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REVIEW

Low flow, minimal flow and closed circuit system inhalational anesthesia in modern clinical practice

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ABSTRACT

Low, minimal flow and closed circuit anesthesia has been pursued since the beginning of the history of anesthesia. For many decades this form of anesthesia has been restricted to devoted enthusiasts and those very fond of gas kinetics. For most clinicians, selecting a fresh flow gas higher than 3-5 L/min was widely accepted as a routine anesthesia technique. The introduction onto the market of new volatile agents as well as advanced anesthesia machines accompanied by highly reliable monitoring systems, made minimal flow or closed system anesthesia feasible on a daily basis. Clinical, cultural, environmental, pharmacological, technological and economic reasons, force the modern anesthesiologist to reconsider the role of minimal flow and closed circuit volatile anesthesia, in clinical practice. This paper analyses the main advantages offered by these anesthesia techniques.

Key words: anesthesia, low flow, minimal flow, closed circuit, body temperature, humidification

Introduction

Anesthesia circuits are traditionally defined as: closed, semi-closed, open and semi-open depending on carbon dioxide absorber presence, flow and inlet position of fresh flow gas (FFG) and minute volume ventilation/FFG ratio. Rigorously defined taxonomy amongst the above mentioned circuits is not possible. Furthermore, this classification does not take into account the metabolic demand of each patient, strictly related to patient's body weight, age and clinical data.

During volatile anesthesia, two conditions have to be observed: optimal narcosis and matching of patient metabolic demand. These criteria are better addressed by a classification such as proposed by Baker e Simionescu. This classification identifies the anesthesia circuit only on FFG basis, and proposes the anesthesia continuum concept with an overlap among the different FFG classes (table 1). (1,2,3)

In spite of Baker and Simionescu's clear and precise classification, many anesthesiologists, during everyday clinical practice, usually consider an FFG of 2-3 litres as low flow anesthesia.

The majority of anesthesiologists, during their clinical practice, usually avoid operating with an FFG lower than 1 l/min due to their cultural and practical beliefs including:

- requirement of in depth knowledge on gas laws and physics applied to clinical anesthesia
- pharmacokinetic and pharmacodynamic features of halogenated agents used until the mid 90's
- lack of accuracy, expense and limited performance of anesthesia machines utilized in anesthesia up to the end of the 90's. (1,2,3)

Cravero reported that in 1994, in the United States, 90% of anesthesiologists utilized 2-5 l/min of FFG and only 12% of physicians used an FFG inferior to 1 l/min. (4,5)

The recent introduction on the market of low solubility halogenated agents and the technological development of high-performing anesthesia ventilators, supplied with feed-back control systems and high precision monitoring systems, make metabolic flow anesthesia safe and feasible on a daily basis. This occurrence represents a great advantage as far as clinical practice, cultural, environmental, pharmacological, technological and cost savings concerns.

Clinical evidence

Tracheal intubation bypasses the upper airways, thus eliminating the main effects on inhaled gases: warming and humidification. In the spontaneously breathing patient, the isothermic saturation boundary of inspiratory mixture (the point where the gases reach 37 ^{o}C and 100% humidity), is located at the 4-5th generation bronchi. After tracheal intubation, as a consequence of upper airway bypass, the isothermic point is shifted down about 10 cm, in

Table 1. Classification of anesthesia circuits according to Baker and Simionescu.

Circuit	Fresh gas flow
Metabolic flow	~ 250 ml/min
Minimal flow	250-500 ml/min
Low flow	500-1000 ml/min
Medium flow	1-2 L/min
High flow	2-4 L/min
Open	> 4 L/min

a bronchial region not suited to deal with dry and cold gases and not able to physiologically condition the respiratory mixture. (6,7,8)

As a consequence of these pathophysiological changes, combined with the cold and dry medical gases coming from the pipeline distribution system, two types of consequences occur:

- body temperature reduction: caused by an increased heat loss from the large part of lung tissue exposed to a cold and dry breathing mixture. This effect is amplified by the peripheral vasodilatation caused by anesthetic agents and by muscle paralysis, which prevents muscle's thermogenous function compensation
- inadequate airway humidification and consequent damage of bronchial mucosa depends on duration and intensity of humidity alteration. Damages occurring in this case involve cilia and mucosa gland destruction causing the flattening of bronchial pseudostratified ciliated columnar epithelium, cellular degeneration and increase in desquamation, potentially leading to epithelial ulcerations. The reactive hyperemia, a consequence of epithelial damages, can be considered as an additional cause of lung dysfunction.

Volatile anesthesia using minimal or metabolic flow circuits can efficaciously prevent the above mentioned complications. According to Kleeman, the temperature of the breathing mixture can reach 30°C after 1 hour of anesthesia with an FFG of 0,6 l/min, while the breathing mixture temperature is not subject to any variation if FFG is maintained to 1,5 l/min or higher.(8) Finally, a rough but explicit sign as far as humidification is concerned with low flow, is the amount of condensed moisture gathered in the respiratory circuit water trap canister.

Cultural considerations

According to Ernst's assertion ...reducing the FFG to the level of the individual uptake, makes the anesthesiologist's working place a physiological laboratory at the patient's head. This statement provides a perfect explanation of the cultural role of low, minimal or metabolic flow anesthesia. Working in such conditions, forces anesthesiologists to improve their clinical and instrumental approach to the patient. (9) Particular interest has to be paid to achieve in depth familiarity and knowledge of the following topics:

- variations on time constant of breathing system in relation to fresh gas changes (a long one with metabolic flow, a shorter one with higher FFG)
- gas kinetics
- technical features and engineering of ventilators.

A proper combination of the above three points combined with the properties of last generation halogenated agents and of their vaporizers technical characteristics, consent fast rise in anesthesia depth even without increasing FFG. Opening of a close/low flow circuit for a rapid wash-out is absolutely required only if a fast recovery from anesthesia is considered necessary.

Metabolic flow anesthesia is easily feasible even with traditional ventilators as long as a reliable monitoring system is available. Both air and N_2O must be omitted from the breathing mixture and only pure O_2 has to be used as the carrier gas; it follows that pre-oxygenation for nitrogen wash out is not required and hypoxic respiratory mixture is impossible to be delivered.

Data on gas mixture compounds uptake can offer helpful information on drug consumption and patient metabolic status, directly influenced by the anesthesia depth.

Anesthesiologist should also be aware of metabolic and decay processes of volatile anesthetic agents and foreign gases accumulation occurring during low flow anesthesia. (10)

Environmental concerns

As far as the environment is concerned, one of the most important disadvantages of inhaled anesthesia has always been pollution both of the workplace, i.e. operating rooms, and of the environment as a whole. It is evident that, using low FFG end re-utilizing the compounds of the expired breathing mixture, the contamination risk does reduce simply as a consequence of the reduced total amount of polluting compounds. Therefore, during low flow or metabolic anesthesia, even taking into account eventual gas leakages from the circuits, the amount of total gases released in the environment is significantly reduced if compared with high flow anesthesia. As early as 1979, Virtue demonstrated that decreasing the FFG from 2,5 l/min to 0,2 l/min, the concentration of N_2O at the patient's head was 9 times lower. It mustn't be forgotten that using a metabolic system with O_2 as the sole carrier gas for halogenated agents, besides reduction of volumes, has the other great advantage of the exclusion of N_2O administration.

Reducing the use of halogenated agents, the risk of environmental pollution will decrease. Halogenated anesthetics, in fact, belong to chlorinated hydrocarbons, substances which can harm the ozone layer. Although the role played by volatile anesthetics is trivial compared to the damage caused by

industries and car traffic, social awareness imposes upon us the task to preserve the environment as much as possible.

Pharmacological considerations

As already mentioned, minimal flow circuits magnify pharmacokinetic and pharmacodynamic properties of last generation halogenated agents (desflurane and sevoflurane). These drugs are characterized by low solubility in body tissues together with low anesthetic potency. Therefore, their MAC is reached with high concentrations in the respiratory mixture. High cost, together with the greater amount of anesthetic required, have long been the major obstacle to their use, despite being synthesized before the 1970's.

Another aspect to be considered is the accumulation of volatile foreign substances inside the circuit during low flow anesthesia, in part as a consequence of the metabolism of anesthetic agents, and partly as a result of the physiological catabolic cascade.

Nitrogen accumulates in the lungs after being released by body tissues; this occurs markedly in obese patients. The main effect of nitrogen accumulation is O_2 dilution in the breathing mixture.

Methane is usually produced by intestinal bacteria and expelled through the lungs. In small amounts, methane can be even part of the gases delivered by the central gas pipeline, since it is present in small percentages in the atmosphere. Low flow anesthesia can cause the accumulation of this gas just because of the trivial wash out of gaseous mixture.

Acetone is another substance derived from the body's metabolism and, since it is usually expelled also through airways, it can accumulate in the breathing circuit when using low FFG. In clinical practice this may be particularly important when treating cirrhotic patients, those suffering from diabetes mellitus and patients on prolonged starvation. It is advisable in such cases not to provide a FFG inferior to 1 l/min, in order to guarantee an adequate acetone wash-out.

Carbon monoxide can usually be found in the blood of smokers as part of the carboxyhemoglobin compound. During low flow ventilation the carbon monoxide will accumulate in the lungs, both deriving from blood wash-out and from metabolism of halogenated agents. We assume that this plays a major role in causing post-operative nausea and vomiting.

We should finally mention the compound A generated by using sevoflurane in low flow circuits. Sevoflurane molecules in fact demonstrate instability at temperatures higher than 38°. During exothermic CO_2 reaction decay in the absorber, if FFG are extremely reduced (as in metabolic flow) the refrigerating effect on the breathing mixture is inadequate, and the temperature will rise even over 38°. For this reason it is still not advisable to use sevoflurane with an FFG lower than 2 l/min.

Finally, due to the pharmacological characteristics of the last inhaling anesthetics, together with the advantages offered by low flow or metabolic flow circuits, volatile anesthesia seems to be more advantageous than intravenous anesthesia, especially in regard to waking time and awareness prevention. (10,11)

Technology

Technological development does not directly involve practitioners. Biomedical devices should respond to users' friendly requirements so as to be helpful during clinical practice, ensuring at the same time a high level of quality and safety. Physicians must be perfectly familiar with the instruments they use at work. They even have to be able to recognize technical limitations and to propose possible solutions and improvements. Such a role is consistent with not only being familiar with technical and clinical aspects but also being able to prevent legal actions concerning clinical practice.

High technology necessarily includes sophisticated control systems, algorithms and auto test procedures to verifying the integrity and functionality of the machine. The high technology checking system is a guarantee not only for the clinician but for the patient too.

As far as technology is concerned, we must mention the Zeus anesthesia workstation produced by Draeger. It represents an exclusive machine directly descending from Physioflex, another Draeger product, which has been the first anesthesia machine able to provide quantitative inhalatory anesthesia, i.e. automatic electronic controlled delivery of the exact patient uptake of O_2, inhaled anesthetic agent and N_2O (if utilized).

Zeus workstation gives less information, compared to Physioflex (which is already out of production), but it is characterized by advanced automation and a user friendly interface console. It is substantially different from all other types of anesthesia ventilators, thanks to a whirl, placed in its internal circuit of 4-litre capacity, which is able to originate a constant flow of approximately 15 l/min. This feature keeps homogeneous and constant the nominal breathing mixture composition, and also generates the driving force necessary to ventilate the patient. The halogenated agent is not delivered into the circuit through a classical vaporizer in line with the fresh gas inlet. An injector quite similar to those utilized in modern car engines, nebulizes the exact amount of drug necessary to keep constant the preset end expiratory concentration, whatever the FFG is. (12,13)

Cost savings

Considering the managing role of physicians in the modern hospital setting, cost savings is one of their major concerns. A very simple example will be more explicit than any dissertation in economy. Supposing a flow of 2 l/min FFG is provided of which 0,5 litres is O_2 and 1,5 litres is air, and assuming average daily anesthesia duration of 4 hours, 120 litres of O_2 and 360 litres of air will be consumed. Assuming 200 anesthesia sessions as the average annual activity of a normal operating theatre, the total consumption will be 96,000 litres, of which 24,000 litres is O_2 and 72,000 litres air. On the con-

trary, utilizing an FFG of 0,5 L/min, the total consumption of medical gases will be decreased to 12,000 litres of O_2 (250 ml/min must be guaranteed) and 12,000 litres of air. If using desflurane as the anesthetic agent- and still on a yearly projection-6,680 ml will be utilized instead of 26,720 ml, simply by reducing FFG from 2 l/min to 0,5 l/min, thus saving 4,400 € net in one year according to current market prices.

Conclusions

Thanks to current technological and pharmacological possibilities, low flow anesthesia or closed circuit anesthesia are not exclusively performed by a few anesthesiologist or "risky fellows" with a deep interest in this technique, but are now normally utilized in everyday clinical practice and it is quite important for this type of anesthesia to become a common tradition amongst all anesthesiologists.

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