Cost savings associated with low flow anesthesia

Kenneth A. Forrester, CRNA, MS
Detroit, Michigan

Low flow anesthetic technique has been extensively written about over the years but its routine practice has remained limited. Heat and humidity retention and a decrease of wasted anesthetic gas has been well documented, but only recently has the focus shifted to cost savings associated with its use. Continuous gas analysis of the inspiratory fraction of oxygen (FiO₂), end tidal carbon dioxide (ETCO₂) and anesthetic agent inspiratory and expiratory concentrations are an important element for a clear understanding of the behavior of low flow anesthesia. Because of this, a review of the principles and functions of mass spectrometry/infrared gas analysis and pulse oximetry are given.

Since the actual characteristics and variables associated with low flow technique (1-2 L/M) differ from that of the higher flow (5-6 L/M), important considerations are described in detail. The actual application of low flow technique, as well as its benefits, are also presented.

Cost savings associated with low flow are presented from various authors and results from our own anesthesia department are also included. Anesthetic agent costs can be expected to decrease by 25-50% yearly.

Low flow anesthesia (1-2 L/M) has never enjoyed the popularity that higher gas flows have (5-10 L/M). This was partly due to fears of patient morbidity and mortality and because continuous gas analysis monitoring was either unavailable or too costly. Practitioners of anesthesia were unwilling to jeopardize patient safety for the cost savings associated with its use. However, with the monitoring technology now available at a reasonable cost, low flow technique should be encouraged in the anesthesia community. Patient benefits are extensive and anesthesia costs are dramatically reduced.

Low flow technique has certain characteristics which make it similar to high flow; however, other characteristics make it vastly different. Continuous gas analysis is an important element for a clear understanding of the behavior of low flow anesthesia. Because of this, a brief overview will be presented regarding gas analysis through mass spectrometry and infrared analysis. The principles of pulse oximetry will also be described.

Methods of analysis

The mass spectrometer will measure both inspiratory and expiratory carbon dioxide concentration, inspiratory and expiratory anesthetic agent concentration, inspiratory fraction of oxygen, inspiratory nitrous oxide concentration and inspiratory and expiratory nitrogen concentration. The detection of these gases is determined by a small
sample of gas taken from a point very close to the oropharynx—either from the nasal passage or from an endotracheal tube. The sample is then ionized in an electron beam and accelerated in a high voltage field through a “slit.” This slit creates a very narrow beam which is then passed through a magnetic field. This field, in turn, causes the individual ions to be deflected in a spectrum according to their molecular weight and charge, with the heaviest ions deflected the least and the lighter ions deflected the most. Each gas species is then collected on a metal plate from which the current is amplified as a measure of concentration of that gas. The individual gas concentrations are then displayed on a screen.2

Mass spectrometry is very useful in assessing adequacy of ventilation and correct anesthesia machine function during delivery of an anesthetic. Elevated end-tidal carbon dioxide (ETCO2) levels would be present in situations such as hypoventilation and poorly functioning, expiratory, unidirectional valves. Many other scenarios exist in which ETCO2 could be elevated so these examples are not meant to be an all inclusive list. The clinical picture should also guide one’s response to elevated ETCO2 levels. Mass spectrometry is also useful for checking the calibration of the vaporizers, end tidal nitrogen (ETN2) concentration determination and when low flow anesthesia is employed, as anesthetic agent concentration will be different from actual vaporizer dial settings.

Infrared

Infrared gas analysis is another method of determining concentration of anesthetic gases and adequacy of ventilatory function. Analysis is based on the principle that the various gases measured absorb infrared light in varying amounts. Infrared monitors use sensitive photocells and filters to detect wavelength absorption of the various gases. Because isoflurane, enflurane and halothane have very similar wavelength absorption, the machine must be programmed to the anesthetic agent which is being utilized. Errors in displayed anesthetic agent concentration would be present if the anesthetic analyzed is different from that programmed. This problem may be eliminated in the near future, as technology has progressed to specific agent wavelength absorption identification without programming.

Uses and functions of the infrared gas analysis machine are essentially the same as those for mass spectrometry. Infrared analysis does have a disadvantage in that it cannot determine end tidal nitrogen (ETN2) concentrations. In cases in which ETN2 monitoring would be important, inferences can be made with the aid of the infrared machine, even though actual numbers would not be displayed. If the inspiratory fraction of oxygen (FiO2) suddenly decreases or the inspiratory fraction of oxygen (FiO2) and the inspiratory fraction of nitrous oxide (FiN2O) do not add up to approximately 95% or greater, it can be inferred that concentrations of nitrogen are present and displacing the oxygen and nitrous oxide. The larger the nitrogen concentration present, the lower percentage the oxygen and nitrous oxide will be in the combination. So even though infrared analysis is incapable of nitrogen determination, it can be indirectly detected.

Pulse oximetry

Pulse oximetry is not a form of gas analysis but it is a method to determine if adequate gas exchange is taking place. It is a relatively precise prediction that adequate oxygenation of the patient is occurring. Pulse oximetry is based on the principle that oxygen saturation of arterial blood can be fairly accurately estimated by light reflected from, or passed through, subcutaneous vessels and skin. Two wavelengths of light are used but only the pulsatile or alternating current component of transmitted or reflected light is detected. This component is entirely due to arterial pulse and arises from a changing blood volume in the field, which means pulse oximetry only works as long as it can detect a pulse. Venous blood and “other” tissue absorb a constant amount of light and are filtered out leaving the variable absorption of arterial blood to be processed and then displayed as arterial saturation of oxygen (SaO2).3 Accuracy of pulse oximeters may be affected by high levels of carboxy- or methoxy-hemoglobin and the presence of intravenous dye. Because patients may not be adequately oxygenated when using low flow technique, the use of a pulse oximeter is mandatory.

Principles of low flow technique

Now that the principles of gas analysis have been described, the actual characteristics of low flow technique can be detailed. Familiarity with high flow appears to explain why anesthesia practitioners have continued to practice this technique over the years, especially when coupled with the fact that rather complicated gas kinetics may make it impossible to predict resulting anesthetic concentrations when fresh gas flows are decreased without correct monitoring.4

Characteristics

Rebreathing of anesthetic gases has consistently been an advantage of low flow anesthesia as this will decrease the anesthetic delivery costs. However, rebreathing has also been one of the greatest areas
of concern as failure to monitor this aspect can have potentially lethal effects on the patient due to carbon dioxide buildup.

With very low flow rates, (0.5 L/M), anesthetic gas uptake by the patient is initially very large in comparison to the fresh gas available in the delivery system. In other words, since the delivery of fresh gas from the anesthesia machine is so low, (0.5 L/M), it is almost as if a “bolus” of anesthetic agent is delivered to the patient. As this flow continues around the system, there is very little anesthetic returned to the circuit after patient uptake. However, there is enough to cause a dilutional effect on the residual gases remaining in the anesthesia circuit. This rebreathing component dilutes the new fresh gas available to actually decrease the anesthetic agent concentration available for re-delivery to the patient. So even though there is an initial large uptake of anesthetic agent by the patient, dilutional and rebreathing effect will actually decrease the agent concentration available for delivery.

With flow rates of 1-2 L/M, the rebreathing and dilutional effects are not as great as 0.5 L/M but are greater than flow rates of 5 L/M. The higher flow rates are associated with only a small proportion of gas uptake by the patient in relation to fresh gas available in the system, as well as very minimal rebreathing of gases. This is because a much larger volume of gases is available for use by the patient.

Another consideration with the low flow technique is nitrogen (N₂) detection. With low gas flows, N₂ dissolved in body tissue will be slowly excreted into the anesthesia delivery system and dilute the agents that are already present. This is an important aspect to be aware of when using the low flow technique but is generally not a problem. With higher fresh gas flows, the N₂ is continually “washed” from the system and does not routinely pose a problem in anesthetic delivery.

**Variables**

Time constant, which is an inverse function of fresh gas flow, plays an important role in determining anesthetic agent concentration. Increasing the carrier gas flow will decrease the time needed to show a change in alveolar anesthetic agent concentration. Conversely, decreasing the carrier gas flow will increase the time needed before a change in anesthetic agent concentration is detected. The lower the flow rate, the longer the time necessary for a change to occur, either increase or decrease in agent concentration. Because of this, vaporizer dial settings are no longer accurate in their delivery of anesthetic agents, or in other words, with low flow anesthesia, a 1% setting on the vaporizer does not typically deliver a 1% concentration.

A formula was developed by Milo Engoren, MD, at Hutzel Hospital in Detroit using algebraic principles to determine anesthetic agent concentration when using the low flow technique and is presented in Table I. These inspiratory concentration calculations of anesthetic agents have been consistently verified by our anesthetic agent analyzers. Formulas to determine percent rebreathing of anesthetic agents are also listed in this table. This rebreathing component is why cost reduction is obtainable when using low flow technique, as a greater percent of the anesthetic gases are reused instead of being eliminated by a scavenging system. Since the formula for inspiratory anesthetic agent concentration is quite difficult, examples are given for 4, 2 and 0.5 L/M total fresh gas flow (Table II). Rebreathing percentages are also included for each flow rate.

### Table I

<table>
<thead>
<tr>
<th>Anesthetic agent inspiratory concentration and percent rebreathing formulas</th>
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<tbody>
<tr>
<td><strong>Inspiratory Concentration</strong></td>
</tr>
<tr>
<td>[ l = \frac{\dot{Q}<em>{FGF , inspir} , (AA</em>{dial}) + (AA_{expir}) , \dot{Q}_{FGF , expir}}{V_M} ]</td>
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<tr>
<td><strong>Percent Rebreathing</strong></td>
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<tr>
<td>[ % , Rebreathing = \frac{V_M - \dot{Q}_{FGF , inspir}}{V_M} ]</td>
</tr>
</tbody>
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**Note:**
- \[ \dot{Q}_{FGF \, inspir} = \text{Fresh Gas Flow in L/minute} \]
- \[ AA_{dial} = \text{Anesthetic agent dial setting} \]
- \[ AA_{expir} = \text{Anesthetic agent expiratory concentration from monitor} \]
- \[ V_M = \text{minute ventilation} \]
- \[ \dot{Q}_{FGF \, expir} = V_M - \dot{Q}_{FGF \, inspir} = \text{fresh gas flow on expiration} \]* \[ \dot{Q}_{FGF \, inspir} \text{ must be } \leq V_M \text{ for % rebreathing to be accurate} \]

### Table II

<table>
<thead>
<tr>
<th>Examples of formulas for Inspiratory concentration and percent rebreathing</th>
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<tbody>
<tr>
<td><strong>4 L total flow</strong></td>
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<tr>
<td>[ l = \frac{4 \times (1%) + (0.7%)1}{5} = \frac{4 + 0.7}{5} = 0.94% ]</td>
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<tr>
<td>[ V_M = 5 \text{ L/minute} ] Rebreathing = [ \frac{5 - 4}{5} = \frac{1}{5} = 20% ]</td>
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<tr>
<td><strong>2 L total flow</strong></td>
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<tr>
<td>[ l = \frac{2 \times (1%) + (0.7%)2}{5} = \frac{2 + 2.1}{5} = 0.82% ]</td>
</tr>
<tr>
<td>[ V_M = 5 \text{ L/minute} ] Rebreathing = [ \frac{5 - 2}{5} = \frac{3}{5} = 60% ]</td>
</tr>
<tr>
<td><strong>500 ml total flow</strong></td>
</tr>
<tr>
<td>[ l = \frac{0.5 \times (1%) + (0.7%)4.5}{5} = \frac{0.5 + 3.2}{5} = 0.74% ]</td>
</tr>
<tr>
<td>[ V_M = 5 \text{ L/minute} ] Rebreathing = [ \frac{5 - 0.5}{5} = \frac{4.5}{5} = 90% ]</td>
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**Note:**
Comparison of high flow to low flow with 1% vaporizer setting and 0.7% expiratory concentration.
Uptake of the anesthetic agent by the body is largely a function of inspiratory concentration and is also an important variable to consider. With higher fresh gas flow rates, the anesthetic uptake will be fast; with lower fresh gas flows, the uptake will be slow. When using lower fresh gas flows, the first breath at induction of anesthesia will contain a certain concentration of anesthetic agent. After about 3-5 breaths, the patient will largely be rebreathing the expired anesthetic agent concentration. In other words, a substantial amount of rebreathing of the expiratory concentration will be diluting the inspiratory concentration. This is why the concentration of anesthetic agent measured by the gas analysis monitor will be lower than that delivered by the vaporizer.

Because of variables in patient uptake, there are two different approaches in the administration of anesthetic agent in the low flow technique. The two applications are used to avoid the anesthetic agent concentration problem and also prevent a prolonged induction time. The first approach requires only that the anesthetic agent vaporizer dial be turned up to the 3-4% setting for induction. This should deliver an approximate concentration of 1.5%. Variations in anesthetic agent concentration are adjusted according to agent monitor readings. It is very simplistic in approach and desired results are easily achieved. The second approach uses a combination of a higher flow rate (5-6 L/M) for induction and emergence while maintenance of anesthesia is accomplished with the low flow technique (1-2 L/M). This is the recommended approach, in this paper, because rapid induction and emergence from anesthesia are accomplished.

To speed induction, the patient is denitrogenated by breathing 100% oxygen for 3-5 minutes. The flow rates are maintained at 4-6 L/M after induction, with the vaporizer on to facilitate rapid deepening of the patient. After approximately 5 minutes, the fresh gas flow rates are decreased and maintained at 1-2 L/M for the “duration” of the case. With approximately 5-10 minutes remaining in the case, the flow rates are once again increased to 4-6 L/M for a more rapid emergence. The rapid emergence is facilitated by the decreased amount of rebreathing of anesthetic agent by the patient. Thus the benefits of low flow anesthesia are maintained and are combined with the speed of anesthetic delivery and emergence associated with higher flow rates.

**Considerations**

The first consideration is that the use of low flow anesthesia requires greater operator vigilance. This should not be considered a hindrance, since vigilance is a plus in the delivery of any anesthetic. Retrospective studies of morbidity and mortality associated primarily with anesthesia have implicated failure in vigilance as a primary cause of injury.

The second consideration is that low flow technique requires a greater reliance on clinical monitoring. The cost savings associated with low flow anesthesia plus the actual safety benefits that continuous gas monitoring brings to the patient are both beneficial. Continuous gas analysis allows for early diagnosis of potentially disastrous situations, and early detection leads to early treatment.

The last consideration is that the sampling size of most of the monitoring equipment ranges from 125-250 mL/M. This is an important consideration when using flows below 1 L/M, as gas sampled may be as much as you are administering, leaving the patient to breathe only hypoxic mixtures. Fortunately, this is not a problem when the 1-2 L/M flow rates are used.

**Benefits**

Minimizing wasted anesthetic gases is a major benefit of the low flow technique as considerably less anesthetic agent is eliminated by the scavenging system, thus leaving more agent to be recycled and reused by the patient. Low flow anesthesia also allows rebreathing of gases that have already been warmed and humidified by the body. Humidification and heat preservation are more apparent with flows below 500 mL/M but are still evident with flows of 2 L/M. When high gas flows are used, there is typically less than 20% rebreathing. However, when low gas flow is instituted, 60-80% rebreathing occurs, thus decreasing temperature and water loss. (See Table II.) Although rebreathing is not as efficient as upper airway warming, it is significant enough to prevent the rapid temperature loss associated with breathing “fresh” cold anesthetic gases.

**Cost savings**

Anesthesia practitioners are now beginning to look for ways to curb spiraling medical costs and the low flow anesthesia technique has become an excellent approach to cost savings. Gas analysis monitoring, now available at a reasonable price, has made low flow a safe and efficient approach to anesthesia. To put medical costs into perspective, medical inflation was 8.3% in 1988, or almost two times the national rate of 4.4%. Medical inflation rates are projected to maintain the 2 to 1 margin over the national rate for the next three years. Hospital inflation, termed “Market Basket,” increased from 5.8% in 1986 to 7.0% in 1988. The hospital inflation rate is also predicted to increase annually over the next three years at a rate of 0.2%.
Medical malpractice litigation has only compounded the cost problem further by making it difficult for practitioners of anesthesia to cover their own malpractice insurance. The current estimated death rate associated primarily with anesthesia is 0.01%. On the outside, this appears to be a very reasonable number. However, this still calculates to approximately 2,000 anesthetic-related deaths per year. Continuous gas analysis, necessary for the low flow technique, could be used to enhance patient safety. In fact, studies have shown that of the 2,000 deaths reported, conservatively 50% of these incidents would have been detected with continuous gas monitoring. This does not mean that all the incidences could have been prevented, but that the potential of early detection may assist in early treatment. Continuous gas analysis thus has the potential of reducing the number of anesthetic mishaps per year.

Insurance carriers have just now begun to join the effort in favor of more elaborate patient monitoring and recent publications have projected a 50% cost savings in premiums by using recommended monitoring equipment. These findings were based on injuries which were classified as preventable. While the critical assumption that a 50% reduction in expense would be achieved, it is felt that savings would occur not only by identifying events in time to prevent injury, but also in disproving claims or preventable events which did not occur. Insurance carriers are also focusing on the fact that while the degree of safety afforded by monitoring is difficult to measure, the failure to monitor appears to increase the risk of injury to the anesthetized patient.

Cost savings associated with low flow anesthesia are substantial and have been quantified by numerous authors. Aldrete et al. did a comparison of cost for 1,000 hours of anesthesia when using 6 L/M total flow versus 0.5 L/M total flow. The results were astounding, showing a 600% savings in anesthetic agent costs ranging from a $1,000 savings for halothane to a $9,100 savings for isoflurane per 1,000 hours of use. Patel and associates further delineated the dollar costs per hour by including both the cost of the anesthetic gases and carbon dioxide absorber usage. Results showed that 95 cents per hour was required for 5 L/M total flow versus 29 cents per hour for a 0.5 L/M total flow for a cost reduction with low flow anesthesia of 330%.

Carbon dioxide absorber costs must be mentioned briefly here as these costs will increase slightly when using the low flow technique. The rebreathing of already warmed and humidified anesthetic gases requires the removal of the patients’ expired carbon dioxide to prevent their levels from reaching toxic proportions. For this reason, the carbon dioxide absorber will be depleted more rapidly than when using higher flow rates. An approximate twofold increase in cost for the absorber should be expected, but most hospitals are currently spending only $2,000-3,000 per year for this product. Absorber costs average around $2,000 at Hutzel Hospital and are based on approximately 18,000 anesthetic hours and 15,000 cases annually. (These numbers are given for comparison only, as not all cases require absorption of carbon dioxide.) This cost is relatively insignificant when the savings previously presented can be achieved with the low flow technique. Cost savings will be dependent, however, on the number of isoflurane hours.

If this cost increase is a concern, studies have shown how to prolong absorber use even further. Spain found that the optimal safe use of carbon dioxide absorber in a double cannister setup occurred when the absorber in the bottom cannister had begun to discolor. The top cannister is then replaced with a new carbon dioxide absorber and is moved to the bottom; the bottom cannister, which is starting to become saturated, is moved to the top. This should provide the longest use of the carbon dioxide absorber.

Since isoflurane is the most commonly used inhalation anesthetic at Hutzel Hospital, a goal was established to determine if a decrease in the cost of this agent could be realized by decreasing fresh gas flows from a 5-6 L/M total flow to a 1-2 L/M total flow. During the last 2 ½ years, the results have been astounding.

Isoflurane usage from the period of December 1986 to June 1987 was 444 bottles at $56 per bottle translating into a cost of $24,864. In the same time period in 1988, a 71-bottle reduction had been achieved to 373 bottles at a cost of $20,888 (Table III). This resulted in a $3,976 cost savings for those equal time spans (Figure 1). The amazing aspect here is that the number of cases using isoflurane had increased by 89 and the actual isoflurane hours had increased by 371. By dividing the total cost for the time period by the total hours of isoflurane use in that time period, a cost per hour can be calculated. This translates into costs of $5.10 per hour using the higher flows in the first time period ver-

<table>
<thead>
<tr>
<th>Bottles</th>
<th>$/Bottle</th>
<th>Savings</th>
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<tbody>
<tr>
<td>444</td>
<td>56.00</td>
<td>71</td>
</tr>
<tr>
<td>373</td>
<td>56.00</td>
<td>3,976</td>
</tr>
<tr>
<td>343</td>
<td>56.00</td>
<td>84</td>
</tr>
<tr>
<td>259</td>
<td>56.00</td>
<td>4,704</td>
</tr>
</tbody>
</table>

Table III: Monthly comparisons of forane usage based on $56.00 per bottle.
used $3.98 per hour when using the lower flow rate in the second time period. The $1.12 per hour difference, when multiplied by the number of hours in the second time period, shows cost savings of $5,881.

Ironically, when carbon dioxide absorber costs were evaluated to be included in this calculation, money expended for its purchase was actually less with the lower flow rates when compared to the higher flow rates. This appears to be related to the fact that initially when the higher flows were used, the carbon dioxide absorber was changed every two weeks, whether it needed it or not. Experience has shown that the carbon dioxide absorber should be changed only when the granules begin to discolor.

A marked reduction in anesthetic costs is also noticed when comparisons are made for the first six months of 1986 and the first six months of 1988. A total of 343 bottles were used in this time period in 1986 compared to 259 bottles in 1988, or an 84-bottle reduction (Table III). This translated into a cost savings of $4,704 (Figure 1), which has been consistent with savings of approximately $4,500 per six-month period, or $9,000-$10,000 yearly, since the low flow technique was instituted at Hutzel Hospital. These savings do not add up to the initial prediction of 50% savings per year in anesthetic agent costs; however, a 25% savings is noted. Total staff compliance with the low flow technique has not been achieved and, as such, has probably skewed the data to the 25% savings. Compliance currently ranges from 75-80%. A savings closer to 50% may be achieved when a 100% compliance is reached by departmental members.

**Conclusion**

Low flow technique is an excellent approach to the delivery of an anesthetic both in terms of patient benefits and cost savings. Continuous gas analysis, which is also a tremendous adjunct for patient safety, has made this technique a safe and cost-effective approach. The combination of low flow technique and continuous gas analysis should stir new interest in its application. It is relatively easy to do, enhances patient safety and decreases anesthetic agent costs. Every anesthesiologist needs to become cost conscious to a certain degree, and this is an excellent opportunity to save money and enhance patient safety.

**REFERENCES**


**AUTHOR**

Kenneth A. Forrester, CRNA, MS, received his BS in anesthesia from Wayne State University in Detroit, Michigan, his MS in business administration from Central Michigan University in Mt. Pleasant, Michigan, and a BS in nursing from Michigan State University in East Lansing, Michigan. He currently is director of anesthesia services at Hutzel Hospital in Detroit, Michigan, and is involved in both clinical and didactic instruction at Wayne State University.

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