

G P Review Article**'Closed Circuit' Anaesthesia**

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SUMMARY

The advantages of using rebreathing circuits in anaesthesia are discussed and the principles for their correct employment are outlined. Practical methods are described. By using closed circuit equipment in the manner described, the initial cost of the apparatus could be recouped within one year, because of the saving in the consumption of expensive imported anaesthetics.

S. Afr. Med. J., 48, 701 (1974).

An inhalation anaesthetic is like a concerto—conducted in three movements, if one ignores the surgical cadenzas. The three movements of the well-conducted anaesthetic are:

The induction, during which the patient is introduced to and thereafter loaded with an anaesthetic drug to produce a general tissue concentration sufficient for anaesthesia. The brain, with its rich blood supply, leads the tissues in uptake and is therefore first affected. Most other tissues have a poorer circulation and thus lag behind the brain in uptake. But until the other tissues also achieve a similar concentration, the brain can lose anaesthetic by redistribution to these organs via the bloodstream, and the later phases of anaesthesia will then be unstable. This first phase takes about 15 minutes and cannot easily be shortened.

Maintenance is usually the main part of the anaesthetic, and what is required here is that a certain concentration of anaesthetic be maintained in the gases breathed, to keep the body content and thus anaesthetic depth constant and stable. Very little anaesthetic is actually absorbed in this phase. It is during this period that vast quantities of anaesthetic are discharged unused into the theatre air when non-rebreathing anaesthetic systems are used. It is during this period that the advantages of rebreathing equipment appear.

Finally, there follows the **recovery period** when anaesthetic inhalation is discontinued, wherein anaesthetic is lost from the body, and normal function returns.

METHODS OF ADMINISTRATION

Using the standard pattern of anaesthetic machine, with its constant-flow flowmeters and accurate vaporisers, there

are two ways of administering an inhalation anaesthetic, depending on the type of breathing circuit used.

With a non-rebreathing method, as typified by the classic Magill's system, the anaesthetic gases make one passage through the lung alveoli before being discharged. It is therefore an essential requirement of the Magill system that the fresh gas flow must be at least equal to the patient's alveolar minute volume of ventilation, if only to ensure adequate carbon dioxide elimination. (Oxygen uptake is less dependent on the fresh gas flow rate because oxygen concentrations can be manipulated.)

The alternative to this is a rebreathing method. Such apparatus makes use of soda-lime to remove carbon dioxide from expired gases, and must be connected to a source of oxygen and other gases or vapours with which to make good what is absorbed by the patient. If one can balance exactly the fresh gas inflow against what is absorbed, then the apparatus becomes a closed-circuit system. In practice this is very difficult to achieve with accurate control of the concentrations of the constituents. It is therefore usual practice to use in a rebreathing system a fresh gas flow that is several times greater than the amount absorbed. Gases are then continuously leaked through an expiratory valve and the system becomes a semi-closed circuit system.

The advantage claimed for the non-breathing system is mainly the certainty one has about the composition of the mixture being breathed.

ADVANTAGES OF THE REBREATHING SYSTEM

When one compares a non-rebreathing system with equipment using soda-lime for carbon dioxide absorption and thus permitting rebreathing of expired gas, it becomes clear that rebreathing techniques, properly conducted, offer a number of advantages:

1. Reduced wastage of expensive anaesthetic drugs.
2. A reduced explosion hazard where explosive agents are used.
3. Water vapour from the patient's breath provides a reasonable level of humidity in the inspired gas, instead of the completely dry medical gases provided by non-rebreathing techniques. Inhalation over several hours of such arid gases can set the scene for postoperative chest complications by their drying effect on mucous membranes of the trachea and bronchi.
4. Increased efficiency of controlled ventilation, with considerable economy in the use of gas.

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Date received: 7 November 1973.

5. Reduced health hazard to operating room personnel. Enough evidence has accumulated on the dangers of long periods of exposure to traces of anaesthetic gases and vapours to justify legislation in at least one country requiring active scavenging of gases escaping from the anaesthetic machine.

FUNCTION OF REBREATHING SYSTEM

Before using rebreathing equipment there are certain basic concepts that have to be mastered. But firstly let it be clearly stated that the circle absorber system, with unidirectional flow of gas through soda-lime, is a far more efficient rebreathing system, albeit more costly initially, than the to-and-fro system of the Waters' canister, and what will be said hereafter applies more closely to the former.

A rebreathing system can always be used as a non-rebreathing system when the fresh gas inflow equals or exceeds the patient's minute volume of ventilation. One is then certain of the contents of the inspired mixture and can work from or come back to this fixed point.

However, as soon as the fresh gas inflow falls below the minute volume of ventilation, the patient will start re-using his expired gas of uncertain composition. The contents of the inspired mixture will then differ from the fresh gas mixture. How great this difference is will depend upon the disparity between the minute volume breathed (or more correctly, the quantity of oxygen and anaesthetic absorbed), and the fresh gas supplied. Of one fact there can be no doubt: since oxygen and anaesthetic are always absorbed throughout any anaesthetic, the concentrations in the expired gas must be below those in the fresh gas inflow line.

The functions of a rebreathing anaesthetic circuit are thus:

- (i) to collect the expired gas that has picked up carbon dioxide and water vapour, and given up anaesthetic drug and oxygen;
- (ii) to remove the carbon dioxide with soda-lime;
- (iii) to make good the deficiencies of oxygen and anaesthetic through appropriate additions of fresh gases.

Two main problems may arise when a 'closed circuit' or rebreathing apparatus is used:

- (i) one can lose track of the percentage content of gases in the system, with either overdosage, or awakening, or hypoxia;
- (ii) carbon dioxide absorption may be ineffective because of faulty valves or exhausted soda-lime. From this may result carbon dioxide narcosis, cardiac arrhythmias with certain drugs, and dilution of the anaesthetic agents.

Trichlorethylene is naturally never used with rebreathing systems, because of the toxic products that may slowly form in the soda-lime.

To understand how these problems may be solved, one should look at the quantities of anaesthetics that can be absorbed during the different phases of an anaesthetic. At

the start of an anaesthetic, nitrous oxide can be absorbed at a rate of up to 1 litre per minute, which will thereafter decline at an uncertain rate over the next 10 - 15 minutes. It takes about 20 minutes to reach body saturation with nitrous oxide, and then uptake is low and usually constant for a long period of time at about 100 - 200 ml/min. This slow uptake is continuous because there is slow absorption by fat, and also a variable amount of loss of the gas through the surgical wound. With inhalation drugs such as halothane or ether the situation differs because saturation with these drugs is slower than with nitrous oxide, as they are more fat-soluble. But one can force their uptake using high concentrations for short periods and achieve the necessary degree of body saturation within the time required for nitrous oxide. (Nitrous oxide uptake cannot be forced.)

From this, one point emerges clearly, namely that during the phase of induction, when the body's uptake is high, anaesthetics must be administered in large total quantities to keep pace with this uptake. However, when the phase of rapid uptake is passed one may safely reduce the total flow of anaesthetics into the rebreathing circuit and be reasonably sure that the rates of uptake will be low and not differ greatly between different patients.

Another aspect, sometimes overlooked, is what becomes of the nitrogen that was in the patient's lungs. This is normally completely washed out in a little over 2 minutes with a non-rebreathing system. The volume of this nitrogen is around 2 litres and if it is retained in a rebreathing system, whose volume is often little more than 2 litres, there will obviously be a considerable dilution of the anaesthetic agents. Nitrogen will be retained for long periods in rebreathing systems unless a high flow of fresh gas is used to sweep it out during the induction of the anaesthetic. If this is not done the retained nitrogen must dilute the anaesthetic and results must be unpredictable.

PRINCIPLES FOR CORRECT USE

The principles for the correct use of the rebreathing system are thus:

1. Use high flows during the first 15 minutes of every anaesthetic to ensure rapid saturation and to wash out nitrogen. These flows should be at least 3 - 4 times the expected maximum absorption rates for oxygen and nitrous oxide. This first phase cannot be speeded up without sacrificing reliability and safety.

2. Only after the 15 minutes' saturation period, when absorption is low and stabilised, can one reasonably turn to low gas flows. If one keeps these flows at several times the then-predictable absorption rates of the two gases, results will be predictable and safety high.

3. If for any reason the seal between the patient and the rebreathing system is broken and nitrogen from room air gains access, it must be washed out again with high flows for at least 5 minutes.

4. When in doubt use the system in the non-rebreathing manner at fresh gas flows of around 8 litres per minute.

PRACTICAL TECHNIQUES

Anyone may devise his own technique provided three facts are considered:

1. During the induction a flow rate of 4 litres per minute should be the minimum for adequate nitrogen washout and to cover the expected uptake rates. With flow rates of more than 8 litres per minute no extra advantage is usually achieved.

2. To calculate what fresh gas flows should be during the maintenance phase, one must first supply the basic mixture at the flow selected, and then add to this what the patient is likely to absorb to keep the concentrations constant. For instance, if one assumes the average figures of about 200 ml/min uptake for both oxygen and nitrous oxide, then with a basal flow of 1 litre/min, consisting of 750 ml/min nitrous oxide and 250 ml/min of oxygen to give a 25% oxygen concentration, the final flows after adding what will be absorbed will be: nitrous oxide 950 ml/min and oxygen 450 ml/min = 32% (to give 75% nitrous oxide!). With a basic flow of 2 litres/min this will give: nitrous oxide 1 700 ml/min and oxygen 700 ml/min = 29%. With a basic flow of 0.5 litres/min this will give: nitrous oxide 575 ml/min and oxygen 325 ml/min = 36% (Note how the required oxygen percentage changes with low flow rates.)

The same principle applies to anaesthetic vapours that are inhaled along with the gas mixture. To the basic anaesthetic concentration must be added the amount absorbed. This is done by raising the inspired concentration.

If one accepts the inaccuracies of present flowmeters at low flows, and the need always to supply 3-4 times what will be absorbed, then one should probably not go below flow rates of 1 litre/min for nitrous oxide and 500 ml/min for oxygen.

3. When using a vaporiser it is customary to place it in the fresh gas flow line and not directly in the breathing circuit. If the vaporiser is in the fresh gas line, then the vapour concentration breathed must always be lower than that delivered by the vaporiser (see above). But if it is in the breathing circuit itself, dangerously high concentrations may build up with low fresh gas flows.

Our own nitrous oxide and halothane technique, which we have used successfully and safely for at least 10 years, is based on the 'Rule of the three 15s': Start with a nitrous oxide and oxygen flow of at least 4 litres/min (3 + 1) for 15 minutes, and a halothane concentration starting at 2% which is adjusted downwards appropriately. After 15 minutes, change flow rate to 1.5 litres/min (oxygen 0.5 litre/min, nitrous oxide 1 litre/min). Set Fluotec Mk II at 1.5%. (At this setting this model Fluotec yields about 1% halothane with the gas flow at 1.5 litres/min, which is further diluted in the breathing circuit to about 0.6-0.7%.)

Anaesthesia is then stable for hours, but one should note that by controlling the patient's ventilation one may raise the output from this model vaporiser.

With the Fluotec Mk III, Abingdon, Forreger, and Dräger Vapor vaporisers, which are all more accurate at low flows, the halothane setting should be at 1% and this will not be changed with controlled ventilation.

If one works at high altitudes it may be necessary to adjust the halothane concentration upwards slightly in view of the reduced potency of nitrous oxide, but the technique is nevertheless effective.

It is possible to use halothane or another vapour in a rebreathing system with oxygen only. Here there is no problem with the concentration of nitrous oxide, and the fresh gas inflow can be further lowered.

One technique described is, after an appropriate induction period with halothane and oxygen at higher flow rates (4 litres/min), to set the oxygen flow at 500 ml/min, with the Fluotec Mk II setting at 3%. According to the Fluotec calibration curve the vaporiser will yield a concentration in excess of 4% at this flow and this setting, but after dilution in the breathing circuit the halothane concentration is about 1%. This is a very good illustration of the considerable difference that can exist between the concentration of a vapour in the fresh gas inflow line and in the gases within a rebreathing circuit. Using such a technique (which approaches a completely closed circuit), it is possible to maintain anaesthesia with a consumption of halothane of between 7 and 10 ml/hour, which is a very economical method, especially when compared with the use of halothane in non-rebreathing systems which may consume up to 100 ml/hour. (With the price of this drug about 10c per ml, the saving is obvious.)

Should one wish to use nitrous oxide and oxygen only (the Liverpool technique), then it is preferable to double the flow rates of nitrous oxide and oxygen to a starting figure of 8 litres/min (6/2) and a maintenance of 3 litres/min (2/1). At high altitudes the reduced potency of nitrous oxide can be made good with 0.2% methoxyflurane or 0.5% halothane.

At the end of all anaesthetics with nitrous oxide it is necessary to use pure oxygen for short periods of time to avoid the hypoxia that develops with the rapid excretion of nitrous oxide.

NOTES ON EQUIPMENT

Soda-Lime

This is normally supplied as white granules containing an indicator dye that turns purple with exhaustion. Soda-lime must contain approximately 15-20% water to be effective. If allowed to dry out it will not absorb carbon dioxide. One should thus buy it in small, well-sealed containers. From tests in our laboratories it would appear that when about half of the canister of soda-lime has turned a light mauve colour, some carbon dioxide will start to break through the absorber. When using a single canister machine, this is the time to change the canister.

If allowed to stand, the colour change in the soda-lime will revert to white. The indicator may then become highly unreliable and not return to a purple colour before about 3-4% carbon dioxide is breaking through. One should thus always change soda-lime at the end of an anaesthetic session and not leave it for the next day, when exhausted soda-lime may be overlooked.

Circle Absorbers

There are a number of designs on the market, among which a wide variation in quality exists. There are certain important points to look for:

1. Make sure that any expiratory valve is far removed from the fresh gas inflow line. If it is not, then your patient may never receive the fresh gas intended for his consumption. The best place for the valve is next to the canister on the expiratory side.

2. The method of sealing the soda-lime canister is critical to the use of low gas flows, since even a small leakage means considerable loss of anaesthetic and possible entry of nitrogen. One should suspect machines that depend on screw-threads exposed to soda-lime dust for sealing, since these pack with dust, often corrode, and then jam. Without doubt the best design would appear to be either a large flat gasket sealing on a flat surface or tapered connexions which slip-fit one into the other, but which are made of brass, which is less susceptible to the alkaline corrosion of soda-lime.

3. The valves should not stick when moist. With sticking, backflow of gas occurs which can lead to loss of fresh gas, and carbon dioxide accumulation.

4. The soda-lime canister size is important. A basic concept is that there should be room enough to accommodate the patient's breath in the intergranule space of the soda-lime, which means a minimum weight of 500 g of soda-lime. There is, however, a definite economy in using a double canister containing 1-2 kg of soda-lime. With such canisters one allows half of the soda-lime to become

completely saturated before discarding it and replacing it with the second half. The first container is then refilled with fresh soda-lime and placed in the second canister position.

Vaporisers

Only accurately calibrated vaporisers should be used with rebreathing techniques, and it is widely accepted that they must be in the fresh gas inflow line. In fact, it will be found that the internal resistance of many modern vaporisers is too high to allow their use in a breathing circuit (unless 'draw-over' units are specified). But the condensation of exhaled water vapour in a circle system makes the performance of any vaporiser thus used unpredictable. Delivery of accurate or at least predictable concentrations at low flows is the prime requirement; temperature compensation is less important because the rate of vaporisation with its cooling effect is low. One should again emphasise that such vaporisers may need to deliver at low flow concentrations of vapour far in excess of normal safe maintenance levels, because of the dilution that takes place in the breathing circuit. (For example, if a patient has the capacity to absorb X mg of halothane vapour per minute, this amount might be supplied as a 0.5% concentration at a high flow or as a 5.0% concentration at a very low flow of gas.)

Cotton wicks used in some halothane vaporisers are very susceptible to 'poisoning' by water or the thymol stabiliser in Fluothane. They should be regularly replaced for accurate performance.
