Low-flow anaesthesia (how to do it)

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The practice of volatile anaesthetic agent delivery using a fresh gas flow less than the minute volume has been with us since the early days of anaesthesia. Its popularity has closely paralleled the introduction of new volatile anaesthetic agents, where the cost saving of using low-flow is a prerequisite to affording a new, expensive agent.

The introduction of Desflurane and Sevoflurane in the South African market over the past few years, along with the 0028 code for low-flow earlier this year has renewed interest in the technique. Some anaesthesia machines now come equipped with "econometers" designed to achieve the optimal fresh gas flow, while also reassuring one that an adequate fresh gas flow is being delivered. With the widespread availability of agent, CO_2 and oxygen monitors the use of low-flow anaesthesia has become a predictable technique that can be titrated against measurable results.

CLASSIFICATION OF FRESH GAS FLOW

Low-flow anaesthesia really means that a carrier gas flow of less than 2 liters per minute is being used to deliver the anaesthetic agent to the patient. Gas flow rates can be categorized into:

* High-flow: a fresh gas flow greater than 4 litres per minute.
* Moderate flow: 2 to 4 litres per minute.
* Low-flow: less than 2 litres per minute.
* Basal flow: 250 to 500ml per minute.

250 ml /min is the absolute minimal oxygen requirement for metabolic processes at rest in a normothermic patient and must therefore be administered as 100% O_2.

WHAT DO WE NEED?

Advances in anaesthetic equipment and monitoring over the past few years have taken the guesswork out of low-flow techniques with the result that end points are easily determined and measured rather than calculated and assumed.
The basic equipment and monitoring for a low-flow anaesthetic is:-

1. Monitors

* Normal routine monitors as required for any anaesthetic. (ECG, pulse oximeter, blood pressure and other monitoring determined by the severity of the case.)
* Capnography and oxygen monitors are essential to measure these two vital parameters that run the risk of changing rapidly when flows are turned down.

A capnograph, oxygen and agent analyzer samples between 50 and 200ml a minute. This creates a "leak" of gas from the circuit, which can appear significant especially at low flows. To compensate for this the fresh gas flow needs to be increased by the amount sampled or the sampled gas needs to be returned to the circuit.

* Agent analysers are not absolutely essential, but are a reassuring confirmation that the patient is receiving the amount of volatile agent that one is intending to give.

2. CO_2absorption

The carbon dioxide absorber is the essential element in the entire system, allowing a closed loop of gas to be recirculated by eliminating the CO_2 being exhaled from the patient's lungs.

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Two types of absorber material are available (Soda lime and Baralyme) that remove CO_2 from exhaled air using chemical reactions. These reactions result in the production of water vapour and heat which are both advantageous to a patient under-going a general anaesthetic as warmed, humidified gas is now delivered into the trachea.

The basic chemical reaction for the metabolism of CO_2 is shown below, demonstrating the production of water and heat.

$$H_2O + CO_2 \prod H_2CO_3$$
$$H_2CO3 + {}_2NaOH \prod Na_2CO_3 + 2H_2O + Heat$$
$$Na_2CO_3 + CaOH \prod 2NaOH + CaCO_3$$

Sodium hydroxide is regenerated in this reaction, but calcium hydroxide is eventually exhausted resulting in the accumulation of CO_2 in the circuit.

Baralyme has a different reaction to soda lime and results in more water being liberated.

Soda lime and Baralyme will undergo a colour change when exhausted and can no longer convert CO_2. This colour change is from white to violet due to a decrease in pH in the canister with increasing CO_2. Colour changes are not completely reliable as fluorescent lights can deactivate the ethyl violet. When the absorber is exhausted a rise in the inspired CO_2 ($FiCO_2$) will be evident on the capnograph.

The canisters storing soda lime come in varying sizes with the large 2 litre canisters taking far longer to be exhausted than the small 500ml canisters. In a totally closed system using low-flows, 450g of soda lime will last for about 2 hours.

3. Volatile delivery

Volatile agents can be delivered to the patient circuit by one of three methods.

a. Vaporiser out of circuit

This is the standard technique used in most anaesthetic delivery systems today. The fresh gas passes through the vaporiser before entering the patient circuit.

b. Vaporiser in circuit

A low resistance vaporiser is placed in the actual breathing circuit and volatile agent is picked up from the vaporiser as the gas travels around the circuit. This type of vaporiser is very rarely used today due to the risk of overdosing the patient because the circuit becomes saturated over time. This occurs due to volatile filled gas passing through the vaporiser and picking up additional volatile agent.

c. Injectable methods of volatile delivery
A cumbersome method of volatile delivery requiring a fair amount of maths, infusion pumps and glass syringes. Despite this it is a well-described method used by low-flow devotees, especially when starting a case.

4. Gas delivery
Gas delivery is performed using a standard anaesthetic machine. Flow meters must be able to deliver flows of less than 1 liter per minute. There are various methods used to achieve this. Flow meters with a variable orifice that have small graduations at low flows and larger intervals at higher flows are required. Some machines have dual flow meters for each gas, the first one graded from 200ml to 1 liter and another from 1 to 10 liters. Machines with electronic flow meters can all deliver flows below 1 liter.

5. Closed circuit
Gas is delivered to the patient and returned via the CO2 absorber in a circular pattern using a "closed system". The same gas is continuously recycled with small amounts being released from the ventilator or breathing valve to allow for additional fresh gas to be introduced, with one way valves producing unidirectional flow around the circuit.

HOW TO DO IT
There are many ways of performing a low-flow anaesthetic, some with highly complex mathematical formulae, but the basic principle is the same. It takes a long time for any change in gas concentration to occur at low-flows. The lower the fresh gas flow the longer this change takes.

What do we need to give?
1. O_2 - a minimum of 250ml of oxygen is needed to meet the basic metabolic requirements of a normothermic, awake patient at rest. So the delivery of at least this amount of oxygen per minute will be safe in an anaesthetised patient. This replacement will be constant provided the metabolic rate remains constant. At flows of less than 1 litre per minute a FiO_2 of at least 50% is recommended. If the metabolic rate increases the minimum amount of oxygen delivered will probably need to be increased.

All circuits have a small leak that will usually be detected by the preoperative machine check (most machines will allow a leak of less than 40ml per minute to pass this test). This leak in addition to the gas loss from sampling lines and uncuffed tubes needs to be added into the minimal amount of gas delivered. This results in most people being comfortable with a minimum of 300 to 500ml per minute fresh gas flow.

2. Volatiles - Usually delivered from a vaporiser out of circuit, are needed to replace metabolized and absorbed volatile agent and gas vented to the atmosphere. A variable replacement is needed as it depends on the solubility and amount of agent metabolized.

3. N_2O - when used as an adjuvant anaesthetic agent must always be added to at least 250ml of oxygen. A constant amount needs to be given as saturation occurs quickly and metabolism is minimal. N_2O may even start to accumulate over time.

4. Air - is often added to 250ml of oxygen to avoid complications from the use of 100% oxygen.

PRINCIPLES OF ALTERING GAS CONCENTRATIONS
Getting a patient anaesthetized with an injectable agent and then maintaining the patient on a volatile agent on low-flow is perhaps the trickiest part of delivering a low-flow anaesthetic. The problem is saturating the entire circuit and patient with the desired concentration of volatile agent.

The following are the principles behind changing any gas concentration using low-flows.
* The entire circuit is made up of about 6 litres. (The tubing makes up about 1500ml, the ventilator or rebreathing bag, about 2000ml, the sodalime absorber 2000ml and the patients tidal volume 500ml.)
* The aim is to obtain a constant concentration of volatile agent throughout these 6 litres at the minimum alveolar concentration (MAC) value we require.
* If we introduce the volatile agent at 1 liter a minute it would take 6 minutes to change all the gas in the circuit.
* Pharmacology has shown that it takes 5 half lives for an injected drug to decay to zero concentration, or 5 doses to reach a steady state.
* Using the pharmacology of injected drugs we assume that it takes 5 changes of all the gas in the circuit to reach steady state.
* As a result we don't want to change 6 liters of gas to get our steady MAC, but 6 x 5 litres (30 litres in total.)
* Using a fresh gas flow of 1 liter a minute would mean that it would take 30 minutes to reach steady state.

Starting a case
Use the above principles at the beginning of a case. The circuit contains no volatile agent. The aim is to saturate it with a certain MAC of volatile agent in a patient who will awaken quickly from the initial dose of induction agent.
1. At 1 liter a minute of flow this will take 30 minutes (longer than some surgical procedures.) To hasten this we start with a high fresh gas flow. 6 liters a minute for 5 minutes would change 30 liters of gas, producing a steady state in about 5 minutes. It is now possible to decrease the fresh gas flow as the circuit is saturated.
2. The concentration of gas in the alveolus (which approximates the patients' blood concentration) is always lower than the concentration of volatile dialed into the vaporiser due to absorption and metabolism. To further speed up the saturation of the circuit, concentration of volatile greater than that that initially required is delivered. This *overpressurisation* produces a more rapid saturation of the circuit. The volatile concentration is now decreased to the required level.

During this initial period nitrogen is washed out of the circuit and replaced with oxygen, nitrous oxide and volatile agent. These compounds will all be absorbed and metabolized resulting in the loss of the nitrogen scaphold in the lungs, promoting atelectasis in lengthy cases. This can be avoided by using air instead of nitrous oxide as the second gas with oxygen. But the prolonged use of air can produce an accumulation of nitrogen which needs to be flushed out with high flows every few hours.

Changing gas concentration
Using the above principles shows that changing the concentration of volatile to a higher or lower MAC while at low-flow can take quite a long time. If the volatile concentration needs to be changed quickly, fresh gas flows must be increased. A fresh gas flow of 4 litres for 2 minutes is suggested.

Maintenance of anaesthesia
Vaporisers out of circuit produce a few problems with maintenance of anaesthesia at low-flows. Due to the metabolism and absorption of volatile agents the concentration of volatile agent in the entire system will slowly decrease over time. When the circuit is receiving a low fresh gas flow the absorbed and metabolized agent is not completely replaced. The result is a further decrease in alveolar volatile concentration. This may result in the patient becoming aware.

Due to their large metabolism Halothane (30%) and Ethrane (3%) are particularly affected by this. The solution to avoid this progressive loss of agent from the circuit is to increase the concentration

dialed into the vaporiser above the target alveolar concentration. Halothane requires a vaporiser setting between 30 and 50% greater than the required alveolar concentration, while a poorly metabolized agent like Desflurane (0.003%) only requires a 10% higher vaporiser setting. Isoflurane is also minimally metabolized (about 0.2%), and requires a setting similar to Desflurane, while Sevoflurane undergoes about 3% metabolism and needs to have a vaporiser setting of about 15 to 20 % higher than the expected alveolar concentration. An agent analyzer eliminates this guesswork.

Nitrous Oxide in a closed circuit will start to accumulate over time as it is minimally metabolized and should be flushed by increasing the fresh gas flow every hour.

Switching off

The same principles apply to wakening the patient at the end of the procedure. If the volatile agent is switched off and the fresh gas flow is not altered the patient can take between 10 and 20 minutes to wake up while the volatile concentration slowly decreases to zero. This is called coasting, and produces a further decrease in gas usage.

PAEDIATRICS

There is limited information on the use of low-flow in paediatrics, with a wide variety of opinions and concerns. Adult circuits with small bore tubing have been used and the technique is similar to adults, with a few precautions.

The use of paediatric circuits with smaller breathing valves has not gained favour as smaller valves actually produce a greater resistance.

Leaks are larger with uncuffed tubes, this often requires a higher fresh gas flow to maintain the volume in the circuit.

All the additional monitoring (sample connections, filters, heat and moisture exchangers, catheter mounts and angle connectors) and breathing valves in the circuit add dead space and resistance to the breathing circuit. The dead space can easily become larger than the tidal volume in very small infants, producing undetected hypoxia and hypercapnia. Care must be taken to keep dead space to an absolute minimum by utilising paediatric filters and sampling systems.

Due to the resistance from the breathing valves, spontaneously breathing infants require much greater work to ventilate adequately, which can produce fatigue, hypercapnia and acidosis. Controlled ventilation is therefore recommended

COMPLICATIONS

There are a few complications that have been described with the use of low flow circuits, mainly associated with metabolism of volatile agents in soda lime.

Sevoflurane was initially not recommended for use in low-flow circuits due to concerns over Compound A causing renal failure in rats. The most recent recommendations are that Sevoflurane can be safely used at flows of 1500-2000ml/min, as the renal problems appear to be unique to rats and are not significant in humans.

Enflurane used at low-flows for prolonged periods of time produces fluoride levels that may be nephrotoxic.

Desflurane can produce Carbon Monoxide when used with dry soda lime.

Various compounds may accumulate with prolonged use, the most commonly quoted being methane gas. The solution in all long cases appears to be to flush the circuit every few hours with higher flows for a few minutes.

WHY SHOULD WE CHANGE?

1. Economics

Numerous studies using calculations, laboratory models, pharmacy records and measured patient data have shown savings in volatile and gas usage of 2 to 4 times when compared to high-flows. The savings comparing fresh gas flows less than 2 litres a minute with those greater than 4 liters a minute are particularly spectacular.

2. Patient safety

The soda lime absorber gases being delivered to the patient are warmed and humidified, aiding in temperature control and tracheal ciliary function.

3. Environmental pollution

Nitrous oxide and volatile agents have been implicated in destroying the ozone layer. A reduction in the amount of agent used may aid this environmental problem.

CONCLUSION

1. When using low-flow the changes in gas concentration and subsequent anaesthetic depth occur slowly, but can be hastened by increasing flow rates.
2. O_2 and CO_2 must be monitored.
3. Agent analysers make the technique a lot easier and more predictable.
4. There is little difference in the amount of gas saving between 1L and 2L/min, but the savings are marked when using a fresh gas flow of 2L/min rather than 4L/min.
5. No matter how "low you go" a normothermic adult at rest needs a minimum of 250ml of oxygen per minute. Under anaesthesia this may decrease, but with hypermetabolism or pyrexia this may increase.
6. A fresh gas flow of 500ml has a larger safety margin than a fresh gas flow of 250ml per minute.

With the widespread availability of agent, CO2 and oxygen monitors the use of low-flow anaesthesia has become a predictable technique that can be titrated against measurable results and should be routinely performed.

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