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1 PREFACE

This booklet is designed as a basic introduction to the field of anesthesia for a variety of interested professional groups. These include healthcare and auxiliary staff, technicians, salespeople, service engineers, cleaners, instructors, and anyone else wishing to learn about the fundamentals of anesthesiology. It is partly based on previous Maquet training material that has been revised and updated.

The information is intended to be simple and accessible to many different user groups and includes diagrams, tables and graphs to illustrate the text and provide a better overview. The presentation is deliberately straightforward and readers interested in the more advanced aspects of anesthesia should refer to specialized textbooks, some of which are listed under "References".

No previous knowledge of anesthesia is required to understand this booklet, which is designed to serve as a useful key to a field that may sometimes appear bewildering to outsiders. Some familiarity with clinical concepts and environments is however an advantage since medical terms are often used in the descriptions. As in many other specialized areas, the use of medical jargon and abbreviations may confuse newcomers. A conscious effort has therefore been made to avoid complex terminology and "insider" shorthand. Readers will also find many specialized words and acronyms explained in the "Glossary" at the end of this booklet. These terms are highlighted in bold the first time they appear in the text.

After two brief introductory chapters, the next five chapters focus on what happens to the patient during anesthesia. The perspective is more technical in remaining chapters where the focus is on the machinery and equipment used. Optimal patient care requires familiarity with all these aspects, although different professional categories may wish to concentrate on the areas most relevant to their interests.
The specialized field of anesthesiology focuses on keeping patients (who may be seriously ill or traumatized) stable and pain-free during surgery - a form of continuous intensive care. Traditionally, anesthesiologists have been at the forefront of critical care medicine. Their work thus involves much more than simply putting patients to sleep.

There is a considerable lack of consensus when it comes to how to refer to the various personnel groups involved in anesthesia. The problem is that both anesthesia and intensive care services are organized differently in different countries. So while it is the anesthetist/anesthesiologist who handles all patient care in some countries, in others the nurse anesthetist may play a central role in uncomplicated anesthesia procedures. To avoid confusion, the terms "anesthetist" and "anesthesiologist" are used somewhat loosely and interchangeably in the text below to refer to the person in charge of the anesthesia procedure, whatever that person's professional title, gender or role.

Anesthesia is generally associated with the hospital environment, particularly the operating room. It is however useful to remember that anesthesia is nowadays also used in the radiology department and the emergency room, as well as during childbirth or MRI examinations, for outpatients and on hospital wards. Meanwhile, hospitalization times are also decreasing steadily all the time. In addition, anesthesia is used for dental surgery, in cosmetic surgery clinics and psychiatric units, as well as on the sites of accidents. The OR, however, remains the most important environment for the anesthesiologist and some familiarity with its layout is therefore necessary.

2.1 SURGICAL WORKPLACES

Surgical workplaces will of course differ in layout from one hospital to the next, depending on the specific uses to which they are put. Some knowledge of concepts and functions routinely used in most such workplaces is however required.

Surgical workplaces can roughly be divided into three areas depending on the level of cleanliness:

- A general access area that is open to all personnel groups and often includes a central reception desk or nursing station, along with a waiting area. Ordinary clothes are permitted here.
- A "clean" area with more restrictive dress, requiring special clothes, including headgear, not worn outside the area. Routines nowadays generally also require the removal of all jewelry and watches, since they are known to be a potential source of infection. The area includes corridors and storage areas, as well as the anesthesiologist's workplace in the OR, where a surgical mask is generally recommended.
- A "sterile" area that includes a large part of the operating room and its contents, in which a surgical mask must always be
worn. Surgeons and their assistants will also put on sterile robes ("scrubs") and gloves after the routine scrubbing-up and disinfection procedures.

Individual operating rooms or theaters may also vary in design and layout depending on practicalities and preferences.

The main components will however be recognizable almost anywhere and will generally include the following:

- an operating table for the patient
- an anesthesia machine
- a stand or cart with work surface for anesthetic equipment and drugs
- a pole for intravenous fluids
- a suction device for removing mucus from the airways and clearing the stomach
- surveillance monitors
- stands for surgical instruments
- a stand for compresses, etc.
- a stand for surgical samples and specimens
- a surgical suction device
- a diathermy or surgical cautery unit
- TV monitor/X-ray equipment
- PC/laptop.

As is obvious from this list and the illustration below, the operating room is often very crowded and freedom of movement may be extremely restricted, particularly for the anesthetist. Hospitals are therefore always on the lookout for equipment that will save space as well as money. It should also be easy to handle and ergonomically designed.

2.2 HISTORICAL OUTLINE

The following is a brief historical overview of the last two centuries of developments in the world of anesthesia. It should of course be remembered that efforts to reduce and control pain naturally predate this summarized outline. Examples include the use in many ancient civilizations of methods such as acupuncture, and plant or herbal extracts such as mandragora, to relieve pain or induce sleep.

- 1799 - The analgesic effects of nitrous oxide were discovered.
- 1818 - The anesthetic effect of ether vapor was discovered.
- 1831 - Chloroform was discovered.
- 1842 - Dr C. W. Long first used diethyl ether for surgical anesthesia.
- 1844 - Dr H. Wells used nitrous oxide for dental analgesia.
- 1846 - Dr W.T. Morton made the first public use of ether for anesthesia.
- 1853 - Dr J. Snow used chloroform on Queen Victoria during the birth of Prince Leopold.
- 1884 - Cocaine was first used for local analgesia.
- 1917 - The face mask was introduced.
- 1920 - Tracheal tubes were introduced by Magill to deliver inhaled anesthetics.
- 1920 - Guedel published data on signs and depths of ether anesthesia.
- 1930 - The circle system and CO₂ absorber were described by Dr Sword.
- 1934 - Thiopental induction was first used by Dr Lundy.
- 1938 - A positive pressure respirator was used during surgery.
- 1942 - Tubocurarine was used for surgical muscle relaxation.
- 1949 - Succinylcholine was used for muscle relaxation.
- 1956 - Halothane was used clinically by Johnson.
- 1960 - Xenon was introduced for anesthesia.
- 1972 - Enflurane was introduced in clinical use.
- 1981 - Isoflurane was used clinically.
- 1985 - Mallampati suggested a special method for assessing intubation difficulty.
1986 - The American Society of Anesthesiologists, ASA, approved the first standards of basic anesthesia monitoring.

1989 - Propofol came into clinical use.

1990 - Pulse oximetry was added to ASA standards.

1992 - Desflurane was introduced in clinical use.

1994 - Sevoflurane came into clinical use.

1996 - etCO₂ (end tidal carbon dioxide) monitoring was added to ASA standards, complementing existing requirements concerning oxygen monitoring.

2005 - New ASA Standards for Basic Anesthetic Monitoring were published in the same year in which ASA also celebrated 100 years as a professional organization for anesthesiologists.
3 ANESTHESIA - A BRIEF OVERVIEW

3.1 BASIC INFORMATION

The word anesthesia comes from a Greek term meaning "without feeling", implying that the patient is not sensitive to external stimuli such as pain. General anesthesia means that the whole body is anesthetized and involves sleep or unconsciousness (hypnosis), painlessness (analgesia), reduced or abolished reflexes and muscular relaxation. In fact, the three concepts are sometimes referred to as "the triad of anesthesia".

Another important component of general anesthesia is amnesia, which means that the patient should have no recollection of any events after consciousness was lost.

Anesthesia is generally subdivided into three types described under the headings below.

3.1.1 LOCAL ANESTHESIA

As the name implies, agents are administered topically as creams, sprays or gels, or by injection, to achieve a purely local effect. The patient is fully conscious, though sometimes mildly sedated by a suitable drug, generally administered orally.

Traditions may vary from one country to the next and a variety of related substances may be used. These include procaine (one of the earliest local anesthetics), lidocaine, etidocaine, prilocaine, mepivacaine and bupivacaine, as well as more recent additions such as ropivacaine and levobupivacaine. Local anesthesia will be familiar to anyone who has been treated by a dentist. Like regional anesthesia, discussed below, it may also serve as a useful complement to other forms of anesthesia.

3.1.2 REGIONAL ANESTHESIA

Local anesthetic agents are injected/infused to achieve a regional effect. Examples include spinal and epidural anesthesia, as well as peripheral nerve blocks. Once again, the advantage is that the patient can be fully conscious but feels no pain. Different agents may be used and the anesthetic drugs are sometimes complemented with opioids administered epidurally or intrathecally.

Regional anesthesia can be used either alone or in combination with other forms of anesthesia to provide excellent operating conditions and prolonged pain relief.

3.1.3 GENERAL ANESTHESIA

This involves a condition generally characterized by

- sleep or unconsciousness
- painlessness
- reduced or abolished reflexes and subsequent amnesia
- when necessary, reduced muscular tonus.

General anesthesia is in turn subdivided into several types depending on how the anesthetic agents are administered:

- inhalation anesthesia, where the agent is administered via inhalation;
intravenous anesthesia, where the agent is given by intravenous injection or infusion;

- balanced or combined anesthesia, where both of the above methods are used. This offers an opportunity of combining the best qualities of different agents, enabling dosages to be adjusted and potential savings to be made, while also allowing anesthetic methods to be adapted to specific needs.

Since the patient under general anesthetic is unconscious, it is imperative for the anesthetist to monitor a number of vital parameters with great care. All life-sustaining care revolves around the airways, breathing and circulation. In the context of anesthesia, this may involve the use of intubation to ensure free airways, manual or machine assisted ventilation to help the patient breathe, and infusion fluids to ensure patient hydration, as well as carefully selected drugs to optimize circulation.

In addition, the anesthetist must monitor and control the level of the patient's consciousness and ensure that he/she remains insensitive to pain with the help of intravenous or volatile, i.e. inhalation, pharmaceuticals. These aspects are of course interrelated and have an impact on each other as well on patient status. Anesthesia is thus a complex and specialized branch of medicine, and different patients require the anesthetist to focus on different aspects. Each procedure therefore needs to be tailored to suit individual needs and prevailing conditions.

3.2 GENERAL ANESTHESIA ROUTINES

Although every patient case is unique and individual hospitals and doctors have different local routines, it is possible to identify a pattern common to most forms of general anesthesia. The section below outlines the various stages involved, while coming chapters will focus more on some of their details.

3.2.1 PREOPERATIVE ASSESSMENT

This is a chance for the anesthetist to meet the patient, inform him/her about the planned procedures, perform a physical examination and discuss any questions. General health status, laboratory values, drug therapy and planned type of surgery are all taken into account in selecting the anesthesia method.
3.2.2 PREANESTHETIC PREPARATIONS

Preparations may vary depending on local tradition. Fasting is often recommended, although patients in some countries are now allowed clear liquids up to 2 hours before planned surgery. Sometimes, carbohydrate drinks may even be given up to 2 hours before induction to prevent post-operative insulin resistance. There are also variations in premedication routines. These involve administering drugs for sedation and anxiety relief either before or after transportation to the operating room (OR). In the OR or a preparatory room, the patient is greeted by the anesthesiologist or anesthetist nurse, who checks lab values and ID. The patient is then moved to the operating table and carefully positioned to avoid discomfort or injury during surgery. For some types of surgery it may be necessary to reposition the patient after he/she has been put to sleep (see chapter 12).

3.2.3 MINUTES BEFORE ANESTHESIA

Routines for the order in which the various steps are taken may vary from one clinic to the next. As a general rule, however, all watches and jewelry should have been removed before the patient arrives in the OR, although it is a good idea always to check that this has been done. (These days, it may also be a good idea to ask about any piercings.) If an intravenous line is not already present, one should be arranged. Oxygen (usually 80-100%) is given via a face mask to increase the amount of oxygen in the lungs before induction (preoxygenation). The anesthetist will also attempt to reassure nervous patients and help them to relax.
3.2.4 INDUCTION

To put the patient to sleep, a short-acting hypnotic agent is given intravenously, although sleep is sometimes also induced by inhalation of an anesthetic agent via a face mask. Whichever method is preferred, a face mask is used to assist patient breathing and a check is made to ensure patent airways. If muscle relaxation is needed for surgery or intubation, muscle relaxants are given. In this case, some form of analgesia (generally an opioid) may also be given to avoid pain during intubation. A laryngeal mask or an endotracheal tube is fitted to administer a mixture of oxygen (30-40%) and nitrous oxide (60-70%), although medical air may also be used for ventilation.

3.2.5 MAINTENANCE

Anesthesia is maintained by continuously supplying the patient with anesthetic agent via inhalation or intravenous infusion. The dosage is adapted to individual needs. Careful monitoring and/or observation are essential. The parameters generally include ventilation, gas concentration, circulation (pulse, blood pressure, ECG), temperature (continuous or intermittent), degree of muscle relaxation, fluid balance (fluids given and lost), metabolism (blood glucose, acid-base balance), and sometimes depth of anesthesia. Sophisticated equipment is not always necessary. A great deal of information can be obtained through careful observation and alertness to changes in status.
3.2.6 ELIMINATION

Anesthetic agents are eliminated via the lungs or broken down by the body and removed as metabolites. Antidotes may be given to counteract specific agents, although this is not common. Once the patient is awake, the laryngeal mask or endotracheal tube is removed (extubation) and pure oxygen is generally given via nasal prongs.

3.2.7 RECOVERY

The patient is taken to the recovery room or postoperative ward for recovery and monitoring of vital functions. Once the patient's condition is stable, he/she is transported back to the ward or possibly even sent home, depending on the type and extent of the surgery performed.

In principle, all procedures involving general anesthesia will follow a pattern similar to the one described above.
**4 PATIENT ASSESSMENT AND PREPARATIONS**

Anesthetic procedures are nowadays commonplace, safe and relatively simple as long as appropriate training has been provided. In fact, the level of risk associated with modern anesthesia is now so low (when the patient’s only medical problem is what brought him or her to surgery in the first place) that it is virtually impossible to perform randomized studies to evaluate the risks associated with new procedures or equipment. This is due largely to developments over the last twenty years, particularly the introduction of reliable equipment and careful monitoring by qualified personnel.

### 4.1 THE PATIENT’S CONDITION BEFORE ANESTHESIA

Thorough knowledge of the patient’s case history, current health status, drug therapy, laboratory values and indications for surgery help prevent unnecessary problems and select the best anesthetic method. Preoperative assessment should be part of hospital routines for all patient categories. The extent and level of detail will however vary depending on the patient’s health status, clinical condition, intended surgery and prevailing circumstances. The most important element is the taking of a careful case history.

#### 4.1.1 PATIENT RECORDS

The case history provides details of the patient’s medical history, including surgical operations and types of anesthesia, as well as allergic tendencies, coagulation disorders, pregnancy, muscular disorders, rheumatic or endocrine disease, neurological or cardiac disorders, hypertension, lung disease and hereditary disorders, such as a predisposition to develop malignant hyperthermia.

#### 4.1.2 PATIENT INTERVIEW AND EXAMINATION

The interview is an opportunity for the anesthetist to ask questions and for the patient to find out more about the planned procedures. The assessment should include general state of health, degree of mobility (particularly mouth and neck), blood pressure, functional heart and lung status, assessment of potential intubation difficulties (see "Endotracheal intubation" in chapter 5), dental status, body height and weight.

Depending on the patient and the intended surgery, it may be necessary to obtain an ECG and a laboratory status. The latter will generally includes hemoglobin, serum electrolytes and serum creatinine, although it may be extended to cover liver status, coagulation and hemostasis status and blood glucose. It is important to discuss current drug therapy, particularly drugs used to treat heart disease, anticoagulants, vasoactive agents, psychotherapeutic drugs and steroids. Alcohol or drug abuse may have adverse effects on anesthesia and the anesthetist should ask about such problems and bear them in mind, even if patient answers may sometimes be unreliable. Inquiries should also be made about bleeding disorders, both hereditary and acquired. The patient’s blood group should also be routinely ascertained or checked ahead of major surgery.
4.1.3 THE ASA SYSTEM

Patients undergoing surgery and anesthesia may differ tremendously in terms of age, constitution and health status. It is therefore useful to assess and categorize them in a standardized manner so as to avoid misunderstandings and improve patient outcome.

When assessing patient status prior to anesthesia, the anesthetist interviews patients and generally groups them in accordance with the globally accepted ASA (American Society of Anesthesiologists) classification outlines below.

- **ASA Class 1**: No systemic or psychiatric disease, the patient is healthy and normal.

- **ASA Class 2**: Moderate systemic disease that does not limit the patient’s activities and is often under good medical control, e.g. a patient with well controlled hypertension or diabetes without medical complications.

- **ASA Class 3**: Moderate or severe systemic disease that does limit the patient’s activities and may be under incomplete medical control, e.g. stable angina pectoris, diabetes with medical complications, previous myocardial infarction or emphysema.

- **ASA Class 4**: One or more severe systemic diseases that are life-threatening. e.g. severe congestive heart failure, advanced renal insufficiency, liver or lung disease, recent myocardial infarction.

- **ASA Class 5**: Severe illness in a patient running a substantial risk of death within 24 hours with or without surgery, although it is considered "best to try".

- **The E designation**: Emergency status. In addition to indicating underlying ASA status (1-5 above), any patient undergoing an emergency procedure is given the suffix "E". A fundamentally healthy patient, for example, undergoing emergency surgery such as an appendectomy is thus classified as 1-E. The E designation is not used when surgery is planned.

- **ASA Class 6**: Organ donors who have already been pronounced clinically dead but are waiting for surgery to be performed.

This information may be included in the anesthesia record chart under preoperative assessment (see chapter 7).

4.2 PREANESTHETIC PREPARATIONS

Different hospitals and anesthetists have their own routines although these tend more or less to follow the outline below.

4.2.1 INFORMATION

Most patients are unnerved at the prospect of anesthesia and surgery, although anxiety levels may vary considerably. It is therefore a good idea to inform the patient thoroughly about the procedure and what to expect.
4.2.2 ENSURING THAT THE STOMACH IS EMPTY

The traditional view is that the stomach should be empty before anesthesia and surgery, since vomiting is a complication which may be life-threatening if aspiration to the lungs occurs. Fasting (both food and drink) is therefore often recommended for 4-5 hours before anesthesia, or longer if patients are pregnant or overweight. Variations in this routine do however occur, particularly with regard to fluid intake (see under "Preanesthetic preparations" in chapter 3 above). In case of emergency that precludes fasting, a rapid sequence induction (RSI) is used.

Fasting may cause dehydration, which is why a preoperative infusion is often given. Attitudes to the use of larger quantities of infusion fluids have however recently become more restrictive.

4.2.3 DRUG THERAPY

The patient's normal drug therapy may require changes due to surgery and anesthesia. Some drugs, such as peroral anticoagulants and aspirin, should be avoided before all types of surgery.

Others, such as insulin treatment, corticosteroids, epilepsy medication and hypertension and heart medication, must be carefully assessed and sometimes adjusted.

4.2.4 PREMEDICATION

If premedication is given, its purpose is generally fourfold:

- to raise the pain threshold
- to sedate the patient and relieve anxiety
- to reduce reflex central nervous activity
- to counteract any side effects of anesthesia and surgery.
5 MANAGING THE AIRWAYS

Airway management is crucial in all forms of general anesthesia, and both the agents and the equipment used for this purpose are kept close to the patient. Even when patients are breathing spontaneously, the anesthetist must always be ready to take control of ventilation. Ensuring free airways and adequate ventilation is essential to safe anesthesia.

5.1 FREE AIRWAYS AND ASSISTED BREATHING

5.1.1 FACE MASK

When surgery is elective and requires general anesthesia, the patient is generally ventilated via a face mask during induction and sometimes after extubation. During the procedure, the patient may either breathe spontaneously or with the anesthetist's assistance in the form of manual or controlled ventilation. For emergency procedures, routines are somewhat different.

Previously, only short operations were performed with the patient breathing spontaneously. Recent developments, such as the laryngeal mask, however, now enable spontaneous breathing during longer procedures as well.

5.1.2 LARYNGEAL MASK

The LMA (for laryngeal mask airway) is becoming increasingly popular as an alternative to the face mask, since it frees the anesthetist's hands and simplifies the job of ensuring free airways.

The laryngeal mask is also widely used as an alternative to endotracheal intubation, since the latter may sometimes give rise to complications and problems.

The mask is positioned so that the tip covers the upper esophageal sphincter, ensuring free passage of air to the trachea. Once the mask is in place, the rim is inflated.
It is primarily used during spontaneous or supported breathing, but is also gaining more widespread acceptance for use in combination with controlled breathing modes.

There is now a growing range of LMAs, both for one-time use and re-use, available in the market in a variety of sizes and designs and with different accessories. Some have also been adapted to allow for the insertion of a gastric tube. These developments contribute to their increasing popularity.
5.1.3 ENDOTRACHEAL INTUBATION

Certain types of surgery or specific patient positions on the operating table may make it necessary to intubate the patient.

This is done with the help of a laryngoscope, which enables the intubator to visualize the larynx. The blades of this instrument are available in different sizes to suit a range of patients.

The endotracheal tube (ETT) is then inserted and positioned so that the tube’s cuff is below the vocal cords. The cuff is then inflated to prevent aspiration and leakage. The tube is also available in a variety of sizes and may be inserted via either the nose or the mouth. It is almost always disposable.

As mentioned in connection with preanesthetic evaluation, potential difficulties associated with intubating patients should be assessed before the procedure. This generally involves assessment of mouth opening and neck extension, as well as vocal cord visualization. Sometimes a special classification system is used, the most widely accepted of which is the Mallampati system.

In cases where major difficulties are envisaged, it may sometimes be necessary to resort to a fiber optic bronchoscope (FOB). All intubation is of course only performed by trained medical personnel and care is always taken not to damage the teeth, mucous membranes, vocal cords or surrounding tissues.

When intubating infants, no cuff is used on the endotracheal tube due to the sensitivity of their mucous membranes, since any swelling
may lead to serious breathing problems after extubation. Allowances must therefore be made in pediatric anesthesia for leakage around the tube.

5.2 PATIENT VENTILATION

The following is a brief outline of gas administration and breathing systems. For a more detailed description of various breathing circuits and of the anesthesia machine as a whole, the reader is referred to chapters 8 and 9.

5.2.1 GAS ADMINISTRATION

Oxygen, nitrous oxide and medical air are provided via pipes from cylinders or the hospital’s central supply. Gas pressure is reduced for medical purposes. The flow rate and concentration of the gases are individually set and altered during anesthesia. Traditionally, the anesthesia machine’s flowmeters allow the anesthetist to set the dosage.

The gases then pass through a vaporizer, when used, containing a volatile agent used for inhalation anesthesia. If such a vaporizer is not in use, the gas mixture is supplied straight to the breathing system.

5.2.2 BREATHING SYSTEMS

Inhalation agents are given via the breathing system, which may differ from one machine to the next with regard to level of sophistication and the degree to which it incorporates rebreathing. At the rudimentary level, most systems will include the following:

- patient tubing
- fresh gas inlet
- bag for manual ventilation
- ventilator
- unidirectional valves and/or pop-off or relief valves
- CO₂ absorbent canister when rebreathing systems are used.

Developments have led to substitutions and additions to this basic breathing apparatus. These are also described in greater detail in chapter 9.

5.3 MANUAL VENTILATION

It must always be possible for the anesthetist to support patient ventilation or control it completely. On most machines, access to a bag for manual ventilation is therefore standard. It should be checked at regular intervals to ensure that it is fully functional. Both bags and tubing come in a variety of sizes for different patients and uses.

5.4 MECHANICAL VENTILATION

In general, the ventilator on the anesthesia machine is used when surgery necessitates muscle relaxation or is due to last an hour or more. However, a certain amount of flexibility is often necessary depending on the patient, the surgery to be performed and local routines and preferences. Mechanical ventilation is discussed in chapter 8.
6 ANESTHESIOLOGICAL METHODS AND PHARMACEUTICALS

The preoperative assessment helps the anesthetist select the appropriate method to use based on the patient’s health status and wishes, the type of surgery to be undertaken or environment in which it takes place and the examination results, etc. The following provides a brief guide to the most common anesthetic methods in use today.

6.1 REGIONAL ANESTHESIA

There are several forms of regional anesthesia (see chapter 3), of which those involving a central block of the spinal cord or the nerves leaving it are perhaps the most widely known and used. They may be used alone or in combination with other forms of anesthesia and are briefly described below.

6.1.1 SPINAL ANESTHESIA

The anesthetic is injected into the cerebrospinal fluid (CSF) that bathes the spinal cord and brain. The needle is generally inserted just below the intervertebral space between the first and second lumbar vertebrae, known as the L1-L2 level, although this may vary with the type of surgery.

A combination of a local anesthetic and an opioid is often used. The extent of the block depends on the level reached by the anesthetic in the cerebrospinal fluid, which is in turn governed largely by the dose administered. This method is common during operations performed below the waist and lasting less than two hours, for example hip surgery and elective caesarean section.

6.1.2 EPIDURAL ANESTHESIA

Again, a local anesthetic is injected in the lumbar (or thoracic) region, but the needle stops in the epidural space surrounding the membrane (or dura) around the cerebrospinal fluid. Normally, a fine catheter is left in place which can be used for post-operative pain relief (epidural analgesia). The anesthetic blocks the nerves that pass through the epidural space as they leave the spinal cord.

Epidural analgesia is perhaps best known for its use during childbirth, although it does have other areas of application, such as for analgesia after major abdominal surgery.

6.1.3 CONTRAINDICATIONS

The main contraindications for regional anesthesia used alone are as follows:

- allergy to local anesthetics
- patient choice
- uncooperative or restless patients
- bleeding disorders
- ongoing anticoagulant therapy
- topical infections.

6.2 GENERAL ANESTHESIA

This common form of anesthesia is generally divided into the following categories:

- intravenous anesthesia
- inhalation anesthesia
- combined (or balanced) anesthesia.

6.2.1 INTRAVENOUS ANESTHESIA

Anesthetic agents that are given intravenously are rapidly distributed. Their actions and possible side-effects are immediate in patients with normal circulation. With inhalation anesthesia, however, it can take several minutes to achieve a specific anesthesia level that only takes seconds to achieve intravenously.

DOSAGE

By combining different drugs, the specific benefits of each can be utilized to tailor anesthesia to the individual patient. Effective analgesics can be carefully dosed and combined with sleep inducing drugs to anesthetize the patient.

METABOLISM AND ELIMINATION

The elimination of intravenous agents depends mainly on liver metabolism and renal function and generally takes longer than that of inhaled agents. Remifentanil, however, which is a relatively recently developed fast-acting opioid, is metabolized by blood and tissue enzymes, so its elimination is not dependent on the liver and kidneys.

FREQUENCY OF USE

Total intravenous anesthesia (TIVA) is less common than combined anesthesia, in which several administration routes are used simultaneously. It is however preferred in some parts of the world or for special purposes, and some experts see a trend towards increasing use.

6.2.2 INHALATION ANESTHESIA

Inhalation anesthesia is a popular method because the gases and agents used are easy to measure and control, with the lungs acting as a kind of "buffer". Less appealing is the fact that we still do not know exactly how inhaled anesthetic agents work.

These agents are volatile liquids that are vaporized and administered to the patient in a gas mixture, generally oxygen-nitrous oxide or oxygen-air. General laws governing gas pressure, volume, temperature, flow and concentration are thus applicable here. It has been suggested that the agents act on the proteins in the cell's lipid membrane and their potency is thus related to their solubility in fat. This also makes sense when one considers that their target organ, the brain, is largely composed of fat.
It also explains why halothane, which used to be a very popular anesthetic agent and is highly lipid soluble, is the most potent of the anesthetic agents, while nitrous oxide, which is comparatively insoluble in fat, has the lowest potency of the agents in clinical use.

Lipid solubility is represented by the oil/gas partition coefficient (OGPC), although in clinical practice, potency is generally associated with the Minimum Alveolar Concentration (MAC). The pharmacokinetics of the agent (how fast it reaches and leaves the brain) must also be considered when discussing inhalation anesthesia. The important factors are the concentration of anesthetic agent in the inspired gas mixture, the choice of gas mixture, alveolar ventilation, the blood flow to the lungs (or cardiac output), the gradient between venous and arterial blood and agent solubility in blood and other tissues. These aspects are all discussed in more detail below.

**MAC - MINIMUM ALVEOLAR CONCENTRATION**

MAC is an index of the anesthetic potency and thus the pharmacological effect of an inhalation agent. It is defined as the agent's alveolar concentration (in percent), as reflected by the expired end-tidal concentration, at which 50% of patients will not move in response to a surgical stimulus (skin incision). 1.3-1.4 MAC is the alveolar concentration needed for surgical anesthesia.

It should be noted that MAC is higher in infants and lower in the elderly, and that both opioids and premedication allow surgery to be performed at a lower MAC. Another important aspect is that if more than one anesthetic agent is used, the MAC values are additive. Thus, 0.6 MAC of nitrous oxide combined with 0.4 MAC of isoflurane is equivalent to 1.0 MAC of isoflurane. Two volatile agents, such as sevoflurane and desflurane, will also have additive effects. Several other concepts are occasionally used in relation to MAC, such as "MAC 95%", "MAC awake" and "MAC aware". They refer to different MAC levels ("MAC aware", for example, is about 0.3 MAC).

**UPTAKE OF INHALATION AGENTS**

During inhalation anesthesia, it is crucial to ensure a rapid and adequate concentration of anesthetic agent in the brain. Since the agent's partial pressure in all tissues eventually approaches that in the alveoli, the alveolar partial pressure at steady state reflects the partial pressure in the brain. It should however be noted that anesthetists (and anesthesia machines) generally measure end-tidal concentrations as volume fractions in percent, rather than as partial pressures, since MAC is also a percentage value.

A high fresh gas flow and high agent concentration in the gas mixture enable the anesthetist to increase the agent's alveolar partial pressure rapidly. These two factors are thus the major determinants of how rapidly the agent is delivered to the brain.

Agent uptake is best described by the rate at which alveolar concentration ($F_A$) rises in relation to inspired concentration ($F_I$). If cardiac output is constant, the increase in the $F_A/F_I$ ratio over time reflects the degree of solubility of the agent in blood.
Wash-in curve for inhalation agents (rate of vapor uptake)

**SOLUBILITY OF INHALATION AGENTS IN BLOOD**

The solubility of an inhalation anesthetic determines how fast it both works and wears off. The less soluble the drug, the faster it works. The term also denotes the amount of agent that dissolves in the blood in relation to the amount present in the alveolar gas at the same partial pressure. Thus if one liter of blood is exposed to one atmosphere of isoflurane, then 1.4 liters of the agent will have entered the blood once steady state is reached.

The solubility of an agent is specified by its blood/gas partition coefficient (BGPC).

A highly soluble anesthetic, such as ether, will thus dissolve to a far greater extent in the blood, thereby successively decreasing the amount in the alveoli (if no further agent is supplied). Nitrous oxide, on the other hand, is highly insoluble. It will therefore remain in the alveoli, with only a small amount (0.47 liters if the same experiment as above is conducted) passing into the blood. Its alveolar partial pressure thus remains high, which means that the partial pressure in the brain will also be high, as explained above. This results in a short induction time.

**GRADIENT BETWEEN VENOUS AND ARTERIAL BLOOD**

The gradient between mixed venous blood and arterial blood depends on the uptake in different tissues. Anesthetic agents have different partition coefficients in different tissues and this naturally affects their uptake. Potent agents (those with low MAC values) that have a high solubility in fat dissolve to a greater extent in fat-rich tissues.

There will thus be a larger partial pressure gradient between venous and arterial blood in fat-rich tissues, such as the brain. The main coefficient of interest here is the oil/gas partition coefficient. An agent with a high coefficient, such as halothane, will have
greater potency at the site of action than an agent with a low coefficient, such as desflurane. In addition, organs with a high rate of perfusion (such as the brain, kidneys, liver and heart) equilibrate more rapidly with the alveolar partial pressure than organs with a lower rate of perfusion.

**CARDIAC OUTPUT**

Higher cardiac output means higher pulmonary blood flow. The agent is therefore more rapidly distributed from the alveoli, reducing alveolar partial pressure. Reduced cardiac output, on the other hand, means decreased uptake of the agent and the alveolar concentration may then be much higher than the concentration in the inspired gas mixture. The net effect depends on the agent used and its solubility, as explained above.

**THE CONCENTRATION AND SECOND GAS EFFECTS**

If a gas with a low potency (or high MAC), such as nitrous oxide, is part of the inspired gas mixture, two phenomena known as the concentration effect and the second gas effect will occur. These are explained below.

Since the required concentration of nitrous oxide is high, its uptake into the blood will be rapid. The expired nitrous oxide volume will be lower than the inspired volume, which means that the oxygen and any second anesthetic agent will be diluted in a smaller volume, leading to the alveolar concentration that the effect is named after.

The alveolar partial pressure of any accompanying gas will also rise more quickly, which means that induction with an inhalation anesthetic is more rapid in the presence of nitrous oxide. This is known as the second gas effect.

6.2.3 PRACTICAL EXAMPLE

The main steps involved in anesthetizing a patient with the help of inhalation agents are described below. As noted previously, combined or balanced anesthesia, in which intravenous agents are used together with volatile inhalation agents, remains the most widely used method.

**INDUCTION**

**INHALATION INDUCTION**

This method makes use of a face mask through which a mix of oxygen and nitrous oxide or oxygen and air is initially given, after which an inhalation anesthetic, such as sevoflurane, is introduced by the anesthetist. An alternative is the single-breath technique for patients able to cooperate, which gives rapid induction within 20-30 seconds. Inhalation induction is used for young children and patients with upper and lower airway obstruction.

**INTRANOVENOUS INDUCTION**

A drug such as propofol or a fast-acting barbiturate is often used during induction to put the patient to sleep. It is administered intravenously while oxygen is given via the mask. This is the most common induction method and is especially appropriate for patients undergoing emergency surgery where
there is a risk of **regurgitation**. The method is then referred to as "rapid sequence induction" (RSI) and is described below (see under "Anesthesia in emergency conditions" in chapter 13).

**RAPID SEQUENCE INDUCTION**

- Tilt the table and ensure that suction is ready. A trained assistant must be present and IV access must be secured. Sometimes, gastric volume is first minimized via a nasogastric tube and occasionally gastric acidity is reduced pharmacologically.

- Preoxygenate the patient for about 3 minutes, if possible.

- Give an appropriate sleep dose of the induction agent.

- Apply **cricoid** pressure (this involves pressing against the cricoid cartilage to push it backwards, compressing the esophagus. Moderate pressure may be applied before loss of consciousness, and firmer pressure maintained until the cuff of the tracheal tube is inflated.)

- Give suxamethonium, 1 mg/kg, and proceed with intubation, checking the position of the tube before releasing the cricoid. Secure the tube.

**MAINTENANCE**

The concentration of the gas is then lowered to the desired level for anesthesia maintenance.

**ELIMINATION AND RECOVERY**

Modern inhalation agents are mainly eliminated via the lungs since they are only metabolized to a very limited extent. Toxicity is largely dependent on the amount metabolized. Agents that are metabolized to a lesser extent are eliminated almost solely via the lungs.

Recovery times are similar to induction times, in that less soluble agents have quicker recovery times. It should however be noted that lengthy periods of anesthesia require much longer recovery due to the accumulation of anesthetic agent in fat-rich tissues.

**INHALATION TO STEADY STATE**

Regardless of induction method, an inhalation agent is now added in fairly high concentrations to an oxygen-nitrous oxide/oxygen-air mixture until steady state is achieved.
One example of the process described above is illustrated in the simplified four-part drawing below.

Induction (IV), sleep
\[O_2 + \text{air} + \text{drug}\]

Induction to steady state
\[O_2 + N_2O + \text{inhalational agent}\]

Maintenance
\[O_2 + N_2O + \text{inhalational agent}\]

Elimination and recovery
\[O_2 + \text{air}\]
6.2.4 NITROUS OXIDE, $\text{N}_2\text{O}$

**NITROUS OXIDE, $\text{N}_2\text{O}$**

<table>
<thead>
<tr>
<th>Color code (cylinder)</th>
<th>Light blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood/gas coefficient</td>
<td>0.47</td>
</tr>
<tr>
<td>Oil/gas coefficient</td>
<td>1.4</td>
</tr>
<tr>
<td>Smell</td>
<td>Weak, sweet</td>
</tr>
</tbody>
</table>

1.0 MAC in

- *100% $\text{O}_2$* \((105 = \text{theoretical value})\)
- *30% $\text{O}_2 + 70\% \text{N}_2\text{O}$* -
- % metabolized -

The low solubility of this gas means that it provides rapid analgesia, although relatively high concentrations are required. It thus serves as a useful complement to other anesthetic agents.

During the first minute of induction, uptake is around 1-1.5 liters when the inspired fraction (or $\text{F}_i$) is 70%, after which it falls quickly to reach around 100 ml after an hour.

The high concentrations of nitrous oxide required affect the uptake of other agents given at the same time (concentration and second gas effects), although only during the initial rapid uptake phase.

**EFFECT ON BREATHING**

$\text{N}_2\text{O}$ is non-irritant and does not cause bronchospasm. It slightly decreases tidal volume, although this is offset by an increase in respiratory rate. It may cause diffusion hypoxia at the end of surgery. It expands air-filled cavities because it is 40 times as soluble as nitrogen, passing from the blood into the cavity faster than nitrogen can diffuse out. This can double the size of a pneumothorax in 10 minutes at a concentration of 70%.

**CARDIAC AND CIRCULATORY EFFECTS**

In experiments, nitrous oxide decreases the contractility of the myocardium, although mean arterial pressure is in practice usually well maintained by a reflex increase in peripheral vascular resistance. For patients who are unable to increase their sympathetic drive, however, the direct myocardial depressant effects may reduce cardiac output. Nitrous oxide does not sensitize the heart to catecholamines.

**METABOLISM AND ELIMINATION**

Due to its low solubility in blood and tissues, nitrous oxide is only minimally metabolized. It is eliminated via the lungs.

**CONTRAINDICATIONS**

$\text{N}_2\text{O}$ should not be used for patients with bowel obstruction, pneumothorax or middle ear and sinus disease. Some clinicians maintain that nitrous oxide use should be restricted during pregnancy because of effects on DNA production and evidence of unwanted reproductive outcomes, but its use remains very popular.

Severe vitamin B12 and folic acid deficiencies also constitute contraindications for nitrous oxide use, and anesthesiologists therefore also need to consider the nutritional status of vegans.

On the whole, there is a slow downward trend in the use of nitrous oxide, although prevailing routines, traditions and preferences may differ from place to place. Among the negative effects of nitrous oxide, frequent reference is made to post-operative nausea, while its effects on the environment, both in general
and at work, are also increasingly cited. It is however still a reliable and useful drug that is relatively inexpensive and has few side-effects. It therefore remains widely used.

6.2.5 SEVOFLURANE

**SEVOFLURANE**

<table>
<thead>
<tr>
<th>Universal color code</th>
<th>Yellow</th>
</tr>
</thead>
<tbody>
<tr>
<td>(bottle and adapter on filling system)</td>
<td></td>
</tr>
<tr>
<td>Blood/gas coefficient</td>
<td>0.6</td>
</tr>
<tr>
<td>Oil/gas coefficient</td>
<td>47</td>
</tr>
<tr>
<td>Smell</td>
<td>Weak</td>
</tr>
<tr>
<td>1.0 MAC in * 100% O₂</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>2.05</td>
</tr>
<tr>
<td>Infants &amp; children</td>
<td>2.4-3.3</td>
</tr>
<tr>
<td>* 30% O₂ + 70% N₂O</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>0.66</td>
</tr>
<tr>
<td>Infants &amp; children</td>
<td>unknown - 2</td>
</tr>
<tr>
<td>% metabolized</td>
<td>&lt; 5</td>
</tr>
</tbody>
</table>

Sevoflurane's solubility in blood is quite low, making it a rapidly acting agent that is easy to adjust during administration.

**EFFECT ON BREATHING**

Sevoflurane produces dose-related respiratory depression, although recovery from such depression is generally rapid due to sevoflurane’s elimination characteristics. It causes an increase in respiratory rate, although minute volume remains unchanged, and a decreased response to hypoxia and hypercapnia. It relaxes bronchial smooth muscle and does not irritate the airways, and its effects are very rapid. These aspects make it ideally suited to inhalation induction and anesthesia maintenance in adults and children. On the other hand, sevoflurane also potentiates the action of depolarizing and non-depolarizing muscle relaxants to a greater extent than either enflurane or halothane.

**CARDIAC AND CIRCULATORY EFFECTS**

Sevoflurane causes a decrease in myocardial contractility and mean arterial pressure. It has little effect on the heart rate and does not sensitize the myocardium to circulating catecholamines. It does not cause ‘coronary steal’ although dose-related hypotension has been noted. For patients undergoing cardiac surgery, recent research suggests that sevoflurane (and desflurane) even has a cardioprotective effect and could help prevent myocardial infarction.

**METABOLISM AND ELIMINATION**

Elimination is rapid due to low solubility. Over 95% is eliminated via the lungs, predominantly unchanged, while less than 5% is metabolized. Sevoflurane is however unstable in the presence of soda lime, producing small amounts of a degradation product known as "Compound A". In rats, this has been shown to damage the kidneys. In humans, however, no effect on renal function has been seen. Low flows, high temperatures, desiccated absorbent containers and potassium based absorbents increase the production of Compound A.

**CONTRAINDICATIONS**

Sevoflurane, like isoflurane, is a trigger agent for malignant hyperthermia. No inhalation agent should be used on patients with a known or suspected genetic tendency to develop malignant hyperthermia.
**DOSAGE**

Dosage is age-related. For children, the dosage during induction is higher than that generally given to adults. The concentration generally required for maintenance is between 0.5-0.8 and 3%.

### 6.2.6 ISOFLURANE

<table>
<thead>
<tr>
<th>ISOFLURANE</th>
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</thead>
<tbody>
<tr>
<td><strong>Universal color code</strong></td>
</tr>
<tr>
<td><strong>Blood/gas coefficient</strong></td>
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<tr>
<td><strong>Oil/gas coefficient</strong></td>
</tr>
<tr>
<td><strong>Smell</strong></td>
</tr>
<tr>
<td><strong>1.0 MAC in</strong></td>
</tr>
<tr>
<td>* 100% O₂</td>
</tr>
<tr>
<td>* 30% O₂ + 70% N₂O</td>
</tr>
<tr>
<td><strong>% metabolized</strong></td>
</tr>
</tbody>
</table>

The effects of isoflurane are very similar to those of enflurane. Nowadays, sevoflurane is often preferred to isoflurane because of its lower solubility, which makes both induction and recovery quicker.

**EFFECT ON BREATHING**

An increased incidence of "airway problems" has been reported during induction with isoflurane compared with sevoflurane. Isoflurane is a respiratory depressant and decreases tidal volume, while having little effect on respiratory rate. It causes a decreased response to hypoxia and hypercapnia and is very irritant to the respiratory tract. It also causes bronchodilation.

**CARDIAC AND CIRCULATORY EFFECTS**

Arrhythmias are uncommon with isoflurane, although blood pressure may decrease in a dose-related manner and a reflex tachycardia may occur. Isoflurane has a mild negative effect on the heart and circulation, causing vascular resistance to decrease and mean arterial pressure to fall. It has been suggested that it causes ‘coronary steal’.

**METABOLISM AND ELIMINATION**

Isoflurane is mainly eliminated via the lungs (95%), with only approximately 0.2% being metabolized.

**CONTRAINDICATIONS**

Isoflurane, like sevoflurane, is a trigger agent for malignant hyperthermia. No inhalation agent should be used on patients with a known or suspected genetic tendency to develop malignant hyperthermia.

**DOSAGE**

Dosage is age-related (see MAC explanation above and values in table). During the first part of induction, the required isoflurane concentration is around 3-4%, while for maintenance, it is between 0.5 and 3%.
6.2.7 DESFLURANE

**DESFLURANE**

<table>
<thead>
<tr>
<th>Universal color code (bottle and adapter on filling system)</th>
<th>Blue</th>
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<tbody>
<tr>
<td>Blood/gas coefficient</td>
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<td>Oil/gas coefficient</td>
<td>19</td>
</tr>
<tr>
<td>Smell</td>
<td>Sweet</td>
</tr>
<tr>
<td>1.0 MAC in * 100% O₂</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>5.75-7.25</td>
</tr>
<tr>
<td>Infants &amp; children</td>
<td>7.20-10.65</td>
</tr>
<tr>
<td>* 30% O₂ + 70% N₂O</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>1.75-4.25</td>
</tr>
<tr>
<td>Infants &amp; children</td>
<td>5.15-7.75</td>
</tr>
<tr>
<td>% metabolized</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Desflurane’s solubility in blood is very low, making it a very rapidly acting agent that is easy to adjust during administration. It is fairly expensive but is often the preferred drug when anesthetizing patients with a high BMI, since it has a low oil/gas coefficient. It does however require a special vaporizer (see section on vaporizers in chapter 8).

**EFFECT ON BREATHING**

Airway problems may occur during induction and an intravenous agent is therefore recommended to put the patient to sleep. A dose-related reduction in breathing has been reported for desflurane.

**CARDIAC AND CIRCULATORY EFFECTS**

Desflurane causes a decrease in myocardial contractility, although sympathetic tone is preserved. It does not sensitize the heart to circulating catecholamines or cause 'coronary steal'. A dose-related decrease in blood pressure has been noted, as well as tachycardia caused by an indirect autonomic effect, generally when agent concentration is increased. This makes the physiological response to this agent somewhat different from reactions to other anesthetic agents.

**METABOLISM AND ELIMINATION**

Desflurane is hardly metabolized at all (only 0.02%).

**CONTRAINDICATIONS**

Desflurane is a trigger agent for malignant hyperthermia. No inhalation agent should be used on patients with a known or suspected genetic tendency to develop malignant hyperthermia. In addition, desflurane is not suitable for induction due to an increased tendency towards airway instability and laryngospasm during induction.

**DOSAGE**

Dosage is age-related. The concentration usually required for maintenance is between 2 and 6%.

6.2.8 ENFLURANE

**ENFLURANE**

<table>
<thead>
<tr>
<th>Universal color code (bottle and adapter on filling system)</th>
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<tr>
<td>Blood/gas coefficient</td>
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<tr>
<td>Oil/gas coefficient</td>
<td>98</td>
</tr>
<tr>
<td>Smell</td>
<td>Ether-like</td>
</tr>
<tr>
<td>1.0 MAC in * 100% O₂</td>
<td>1.8</td>
</tr>
<tr>
<td>* 30% O₂ + 70% N₂O</td>
<td>0.57</td>
</tr>
<tr>
<td>% metabolized</td>
<td>2.4</td>
</tr>
</tbody>
</table>
The effects of enflurane are very similar to those of isoflurane (see above). Enflurane is however more soluble, resulting in slower induction and recovery.

**EFFECT ON BREATHING**

Breathing is affected even during the early stages of enflurane anesthesia. The breathing pattern typically displays small tidal volumes and high breathing frequency.

**CARDIAC AND CIRCULATORY EFFECTS**

Enflurane is characterized by peripheral vasodilation and a tendency to bradycardia, leading to a drop in blood pressure. The deeper the anesthesia, the more pronounced the effect.

**METABOLISM AND ELIMINATION**

Enflurane is metabolized to a lesser degree than halothane. 2.4% is metabolized in the liver and eliminated in the urine, while the rest is eliminated via the lungs.

**CONTRAINDICATIONS**

No inhalation agent should be given to patients with a known or suspected genetic tendency to develop malignant hyperthermia.

EEG changes may occur when higher concentrations of enflurane are used. It is therefore not used on patients with epilepsy. The metabolites of enflurane may cause renal damage in higher concentrations. Enflurane is therefore not used on patients with known or suspected renal insufficiency.

**DOSAGE**

Enflurane is not used for gas induction. In an oxygen and nitrous oxide mixture (30-40%: 60-70%), the maintenance concentration is usually between 0.6 and 3%.

**6.2.9 HALOTHANE**

<table>
<thead>
<tr>
<th><strong>HALOTHANE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Universal color code</strong></td>
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<tr>
<td><strong>(bottle and adapter on filling system)</strong></td>
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<tr>
<td><strong>Blood/gas coefficient</strong></td>
</tr>
<tr>
<td><strong>Oil/gas coefficient</strong></td>
</tr>
<tr>
<td><strong>Smell</strong></td>
</tr>
<tr>
<td><strong>1.0 MAC in</strong></td>
</tr>
<tr>
<td>* 100% O₂</td>
</tr>
<tr>
<td>* 30% O₂ + 70% N₂O</td>
</tr>
<tr>
<td><strong>% metabolized</strong></td>
</tr>
</tbody>
</table>

Halothane is a very potent hypnotic agent (see MAC values) although it has a much weaker analgesic effect. It is one of the early inhalation anesthetics and is not widely used today due to its serious side-effects and the development of new and better agents. In some countries, it is not even registered for sale.

**EFFECT ON BREATHING**

Similar to the effect of enflurane.

**CARDIAC AND CIRCULATORY EFFECT**

Similar to the effects of enflurane, although halothane causes more arrhythmias.
METABOLISM AND ELIMINATION

15-20% is metabolized in the liver and eliminated in the urine. The metabolites are immunologically active and may cause a fatal form of hepatitis. Halothane has therefore been withdrawn from most markets.

CONTRAINDICATIONS

When and if halothane is still used (see above), it should be avoided when patients suffer from liver disease or have previously been exposed to halothane and afterwards shown signs of abnormal liver function (tiredness, fever, icterus, known jointly as “halothane hepatitis”).

As always, no inhalation agent should be given to patients with a known or suspected genetic tendency to develop malignant hyperthermia.

6.2.10 OTHER AGENTS

XENON

Xenon is a noble (or inert) gas with even lower solubility than nitrous oxide and high potency (MAC = 71%). With no major depressant effects on the cardiovascular system or irritant effects on the airways, it has great appeal as an anesthetic agent. It is however extremely expensive and relatively complicated for the anesthetist to control. It is not currently used in the US, so most data comes from Europe, where it is believed that it will be increasingly used in the future despite its high costs.

HELIUM AND OXYGEN/HELIUM MIXTURES

Helium is a light noble gas present in air and natural gas from which it is extracted. It is supplied either as Heliox (21% O₂, 79% He) in cylinders marked with the colors used locally for helium (brown) and oxygen (e.g. white in Sweden, green in the USA), or as 100% helium in brown cylinders. Helium has a lower density than oxygen, nitrogen and air. During turbulent flow, velocity is higher when Heliox is used. This reduces work of breathing in patients with upper airway obstruction, such as a tumor. Its use has also been proposed in patients with severe asthma and other lower airway disease. For anesthesia purposes, Heliox may in future improve gas flow in patients with chronic obstructive pulmonary disease (COPD), pulmonary hypertension or severe hypoxia.

6.3 COMBINED ANESTHESIA

This is a common form of anesthesia in which both inhalational and intravenous anesthetic agents are administered in an attempt to combine the best qualities of different agents to anesthetize and relax the patient. The component agents are selected to suit the specific patient’s status and the surgery to be performed.

6.4 MUSCLE RELAXANTS

Muscle relaxants affect only the skeletal muscles and have no anesthetic or analgesic effect. They are used only when the patient is asleep. They paralyze the respiratory muscles, so the anesthetist must be able to ventilate the patient before administering them.

Muscle relaxants are frequently given to facilitate endotracheal intubation. In addition, abdominal surgeons often require muscle relaxation in their patients to enable them to
operate. Deep anesthesia will generally ensure muscle relaxation, but it is most common to use muscle relaxants to avoid any risks this might entail.

There are two different kinds of muscle relaxants:
- non-depolarizing.
- depolarizing

In simple terms, the depolarizing agents mimic the appearance and effect of the body’s normal neurotransmitter, acetylcholine, binding to its receptors at the neuromuscular junction and causing prolonged depolarization of the muscle, thereby making it unresponsive to new impulses. The muscle is effectively paralyzed.

The most common depolarizing agent is succinylcholine (suxamethonium) and it is mainly used prior to intubation.

Its most common side-effect (apart from post-operative muscular pain caused by initial muscular contraction) is bradycardia, especially if more than one dose is given. This can be prevented by the prior administration of atropine. Children develop this complication more commonly than adults. It may also cause raised potassium levels and may even trigger the onset of malignant hyperthermia in patients with this genetic disorder.

Non-depolarizing agents, meanwhile, are similar in appearance to acetylcholine, but not in effect. They block its receptors at the neuromuscular synapse and prevent any depolarization and subsequent muscle contraction. They are water soluble, polar molecules and thus do not cross the blood-brain barrier and have no effect on the central nervous system. All non-depolarizing drugs should be used with care in patients suspected to be suffering from myasthenia gravis (a neuromuscular disease) or myasthenic syndrome, since these patients are extremely sensitive to their effects.

A large number of non-depolarizing agents have been developed in recent decades based on the earliest drug, pancuronium. They include vecuronium and rocuronium, as well as atracurium and its more recent derivatives, with their slightly modified effect profiles.

They are initially used in fairly large doses supplemented as and when necessary with smaller maintenance doses. Cardiovascular effects are minimal, although some may render the patient vulnerable to bradycardia during anaesthesia.

To assess the degree of neuromuscular block, a number of monitoring tools are recommended. These are discussed later (see chapter 10).

6.5 OUTLINE OF A TYPICAL ANESTHESIA PROCEDURE

There are certain basic steps that are the same in all anesthesia procedures. They are briefly outlined in the text and diagrams below.

6.5.1 PREOXYGENATION

A face mask is used to give the patient 80-100% oxygen for a few minutes before induction to ensure high oxygen saturation and prevent complications.
6.5.2 INDUCTION

For IV induction, a drug such as propofol or thiopental is given intravenously to put the patient to sleep. The alternative is inhalation induction (see discussion under section 6.2.3).

A check is performed to ensure free airways and make sure that manual ventilation is possible. Once deep sleep is achieved, muscle relaxants are given if required.

Intubation is then performed, if necessary, or a laryngeal mask is fitted. Analgesics and/or inhalation agents are administered via the tube/mask. Careful observation and monitoring are important throughout the procedure.

6.5.3 MAINTENANCE

The gas mixture is administered as needed, and adjustments are made using inhalation agents and/or intravenous injections.

Careful monitoring is crucial to ensure patient safety, but the value of clinical observation should not be underestimated. Changes in the patient’s condition are generally perceptible to an alert anesthetist or nurse.

When surgery has been completed, the anesthetic agent ceases to be given and extubation is performed when the patient is awake and breathing spontaneously and the muscle relaxant wears off or is reversed.

6.5.4 RECOVERY

Oxygen is given via a mask to prevent complications. Nasal prongs can also be positioned to supply the patient with oxygen. Once the patient is breathing normally, it is time for transport to the recovery room/post-operative ward.

6.6 EFFECTS OF ANESTHESIA

Both breathing and circulation are always affected by general anesthesia. In some cases, regional anesthesia, particularly when it is "high", may also cause a blood pressure drop, as well as affecting breathing.

6.6.1 BREATHING

NORMAL REGULATION OF BREATHING

The volume and frequency of breathing are controlled by impulses from a cluster of nerves in the brain stem called the respiratory center. These impulses are governed by information from different receptors in the body: central receptors close to the respiratory center and peripheral receptors in the carotid arteries.

The impulses from the central receptors depend mainly on the carbon dioxide level in the blood, which also affects the pH value in the fluid surrounding the brain and spinal cord (cerebrospinal fluid, CSF).
The pH value of the cerebrospinal fluid has a direct effect on the respiratory center, since a low pH (high CO₂ level) stimulates breathing, and a high pH (low CO₂ level) causes a decrease in breathing activity.

The peripheral receptors are also affected by the pH value of the blood, since low blood pH stimulates breathing.

*The Physiology of Respiration (Training Material Workbook)* provides a simple summary of respiratory anatomy and a somewhat more detailed summary of respiratory physiology.

**CHANGES IN BREATHING**

Certain inhalation agents may cause a decrease in breathing, leading to alveolar hypoventilation.

**COMPRESSIBLE VOLUME**

Controlled ventilation always entails a certain volume of gas being compressed in the apparatus and patient tubing, etc. Compressible volume should therefore be calculated and added to minute volume if it has not already been automatically compensated for by the machine. Compressible volume is described in more detail in chapter 8.

**DEAD SPACE**

Dead space is defined as the volume in which no gas exchange takes place. It is generally divided into anatomic, physiological and apparatus dead space.

All apparatus naturally contributes to increasing total dead space: a face mask may double it, for example (more apparatus dead space), while endotracheal intubation causes a smaller increase. Dead space is an important aspect to consider when assessing patient ventilation and is also described in more detail in chapter 8.

**COMPLIANCE**

General anesthesia may alter the elasticity of the chest, reducing functional compliance in proportion to the depth of anesthesia. Drugs, type of surgery and body position on the operating table all affect functional compliance and breathing.

**6.6.2 CIRCULATION**

Blood pressure drops are common when many anesthetic agents are administered. To counteract such falls, fluids are infused and sometimes vasoactive drugs may also be used to normalize patient blood pressure.

**VAGAL REFLEXES**

During general anesthesia, pressure from the surgeon on certain abdominal organs or stimulation of the airways may cause vagal reflexes, slowing the heart rate, reducing blood pressure and causing a drop in stroke volume.

**ARRHYTHMIA**

Some inhalation agents affect the heart rate although arrhythmia may also be the result of hypo- or hypervolemia.
BRADYCARDIA

This is caused by many drugs, especially succinylcholine, fentanyl, alfentanil and remifentanil.

TACHYCARDIA

Combined with an increase in blood pressure, this may be a sign of poor pain control, insufficient depth of anesthesia or even awareness.

Tachycardia and low blood pressure, on the other hand, indicate blood loss or incipient shock.

BLOOD LOSS

This is monitored by the anesthetist on an ongoing basis and compensated when necessary with transfusions. Significant losses are signalled by tachycardia, low blood pressure and peripheral coldness. If untreated, there may be a further fall in blood pressure. Such losses must be compensated to prevent the development of shock.
Agents used in general anesthesia

**Sedation/amnesia**: benzodiazepines, propofol

**Hypnosis during induction**: propofol, thiopenthal.

**Analgesia**: opioids, both traditional (fentanyl) and new faster-acting drugs (alfentanil, remifentanil, sufentanil)

**Muscle relaxation**: non-depolarizing/depolarizing agents

**Amnesia, hypnosis, analgesia (+ some muscle relaxation)**: inhalation agents

---

Effects on essential anesthesia parameters ("the triad of anesthesia") of drugs routinely used during balanced anesthesia

<table>
<thead>
<tr>
<th></th>
<th>Hypnosis</th>
<th>Analgesia</th>
<th>Relaxation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrous oxide</td>
<td>++</td>
<td>++</td>
<td>0</td>
</tr>
<tr>
<td>Volatile inhalation agents</td>
<td>+++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>IV barbiturates</td>
<td>+++</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Muscle relaxants</td>
<td>0</td>
<td>0</td>
<td>+++</td>
</tr>
<tr>
<td>Opioids</td>
<td>+</td>
<td>+++</td>
<td>0</td>
</tr>
</tbody>
</table>
7 KEEPING A RECORD

A record is kept of each patient case on an anesthesia record chart. This documents everything that has happened to the patient in the OR.

Records are still by and large paper-based, although computerized systems are now being introduced. They have not yet however gained general acceptance. The latest ASA poll (2006) showed that they were not used in more than around 20% of cases in the USA.

The layout of the patient record may differ from one hospital and country to the next, but the chart generally includes the following points:

- patient details
- date
- preoperative assessment (including ASA classification)
- (premedication and preoperative fluids, if any)
- (certain laboratory values)
- position of patient on table
- peripheral cannulation
- choice of airway management
- record of gases used
- breathing system used
- ventilator used
- drugs administered
- infusion fluids and blood transfusions
- blood pressure (BP) every 5 minutes
- pulse rate and oxygen saturation every five minutes
- neuromuscular transmission
- ventilatory status (etCO₂, respiratory rate, tidal volume)
- temperature monitoring
- clinical notes, such as excessive bleeding, allergic reactions, etc.
- estimated fluid loss
- estimated blood loss
- time of anesthesia induction
- time at which surgery began
- time at which surgery ended
- time of anesthesia termination
- prescriptions.
# Anesthesia Record

**Date of surgery:**

**Surgery:**

**Start time**

**Age**

**Weight (kg):**

**Surgeon(s):**

**Pre-operative airway assessment codes (#1)**

**Mouth opening:**

**Neck extension:**

**Visualization:**

**Fasting status:**

**Hemoglobin:**

**Anesthetic considerations**

- [ ] Machine check OK
- [ ] ASA class:

<table>
<thead>
<tr>
<th>Standby</th>
<th>Sedation</th>
<th>Regional</th>
</tr>
</thead>
</table>

## General

- [ ] Pre-oxygenation
- [ ] Endotracheal tube
  - Size: ___________
  - Intubation: _______
  - Difficulty: _______
- [ ] Non-traumatic
- [ ] Air entry right = left
- [ ] Rapid sequence induction
- [ ] With cricoid pressure
- [ ] Other:
  - [ ] Face mask
  - [ ] Laryngeal mask
  - [ ] Airway circuit
  - [ ] Bain circuit
  - [ ] Mechanical ventilation
  - [ ] Ventilation
    - Tidal volume: _______ mL
    - Rate: _______ min
  - [ ] ECG lead
  - [ ] Pressure points padded

## Intravenous lines

<table>
<thead>
<tr>
<th>Fluids</th>
<th>Size</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>_______</td>
<td>_______</td>
<td>_______</td>
</tr>
</tbody>
</table>

## Monitors

- [ ] ECG (electrocardiogram)
- [ ] BP (blood pressure) cuff
  - Size: _______
  - Site: _______
- [ ] Arterial line
  - Size: _______
  - Site: _______
- [ ] Central venous line
  - Size: _______
  - Site: _______
- [ ] Pulmonary artery line
  - Site: _______
- [ ] Peripheral nerve stimulator
- [ ] Stethoscope
- [ ] Other:

## Agents and Dose

- [ ] Agent
- [ ] Dose

## Time

- Position: 200
  - 180
  - 160
- Heart rate (HR): 140
  - 120
- Blood pressure
  - Systolic: 120
  - Diastolic: 100
- Tidal volume: 80
- Rate: 60
- Minute: 40
- Blood loss (mL)
- Urine (mL)

## Temperature (°C)

- O2 saturation (SaO2)
- End tidal CO2 (ETCO2)
- Airway pressure

## Events:

**Input:**

**Output:**

---

**End time:**

**Neuromuscular block reversal:**

<table>
<thead>
<tr>
<th>Post-Anesthetic Care Unit</th>
<th>HR</th>
<th>BP</th>
<th>RR</th>
<th>SaO2</th>
<th>FiO2</th>
</tr>
</thead>
</table>

*1, 2, 3 — see code definitions and pre-operative patient assessment overleaf...*  

**Anesthetist / Assistant:**

---

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8 THE ANESTHESIA MACHINE

Anesthesia machines may differ in appearance, size and degree of sophistication but generally speaking, they consist of sections for

- ventilation
  - source of gases (pipes and/or cylinders)
  - flowmeters/mixer for gas dosage
  - vaporizers for storing and dosing inhalation agents
  - patient breathing system
  - manual ventilation bag and ventilator
  - suction device
  - gas evacuation
- space for monitoring equipment
- accessories
- storage space
- worktop.

It is extremely important to test the anesthesia machine every time it is used. This involves testing many of the individual parts before each use, as well as the functioning of the system as a whole before connection to the patient.

Different manufacturers issue different recommendations concerning checkout procedures, both prior to use and between patients. The same applies to the authorities in different countries (such as the FDA in the US and the relevant regulatory authorities in the EU) and the routines of different hospitals and healthcare institutions.
It is therefore crucial for personnel to familiarize themselves with the requisite procedures in their own workplaces.

There is a great deal of information for the anesthetist/nurse to monitor throughout anesthesia, including oxygenation, ventilation, blood pressure, heart rate, muscle relaxation, fluid status, acid-base balance, anesthesia depth, etc.

8.1 CART OR COLUMN

The cart or column should preferably be tailored to the environment of the OR. This may involve making it mobile, ceiling-mounted or wall-mounted and equipping it to suit specific anesthetist or hospital requirements. Space is restricted and it is also an advantage if the machine is lightweight and easy to handle. On the other hand, the anesthetist requires a comfortable and ergonomically adapted workplace with space for all the equipment needed. The design therefore involves striking a balance between what is desirable and what is practically feasible.

8.2 SOURCE OF GASES

The various gases used (oxygen, nitrous oxide and medical air) may be piped via the wall from central storage cylinders or come from smaller cylinders in the OR or on the cart itself. There may also be extra cylinders on the cart in case of failure of the usual source.

Oxygen is stored in cylinders as a compressed gas at a pressure of 20000 kPa. The volume of decompressed oxygen is therefore proportional to the pressure indicated on the pressure gauge. Nitrous oxide, on the other hand, is a liquid that is stored at a pressure level of around 5170 kPa or 750 psi, so that it vaporizes in the cylinder. This means that the pressure level indicated on the pressure gauge is not relevant to the amount of gas left in the cylinder.

Because of the high internal pressure, pressure regulating valves have to be used on the cylinders.

8.2.1 IDENTIFICATION OF GASES

Correct identification of the gas being supplied to the anesthesia machine is clearly vital if potentially lethal accidents are to be avoided. A number of different measures are taken to ensure this:

- Color coding of cylinders provides a rapid means of identifying their contents. However, the definitive indicator of the contents is always the label.
The gas tubing and connectors are color coded and the connectors are usually design coded (see below) for specific gases to avoid any confusion or incorrect connection.

A gas-specific pin-index system is provided on small cylinders: pins on the yoke of the machine mate with holes drilled in specific positions on the valve of the cylinder to provide a mechanical means of preventing incorrect connection. Especially when small individual cylinders are used, these precautions should be included in the design of the flowmeters and/or the ventilator.

Gas-specific connectors are used on large cylinders that make it impossible to attach a regulator or fitting to the wrong cylinder.

8.2.2 OTHER SAFETY ASPECTS

Built-in safety systems that automatically shut down the nitrous oxide supply in case of low oxygen levels or total oxygen failure are crucial. They are known as hypoxia guards and are designed to prevent hypoxic gas mixtures from ever being administered to the patient even in the unlikely event of the anesthetist mistakenly setting a fresh gas flow of, for example, 100% nitrous oxide.

8.2.3 GAS ANALYZER/OXYGEN MEASUREMENT

It is now mandatory for the anesthesia machine to provide the anesthetist with a means of sampling the oxygen administered to the patient. This is the most reliable method of ensuring that the patient has an adequate oxygen supply and that no errors have been made in the gas connections. In addition to using a gas analyzer, it is recommended to use pulse oximetry to monitor the patient’s oxygen saturation levels.

8.3 FLOWMETERS

The flowmeter allows the operator to control and know the flow rate of each gas, usually in liters or subunits of liters per minute.

Traditionally, the flow rate and concentration of the gases are individually set for each patient and are often altered during anesthesia.

The conventional flowmeter is a vertical glass tube that is wider at the top and contains a light float. Each is calibrated for a specific gas. When the gas is turned on, the float stabilizes and rotates at a height inside the tube where the force of the gas flow is equal to the weight of the float. The gases from each flowmeter are then mixed.

Newer flowmeter units have built-in safety features, including shutting down the N₂O supply and sounding an alarm if the oxygen
supply should fail (see above). Many also have a preset minimum oxygen concentration which varies from one manufacturer to another, although it never falls below 21%.

Flowmeters are typically pneumatic, but electromagnetic digital flowmeters are now gaining popularity.

8.4 VAPORIZERS FOR INHALATION AGENTS

A vapor formed from the volatile liquid anesthetic agent is added to the gas mixture by the anesthesia machine's vaporizer, whose function is to deliver a safe, reliable concentration of volatile agent to the patient. The output of older vaporizers is affected by the flow rate, the ambient temperature and the amount of inhalation agent, although more modern vaporizers compensate automatically for variations in these parameters.

In terms of safety, there are unique color codes for each agent, a special key filling system with specific design coded adapters to prevent the vaporizer from being filled with the wrong liquid, and anti-spill mechanisms.

The vaporizers also undergo regular overhauls to ensure that the set concentrations do not vary, although in more traditional types of equipment, the concentrations delivered may vary at low fresh gas flows. Nowadays, the monitoring of anesthetic agent concentration in the patient breathing system is therefore standard, especially during low flow anesthesia.

It is useful to have some understanding of the basic principles of anesthetic vaporizers, including the principles that affect vaporizer output and how they influence vaporizer design. Generally speaking, there are traditional simple vaporizers, often of the drawover type, and more modern precision vaporizers. The latter are common in developed countries and are generally flow and temperature compensated, as well as being unaffected by positive pressure ventilation. Drawover vaporizers are basic and robust, have a low resistance to flow and so do not require pressurized gases. Because their performance is variable, accurate calibration is more or less impossible. They are common in countries that have fewer resources to invest in equipment.

Precision vaporizers have developed in recent years and newer vaporizer designs enable control of the vaporizer by a central processing unit in the machine. The concentration of vapor is then monitored on an ongoing basis and adjusted by altering the fresh gas flow through the vaporizer. Some of the different types on offer now include:

- the plenum vaporizer, where the incoming gas is accurately split into two streams. One passes straight through the vaporizer in the bypass channel, while the other is diverted into the vaporizing chamber. Gas in the vaporizing chamber becomes fully saturated with volatile anesthetic vapor. This gas is then mixed with the gas in the bypass channel before leaving the vaporizer. Modern vaporizers of this type are not sensitive to variations in temperature and pressure;

- the injection principle vaporizer, where the gas flow is throttled, causing a pressure difference between the liquid reservoir and vaporizer outlet. The difference is proportional to the degree of throttle and is
used to inject the desired amount of agent into the gas flow. The use of the injection principle allows accuracy to be maintained regardless of patient tidal volume;

- the electronic vaporizer, where electronically controlled valves ensure higher accuracy.

There is also an agent-specific vaporizer constructed for use with desflurane. Because of its unique physical properties, desflurane requires a special vaporizer in which the agent is heated, pressurized and added directly to the gas stream.

Below is a diagram of one recent development - an electronic vaporizer with injector system.

8.5 USING A VENTILATOR

Traditional ventilators used for anesthesia have generally been simple, since they were only used to replace manual ventilation when the anesthetist needed his/her hands free. Surgery is rapidly becoming more complex and growing numbers of patients, who are both older and more severely ill than ever before, are now eligible for surgical interventions. The need for more advanced anesthesia machines with ventilators that offer additional and more sophisticated ventilation modes has therefore increased.

Ventilators are generally pressure, flow and time (cycle) regulated. This refers to the mechanism used to switch from inhalation to exhalation.

The text and figure below have been adapted from a number of relevant articles listed under "References".

Most recent ventilators used for anesthesia include specific design characteristics that have been more or less standard for all across manufacturers (see figure below). They have a bellows that delivers inspiratory gas when pressurized by an external gas source (bag-in-bottle design). Exhalation is passive and there is a circuit to reuse variable amounts of exhaled gas in the inspiratory limb. A fresh gas flow (FGF) also contributes to the flow delivered to the patient, while a CO2 absorber is used to remove CO2 from the gas delivered to the patient.

This design has remained the same for many years, although anesthesia ventilators are now changing to meet new demands (see chapter 9).
In terms of safety and alarms, a minimum requirement for all simple ventilators is that they should alert the user in case of disconnection or if the upper pressure limit is reached. It should be noted that for infants and children, special equipment is used.

8.5.1 COMPRESSIBLE VOLUME

Part of the inspiratory minute volume is needed to compress the gas in the apparatus and tubing and thus fails to reach the patient. This means that the choice of breathing system, tubing and ventilator affects the compressible volume. If the tubing, connectors, valves and canister have a large internal volume, a higher fresh gas flow will be required.

To lower the compressible volume, it is a good idea, at the machine design level, to position the manual ventilation bag or ventilator as close to the patient as possible. The compressible volume should be calculated and added to the minute volume if the ventilator does not compensate automatically for it.

8.5.2 DEAD SPACE

Dead space is by definition the volume in the airways where no gas exchange takes place. The alveolar ventilation volume is thus tidal volume minus dead space.

Anatomic dead space is proportional to the size of the patient and includes the volume from nostrils and mouth down to the upper bronchioles. It is generally around 2 ml/kg of body weight and is decreased by endotracheal intubation and tracheostomy.

Apparatus dead space includes many of the accessories associated with the Y-piece that are necessary to ventilate a sleeping patient, such as a Y-piece, connection tubes and the humidifier unit. It is often around 50 ml.

Physiological dead space (which is alveolar plus anatomic dead space) is a dynamic concept and depends on the efficiency of gas exchange. Poor diffusion capacity increases physiological dead space, as do some forms of controlled ventilation and some pathological processes.

8.6 MONITORING

The monitoring systems used to follow the patient's vital signs and inspired and expired gas concentrations are described more fully in a separate chapter below.
8.7 GAS EVACUATION OR SCAVENGING SYSTEM

From the point of view of both ecology and the work environment, gas evacuation is an important standard feature of most anesthesia machines.

In the diagram below, the green arrow shows gas coming from the patient (left) and moving towards the gas evacuation system (right), while the orange arrow (right) shows the inflow of room air when needed.

There are passive through-the-wall systems or active systems with a central vacuum or active ducts. The systems also include built-in protections against subjecting the patient to negative pressure.

8.8 SUCTION DEVICE

The suction device is a crucial part of the equipment, since all anesthesia entails a risk of aspiration and the consequences for the patient may be serious. The suction device forms an integral part of the equipment needed to ensure free airways and manage the patient safely.

The device must therefore have both high capacity in case of vomiting or regurgitation, and offer lower capacity for simply clearing the airways. Like all other parts of the equipment, it must be carefully checked before use on each new patient.

There are passive through-the-wall systems or active systems with a central vacuum or active ducts. The systems also include built-in protections against subjecting the patient to negative pressure.
9 DIFFERENT BREATHING CIRCUITS

The function of a breathing circuit is to deliver oxygen and anesthetic agent to the patient while at the same time removing carbon dioxide from the circuit.

There are several ways of classifying the breathing circuits or systems used in anesthesia machines. Over time, a wide range of names has been used to describe them. In order to understand the often confusing nomenclature surrounding these systems, a short review of the historical background is appropriate. Many of the older classifications are no longer adequate, particularly now that gas analyzers have become an essential feature of the anesthesia machine. This historical review will be followed by a suggestion for a more suitable practical classification of breathing systems.

The selection of a specific system naturally involves assessing the clinical situation (type of surgery and anesthesia), although it is also inevitably connected with personal preferences, financial priorities and potential benefits. This chapter focuses less on these aspects than on classifying the systems in practical and functional terms.

9.1 OLDER CLASSIFICATION

Historically speaking, breathing systems have been classified in terms of their degree of openness to the surrounding atmosphere. This means that they are in principle either open or closed, with systems in between that are variously and often confusingly described as semi-open and semi-closed. The list below is based on this old-fashioned and now redundant nomenclature, dividing breathing systems as follows:

- Open systems in which the anesthetic is given via the atmosphere (through a mask and/or cloth). This was the first method used to anesthetize patients.

  The classic if somewhat outdated example is ether administered via a cloth inserted into an open mask. Totally open systems are thus primarily of historical interest.

- Closed systems in which the anesthetic gas is given via tubing from a reservoir. The carbon dioxide in the system is eliminated chemically and only the amount of oxygen and anesthetic agent that is actually consumed is supplied. Such a system is reminiscent of the breathing circuits used by certain military divers, for example.

- Finally, the terms semi-open and semi-closed, described by Moyers in 1953, tend to confuse rather than clarify the issue and are therefore best avoided. Moyers himself referred to a system with a reservoir but without rebreathing as semi-open, while...
a circuit with a reservoir and partial rebreathing was semi-closed. Different authors, however, have meant different things when using these terms.

Due to this lack of consistency, this classification will not be applied to the presentation below. In the modern circle systems presented there, it is the fresh gas flow that determines the degree of openness.

9.2 FUNCTIONAL CLASSIFICATION

A more practical classification divides anesthetic breathing systems as follows:

- non-rebreathing systems, the classic example of which is the breathing circuit of an ICU ventilator (see survey below)

- rebreathing systems, which are in turn divided into:
  - partial rebreathing systems without CO₂ absorption, where the fresh gas flow regulates the elimination of carbon dioxide
  - circle systems with CO₂ absorption, which are by far the most widely used systems in clinical practice today. Normally, a circle system is a partial rebreathing system with CO₂ absorption. The fresh gas flow generally plays no part in the elimination of carbon dioxide. It does, however, determine the degree of rebreathing of oxygen and anesthetic agent. It should be noted that a very high fresh gas flow (higher than the inspiratory peak flow) will transform the circle system into a non-rebreathing system. On the other hand, modern gas analyzer technology has enabled the fresh gas flow to be minimized without jeopardizing patient safety. This has resulted in more widespread use of low flow anesthesia (see chapter 11), which is as close as one gets in clinical practice to a closed system (although it is now in fact possible to construct a truly closed circle system as well).

The various systems are described and illustrated in the breathing system survey in section 9.3 below.

9.3 BRIEF SURVEY OF CONTEMPORARY BREATHING CIRCUITS

9.3.1 NON-REBREATHING SYSTEMS

In these systems, only fresh gas is supplied to the patient and no gas or anesthetic agent is recycled. Valves are used to prevent exhaled gas from entering the inspiratory limb and mixing with inhaled gas. The gas mixture given to the patient usually needs to be heated and humidified to prevent damage to the airways.

A traditional ICU ventilator is one example of a non-rebreathing system. Anesthesia machines using non-rebreathing circuits of
this type have a "fresh gas flow" equal to the minute volume. This means a high consumption of anesthetic agents since nothing is recycled.

On the other hand, the ventilation performance of these systems is often good and they may therefore be preferred when anesthetizing patients with severe pulmonary disease and children, where the fresh gas flow per se is low.

9.3.2 REBREATHERS - PARTIAL REBREATHER WITHOUT CO₂ ABSORPTION

These systems use both fresh and recycled gas. Exhaled gas heats and humidifies the inspired gas. The systems have a surplus valve and are generally referred to as Mapleson systems, where each variant has a different letter (Mapleson A to F) depending on the position of the valve and the fresh gas inlet.

These systems require relatively high fresh gas flows, which generally entails a high consumption of anesthetic agents.

One Mapleson variant that is still used is the Bain system shown below, which is a modification with an inner tube for fresh gas. The inspired gas is heated by and mixed with exhaled gas close to the mask or tube. Although somewhat old-fashioned and not particularly sophisticated, the Bain system has remained popular in many parts of the world largely because of its simplicity and ease of use, and because the patient receives the same gas mixture (of fresh and recycled gas) during spontaneous and controlled ventilation.

There is also the very simple Ayre's T-piece system shown below, where the fresh gas flow once again determines the level of rebreathing. This system is mainly used to ventilate smaller infants.
Another example of partial rebreathing without CO₂ absorption is the modification of the Ayre’s T-piece, the Jackson-Rees system. It uses a reservoir bag for gas and requires a fresh gas flow that is 3-5 times higher than the minute volume.

9.3.3 REBREATHERING SYSTEMS - CIRCLE SYSTEMS WITH CO₂ ABSORPTION

These systems were designed to use a low fresh gas flow to economize on the use of agents and avoiding side-effects. As leakage lessened due to more sophisticated equipment, anesthetists were quick to see the benefits of lower flows. The systems use two unidirectional valves, a relief valve, a CO₂ absorber, a manual ventilation bag and tubing to connect all the parts, resulting in a simple circle system that is not totally closed to the surrounding environment. One example is the circle system with a fresh gas flow higher than the patient’s needs. Benefits relate to both recycling of unused gas and inhalation agent and automatic gas humidification and heating.

A circle system reuses a specific amount of exhaled gas, passing it through a CO₂ absorbent. This eliminates the carbon dioxide and simultaneously heats and humidifies the gas. The latter still contains nitrous oxide and anesthetic agent not taken up by the patient and is mixed with fresh gas as it returns to the patient.

As mentioned above, the circle system can in fact be used not only as a partial rebreathing system, but also as a non-rebreathing or total rebreathing system. The amount of rebreathing depends on the fresh gas flow, although at rates above 4 liters/minute, most of the economic advantages of the system are lost.

Using low flows in a circle system does however mean that it takes a while for the altered settings to take effect. When rapid changes in fresh gas or inhalation agent concentrations are required, a high fresh gas flow or a significant increase in anesthetic agent concentration is needed.

As mentioned above, the circle system can also be used for total rebreathing, which minimizes the amount of exhaled gas that escapes from the system. This maximizes
efficiency with regard to use of gases and volatile agents, since once steady state is reached, the amounts of fresh gas required are very low (see chapter 11).

Interest in these systems has grown due to improvements in the accuracy of gas concentration measurement and dosage, the elimination of leakage, the increasing costs of gases and anesthetic agents and growing environmental awareness. On the other hand, there are certain safety concerns with a closed system. These relate to smaller safety margins and potential risks connected with the production of Compound A (see discussion of sevoflurane in chapter 6).

9.4 THE CARBON DIOXIDE ABSORBER

A canister is used to hold the absorbent substance, often a mixture known as soda lime. The CO₂ reacts with the absorbent, producing both heat and water to humidify and warm the rebreathing gas.

There is also an indicator that changes color as the soda lime becomes depleted. The carbon dioxide absorbent canister is illustrated below.

9.5 RECENT MODIFICATIONS AND INNOVATIONS

9.5.1 ADVANCED VENTILATORS WITH BREATHING SYSTEMS

Modern anesthesia machines have improved considerably in terms of their usability in both outpatient and intensive care. They have also become increasingly sophisticated. Much of the discussion below is based on the relevant articles listed in the "References".

Today's anesthesia machine ventilators are in fact approaching the performance of ventilators used in the ICU. Anesthesia machines need to deliver a gas mixture of
known composition and now also recirculate exhaled gases into the system. Most therefore include a CO₂ absorber and a bellows-style or piston driven ventilator.

This design implies a large internal volume, which leads to progressive decreases in tidal volume delivery when airway pressures increase. Modern ICU ventilators, on the other hand have much smaller internal volumes. They are thus less vulnerable to high airway pressure. Accordingly, new anesthesia machines are now being designed to offer better performance to suit critically ill patients. The reduction in internal volume has also enabled more precise ventilation of infants and children. These technological advances have led to greater flexibility in perioperative care.

These advances also extend the range of patients that can be supported by an anesthesia machine and make new ventilation modes available to the anesthetist. These combine patient- and ventilator-initiated breaths and may enable spontaneous breathing techniques to be used for longer periods and facilitate rapid changes in anesthetic depth.

9.5.2 REFLECTOR SYSTEMS

Another new concept is to use a reflector system, which may allow the anesthetic agent to be reused more efficiently. Different types of reflector system are mentioned in these discussions.

One example of such an agent conserving device is the volume reflector. It uses a reservoir tube in which the anesthetic agent contained in the exhaled gas is temporarily stored and recycled. It is based on a very simple idea that is similar to a bellows, and it enables rebreathing of all gases, including nitrous oxide.

The idea of reflector systems is to economize on the use of expensive agents and enhance the efficiency of the anesthesia process.
10 MONITORING

During anesthesia, it is obligatory to monitor a number of parameters and vital functions to ensure patient safety. The type of surgery to be performed and the health status of the patient determine how sophisticated the monitoring needs to be. Technological advances have also increased the number of variables that can be monitored and anesthesia machines therefore offer a more or less extensive range of possibilities. The crucial aspect here is to provide the anesthetist/nurse with the information he/she requires, presented in a clear and reliable way.

It is however important to stress that the no-tech or low-tech approach should never be forgotten: observe the patient, feel the pulse, watch and listen for signs of distress or other clues to status, even if you have access to highly sophisticated apparatus.

10.1 OXYGENATION

10.1.1 MONITORING INSPIRED OXYGEN LEVELS IN THE BREATHING CIRCUIT

A sample of the contents of the breathing tubes is drawn sidestream into a gas analyzer, which uses O₂ sensors based either on a galvanic fuel cell (inspired O₂) or on magnetic or magnetoacoustic technology to monitor oxygen levels. The sampled air is passed through a sensor before being returned to the circuit. Special care should be taken with infants and small children, since the analyzer "steals" a large part of the tidal volume from the patient.

10.1.2 PULSE OXIMETRY

This non-invasive method of monitoring oxygen saturation is now standard almost everywhere. Normal \(\text{SpO}_2\) values are between 95 and 100% in adults, but lower for neonates and the elderly.

A sensor is applied to the finger, for example, sending pulses of red and infrared light through the tissue. This enables the calculation of the percentage of oxygen-carrying hemoglobin molecules, known as oxygen saturation. The oximeter will also display a pulse curve known as a plethysmograph, where the amplitude reflects peripheral perfusion and the pulse rate can also be displayed.

Other suitable sites for application of a sensor include the ear lobe and foot.
The reliability of the oximeter is limited in patients with poor peripheral circulation (e.g. patients with hypothermia or heart disease), while carbon monoxide poisoning may lead to falsely high values.

10.2 VENTILATION

10.2.1 CAPNOGRAPHY (ETCO₂)/CAPNOMETRY

Capnometry enables a number of important parameters, such as end-tidal carbon dioxide levels, inspired CO₂ levels and respiration rate, to be monitored. Capnography reflects a slightly delayed or real-time CO₂ wave form, while the capnometer presents only values. CO₂ levels are affected by both ventilation and metabolism, making capnography a useful method of following the respiratory process.

Capnography/capnometry is an important tool when intubating patients, since any carbon dioxide response detected shows that the tube is correctly positioned in the trachea.

The most common method is based on the use of infrared sensors that detect infrared light that is passed through a sample of airway gas. An example of a normal capnogram is provided below.

The sample may be taken using either mainstream or sidestream technique. The former uses a sensor placed in line with the ventilator tubing (e.g. between the Y-piece and the tubing). In the sidestream method described above, on the other hand, the sampled air is removed and passed through a sensor before being returned to the circuit.

10.2.2 RESPIRATORY RATE

When the patient is breathing spontaneously, the respiratory rate is used to estimate both ventilation efficiency and depth of anesthesia, with a slower rate indicating deeper anesthesia.

There are various techniques for measuring respiration rate. Impedance pneumography is an older method used in conjunction with ECG monitoring. The newer method used in conjunction with capnography (see above) calculates the rate on the basis of the capnogram wave form and is less prone to artifact-induced error caused by movements.

10.3 BLOOD PRESSURE AND PULSE

10.3.1 NIBP (NON-INVASIVE BLOOD PRESSURE)

This is the traditional method of checking a patient's blood pressure. It is routine to monitor it during anesthesia, generally via a cuff on the arm. Normal systolic blood pressure is between 90 and 150 mm Hg, while diastolic is between 60 and 80 mm Hg. Mean BP should be in the interval 70-90 mm Hg. In addition to the standard manual systems, there are automatic systems for measuring BP with the help of oscillometry.
10.3.2 IBP (INVASIVE BLOOD PRESSURE)

This is common during lengthy surgery or when the patient’s health is poor. It is more rapid than NIBP. It is often used on patients with heart disease, as well as on critically ill or hemodynamically unstable patients.

The measurements are obtained from a catheter positioned in the patient’s vascular system, e.g. the radial artery in the wrist for monitoring peripheral arterial blood pressure. Central venous pressure may be monitored as well (mainly as a reflection of volume status), although it is nowadays often used in combination with other information.

10.3.3 SPO$_2$ AND ECG

Pulse oximetry, discussed above, is also a useful method of following the patient’s pulse, as is the electrocardiogram, discussed below.

10.4 ECG

The electrocardiogram provides information about the electrical activity of the heart and is mainly used to identify various types of arrhythmia. It is the oldest monitoring parameter and is a standard feature of most anesthesia machines, although its contribution to minimizing morbidity during anesthesia is relatively small.

The events recorded by the ECG are the depolarization and repolarization of the heart. First the electrical stimulation originating from the sinoatrial node in the right atrium spreads through the atria, causing them to contract (the P wave), then through the ventricles (whose contraction is reflected in the QRS wave). This is followed by the repolarization process (reflected in the final T-wave).

10.4.1 S-T MONITORING

The S-T segment of the ECG represents the phase in the cardiac cycle between the end of depolarization (i.e. contraction of the ventricles) and repolarization (i.e. relaxation and refilling of the ventricles).

The segment is monitored to detect elevations or depression, since these may be early signs of myocardial ischemia (insufficient blood supply).

10.4.2 TEE (TRANS-ESOPHAGEAL ECHOCARDIOGRAPHY)

This is a method used to monitor cardiac function, particularly contractility and filling. By following the movements and volume of the various chambers of the heart, it enables the clinician to treat the patient before any serious problems arise. In many situations, it has replaced the use of the more invasive pulmonary artery catheter.
10.5 MULTIGAS ANALYZER/ANESTHESIA GASES

The gas monitoring system measures inspired and expired values of oxygen, carbon dioxide, nitrous oxide and the most common anesthetic agents (see section on methods and agents above).

A sample of the contents of the breathing tubes is drawn using the sidestream technique (see above). It is then fed into the gas analyzer, which uses infrared light of different wavelengths to determine the levels of CO₂, NO₂ and inhalation agents. O₂, on the other hand, is monitored using O₂ sensors (see 10.1.1 above).

The development of accurate gas monitoring systems has enabled safe and widespread use of low flow anesthesia (see chapter 11).

10.6 BODY TEMPERATURE

The maintenance of normal body temperature is important in many patients, since it has been shown to have a positive effect on coagulation and diminish the risk of wound infections. Close monitoring of body temperature is particularly important in children and patients where there is reason to suspect a risk of either hypothermia or malignant hyperthermia.

It is best measured in highly perfused tissues (oral, rectal, in the ear) since this is more reliable than measurements taken at the skin surface. Recent technical innovations also allow temperature to be measured either in the bladder via a specially adapted catheter, or in the esophagus.

10.7 NEUROMUSCULAR TRANSMISSION (NMT)/MUSCULAR RELAXATION

The monitoring of neuromuscular transmission, NMT, is particularly important when administering and titrating muscle relaxants and reversing their effects.

The degree of muscle relaxation is an important parameter and there are several methods available nowadays for monitoring it.

The method most commonly used is Train of Four, or TOF, monitoring, in which the magnitude and type of neuromuscular blockade are measured. Four electrical currents are applied for 2 seconds to a peripheral motor nerve and the ratio of the amplitude of the fourth evoked mechanical response to the first one is observed. If the response decreases over time, the patient is still under the influence of muscle relaxants.

10.8 BIS/ENTROPY/AUDITORY EVOKED POTENTIAL (AEP)

Electroencephalography (EEG) measures cortical activity in the brain and the patterns change during sleep and anesthesia. It can therefore be used as an indicator of the depth of anesthesia.

Several methods can also be used to process the information obtained from an EEG so as to make interpretation easier, the most successful of which is described below.

The bispectral index (BIS) monitor provides a dimensionless number obtained from automatic analysis of EEG waveforms. This number ranges from 0 (EEG silence) to 100
(fully awake adult), while numbers between 40 and 60 are expected during general anesthesia. BIS monitors the depth of anesthesia, enabling the appropriate titration of anesthetic drugs. This makes for faster wake-ups and better recovery, and reduces intraoperative awareness.

BIS measurements can help healthcare professionals tailor the type and dosage of anesthetic or sedative medication to the needs of each patient. The method is however not yet widely used. There are several sources of error and the BIS monitor follows trends rather than absolute values.

**10.9 SVO\textsubscript{2}**

\textbf{SVO\textsubscript{2}} is a form of invasive pulmonary artery oximetry that measures venous oxygen content, or saturation, in the blood returning to the heart. This gives an indication of oxygen demand and consumption, with normal values between 60 and 80%.

To obtain these measurements, a very fine (Swan-Ganz) catheter is inserted into a central vein and led into the pulmonary artery. Spectrophotometry is used to estimate the oxygen content in the blood. This method also provides an opportunity to monitor cardiac output (see below).

\textbf{ScvO\textsubscript{2}} (where "\textsubscript{c}" stands for cava) is a form of invasive central venous oximetry that involves using a central venous catheter placed in the vena cava. This type of catheter is increasingly used in place of a pulmonary artery catheter, since the pressures measured using both methods are considered to be approximately equal.

**10.10 CARDIAC OUTPUT (CO AND CCO)**

This is a measure of the amount of blood pumped by the heart and is generally stated in liters per minute. Normal values lie between 4 and 8 liters per minute for healthy adults and are affected by vascular resistance, heart rate and contractility.

Thermodilution is the method generally used to measure cardiac output with the help of a pulmonary artery catheter, often in conjunction with \textbf{SvO\textsubscript{2}}. It results in a curve from which the desired volume may be calculated. A more recent technique measures the output continuously (\textbf{CCO}).

Non-invasive and less invasive methods of monitoring cardiac output and other hemodynamic parameters by using special algorithms have now been developed to avoid insertion of a Swan-Ganz catheter in the pulmonary artery.

**10.11 URINE OUTPUT**

Urine output is measured to help monitor fluid balance and circulation status. This may involve the insertion of a catheter. Urine volume is the most important parameter to note. Ultrasound is now also a common method of monitoring residual urine volume in many recovery rooms.
10.12 BLOOD LOSS

This may be either measured or estimated and may be actively compensated with the help of transfusions, if necessary, to raise blood pressure, enhance oxygenation and prevent vascular collapse. Even small losses are generally compensated in children, although the attitude to compensation is nowadays somewhat more restrictive in adults.
11 LOW FLOW ANESTHESIA

Low flow anesthesia has gained ground in recent years and has become increasingly accepted as the preferred mode of anesthesia. It requires a reliable gas monitoring system and a rebreathing system with a CO₂ absorber. It is as close as one can get in clinical practice to a closed system. Although the extent of rebreathing and the fresh gas flow used may vary (low flow, minimal flow and closed system anesthesia), the basic principle remains the same.

The benefits of low flow anesthesia are both financial (cutting costs of increasingly expensive anesthetic agents) and environmental. During low flow anesthesia, it is crucial to analyze the oxygen, carbon dioxide and anesthetic agent in the breathing system. Now that reliable gas analyzers are available, low flow anesthesia is as safe as anesthesia using a non-rebreathing system.

11.1 PRINCIPLES OF LOW FLOW ANESTHESIA

Low flow anesthesia involves the use of both intravenous and volatile agents. The precise limits of low flow anesthesia are not clearly defined, but a fresh gas flow below 2 liters is generally considered low flow in the US, while in the EU, low flow is generally below 1 liter.

The technique is based on the patient’s physiological needs. The proportion of rebreathing and desired fresh gas flow setting are adjusted to the patient’s status (oxygen consumption and CO₂ production, etc.)

The uptake of N₂O and other inhalation agents is high in the first few minutes of anesthesia, falling once the tissues become saturated.

When uptake falls, the concentration at the vaporizer may be lowered to ensure that the exhaled amount does not rise. One alternative here is to allow the concentration difference between inspired and expired gas to decrease the fresh gas flow. The exhaled gas is used for rebreathing once it has passed a CO₂ absorber. This means that both fresh gas flow and the quantities of volatile agents used can be decreased.

Accurate monitoring is essential to avoid complications and help the anesthetist tailor the anesthesia to the needs of the patient.

11.2 LOW FLOW TECHNIQUE

While there are no general rules for administering low flow anesthesia, one possible procedure is outlined below.

11.2.1 PREOXYGENATION

Extra oxygen is administered for some 3-5 minutes, usually via a face mask. Thorough oxygenation is still the best safeguard against complications. The patient is generally put to sleep with an intravenous agent during this phase and if necessary intubated.

11.2.2 HIGH FLOW - INDUCTION TO STEADY STATE

A fresh gas flow using standard flows of oxygen and nitrous oxide/air is given for some 6-10 minutes. Nitrogen from the body’s own nitrogen stores is gradually eliminated from
the body and replaced by nitrous oxide. Although nitrous oxide is still used relatively often, the current trend is pointing towards a decline in its use.

11.2.3 **MAINTENANCE**

When the uptake of gases stabilizes and the patient is comfortably asleep, oxygen is always administered as required by the patient.

The nitrous oxide flow depends on uptake and the inspired oxygen fraction, as shown continuously on the monitor.

With regard to inhalation agents, the vaporizer is initially used in the traditional manner (i.e. high flow) for 6-10 minutes. As the patient’s volatile agent requirement decreases, the flow can be set to a lower value for maintenance purposes.

The patient is carefully monitored throughout anesthesia, and the various values can be adjusted to suit changing patient needs.
11.2.4 ELIMINATION AND RECOVERY

High flow and increased oxygen concentrations are once again administered for 5-10 minutes to eliminate the anesthetic agent. The nitrous oxide has already been turned off and the extra oxygen supply should be maintained for at least 5-10 minutes after recovery to avoid diffusion hypoxia.
12 SAFETY CONSIDERATIONS

In anesthesia, the patient is dependent on the skill and experience of healthcare professionals and on high standards of safety, as well as built-in precautions in the equipment they use. Here, as elsewhere, prevention of patient injury is crucial.

The anesthesia machine is always checked before use, including the patient breathing system and suction device. As mentioned above, it is crucial for personnel to be thoroughly familiar with the relevant routines governing safety and checkout procedures. All members of staff should be updated on the latest developments on an ongoing basis. Warnings, cautions, recommendations and instructions concerning intended use should also be followed at all times.

Although incidents are rare and complications unusual, there are a number of risks associated with anesthesia of any kind and both personnel and patients should be aware of these. While every effort is made to minimize them, anesthesia can never be totally risk-free.

12.1 RESPIRATORY COMPLICATIONS

Respiratory complications may arise during the induction and recovery stages of general anesthesia. Obstruction of the upper airways, laryngospasm and bronchospasm, may occur and an assessment of the risk of airway problems should therefore be performed before anesthesia.

Anesthesia has an effect on spontaneous breathing, which is normally stimulated primarily by an increase in carbon dioxide levels. This regulatory system becomes increasingly insensitive to raised carbon dioxide levels as anesthesia deepens. This may lead to carbon dioxide retention. The regulatory system also gradually becomes insensitive to lack of oxygen as depth of anesthesia increases.

External apparatus dead space must always be considered, since face masks may double this dead space, while intubation decreases it.

One reason for reduced compliance may be the use of surgical retractors and abdominal packs that press the diaphragm upwards during open abdominal surgery. Even the position of the patient (such as the Trendelenburg position) may have a negative impact on breathing, as may some of the drugs used during anesthesia. The use of large amounts of intraabdominal carbon dioxide during laparoscopy may also affect both respiration and circulation.

12.2 CARDIOVASCULAR COMPLICATIONS

Falls in blood pressure are primarily treated by increasing the fluids infused or tipping the patient to lower the head below the level of the rest of the body (Trendelenburg position). If these procedures should fail, patient blood pressure may also be raised pharmacologically.

Vagal reflexes are most common at the beginning and end of general anesthesia. Sensory stimulation normally leads to an increase in the heart rate. Vagal stimulation of various kinds may however cause bradycardia.
and a lowering of stroke volume and blood pressure. Pressure on certain abdominal organs during surgery may also cause vagal reflex activity.

Tachycardia accompanied by high blood pressure may also be a sign of inadequate anesthesia.

Rapid changes in the concentration of desflurane may also cause tachycardia and during isoflurane or desflurane anesthesia, tachycardia may cause coronary ischemia.

12.3 NERVE AND OTHER INJURIES - THE IMPORTANCE OF PATIENT POSITIONING

Anesthesia depresses the autonomic nervous system and thus the capacity to make the physiological adaptations needed when changing body position. Nerve injuries may result from pressure or strain or be due to the fact that the patient has been anesthetized. Anesthetists and surgeons should thus be aware of the effects of the most common surgical positions, the areas vulnerable to injuries, and the precautions needed to prevent them.

The main positions of interest are:

- the supine or horizontal position, in which most patients are anesthetized and then repositioned if necessary;

- the head-down position, including the famous but now little-used Trendelenburg position with the head and body tilted downwards 45 degrees from horizontal. Most head-down positions involve a tilt of 10-15 degrees in combination with various anglings of the lower body;

- the lithotomy position, with a 90 degree flexion of both hips and knees and abduction of the hips, mainly used for pelvic and perineal surgery;

- the prone position, which involves lying on the stomach;

- the lateral position, with the patient lying on either the right or the left side;

- a number of more specialized positions, including, for example, the modified sitting position and the lumbar spinal surgery position, sometimes modified as the knee-elbow position, which may involve the use of a special operating table for spinal surgery.

Safe positioning of patients involves team work between anesthesiologist, surgeon and nurse. All aspects of positioning should be planned in advance and tasks assigned, and the accessories needed should be checked beforehand.

Positions associated with major physiological changes (like the modified sitting position) should be achieved in a stepwise fashion, checking hemodynamic and other parameters and adjusting anesthesia depth. The position of the endotracheal tube or laryngeal mask should also be checked. Padded cushions should be kept under areas vulnerable for nerve compression. Bony areas may be left in contact with the mattress. However, if the surgical time is likely to be prolonged, or if the patient is likely to be hypothermic or hypotensive, they also need to be well padded. It is preferable to have all the joints in the body (except the ankle) in minimal flexion. During anesthesia, the eyes should be
kept closed and the ears may be protected with the help of ear plugs. Finally, the patient should be covered as much as possible so that heat loss is minimized, except in the case of artificially induced hypothermia (used for open heart surgery, for example).

12.4 VOMITING AND REGURGITATION

Anesthetized patients always run the risk of vomiting and regurgitation, particularly during induction if the airway is not free and gas is pumped into the stomach.

Endotracheal intubation diminishes the risk of aspiration, although the laryngeal mask does not. There is also a higher risk of vomiting after anesthesia and surgery, although the patient is then conscious and generally able to move and communicate.

12.5 SHIVERING

Shivering may occur after all general anesthesia and is not necessarily due to heat loss.

Shivering greatly increases oxygen consumption, causing hypoxia, hypercapnia and even acidosis. Moreover, oxygen transportation often decreases during shivering. The treatment involves administration of pure oxygen and sometimes very small doses (10-20 mg) of pethidine are given intravenously with almost immediate effect.

12.6 AWARENESS

This may occur if the patient is not fully unconscious and hears sounds or words, or even feels pain, without being able to communicate his or her condition. It is generally associated with the use of muscle relaxants, while technical failures rarely cause awareness.

Inhalation anesthesia without the use of muscle relaxants minimizes the risk of awareness, as long as the induction phase is adequately completed and sufficient time is allowed for the agent to equilibrate and provide full anesthetic effect.

12.7 MALIGNANT HYPERTHERMIA

Some patients have a rare genetic predisposition to develop malignant hyperthermia (or hyperpyrexia). When volatile agents are used, body temperature and metabolism both rise dramatically in these patients. Increased metabolism is reflected in higher etCO₂ values. Suxamthonium may also be implicated in malignant hyperthermia.

All inhalation agents appear to produce these side-effects, which may, if they go untreated, ultimately cause death. The complication is very rare and runs in certain families.

12.8 GAS LEAKAGE

Anesthesia machines may occasionally have problems with leakage, which may occur from vaporizers, flowmeters, patient tubing, connectors or any of the other components of the apparatus. All leakage should be avoided to maintain safety in the OR and ensure environmental friendliness. The use of low flow anesthesia has been shown to reduce occupational exposure to anesthetic agents.
By performing a checkout procedure prior to low flow anesthesia, leakage can be detected. Low flow anesthesia may not be used if leakage is higher than 100 ml.

12.9 AIR POLLUTION

In theory, nitrous oxide has a negative impact on the environment, both at the OR level via leakage and at the global level, since it is a potent greenhouse gas. The effect of nitrous oxide emissions from hospitals is however negligible when compared with emissions caused by other human activities. There is still insufficient research into the long-term effects of lengthy exposure to volatile anesthetic agents, although regulations involving very low occupational limits are in place so as to protect personnel from all unnecessary exposure.
12.10 ELECTRICAL HAZARDS

The most common source of malfunctions caused by electric current is surgical diathermy, which may cause serious failures in medical devices and interrupt their functioning.

There is also a general recommendation to avoid the use of cell phones in the vicinity of medical devices as the signals may interfere with the way the equipment functions. Routines may however vary from one country or hospital to another. Modern mobile telecommunication systems also carry a much lower risk of interference than older systems.
Anesthesia is used in the OR not only for routine surgery, but also for special types of surgery that involve special anesthesiological requirements. Pediatric care, neurosurgery, transplantation and cardiovascular surgery are just a few examples. Anesthesia is also used in other parts of the hospital, such as for sedation within intensive care (the ICU) or in MR environments. This section presents some of these special applications, although readers looking for more in-depth information should consult specialized works on anesthesia (see References).

### 13.1 PEDIATRIC ANESTHESIA

It is not just in size that children and infants differ from adults. The following sections cover the main points to remember when anesthetizing children.

#### 13.1.1 AIRWAY ANATOMY

The mucous membranes are more sensitive to trauma in children. In addition, the appearance of the larynx differs, with the narrowest point located just below the vocal cords rather than at their level.

This means that when endotracheal tubes are used, the cuff is not inflated so as to avoid the risk of trauma and swelling. However, this may increase the risk of leakage, although this is not generally a problem in practice.

#### 13.1.2 DEAD SPACE

In relative terms, there is more dead space when a child is anesthetized than when an adult is. The space should therefore be limited wherever possible and compensation should be made for it.

#### 13.1.3 BREATHING

The breathing rate is faster in children, who are often mouth-breathers. This must be taken into account when using a face mask since it may make it more difficult to maintain a free airway.

#### 13.1.4 HYPOVENTILATION

Children are more susceptible and sensitive to hypventilation. Obstruction of the airways is quick to result in bradycardia and respiratory acidosis.
13.1.5 COMPRESSIBLE VOLUME

This should be minimized when children are anesthetized, which makes the choice of breathing system and ventilator crucial.

13.1.6 CIRCULATION

Children’s heart rate is faster, their blood pressure lower and their cardiac output high in relation to body weight. Even small blood losses may be significant in children and are therefore compensated. The aim should be to avoid hypovolemia and maintain normovolemic patients.

13.1.7 METABOLISM

Children have a higher metabolic rate than adults, which means that they break down drugs and pharmaceuticals more rapidly. The concentration of anesthetic gases thus generally needs to be raised.

13.1.8 BODY TEMPERATURE

Children’s body temperature, especially that of neonates and infants, is less stable than that of adults. It is therefore important to monitor body temperature more closely. Often a hot air warmer is used to maintain normal body temperature.

13.2 ANESTHESIA FOR NEUROSURGERY

The focus here is on lowering intracranial pressure, which means special demands on anesthesia, including:

- maintaining free airways at all times;
- adequate oxygenation and CO₂ elimination. Previously, hyperventilation was used to lower intracranial pressure, although the tendency now is to strive for normoventilation;
- suitable intravenous infusions using agents such as cortisone and hypertonic fluids to reduce edema in the brain and thus lower pressure;
- maintaining stable blood pressure without fluctuations;
- careful patient positioning, sometimes in the sitting position, and the use of special drugs and accessories to enhance peripheral circulation;
- using suitable anesthetic agents and drugs such as muscle relaxants to prevent the patient from coughing or straining.

13.3 ANESTHESIA FOR CARDIOVASCULAR SURGERY

Thoracic surgery imposes special demands on the anesthetist, including:

- effective ventilation/respiration must, as during all surgery, be maintained;
- it must be possible to ventilate the lungs individually during lung surgery;
- equipment to counter induced hypothermia must be at hand;
- special cardiovascular drugs must be available in case of emergency;
- pleural drains are almost always needed;
it is even more important than usual for the patient to have an adequate cough reflex shortly after recovery so as to avoid postoperative complications.

13.4 ANESTHESIA DURING LAPAROSCOPY

This type of surgery using a laparoscope is increasing in popularity and more and more interventions are now performed laparoscopically.

The technique requires the patient to be slightly tipped and the abdomen to be filled with CO₂. Although it requires special skills in the operating surgeon, it enables relatively complicated surgery to be performed without large skin incisions. The high level of visual detail contributes to enhancing accuracy and patient safety.

It may also give rise to a number of physiological effects including:

- major changes in compliance
- CO₂ retention and embolism
- risk of bradycardia and arrhythmia
- other cardiovascular effects caused by the rise in intraabdominal pressure
- pneumothorax.

13.5 ANESTHESIA DURING ARTHROSCOPY

The patients here are often relatively healthy outpatients, necessitating rapid recovery from anesthesia if regional anesthesia, often the method of choice in such cases, is not used.

This in turn means that inhalation anesthesia using agents eliminated via the lungs and with low solubility is generally preferred when general anesthesia is given. The idea is to avoid long stays in hospital. Short-acting IV agents such as propofol are also popular.

13.6 ANESTHESIA DURING TRANSPLANTATION

The special demands imposed here depend on the organ to be transplanted and include:

- blood flow and perfusion have to be adequate and constant before, throughout and after surgery;
- total muscular relaxation is often used;
- special drugs must be at hand.

13.7 ANESTHESIA IN BURNS UNITS

Burns patients are often anesthetized during painful bandaging and may face special complications, including:

- frequent hypovolemia
- serum potassium levels may increase during anesthesia if depolarizing muscle relaxants are used, causing large amounts of potassium to be released from cells in damaged tissues, with an ensuing risk of cardiac arrest
a high risk of respiratory distress
a high risk of circulatory instability
frequent septicemia.

13.8 ANESTHESIA FOR EAR, NOSE AND THROAT SURGERY

ENT anesthesia techniques may differ from those used in other specialized fields. The most important aspects include the shared airway, the difficult airway, emergence and extubation, special airway equipment, apnea and rapid case turnover. Preoperative assessment is crucial, particularly prediction of difficult intubation. Patients may be of all ages and include those with:

- stridor
- intubation difficulties
- sleep apnea
- concomitant diseases.

Special points to remember include:

- The use of local techniques and surface analgesia;
- The special nature of ENT emergencies (including croup, epiglottitis and foreign bodies);
- Frequent use of laryngoscopy and bronchoscopy;
- The need for familiarity with special tubes, gags and equipment for microlaryngoscopy, bronchoscopy and laser surgery (e.g. Venturi devices, ventilating bronchoscope and fiber optic bronchoscopy);
- The use of HFO, ventilation with high frequency oscillation;
- Middle ear surgery may involve special hypotensive techniques;
- Major head and neck surgery sometimes entails special positioning;
- Emergency airway management may be needed, including tracheostomy;
- ENT anesthesia is often pediatric anesthesia;
- ENT anesthesia often involves assessing and managing the difficult airway, including fiber optic intubation;
- ENT anesthesia may also involve managing major facial injuries.

13.9 ANESTHESIA FOR OUTPATIENTS

General anesthesia is frequently offered to particularly sensitive patients who suffer from severe anxiety or are afraid of pain. In addition, it is becoming increasingly popular to perform surgery on outpatients who are sent home the same day as surgery is performed. This imposes special requirements including:

- use of fast-acting drugs
- relatively healthy patients
- rapid recovery
13.10 ANESTHESIA IN MR ENVIRONMENTS

Many patients, and especially children, find MRI examinations difficult to cope with, since they have to lie still for long periods inside the machine. As the use of MRI equipment becomes more widespread, the need to anesthetize certain patients is increasing. This involves the same kind of requirement as listed above for outpatients, but because the MR environment is a highly specialized one, it also imposes specific requirements on the equipment used there, which must be capable of withstanding the powerful magnetic fields used. Another requirement is that such equipment should not affect the MR apparatus.

13.11 ANESTHESIA IN THE ICU

Anesthesia in the ICU focuses mainly on sedation and analgesia. It is often necessary to sedate patients or anesthetize them while certain procedures are performed, or even for long periods while they undergo treatment. These patients are often extremely ill and require specialized anesthesiological care. Generally speaking, an ICU ventilator is used and intravenous anesthetic agents administered via a central line. The needs of the ICU are imposing growing requirements on the equipment used there. It has been suggested that special anesthesia machines could be developed with access to sophisticated modes of mechanical ventilation and the highest levels of reliability for use in the ICU.

When patients who are agitated or anxious require sedation ahead of difficult procedures, ICU personnel need to consider various means of sedation and pain relief so as to meet the patients' needs.

The following are some of the indications for sedation in the ICU:

- facilitation of mechanical ventilation/airway management
- pain relief
- fear and/or anxiety
- sleeping problems
- amnesia during neuromuscular blockade
- control of agitation

The drugs most commonly used include benzodiazepines, propofol and opioids (for analgesia).

13.12 ANESTHESIA AND THE OLDER PATIENT

The elderly population is growing as people are living longer. In Europe, Japan and the USA, people over 65 represent 15% or more of the population and many of them seek surgical care. The increased risk involved in hospital care of older patients is related both to their age and to the fact that more and more of them are seriously ill when hospitalized.

Although the ageing process is highly individual, it is often characterized by degeneration of organ systems and tissues and loss of functional reserves, as well as a decreasing ability to cope with anesthesia and surgery. The systems most affected include...
the respiratory, cardiovascular, renal, and central nervous systems. It is also important for the anesthetist to remember that patients' skin, dental and nutritional status should be taken into account.

13.13 ANESTHESIA AND MATERNITY CARE

Obstetric anesthesia and analgesia constitute the only area of anesthetic practice where two patients are cared for simultaneously. Pregnancy is a physiological rather than a pathological state and patient expectations are therefore high - the mother expects full involvement in her choice of care.

The majority of the workload is the provision of analgesia in labor and anesthesia for delivery, although multidisciplinary care for sick mothers is increasingly important. Knowledge of techniques such as epidural and spinal anesthesia is essential, as well as familiarity with and planning for obstetric emergencies, should they arise.
Whenever there is a risk that the patient’s stomach may not be empty (emergency surgery or other unforeseen situations), the anesthetist will generally choose rapid sequence induction (described in more detail in Chapter 6).

Anesthetists and other healthcare professionals may also be called to the scenes of accidents and emergencies to take care of patients on site. This involves familiarity with routines that apply in the pre-hospital environment, pre-hospital analgesia and practical methods for rapid patient assessment. Special drugs, equipment and procedures may be used and multidisciplinary trauma teams are often formed. These specialists are often experts on advanced airway management, intravenous and other forms of cannulation, thoracotomy and laparotomy.

One of the main complications among trauma patients is shock, or acute circulatory failure, with hypovolemia as the most common cause.
13.15 ANESTHESIA IN THE DEVELOPING WORLD

In 1960, the per capita gross domestic product (GDP) of the 20 richest countries was 18 times that of the 20 poorest. By 1995, the gap between the richest and poorest nations had more than doubled to 37 times. Only a small minority of the world’s population have access to a computer, and there is also a striking disparity between rich and poor nations. According to the International Telecommunications Union, there were 61.1 personal computers per 100 people in North America as compared with 6 in the East Asia/Pacific or Latin America/Caribbean regions in 2001. Access to qualified medical care is likewise unevenly distributed at the global level. Most of the sophisticated equipment and high standards of care that we take for granted in the western world are unavailable to people in developing countries.

There is a great need to collaborate with developing nations on the education of anesthetists and to work with governments and other agencies. In many cases, collaboration involves assistance in the form of advice and even of trained and experienced specialists who can provide help where needed. There is also a tremendous need for training and personnel, as well as material and equipment. Fortunately, some such efforts are now being made as attitudes begin to change and progress is made.
Medical professionals often use terms and expressions that may be unfamiliar to outsiders. They also sometimes assign specialised meanings to otherwise familiar words and this may require explanation. As is the case with all specialist terminology, its use may be more justifiable in some cases than in others. As a rule, however, excessive use of jargon is a barrier to understanding, rather than an aid.

Health professionals in general also have an unfortunate tendency to use acronyms and abbreviations that occasionally make their language obscure or difficult to interpret. Some of these terms and abbreviations are explained below, although there are of course local variations that are beyond the scope of this short glossary.

**Acidosis** - condition characterized by a low pH (acidity) caused, in the case of respiratory acidosis, by accumulation of CO₂ due to inadequate respiration, as opposed to metabolic acidosis, where the excess acid is due to metabolic processes.

**Alveoli** (plural form of alveolus) - the smallest space units in the lungs formed by the terminal air-filled sacs at the end of the bronchioles, where gas exchange takes place.

**Analgesia** - originally a state of painlessness, although it now mainly means pain relief. Analgesics are thus drugs used to relieve pain.

**Amnesia** - lack of memory.

**Anesthesia** - a state of being "without feeling", insensibility to most external stimuli, including pain.

**Angina pectoris** - chest pain originating from the heart, sometimes referred to (in English) simply as angina. It is generally a sign of myocardial ischemia (inadequate blood supply) and is a relatively common symptom, particularly after stress or effort, in patients with known heart disease.

**Anticoagulants** - pharmaceuticals designed to prevent, suppress or delay the clotting process in blood.

**ASA** - American Society of Anesthesiologists. In medical charts and case histories, the term may also be used to refer to acetyl salicylic acid, a drug generally known as aspirin.

**Aspiration** - accidental sucking in of food particles or fluids into the lungs.

**Awareness** - a condition in which the patient is not fully anesthetized and may therefore be aware of some of the things that go on in the OR without being able to communicate this fact.

**BGPC** - blood/gas partition coefficient, a measure of the solubility of an anesthetic agent in blood.

**BMI** - Body Mass Index, a key index for relating body weight to height and assessing obesity. BMI is calculated by dividing a person's weight in kilograms (kg) by their height in meters (m) squared.

**Bradycardia** - a slower heartbeat than is normal, i.e. generally < 50 in adults.

**Bronchospasm** - spasmodic contraction of the bronchi, as in asthma.
Capnometry/Capnography - monitoring of patients' inhaled and exhaled carbon dioxide levels.

Carbon dioxide retention - inadequate elimination of carbon dioxide, CO₂.

Cardiac output (CO) - the effective volume of blood pumped out by the heart per unit of time (l/min).

Catecholamines - amines derived from a special amino acid (tyrosine), examples of which include adrenaline, noradrenaline and dopamine. They act as hormones or neurotransmitters, raising blood pressure and heart rate, among other things.

CCO - continuous cardiac output. Definition as for "Cardiac output" above, but monitored continuously.

Coagulation and hemostasis status - a panel of tests that provide information about coagulation status and bleeding tendencies.

Compliance - a measure of the elasticity of the lungs and thoracic wall, expressed as the volume change per unit change in pressure.

Compressible volume - the part of the inspiratory minute volume needed to compress the gas in the apparatus and tubing and therefore not reaching the patient.

COPD - chronic obstructive pulmonary disease, comprising any disorder that persistently obstructs bronchial airflow. COPD mainly involves two related diseases - chronic bronchitis and emphysema. Both cause chronic obstruction of air flowing through the airways and in and out of the lungs. The obstruction is generally permanent and becomes worse over time.

Coronary steal - the detrimental redistribution of coronary blood flow whereby blood is diverted from underperfused areas toward better perfused areas.

Cricoid cartilage - ringshaped cartilage forming the lower and back part of the larynx at the level of C6.

CSF - cerebrospinal fluid, which surrounds the brain and spinal cord.

Dead space - for each breath taken, there is a part that is not involved in gas exchange. There are three types of dead space - anatomic (the trachea and bronchi, which have no alveoli), apparatus or external (the endotracheal tube and other pieces of tubing with bidirectional gas flow), and physiologic (the apical areas of the lung with ventilation but no perfusion).

Diathermy - the use of electrocautery for cutting and coagulation or cauterization, as for sealing a blood vessel, resulting in local tissue destruction. Diathermy may be either monopolar or bipolar.

Edema - accumulation of fluid in serous cavities (e.g. lungs) or connective tissue.

ECG - electrocardiography uses electrodes placed on the body to monitor electrical activity in the heart. The ECG curve has a characteristic appearance that also provides information about the condition of the heart muscle.

EEG - electroencephalography uses electrodes placed on the head to monitor activity in the brain cortex, which is then graphically displayed in the form of waves.
**Elective** - a procedure that is planned and scheduled, as opposed to emergency procedures.

**Emphysema** - a pathological increase in the size of the alveoli, involving their distension or rupture and leading to progressive loss of pulmonary elasticity. It is a common complication among smokers.

**Endocrine disease** - disease involving disorders of the endocrine glands and hormones of the body, for example, and including such conditions as diabetes and thyroid disease, as well as many less common disorders.

**etCO₂** - end-tidal concentration of carbon dioxide.

**ETT** - endotracheal tube used for endotracheal intubation.

**Extubation** - removal of an endotracheal tube.

**Fₐ** - alveolar concentration (or fraction) of a gas.

**Fᵢ** - inspired concentration of a gas.

**Fₐ/Fᵢ ratio** - the change in this ratio over time describes the wash-in curve of a gas such as an anesthetic agent (and thus its solubility in blood).

**FGF** - fresh gas flow.

**FOB** - fiber optic bronchoscope. a flexible instrument used to view the trachea and bronchi.

**Hemoglobin** - the molecule in red blood cells that transports oxygen.

**Hypercapnia** - a condition characterized by a higher than normal level of carbon dioxide in the blood.

**Hyperpyrexia** - see hyperthermia.

**Hypertension** - elevated arterial blood pressure.

**Hyperthermia** - a condition, sometimes known as pyrexia, in which body temperature is elevated.

**Hyperventilation** - ventilation that exceeds normal physiological requirements.

**Hypnosis** - although now use in a slightly different sense, the term originally refers to a sleeplike condition.

**Hypnotic agent** - a drug that puts patients to sleep.

**Hypotension** - low arterial blood pressure.

**Hypothermia** - a condition in which body temperature is lowered.

**Hypoventilation** - inadequate or reduced ventilation that does not meet physiological requirements.

**Hypovolemia** - decreased volume of circulating fluid in the body.

**Hypoxia/hypoxemia** - condition in which O₂ levels in the blood are reduced.

**Icterus** - jaundice.

**Intrathecally** - drugs given intrathecally are administered into the cerebrospinal fluid surrounding the spinal cord and brain.
**Intubation** - insertion of a tube, generally endotracheal.

**Laparoscopy** - examination of intra-abdominal organs using a laparoscope. The term is now often used to denote surgical intervention during the above procedure.

**Laryngoscope** - a flexible, lighted tube used to look at the inside of the larynx. It is inserted through the mouth into the upper airway.

**Laryngospasm** - spasm of the larynx causing closure of the vocal chords and severe airway obstruction. A complication of intubation/extubation.

**Larynx** - upper part of the respiratory tract (above the trachea) containing the vocal cords.

**Liver status** - a group of laboratory values that reflect liver function, the most important of which are the ASAT, ALAT, LD, ALP and GT (liver enzymes) and bilirubin tests.

**LMA** - laryngeal mask airway, a device used for maintaining a patent airway without endotracheal intubation. It consists of a tube connected to an oval inflatable cuff that seals the larynx.

**MAC** - Minimum Alveolar Concentration, an index of the anesthetic effect and potency of an inhalation agent in relation to alveolar concentration. 1.0 MAC is the concentration required for lack of reflex response to skin incision in 50% of patients. 1.3-1.4 MAC is the concentration usually required for surgical anesthesia. MAC values are affected by patient age (lower for old people and higher for infants and children) and the use of other inhalation agents (when MAC values are additive).

**Malignant hyperthermia** - a genetic disorder (sometimes referred to as malignant hyperpyrexia) triggered by exposure to volatile agents that causes a life-threatening condition of rapidly increasing body temperature, hyperventilation and tachycardia. Early signs include high muscle tone, rigidity and an increase in etCO₂. Untreated, the condition can lead to cardiac arrest.

**Metabolism** - the range of biochemical processes occurring within any living organism and involving the build-up and breakdown of substances. The term is commonly used to refer specifically to the breakdown of food and its transformation into energy.

**Metabolites** - breakdown products (often of pharmaceuticals) resulting from metabolism by the body.

**Mixed venous blood** - the blood in the pulmonary artery that has returned to the right side of the heart from all parts of the body.

**Myocardial infarction** - an infarct in part of the heart muscle, often known as a heart attack.

**Myocardium** - the heart muscle.

**OGPC** - oil/gas partition coefficient, a measure of the lipid solubility of an anesthetic agent.

**Opioid** - chemical substance with a morphine-like action in the body, mainly used for pain relief.

**Peroral** - administered through the mouth as opposed to other administration routes, generally in relation to medication.
Plethysmograph - curve measuring the amount of blood flowing through an organ and the organ’s blood content.

Pneumothorax - a collection of air or gas in the pleural space of the lung, causing the lung to collapse. It may be caused by an open chest wound allowing air to enter, by a rupture of the surface of the lung due to lung disease such as emphysema, or by a severe bout of coughing. It may also occur spontaneously.

Pop-off valve - valve used in breathing systems for releasing excess gas at a certain pressure.

Regurgitation - passive backward flow, e.g. of stomach contents from the ventricle.

RSL - rapid sequence induction, a variation of the standard induction technique for patients under anesthesia. It is performed when immediate definitive airway management through intubation is required, especially in emergencies when there is a risk of aspiration.

Serum electrolytes - laboratory values indicating levels of important electrolytes in the blood. The main electrolytes tested are sodium and potassium. High or low levels of the latter (hyper- and hypokalemia), in particular, may have a negative impact on cardiac rhythm.

Serum creatinine - laboratory value that provides a quantitative estimate of kidney function.

Shivering - a condition resulting from low body temperature following anesthesia in which metabolism increases, causing higher oxygen consumption. It is therefore treated with pure oxygen and sometimes small doses of pethidine given intravenously, as well as by warming the patient and preserving body heat.

Solubility - the ability to dissolve, generally measured by the amount (in ml) of a substance that will dissolve in another quantified substance.

SpO₂ - the percentage of oxygen-carrying hemoglobin molecules, or oxygen saturation, in peripheral blood as measured non-invasively by pulse oximetry.

Stridor - a harsh high-pitched crowing sound during inhalation or exhalation associated primarily with airway obstruction.

Stroke volume - the volume (in ml) of blood pumped out by the heart with each beat.

SvO₂ - oxygen saturation in mixed venous blood (as opposed to arterial blood - SaO₂, or peripheral blood - SpO₂), a spot value measured invasively as the percentage of hemoglobin occupied by oxygen.

Tachycardia - an accelerated heartbeat, generally > 100 in adults.

TIVA - total intravenous anesthesia, a form of general anesthesia involving the intravenous administration of hypnotic agent, analgesic drugs and muscle relaxants and excluding simultaneous administration of any inhaled drugs.

TOF - train of four, a method used for measuring magnitude and type of neuromuscular blockade. It is based on the
ratio of the amplitude of the fourth evoked mechanical response to the first one, when four electrical currents are applied for 2 seconds to a peripheral motor nerve.

**Trachea** - the part of the airway referred to as the windpipe between the larynx and the bronchi.

**Trendelenburg position** - position on the operating table in which the patient is supine with head tilted down in relation to the rest of the body.

**Vagal reflexes** - reflexes relating to the vagus nerve and causing bradycardia, reduced stroke volume and a fall in blood pressure.

**Vasoactive agent** - a drug causing constriction or dilation of blood vessels.

**Vasoconstriction** - narrowing of the diameter of blood vessels resulting from contraction of their muscular walls. This is the opposite of vasodilation.

**Vasodilation** - widening of the diameter of blood vessels resulting from relaxation of their muscular walls. Vasodilation is the opposite of vasoconstriction.
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