Maintenance of anaesthesia

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Abstract
The anaesthetist must have a sound pharmacological knowledge with respect to maintenance of general anaesthesia but this is by no means their sole responsibility during this, the longest phase of anaesthesia. The anaesthetist must be constantly vigilant to detect those factors that might jeopardize patient wellbeing or safety as well as giving consideration to those paraclinical matters in the wider context of healthcare service provision.

Keywords General anaesthesia; maintenance; paraclinical elements of anaesthesia; responsibilities during anaesthesia

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Learning objectives

After reading this article, you should be able to:

- outline the pharmacological issues with respect to the maintenance of anaesthesia
- identify five clinical priorities, not related to anaesthesia, that are the anaesthetist's responsibility during maintenance
- list five paraclinical considerations during the maintenance phase

General anaesthesia is a state of induced unconsciousness that involves reversible abolition of responsiveness, awareness and recall in the subject for the duration of the anaesthetic. Anaesthesia can be considered in three phases: induction, maintenance and emergence. This article will examine factors pertinent to the maintenance of general anaesthesia.

Pharmacology

A balanced general anaesthetic consists of the three elements (the triad of anaesthesia): hypnosis, analgesia and muscle relaxation. Historically a single agent such as ether accomplished all three elements. Now anaesthetists customize every anaesthetic to suit the patient and proposed surgery. Agents that individually address each component of the triad are selected and titrated. In order for a general anaesthetic agent to produce a sustained clinical effect it is necessary to maintain a defined plasma concentration and consequently effect-site (brain) concentration. The mode of administration by which agents are delivered to the plasma gives a convenient method of categorization.

Inhalational anaesthesia

Supplementary oxygen is administered throughout all general anaesthetics whether the patient is breathing spontaneously or mechanically ventilated. Although the patient's basal metabolic rate and thus oxygen consumption are generally reduced, there are a number of processes which render oxygen absorption and delivery inefficient, as follows.

- Anaesthesia and opioids suppress ventilation sufficient to produce a hypoventilation hypoxaemia in a spontaneously breathing patient.
- In the supine position basal atelectasis develops resulting in ventilation–perfusion mismatch and shunt hypoxaemia. This is exaggerated with increasing patient age.
- If a head-down position is adopted, abdominal contents push the diaphragm cephelad leading to progressive encroachment of the patient's closing capacity on their functional residual capacity. This results in cyclical small airway collapse.
- The protective mechanism of hypoxic pulmonary vasoconstriction, which usually limits perfusion of poorly ventilated alveoli, is abolished by volatile anaesthetic agents with consequent shunt hypoxaemia.

There have been studies which have shown a tendency to reduced postoperative nausea and vomiting when fractions of inspired oxygen greater than 0.8 are used, but the association has not been consistently demonstrated.[1] During prolonged ventilation on the intensive care unit, fractions of inspired oxygen of 0.5 or less may be tolerated indefinitely without pulmonary or neurological sequelae. The potential for oxygen toxicity increases directly with inspired concentration of oxygen in excess of 0.5 and duration of therapy.

The use of nitrous oxide is diminishing as a supplementary anaesthetic agent and analgesic as more is understood about its side effects. The results of the ENIGMA trial[2] prompted many anaesthetists to abandon nitrous oxide for major surgery as it was associated with higher rates of serious surgical complications as well as severe nausea and vomiting (Table 1).

Volatile anaesthetics agents are halogenated ethers which share many physicochemical, pharmacodynamic and pharmacokinetic characteristics. The characteristics most relevant to maintenance of anaesthesia are: wash-in, distribution and potency (and thus their minimum alveolar concentration). Their washout at the end of the anaesthetic is considered an aspect of emergence.

The inhalational route of drug administration is a multistep process, each step relying on a positive gradient of partial pressure from one phase to the next to ensure the ingress of agent into the patient's brain. A vaporizer delivers a clinically useful concentration of volatile anaesthetic agent to the fresh gas flow,

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Use of nitrous oxide in the carrier gas during a general anaesthetic

Advantages	Disadvantages
Very insoluble — rapid onset/offset	Increased postoperative nausea and vomiting
Concentration effect at induction	Increased postoperative wound infection, pneumonia, atelectasis following major surgery
Analgesic	Diffusion hypoxia
MAC-sparing	Methionine synthetase inhibition — megaloblastic anaemia
Good for short, intensely stimulating procedures	Immunosuppression
Cardiorespiratory stability	Air space expansion
Reduced awareness	Subacute combined degeneration of the cord
Inexpensive	Homocysteine elevation — cardiac risk
	Poorer quality recovery
	Greenhouse gas

MAC, minimum alveolar concentration.

Table 1

so there is a positive gradient from common gas outlet to breathing system. The circuit concentration of agent will rise as a function of the rate at which agent molecules are added to it (which is in turn a function of the fresh gas flow rate and the dialled vaporizer setting). There is then a gradient between circuit and patient airway, patient airway to alveolus, alveolus to pulmonary capillary and ultimately blood to brain. It can be seen that a number of factors influence volatile anaesthetic agent wash-in during the transition between induction and maintenance of anaesthesia:

- fresh gas flow rate and dialled vaporizer concentration
- volume and pattern of respiration (especially presence of end-expiratory pause)
- volume and nature of breathing circuit (re-breathing versus non-re-breathing)
- patency of small airways
- adequacy of ventilation–perfusion matching
- agent solubility in blood
- pulmonary blood flow (i.e. cardiac output)
- blood–brain solubility
- solubility of agent in other tissues which affects the distribution of agent and thus influences ongoing rate of delivery.

During the transition from induction to maintenance the anaesthetist may increase fresh gas flow rates and vaporizer settings to 'flood' the breathing circuit with volatile agent promoting a steeper concentration gradient into the patient (the overpressure technique). This is not suitable for agents such as desflurane where a rapid increase in inspired concentration can produce airway irritation and sympathetic stimulation (increased heart rate and blood pressure). Fortunately desflurane is so insoluble in blood that overpressure is not required for rapid uptake and more modest fresh gas flows may be employed from the start. The blood:gas solubility coefficient of a volatile agent is a major determinant of rate of equilibration (Figure 1). In the alveolus, soluble agents rapidly and easily dissolve in pulmonary capillary blood before that blood returns to the heart. Although a larger quantity of the soluble agent is deposited in the blood, a concentration gradient between alveolus and blood is maintained such that the partial pressure of the agent in the alveolus and blood is slower to equilibrate. It is the partial pressure of the agent in the blood (and ultimately the brain) and not the absolute quantity that is responsible for its clinical effect. It follows that a less soluble agent will reach equilibrium faster (as a lesser quantity of agent dissolves into the blood) and its wash-in time will be quicker. This is illustrated by comparing the wash-in graphs in Figure 1 to the blood/gas partition coefficients.

Similarly, a reduced cardiac output quickens wash-in of a volatile agent because the pulmonary capillary transit time will be longer. This enhances progress towards equilibration of alveolar and blood partial pressure on every pass through the lungs.

The potency of a volatile anaesthetic agent may be expressed in terms of its minimum alveolar concentration (MAC). These values are derived from population studies of subjects in contexts that are not entirely comparable to our daily practice of anaesthesia. Caution must be exercised before applying MAC values to individual patients because of the number of factors which influence MAC. MAC is the percentage concentration of volatile in stated carrier gas, at steady state (for at least 15 minutes) and at sea level that will obtund spontaneous physical movements in response to a surgical skin incision in the groin in 50% of un-premedicated, unparalysed patients aged 40 years. It is very unusual that these pre-conditions would be satisfied in clinical practice. It precludes the use of benzodiazepines and opioids at induction as these reduce MAC. Movement is

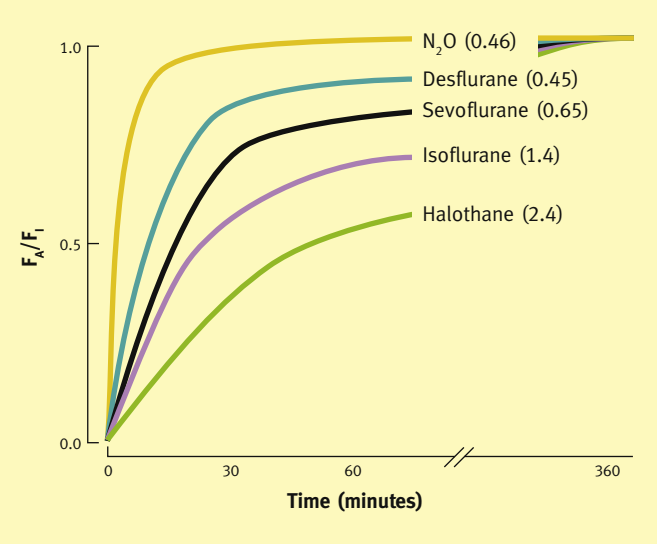

Figure 1 For the less soluble agents, alveolar partial pressure and thus arterial partial pressure more rapidly equilibrate with inspired partial pressure. F_A = fractional concentration of the volatile agent in the alveolus. F_I = fractional concentration of the volatile agent inspired. Values in brackets are the blood:gas partition coefficients of the agents.