependent on the relative position of various components, e.g. inspiratory, expiratory and overflow valves, Eger & Ethans (1968)[2], have demonstrated that, if overflow and the uni-directional valves are placed close to the patient (Fig. 2), the efficiency is at optimum during spontaneous as well as under controlled ventilation. However, the system suffers from various disadvantages. It is cumbersome and exerts high resistance to expiration.

(b) *Re-breathing Circuits*

Mapleson (1954)[3] has classified these circuits into five groups (A, B, C, D and E). The diagram (Fig. 3) adopted from Mapleson illustrates the differences between them.

(i) *The Mapleson A or Magill Attachment*

This attachment has been extensively studied and is the most commong anaesthetic circuit in use. During spontaneous breathing, re-breathing of alveolar gases will not occur unless FGF is reduced to the alveolar ventilation level. To prevent re-breathing FGF must be at least 70% of respiratory minute volume. The efficiency of the system depends on the flushing effect of FGF to expel expired gases. If FGF level falls below alveolar ventilation, the degree of CO_2 retention will be an inverse function of FGF, and

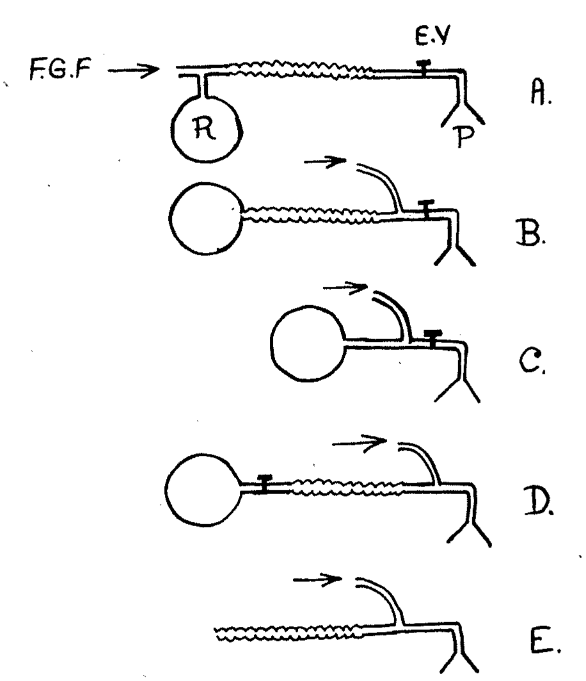

Fig. 3
SEMI-CLOSED RE-BREATHING CIRCUITS
Mapleson classification.

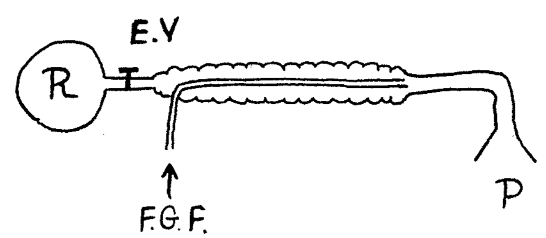

Fig. 4
BAIN CIRCUIT
Mapleson type D modification.

therefore, hyperventilation by the patient will not affect alveolar gas composition.

During controlled or assisted ventilation, considerable degree of re-breathing may occur. This can be reduced by venting out a greater amount of alveolar gas from the circuit by deploying higher FGF, reducing respiratory rate, or by increasing tidal volume. The placement of the expiratory valve close to the patient head in this system is its main disadvantage. The valve adjustments and venting of gas can be difficult especially during head or neck surgery.

In circuits B, C and D, fresh gas is introduced close to the patient. This arrangement appears to be advantageous but Sykes (1968)[4] has demonstrated that during spontaneous breathing all systems behave less efficiently than circuit A. With controlled or assisted ventilation most of the fresh gas input is delivered to the patient during inspiration particularly in system D, therefore system D causes less re-breathing than circuits B and C.

(ii) *Mapleson E or T-piece circuit*

This is the only valveless system without a reservoir bag described by Ayre in 1937. In this system during expiration dead-space gas passes down the open end of the tube first and the alveolar gas last. The concentration of fresh gas towards the patient end of the tube increases as expiration progresses. If FGF is greater than the peak inspiratory flow rate (at least 2.5–3 times the minute volume) all the inspiration will consist of fresh gas.

Controlled ventilation can be maintained by intermittent occulsion of the expiratory limb, a principle used in many paediatric ventilators. The main advantage of this system is the absence of resistance to expiration, an important advantage in the case of small children. Many modifications of the T-piece circuit are available, e.g. Jackson-Rees (with an addition of open ended reservoir to expiratory limb) and Rendell-Baker paediatric system.

(iii) Bain circuit (Mapleson D modification)

This system is a modification of Mapleson D type circuit introduced by Bain and Spoerel (1972)[5]. It comprises a 1.8 metre length of light weight conductive corrugated plastic tubing 22 mm in diameter. Through this runs a smaller bore tube of 7 mm diameter. Fresh gas is introduced through the inner narrow tube. Reservoir bag and expiratory valve are placed at the anaesthetic machine end of the circuit (FIG 4).

For spontaneous breathing a FGF of 1.5-2.0 times the minute volume is necessary to prevent re-breathing. During controlled ventilation FGF of 70 mls/kg body weight/minute into the system would produce normocarbia when venting with a tidal volume of 10 mls/kg body weight and a frequency of 12-14 per minute, as demonstrated by Henville & Adams (1976)[6].

This system is useful when access to the patient is difficult e.g. head and neck surgery. It also facilitates the scavenging of the expired gases. Hazards, however, can occur if the inner tube becomes dislodged or broken resulting in a considerable increase in the patient' s dead-peace.

(iv) Lack circuit (Mapleson A Modification).

This is a coaxial modification of the Magill system introduced by Lack (1976)[7]. The main objects were to overcome the disadvantage of accessibility and to prevent theatre pollution. FGF is directed through an outer corrugated tube and exhaled gases are collected and discharged through an inner expiratory limb. The reservoir bag and the expiratory valve are placed at the end of corrugated tubing (fig. 5).

The prototype was evaluated by Barnes et. al. (1976)[8]. The resistance of the system was found to be unacceptably high with marked evidence of re-breathing when FGF equalled minute volume. It was estimated that FGF of $1^1/_2$ times the minute volume would be required to prevent re-breathing of alveolar gas. Subsequent improvements on the production model by increasing the capacity of inspiratory limb to 500 mls and a 50% reduction of expiratory resistance need to be further evaluated in long term usage.

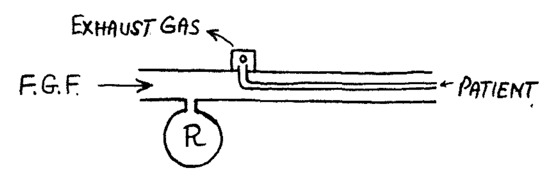

Fig. 5
LACK CIRCUIT
Mapleson type A modification.

(c) Non-rebreathing Circuits.

In this system a non-rebreathing valve is placed to the patient, most conveniently as a modification to Mapleson A,B or C circuits, where it replaces the expiratory valve. Sykes (1959)[9] has described many different designs of such valves. Under ideal conditions (FGF is equal to minute ventilation), the system will allow full control over the inspired atmosphere. In practice, however, reproducibility is difficult to attain under all conditions of ventilation. A small discrepancy between FGF and patient minute volume can cause serious disfunction of the circuit.

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