

**Dr. S. Ahanatha Pillai, M.D., D.A.**

Former Professor of Anaesthesiology,  
Madurai Medical College and Govt. Rajaji Hospital,  
Madurai – 625 020. Tamil Nadu.

**Emeritus Professor, The Tamil Nadu Dr. M.G.R. Medical University, Chennai.**

Email: [ahanathapillai@gmail.com](mailto:ahanathapillai@gmail.com)

## Low Flow Anaesthesia Technique

### The merits and demerits

From the times of open drop administration of anaesthesia using Ether and Chloroform, the pollution of theater atmosphere has been discussed with due concern. But nothing effective could be achieved because of the primitive techniques used.

The first important concern is the massive pollution of the operation theater atmosphere by the anaesthetic gases and vapours. Chronic exposure of the personnel to these pollutants has been proved to be a serious professional health hazard. For the past four decades, there had been various attempts made to reduce the theater pollution to prevent the occupational health hazards. The most important being the scavenging of anaesthetic gases and vapours.

But, in the recent past, it has been established that the chlorofluorocarbons – the volatile anaesthetics and N<sub>2</sub>O emitted from our anaesthetic machines have caused severe ecological damage by their ozone depleting effect. N<sub>2</sub>O is proved to be a gas producing greenhouse effect and global warming. N<sub>2</sub>O liberated from operation theaters constitutes 1 % of the total N<sub>2</sub>O in the global atmosphere.

In developed countries use of effective scavenging systems to evacuate these pollutants out of the theater is mandatory. However, their contribution to the ecological damage could not be stopped by that way.

Continuous efforts are being made to reduce the emission of these pollutants in to the atmosphere. So, there had been a constant search for cleaner techniques of anaesthesia that would be less polluting to the atmosphere. One technique advocated is the recycling the anaesthetic gases and inhalational agents using low flows and closed circuit and that is 'Low Flow Anaesthesia technique' (LFA) which reduces this danger to the minimum.

Incidentally the increase in cost due to the wastage of inhalational agents also caused concern. 'Low Flow Anaesthesia technique' effectively addresses that issue. It is estimated that a cost saving of more than 75 % on anaesthetic agents could be done in this technique.

### History

Long before these aspects could be understood, closed circuit anaesthesia with carbon dioxide absorption using caustic potash was used as early as 1850 by **John Snow**. **Ralph Milton. Waters** used a to-and-fro system with CO<sub>2</sub> absorption in 1924. The German gynecologist Carl J. Gauss and the chemist Hermann D. Wieland advocated the use of a circle system for application of purified acetylene as an inhalation anaesthetic. The introduction of the highly combustible anaesthetic gas cyclopropane in 1933 urged

anaesthetists to use fresh gas flows as low as possible to reduce pollution of the operating room and thus to minimize the risk of inadvertent explosions. **Brian Sword** first described the circle breathing system with sodalime absorber for closed circuit anaesthesia in 1930.

Low flow, partial rebreathing anaesthetic techniques were first described by **Foldes** and colleagues 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, and 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

## Concept

In a closed anaesthetic breathing system, if fresh oxygen required for the basal metabolic requirement is added to the circuit, and all the exhaled carbon-dioxide is removed efficiently, the same anaesthetic mixture could be breathed repeatedly without harm and the fresh gas flow rate (FGF) could be reduced to the minimum.

Hence the basic requisite for 'LFA' is a closed breathing system with CO<sub>2</sub> absorption.

Closed anaesthetic breathing systems can be used in different ways:

- If a fresh gas flow equal to the minute volume of the patient is used, the share of rebreathing will be negligible. Nearly completely the expired air will vented out off the system as excess gas via the APL-valve. The patient gets nearly pure fresh gas.
- If a flow of 4.0 l/min is used, the share of rebreathing will increase to about 20%. The patient inhales a gas the composition of which still resembling that of the fresh gas.
- If the flow is reduced to at least 2.0 l/min or lower values, the share of rebreathing will reach 50% or more. Thus, only when low fresh gas flows are used the share of rebreathing will become significant, and so judicious use is made from the rebreathing technique.

## The principle of LFA

*If the exact amount of uptake of oxygen, anaesthetic gases and volatile anaesthetics are known precisely and that amount is fed into the breathing system only to replace the amount absorbed, anaesthesia could be well managed with very low FGF.*

Though it is understood easily, it is no way easy to practice because of the technical difficulties encountered in maintaining anaesthesia with low flow rates. There are complicated equations and hair splitting calculations for arriving at the exact amount of oxygen, nitrous oxide and volatile agents taken up by the patient. They more are of academic value to understand the problem than practical and often frighten the

anaesthesiologist. Example is Brody's equation to calculate the exact amount of O<sub>2</sub> absorbed.

The 'Low Flow Technique' is advocated mainly on considerations of environmental pollution and cost factors, it has to be realised that it has many inherent problems that are to be addressed and solved before it could be affirmed that it is entirely safe in all situations. If all the problems are addressed well, it can be practiced safely.

The following discussions will enumerate the problems and the solution for each so that LFA could be safely employed.

### **Definition**

*Any technique that utilises a fresh gas flow (FGF) that is less than the alveolar ventilation can be classified as 'Low flow anaesthesia'.*

Baum et al had defined it as a technique wherein at least 50% of the expired gases had been returned to the lungs after carbon dioxide absorption. This would be satisfied when the FGF was less than about two liters per minute.

Baker has classified the FGF used in anaesthetic practice into the following categories:

- Metabolic flow: about 250 ml /min
- Minimal flow: 250-500 ml/min.
- **Low flow: 500- 1000 ml/min.**
- Medium flow: 1 - 2 l/min.

It is necessary to analyse these categories to ascertain how far they are safe.

- **Metabolic flow:** about 250 ml/min

Though this category is included in the classification, it has to be realised that it is never used and is potentially dangerous.

- **Minimal flow:** 250 - 500 ml/min

FGF of 500 ml / min is acceptable only when this whole volume constitutes of oxygen and no other gases added.

- **Low flow:** 500 – 1000 ml/min

This flow is quite acceptable because 500 ml / min oxygen could definitely be administered and the remaining 500 ml may be N<sub>2</sub>O or any other carrier gas.

- **Medium flow:** 1000 – 2000ml / min

With this flow rate, there could be absolutely no problem, as the volume is more than sufficient for the basic needs and to compensate the problems.

*In all practical considerations, utilisation of a fresh gas flow less than 2 liters /min may be considered as low flow anaesthesia technique.*

Before discussing the problems of LFA, an orientation of two terms – ‘**reserve volume**’ and ‘**time constant**’ is essential.

### **Reserve volume**

It has two components; one is related *to the apparatus* and the other related *to the patient*. The circle breathing system is often bulky and has a volume roughly more than 4 liters depending upon the components. The system that incorporates an anaesthetic ventilator has more reserve volume. Besides this, the FRC of the patient, which is roughly 3 liters, is added. These two parts of reserve volume together constitutes a total reserve volume of more than 6 liters. The anaesthetic gases and vapours (FGF) has to be fed into this large reserve volume. With the addition of FGF, the rate of change of composition of the reserve volume is exponential.

When we make an alteration in the flow rate of gases or concentration of volatile anaesthetic agent, it must be reflected immediately in the composition of the gases in the breathing system for effective modulation of the plane of anaesthesia. This usually happens when high FGF is used. If the reserve volume is about 6 liters and the FGF is 6 liters, the changes are reflected almost immediately. But that does not happen when the FGF is lower. There is a varying time lag for the equilibrium to be achieved in the reserve volume. It takes some time for the gases in the breathing system to change to the new concentration.

The time required for the changes to occur is governed by **the time constant**.

### **Time constant**

*Time constant is the value, which is equal to the reserve volume divided by the fresh gas flow (RV / FGF).*

For example, if 1 liter of FGF is added to this reserve volume of about 6 liters, it gets diluted at least 6 times and the time constant is  $6 / 1 = 6$ . If the FGF is reduced to 0.5 liter, the value is  $6 / 0.5 = 12$ . When the time constant is long there will be dilution of the anaesthetic causing delay in induction. As the FGF is low, longer time taken for reaching equilibrium.

As discussed, the ‘Low flow anaesthesia’ incorporates certain inherent problems very specific to low FGF itself. It is essential to understand the problems and address them effectively to assure safety in this technique.

### **Problem 1: Dilution of Oxygen and Volatile anaesthetic concentration**

Large reserve volume of air in the breathing system constituted by intergranular space, breathing hoses, reservoir bag, anaesthetic ventilator etc will dilute the oxygen and anaesthetic agents initially. There is a high risk of developing hypoxic mixture. If 30 % oxygen is administered, by mixing with this large reserve volume there will be a serious drop in the percentage of oxygen to a very low level below 15 %. The patient would be breathing hypoxic mixture. This problem can be offset by initial *denitrogenation* of the lung before induction and using high flow rate initially for 10 minute. It is advocated using 50 % of oxygen in the FGF to prevent hypoxic mixture.

Incidentally, this mixing of FGF in reserve volume lowers the concentration of volatile anaesthetic vapour delivered. This will cause delay the induction. Dilution of anaesthetic agents and the delay in induction could be offset by using higher concentration of volatile anaesthetic agent and switching to the desired percentage after about 10 minutes.

**Problem 2:** Oxygen for basal metabolism, ventilation /perfusion mismatch in lung

Minimum oxygen requirement for basic metabolic needs is about 250 ml / minute. If the FGF delivered is reduced to 250 ml (Metabolic flow category) of oxygen the patient will be deprived of basic need of oxygen and will suffer hypoxia.

*Ventilation perfusion mismatch* that occurs inevitably during any anaesthesia and any pathology in the lung that causes further increase in the mismatch will not permit all the 250 ml of oxygen delivered to the lung to diffuse across alveolar capillary membrane into the blood. To compensate this deficiency, at least double the basic metabolic need; 500 ml / min oxygen must be delivered in any breathing system so that the oxygen required for basic metabolism reaches the blood.

This has to be constantly monitored in the system by oxygen analyser that the mixture contains at least 30 % oxygen. Pulse Oximeter would help to assure adequate oxygen saturation and tissue oxygenation.

If N<sub>2</sub>O is not used, 500 ml of Oxygen as FGF is acceptable. So, if N<sub>2</sub>O is used in the mixture, at least 50 % N<sub>2</sub>O is needed for serving any useful purpose of analgesia. Hence the total volume could not be less than 1000 ml / min.

Therefore, double the volume of basal metabolic requirement of oxygen (500 ml) is a must in any LFA.

**Problem 3:** Difference in uptake of oxygen and nitrous oxide, percentage build up of N<sub>2</sub>O with time.

When 500 ml / min of oxygen is fed into the breathing system, about 250 ml is utilised by the metabolic process and the remaining 250 ml only is available in the breathing circuit for rebreathing by the patient. Whereas, uptake of N<sub>2</sub>O is very high initially; this will be followed by a gross reduction in uptake. In highly perfused tissues like brain, heart and kidney the saturation is achieved in about 10 minute; moderately perfused tissues like muscles take about 30 minutes and poorly perfused tissues- fat take

about an hour. After one hour, there will be negligible uptake of N<sub>2</sub>O which causes build up of N<sub>2</sub>O in the system diluting the percentage of oxygen. This effect is likely to cause hypoxic mixture that has to be kept in mind.

**Problem 4:** Dilution effect of volatile anaesthetics causing difficulty in maintaining anaesthetic plane.

There is continuous uptake of volatile anaesthetic from the gas mixture. When a low volume of gases carrying the vapour enters the lungs, large amount of vapour will diffuse into blood. Therefore, gas mixture returning to the breathing circuit contains lower concentrations of the volatile anaesthetics. When the FGF mixes with this, the concentration of volatile agents delivered by the vapouriser is reduced. This results in difficulty in maintaining the required plane of anaesthesia. Setting a higher percentage and higher flow for the first 10 minutes may obviate this problem. Still frequent adjustments in the concentration may be needed.

**Problem 5:** Long 'time constant' causes delay in recovery

Due to the long '*time constant*' in LFA, during the recovery phase, there will be delay. Because of the low flow, the reduction in concentration of volatile anaesthetic is slow.

For combating the problem, the vaporizer can be switched off about 15 to 20 minutes before the definite end of the surgical procedure. If the low flow is maintained, the decrease of the anaesthetic's concentration is delayed and slow. During that time NMB may be reversed and recovery of spontaneous breathing allowed. Ventilation may be supported by using the SIMV ventilation mode or by manual assistance of the ventilation. About five minutes before extubation the anaesthetic gases are washed out by switching to high flow of 100 % oxygen.

In some anaesthetic machines, a special charcoal filter is switched on to trap the volatile anaesthetic agents to reduce the concentration rapidly.

All these problems can be averted by using the modern machines meant exclusively for LFA such as **Zeus IE**, Dragger® Germany

### **Merits of LFA**

There are four areas where definite benefits derived from LFA, namely ecological, environmental, economy and pulmonary functions during anaesthesia.

**Ecological:** Fluorocarbons and nitrous oxide attack the earth's ozone layer. Nitrous oxide consumption, which is an important ozone-depleting and heat-trapping gas contributing for greenhouse effect that is emitted from anaesthesia, is reduced. With low flows, these ecological dangers are reduced.

**Environmental:** 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.

**Economy:** Significant savings can be achieved with lower flows of nitrous oxide and oxygen, but the greatest savings occurs with the potent volatile agents resulting in significant savings of > 75%. These are partly offset by increased absorbent usage, but this cost is small.

**Pulmonary function:** Anaesthesia with low fresh gas flow improves the flow dynamics of inhaled anaesthesia gases, increases muco-ciliary clearance, maintains body temperature and reduces water loss.

### Demerits

- More attention is required. With closed system low flow anaesthesia, fresh gas flow into the system must be kept in balance with uptake. This requires frequent adjustments.
- There is a high possibility of hypoxic mixture being delivered to the patient, particularly when the FGF is very low, say 500 ml / min.
- Uptake of O<sub>2</sub>, N<sub>2</sub>O and volatile agents are relatively unpredictable. It needs complicated equations and calculations to estimate. For example, Brody's equation for calculating the uptake of oxygen.
- Induction and Emergence are slow and related to the lower flow rate and long 'time constant'.
- In low flow anaesthesia, the composition of anaesthetic gases changes continuously during the course of anaesthesia, making intermittent adjustments to fresh gas composition necessary.
- An uncertain inspired concentration is a problem. Inability to quickly alter inspired concentrations because of long 'time constant'. 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 haemodynamic responses due to inadequate plane of anaesthesia. This is a significant disadvantage only if the user of Low Flow Anaesthesia 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.
- Hypercarbia is imminent. 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. Faster exhaustion of soda lime occurs in LFA.
- Accumulation of undesirable trace gases in the system is a possibility. The accumulation of undesirable gases is most likely only a problem with closed-circuit anaesthesia, because low flows provide a continuous system flush. With closed system anaesthesia, flushing with high fresh gas flows once an hour will decrease the concentration of most of these substances.

*Carbon monoxide* from the interaction of desiccated absorbent and anesthetic agent is a reason. 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. However, if desiccated absorbent is present, low flows tend to increase the amount of carbon monoxide present in the system. Desflurane, more than enflurane and isoflurane react with absolutely dry carbon dioxide absorbents by generating carbon monoxide. Carbon monoxide may be produced from the breakdown of hemoglobin or exhaled by smokers can accumulate in the closed circle system.

*Acetone, methane, hydrogen, and ethanol* may possibly accumulate in the system in certain circumstances. However, dangerous levels are reached only after hours of closed system anesthesia. Methane can disturb infrared analysers. The common intoxicant ethanol can also accumulate.

*Compound A - haloalkene* is likely to accumulate with in the limit of 50 – 60 ppm. It has been established that only when the load is more than 800 ppm it is likely to cause nephrotoxicity. Hence the accumulation of compound A is considered clinically insignificant.

## **Monitoring**

### **LFA with N<sub>2</sub>O**

- Continuous FiO<sub>2</sub> monitor. Inspiratory oxygen concentration monitoring with alarm set at 30 %
- Continuous monitoring of sufficient gas filling in the breathing system monitored by monitoring minute volume.
- Continuous monitoring of concentration of anaesthetic agent. End tidal anaesthetic concentration helps in adjusting the vapouriser setting.
- Continuous monitoring of inspired and expired CO<sub>2</sub> concentrations.
- Pulse Oximeter to ensure adequate oxygen saturation

### **LFA without N<sub>2</sub>O**

Low flow anaesthesia without nitrous oxide is simple. The loss of analgesic effect can be compensated by a moderate increase in the additive dose of opioids, while the reduction in hypnotic effect can be countered with an increase in the concentration of the inhaled anaesthetic agent by only 0.2-0.25% of the MAC value of the respective agent used.

Because only oxygen and the anaesthetic agent are absorbed, total gas uptake is noticeably reduced and denitrogenation is no longer necessary. The initial phase of low flow anaesthesia, when high fresh gas flow rates are used, can be kept much shorter.

By eliminating nitrous oxide uptake, the breathing system filling is improved following the reduction of fresh gas flow even down to 0.5 L/min, than in low flow anaesthesia using a nitrous oxide/oxygen carrier gas mix. When using anaesthesia



machines with very airtight, compact breathing systems, the conduction of non-quantitative anaesthesia with closed systems is possible, where fresh gas flow can be reduced to patient oxygen uptake. This can be estimated with the help of the Brody Equation and is about 250-350 ml/min for adults.

At this low flow rate, however, the limits of the vaporizer's capability to emit sufficient amounts of agent into the fresh gas stream are reached, which, as a rule, are approximately  $3 \times \text{MAC}$  of the respective anaesthetic agents. The new volatile anaesthetics with reduced solubility, sevoflurane and desflurane, are much better suited for use with fresh gas flows corresponding to the rate of patient oxygen uptake.

## **Equipments**

The minimum requirement for conduct of low flow anaesthesia is effective absorption of  $\text{CO}_2$  from the expired gas, so that the  $\text{CO}_2$  free gas can be reutilised for alveolar ventilation.

The **Zeus IE**, a quantitative closed-loop anaesthesia machine, developed by Dräger® Löbeck, Germany. It is a sophisticated machine meant for LFA, capable of automatically adjusting administration of oxygen and carrier gas by closed loop feed back mechanism. It delivers the right absorbed amount of volatile agent only through direct injection of the volatile agent.

## **Conclusion**

As anaesthesiologists, our contribution in global warming is considerable and progressively increasing because of the release of chlorofluorocarbons and  $\text{N}_2\text{O}$  into the atmosphere. We have greater responsibility towards the society, more broadly towards the globe in which we live in reducing this environmental insult. Apart from opting for environment friendly anaesthetic techniques like regional anaesthesia or TIVA, one of the vital steps in that effort is resorting to LFA which is sure to minimise emission chlorofluorocarbons and  $\text{N}_2\text{O}$  into atmosphere.

An estimated saving of more than 75 % in the cost of anaesthetic gases and volatile anaesthetic agents is an additional advantage of this technique. Improved pulmonary function by way of the improved flow dynamics of the gas distribution in the lung and preservation of the mucociliary escalator function are advantageous. Incidentally heat and humidity preservation are also added benefits.

Extreme care is necessary in performing this technique is essential as the very nature of this system requires that the exact amount of anaesthetic agents taken up by the body be known, since that exact amount has to be added into the circuit. *Any error in this could lead to potentially dangerous levels of anaesthetic agent be present in the inspired mixture with its attended complications.* If adequate care is taken in eliminating the problems discussed above, this technique could be safely used. In the years to come the sophisticated machines providing quantitative closed loop anaesthesia such as 'Zeus IE' – Dräger may come in to common use to achieve this.