

Low Flow Anaesthesia

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In a time of increased concern over spiralling costs and the environmental impact of chlorofluorocarbons, there is a great impetus to use cost saving and cleaner techniques of general anaesthesia. TIVA provides an environment friendly alternative but very expensive in terms of drugs and equipment costs. The other is recycling the anaesthetic gases and inhalational agents using low flows and closed circuit which addresses the two aforementioned issues.

Closed circuit anaesthesia with carbon dioxide absorption was used as early as 1850 by John Snow (1). Because of the high costs and limited availability of anaesthetic agents, early investigators frequently used closed circuit techniques. Brian Sword first described the circle breathing system and delivery of closed circuit anaesthesia in 1930 (2). Lack of efficient vaporizers along with poor understanding of the pharmacokinetics of the newly developed halothane led to the resurgence of high flow techniques.

Low flow, partial rebreathing anaesthetic techniques were first described by Foldes and colleagues (3) in 1952 which involved fresh gas flows of 1 l/min or less. He used high fresh gas flows for induction and the first 10 min of the case, then reduced flows of oxygen and nitrous oxide to 0.5 l/min for the duration of the case.

Virtue, in 1974, reduced gas flows even further in his *minimal flow anaesthesia technique*: After a similar high flow period for induction and the first 15 min of the anaesthetic he reduced the fresh gas flows to 0.2 l/min of nitrous oxide and 0.3 l/min of oxygen for a total flow of 0.5 l/min (4).

Definitions: Low-flow anesthesia has been variously defined as an inhalation technique in which a circle system with absorbent is used with a fresh gas inflow of

Less than the patient's alveolar minute volume,

less than 4 L/minute (5),

3 L/minute or less (6)

0.5 to 2 L/minute (7)

less than 1 or 1.5 L/minute (8), or

0.5 to 1 L/minute (9), or,

500 mL/minute (10).

Closed circuit anesthesia represents the furthest extreme of low- flow anaesthesia in which the fresh gas flow equals uptake of anesthetic gases and oxygen by the patient and system and gas sampling. No gas is vented through the APL valve.

Principles of Low flow anaesthesia:

A gas flow in excess of the minute volume will provide readily predictable inspired gas concentrations, which will be more or less the same for any patient, using any breathing system, at any stage of the anaesthetic and will be unaffected by agent uptake by the patient. However, as the carrier gas flow is reduced and more exhaled gas is retained within the breathing system (increased rebreathing fraction), gas uptake by the patient will increasingly affect the exhaled and hence the inspired gas mixture. Once the flow rate is reduced to near the patient's requirements, the fresh gas mixture will closely reflect the uptake of each of its components by the patient. The increasing deviation of the inspired gas mixture from that set at the rotameters means that these techniques are critically dependent on gas monitoring. This shift towards a quantitative concept of gas delivery is the fundamental defining feature of low-flow techniques.(11)

Flow technique nomenclature (EU)

High Flow	> 1000 mL / min
Low Flow	1000 mL / min
Minimal Flow	500 mL / min
Metabolic (closed)	250 mL/min "by the book"
Metabolic (closed)	140 - 180 mL/min typical
Uptake (titration)	140 – 180 mL/min typical

In each of these systems, the extent of rebreathing varies with the fresh gas flow (FGF) from over 85% rebreathing when fresh gas flow is 1.0 L/min to nearly 100% for closed circuit flows. Since rebreathed gas contains lower concentrations for the volatile anaesthetics and mixes with the FGF, the inspired concentration is lower than that delivered by the vaporizer. In higher flow systems, the vaporizer concentration setting approximates the inspired concentration. However in low-flow systems where rebreathing is extensive, higher in-line vaporizer settings are usually necessary to maintain a desired inspiratory concentration.(12). This effect becomes more pronounced as the FGF is reduced as seen in Table 1:

Equipment needed to conduct Low flow anesthesia:

A standard anesthesia machine with specific flow meters can be used. The key features for gas delivery are flow meters calibrated to flows down to 50 ml min^{-1} and a leak-free circle system. The use of minimal flow anaesthesia is difficult or impossible if the anaesthetic machine has an obligatory oxygen flow of 200 ml min^{-1} , since techniques using near basal oxygen requirement will probably require lesser amounts to be delivered.

Many new anesthesia machines have been developed in Europe within the past few years. One of these is the Physioflex machine (**13, 14**). Being designed exclusively for closed circuit use, it eliminates many limitations found in most other anaesthesia machine designs when implementing closed circuit techniques. This machine uses a recirculated circle breathing system that adjusts the volume of circuit based on the ventilatory requirements of the patient. The circuit has been integrated with respiratory monitors for automatic feedback control of gas concentrations. Potent anesthetics are introduced through direct injection by a pump also under closed loop feedback control. Anesthetic levels can be reduced quickly by a charcoal filter that is switched in out of the circuit as needed.

Vaporizers

Anesthetic agent can be added to the circle in two ways.

Calibrated Vaporizers

Vaporizers capable of delivering high concentrations and that are accurate at low fresh gas flows are required.

Liquid Injection

Anesthetic liquid can be injected directly into the expiratory limb (**15,16,17**). Care must be taken that only small amounts are injected at a time and that the syringe containing the liquid agent is not confused with those containing agents for intravenous injection. Liquid agent may cause deterioration of components in the system (**18**).

In-circle Vaporizer

In-system vaporizers have been used successfully with both spontaneous and controlled ventilation (**19, 20**).

Monitors

Continuous measurement of oxygen concentration should be mandatory. It is helpful to monitor other gases and vapors. With side stream monitors, the fresh gas flow must be increased to compensate for gases removed by the monitor (at rates of $50 - 250 \text{ ml / min}$) unless the gases are returned to the breathing system (**21**).

Techniques

Induction

Anesthetic induction by using low fresh gas flows can be accomplished by injecting measured amounts of liquid anesthetic directly into the expiratory limb of the circuit. Problems associated with this include the following: (a) large body stores of nitrogen will be released into the breathing system and will dilute concentrations of other gases; (b) if nitrous oxide is being used, it will take a prolonged period of time to establish concentrations high enough to have a clinical effect; and (c) rapid uptake of nitrous oxide and volatile agent as well as high oxygen consumption during this period mean that the anesthesia provider will have to make frequent injections and adjustments at a time when he or she is likely to be busy with other tasks.

More commonly, induction is accomplished by using high flows to allow denitrogenation, establish anesthetic agent concentrations, and provide oxygen well in excess of consumption.

During intubation, the vaporizer should be left ON and the fresh gas flow turned to minimum or OFF (22, 23). After gas exchange has stabilized, lower fresh gas flows are used.

Maintenance

During maintenance, nitrous oxide and oxygen flows and vaporizer settings should be adjusted to maintain a satisfactory oxygen concentration and the desired level of anesthesia. If closed system anesthesia is used, a constant circuit volume is achieved by one of the following methods.

Constant Reservoir Bag Size

If the bag decreases in size, the fresh gas flow rate is increased; if the bag increases in size, the flow is decreased.

Ventilator with Ascending (Upright or Standing) Bellows

Constant volume can be achieved by adjusting the fresh gas flow so that the bellows is below the top of its housing at the end of exhalation. It is important that no negative pressure be transmitted to the bellows from the scavenging system, as this could cause the bellows to be held aloft in the presence of inadequate fresh gas flow (24).

Ventilator with Descending (Inverted or Hanging) Bellows

The fresh gas flow should be adjusted so that the bellows just reaches the bottom of its housing at the end of exhalation.

If a rapid change in any component of the inspired mixture is desired, the fresh gas flow should be increased. If, for any reason, the integrity of the circle is broken, high flows with desired inspired concentrations should be used for several minutes before returning to low flows. If closed system anesthesia is used, it is recommended that high flows be used for 1 to 2 minutes at least once an hour to eliminate gases such as nitrogen and carbon monoxide that have accumulated in the system.

Emergence

Recovery from anesthesia will be slower if low flows are used. High flows are usually needed at least briefly to clear nitrous oxide. Coasting, in which anesthetic administration is stopped toward the end of the operation and the circuit is maintained closed with enough oxygen flow to maintain a constant end-tidal volume of the ventilator or reservoir bag, can be used. A

charcoal filter placed in the inspiratory or expiratory limb will cause a rapid decrease in volatile agent concentration (25).

Advantages

Economy

Significant savings can be achieved with lower flows of nitrous oxide and oxygen, but the greatest savings occurs with the potent volatile agents (26,27,28). These are partly offset by increased absorbent usage, but this cost is small.

Reduced Operating Room Pollution

With lower flows, there will be less anesthetic agent put into the operating room. However, the use of low-flow techniques does not eliminate the need for scavenging, because high flows are still necessary at times. Since less volatile agent is used, vaporizers have to be filled less frequently so that exposure to anesthetic vapors during filling is decreased.

Reduced Environmental Pollution

Fluorocarbons and nitrous oxide attack the earth's ozone layer, and nitrous oxide contributes to the greenhouse effect (29,30). With low flows, these ecological dangers are reduced.

Estimation of Anesthetic Agent Uptake and Oxygen Consumption

In a closed system without significant leaks, the fresh gas flow is matched by the patient's uptake of oxygen and anesthetic agents (31,32). Changes in volume may be attributed principally to uptake of oxygen or nitrous oxide because the volume contributed by the potent inhalational agents is usually not significant.

Buffered Changes in Inspired Concentrations

The lower the fresh gas flow, the longer it takes for a change in concentration in the fresh gas flow to cause a comparable change in the inspired concentration.

Heat and Humidity Conservation

With lower gas flows, inspired humidity will be increased, and the rate of fall in body temperature reduced (33,34,35). The incidence of shivering is lowered.

Less Danger of Barotrauma

High pressures in the breathing system take longer to develop with lower flows.

Disadvantages

More Attention Required

With closed system anesthesia, fresh gas flow into the system must be kept in balance with uptake. This requires frequent adjustments.

Inability to Quickly Alter Inspired Concentrations

The use of low fresh gas flows prevents the rapid changes in fresh gas concentration in the breathing system that occurs with high gas flows. As a result, it may be more difficult to control acute hemodynamic responses (36). This is a significant disadvantage only if the user

insists on using low flows at all times. The clinician who uses low flows should accept that when it is necessary to change inspired concentrations rapidly, higher flows should be used.

Danger of Hypercarbia

Hypercarbia resulting from exhausted absorbent, incompetent unidirectional valves, or the absorber being left in the bypass position will be greater when low flows are used.

Accumulation of Undesirable Gases in the System

The accumulation of undesirable gases is most likely only a problem with closed-circuit anesthesia, because low flows provide a continuous system flush. With closed system anesthesia, flushing with high fresh gas flows once an hour will decrease the concentration of most of these substances. Alternately, a diverting gas monitor with the sample gas scavenged instead of being returned to the circle system can be used to remove small amounts of gas .

Carbon Monoxide

Carbon monoxide from the interaction of desiccated absorbent and anesthetic agent was discussed earlier in this chapter. Since low-flow anesthesia tends to preserve the moisture content of the absorbent, it may protect against the production of carbon monoxide resulting from desiccated absorbent (37). However, if desiccated absorbent is present, low flows tend to increase the amount of carbon monoxide present in the system. Carbon monoxide produced from the breakdown of hemoglobin or exhaled by smokers can accumulate in the closed circle system (38,39).

Acetone, Methane, Hydrogen, and Ethanol

Acetone, methane, and hydrogen accumulate during closed system anesthesia (40,41,42). However, dangerous levels are reached only after hours of closed system anesthesia (263). Methane can disturb infrared analysers. The common intoxicant ethanol can also accumulate.

Compound A

It is accepted that prolonged sevoflurane anaesthesia with low fresh gas flows results in proteinuria, glycosuria, and enzymuria. However, this is not, and has not been shown to be, associated with any clinical manifestations, even when such a technique is applied to patients with pre-existing biochemical renal abnormalities. Furthermore, it occurs if isoflurane is used in place of sevoflurane and seems also to be independent of carrier gas flow rate. (43,44)

Much of the laboratory work on renal toxicity was undertaken on rats, where compound A causes acute tubular necrosis at concentrations in excess of 250 ppm. It is now clear that these studies were invalid due to the marked differences between human and rat renal biochemistry. The generally held view is that compound A has a considerable margin of safety in humans at the concentrations typically found during low-flow sevoflurane anaesthesia (around 15 ppm).

The FDA recommended that sevoflurane not be used with fresh gas flows of less than 2 L/minute. This recommendation has been revised in 1997 to suggest that flow rates of 1 L/minute are acceptable but should not exceed 2 minimum alveolar concentration (MAC)-hours. Some investigators feel that Compound A should not be a real clinical concern and that restricting the use of low fresh gas flows with sevoflurane cannot be justified .

Argon

If oxygen is supplied from an oxygen concentrator, there will be an accumulation of argon with low fresh gas flows (45).

Nitrogen

Even with initial denitrogenation, nitrogen will accumulate in the closed breathing circuit (199). If oxygen is being supplied by an oxygen concentrator, malfunction of one of the concentrators can cause nitrogen to appear in the product gas (45). Infrared monitors add air to the sample gas after the sample is analyzed. If the gas exhausted is returned to the breathing system, nitrogen accumulation will be greater than expected.

Other

An acrylic monomer is exhaled when joint prostheses are surgically cemented (46). During this period, the system should be vented to prevent rebreathing of this chemical.

Uncertainty about Inspired Concentrations

One of the effects of rebreathing is that the inspired concentrations cannot be accurately predicted. However, absolute or near-absolute knowledge of inspired anesthetic agent concentrations is not necessary for safe anesthesia conduct, because patients' responses to drugs vary widely.

Faster Absorbent Exhaustion

The lower the fresh gas flow, the faster the absorbent is exhausted.

Circle System for Pediatric Anesthesia

It was once believed that small patients required special breathing circuits and ventilators. However, studies show that adult circle systems can be used even in small infants and with low fresh gas flows (47,48,49,50)

It is important not to add devices with large dead space or resistance between the Y-piece and the patient. Use of an HME/filter in this location causes the dead space to be unacceptably high for the spontaneous breathing infant (51).

One problem with the circle system is its large gas volume. The compression of that gas makes it difficult to determine the actual minute ventilation that the patient is receiving, unless measurements are done at the Y-piece (52). In the past, special pediatric circle systems with small absorbers were used. These are no longer commercially available. What is referred to as a pediatric circle system today is usually a standard absorber assembly with short, small-diameter breathing tubes and a small bag. This allows a rapid and easy changeover from an adult to a pediatric system and allows use of equipment with which most anesthesia providers are familiar.

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Table 1: Effects of FGF rates on rebreathing, circuit concentration and VOC dial settings

Category	High flow 5L/Min	Inter Mediate 2.5 l/min	Low flow 1 l/min	Minimal Flow 0.5 l/min	Closed circuit 0.3 – 0.5 l/min
Percentage rebreathing	0%	52%	86%	97%	100%
Circuit concentration with vaporizer set to 1% (at 1 h)	1%	0.94%	0.68%	0.54%	N ₂ O 0.52% No N ₂ O 0.39%
Vaporizer setting for in inspired concentration of 1% (at 1 h)	1%	1.1%	1.4%	2.0%	N ₂ O 2.4% No N ₂ O 3.2%

For an average 70kg patient with a minute ventilation of 4.8 l/min

N₂O : Nitrous oxide

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