Reading Material for

Anesthesia Technician

(Paper-A)

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PREFACE

This is a two years post matric teaching program of Anesthesia Technician for the students of Allied Health Sciences. The purpose of this reading material is to provide basic education to the paramedics about anesthesia. This reading material attempts to cover almost all the basic theoretical knowledge required by students about anesthesia so that they can perform their work better in collaboration with anesthesiologists in operation theaters.

This reading material aims at using basic language skills to make it easier for better understanding of the subject. The contributors have put up the best efforts to make it concise and provide all the important concepts including the practical aspects.

Hopefully, this reading material provides the best of the knowledge in favour of students. .

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Section I OPERATION THEATRE AND HOSPITAL ENVIRONMENT

Chapter 1

INTRODUCTION TO OPERATING DEPARTMENT, ORGANIZATION, DESIGN AND PROTOCOLS

IMPORTANT TERMS

ASCEPTIC /; free from harmful bacteria, viruses and other microorganisms

AMBULATORY SURGERY: a type of surgery which does not require hospital admission

1.1 INTRODUCTION

When a surgical procedure is required the patient's care will be initiated [started] by the operating room (OR) staff or surgical team. The responsibility of the operating room staff is to provide care and assistance to the patient within the duration of the procedure. The operating room personnel shares responsibility for the well-being and comfortability of the patient. Everyone within the surgical team possesses a unique staff role in the OR. The privacy and safety of all patients is the top priority for everyone.

1.2 WHAT IS AN OPERATING ROOM?

The Operating Room, or, is a large, sterile room where surgeons operate on patients. It is equipped [prepared] with surgical tables, monitors, and other equipment necessary for surgery. There are many types of operating rooms depending on the type of surgery. The room is typically cool and quiet, and the air is sterile and clean.

The typical operating room will consist of a surgical table that can be rotated and adjusted through the procedure. All tables have weight restrictions [limitations] and removable pieces for the back and legs. This allows for more flexibility for the patient and optimal ergonomics [working efficiency] for the surgeon and the team.
The operating complex has several rooms for changing, supplies and equipment. Most of the operating rooms have a separate room for scrubbing and preparing the sterile tables. Most operating rooms have a sluice [channel] that connects the operating room (OR) to the corridors of the OR complex to optimize the airflow in order to support infection prevention.

1.2.1 Estimated Industry-Standard Operating Room (OR) Sizes

- Small OR - 400 sq.ft

- Standard OR - 500 sq ft
- Orthopedic OR - 600 sq ft
- Cardiac OR - 600 sq ft
- Neurological OR - 600 sq ft
- Hybrid OR - 650 sq ft (Plus 120 sq ft separate control room)
- Transplant OR - 800 sq ft

Determining the size of any operating room requires factoring in the above estimates, while also accommodating for future changes. The room will need to be optimized for the various equipment, supplies, staff, and general work flow.

1.3 OPERATING ROOM DESIGN AND LAYOUT

Here is a brief overview of the Operating room design and layout:

- The surgical table is placed centrally in the room, giving the surgical team easy access to the patient on the surgical table.
- A ventilation panel located directly above the surgical table is typically used to provide ventilation. By doing so, ambient air is directed away from the surgical site, carrying potentially contaminant dust particles with it.
- The anesthesia machine is placed at the end of the table where the patient's head is positioned and close to the OR door providing quick access for the anesthetic team in case of an emergency and anesthetic care that is convenient [easy] and efficient.
- The suction device can be used to evacuate blood, body fluids, and smoke during surgery. This makes the suction device a necessary component of surgical procedures and anesthetic care provision.
- A refrigerator is used to preserve specimens and store medications at desired temperatures.
- At least one operating light is installed directly above the surgical table. The lamp head can be adjusted to focus the light at different angles and intensities.
- The warming cabinet should be warmed to prevent hypothermia [low body temperature] (leading to coagulation disorders).
- The position of the surgical team depends on the specific procedure to be carried out.
- The temperature of the Operating room is usually cold. The patient is kept warm using warmed blankets and/or mattress. Working under an operating light with protective gears on might cause the team to sweat, which can, in turn, compromise sterility.

1.4 OPERATING ROOM ZONES

The Operating Room is divided into different zones (sterile, clean, protective, and disposal) to prevent air contamination and regulate materials' transportation.

1.4.1 The sterile zone

The sterile zone consists of the Operating rooms and clean preparation areas. In this zone, the highest level of aseptic conditions needs to be maintained. The ventilation system helps maintain air pressure gradient, minimizing airflow from the corridor to the OR.

1.4.2 The clean zone

The clean zone consists of the store areas, preoperative/holding room, recovery room, or PACU and OR staff rooms. It surrounds the sterile area and connects it to the protective area. Only staff wearing appropriate surgical wear should enter the clean area.

1.4.3 The protective zone

The protective zone includes dressing rooms, reception, and waiting areas. The zone surrounds the clean zone and forms a protective area between the clean zone of the OR and the rest of the hospital.

1.4.4 The disposal zone

The disposal zone includes the decontamination rooms and disposal corridors. The soiled instrument uses linen. Operating debris is removed via the disposal zone.

1.5 COMMON OPERATING ROOM EQUIPMENT

- Anesthesia Machine
- Anesthesia Monitor
- Video Monitors and Cameras
- Anesthesia cart
- C-arm
- ESU
- Surgical Microscope
- EKG Machine
- Operating Table
- Operating Lights
- Auto-transfusion
- Laser
- Forced Air Warmer
- SCD
- Pneumatic Tourniquet
- Blood Warmer
- Defibrillator
- Case Cart / Crash Cart
- Prep Tables
- Back Tables
- Specialty Cart
- IV poles
- Mayo stands
- Ring stands
- Kick buckets
- Hazardous waste bins
- Trash bins
- Storage Cabinets
- Desk / Computer
- Linen hamper

1.6 OPERATING ROOM HAZARDS

Operating room hazards can include everything from surgical tools that can cause injury to personnel to the potential for infections.

1.6.1 Sharp objects

Many sharp objects in an operating room can cause injury if not handled properly. These objects include scalpels, scissors, and needles. Without proper precautions, these sharp objects can result in a serious injury to the patient or medical personnel. Surgical tools, like scalpels, needles, and scissors, should be handled with care by healthcare providers. All sharp objects should be properly sterilized before being placed back into the operating room.

1.6.2 Infections

Using contaminated instruments during surgery can cause an infection to spread through the patient's body. These infections are often life-threatening and require immediate attention. To prevent the spread of infection, healthcare providers should only use sterile instruments. Additionally, all instruments that come in contact with the patient's body should be properly disinfected.

1.6.3 Strains

When a patient is mal-positioned on the operating table, this can easily result in muscle strain or compromised nerves. A strained muscle can be incredibly painful, especially when the injured part remains inside the body. If a patient is undergoing surgery and complains of pain, this might be caused by mal-positioning on the operating table. **1.6.4**

Fire

Although rare in modern ORs, a fire outbreak can still occur. ORs are designed considering the correct location of fire extinguishers, installation of fire alarms, and gas shut-off valves.

1.6.5 Inadequate ventilation

If the air quality within the operating room becomes too poor, it can become toxic and dangerous for patients.

1.7 SURGICAL LIGHTS

Surgical lights, also known as surgical lighting or operating lights, are mainly used in hospital operating rooms and ambulatory surgery centers, but can also be used in various locations throughout the facility to provide high quality lighting for procedures. Examples include emergency rooms, labor and delivery, examination rooms, and anywhere where procedures are completed. They are used by clinicians, surgeons and proceduralists.

A surgical light illuminates the operative site on a patient for optimal visualization during a procedure. Surgical lights can provide hours of bright light without excessively heating the patient or staff. A variety of lights are available to meet the needs of providing optimal visualization during surgery and procedures. An examination light is used during medical exams, while operating room lights are used during surgical procedures.

1.7.1 Types of surgical lights

There are various types of surgical lights, performing a distinct role. Most lights are either used before the surgery, during the surgery or after the surgery, depending upon the task for which it has been designed.

Mounted/Lamp/Incandescent

The configuration of surgical lighting includes wall-mounted, floor stand, or ceiling mounted.

Ceiling mounted lights are highly used because of their capability to be mounted on a fixed point on the ceiling where the procedure is carried. Wall-mounted lights, as the name goes, are usually fixed on the wall of the operating room. However, as per studies, examination lights are used together with wall-mounted lights for greater mobility.

The incandescent lights [routinely used lights] preferably halogen bulbs are effective in the own way, however, they are no match to LED lights. They work for up to 1200 hours less than the shelf life of an LED light

LED Headlights

LED headlights came into practice much later than the incandescent lights. It has been able to replace fiber optic xenon systems which are typically used in head-mounted surgical lights. LED headlights make use of a single diode to bring out light by converting electricity.

1.7.2 Characteristics of operating lights

- Shadow control
- cold light
- multi-reflective system design

  make sure the surgical area is shade-free; Equipped with cold light filter and cold light reflector to minimize heat radiation.

- Lightweight structure
- wide range of adjustment
- stability, with removable light handle,

  operators can easily adjust the lighting needed for surgery by adjusting the light handle and central control panel.

1.8 THE PERIOPERATIVE TEAM

- The Anesthesia provider
- Anesthesia Technologist
- Anesthesia Technician
- Surgeons
- Surgical technologist
- Nurses

1.9 THE ROLE OF THE ANESTHESIA TECHNICIAN

A major role of the AT is to support the anesthesia provider. Additionally, ATs work closely and partner with all other members of the surgical team. The scope and responsibilities of the AT may vary based on the institution and region. Some of these include partnering with the perioperative team, anesthesia machine checkout, room turnover, supply, and resource covering multiple areas.

1.9.1 Assisting the Anesthesia Provider

A large part of the AT's time is dedicated to direct assistance of the anesthesia provider. This may include assisting with regional blocks, transporting patients, placement of monitoring equipment, airway management, invasive line placement, use of ultrasound devices, and troubleshooting equipment.

1.9.2 Partnering with the Perioperative Team

The AT is in and out of the surgical suites before, during, and after the procedure. ATs are an integral part of keeping the patient safe, responding to emergency situations, assisting with delivery and checking of blood products, and facilitating lab draws and point-of-care testing. They may assist the intra-op team with lateral transfers and patient positioning, paying special attention to the head, airway, and lines. The AT is an essential part of the transport team for critically ill patients between OR, imaging suites, and intensive care unit.

1.9.3 Anesthesia Machine Checkout

The anesthesia machine checkout is the full inspection of the anesthesia machine according to the manufacturer's recommended procedure. This complete workup needs to be performed every morning by the AT and/or the anesthesia care provider.

1.9.4 Room Turnover

Room turnover is the term used to describe the time after one patient has left the OR or procedure room while the room is being cleaned and prepped for the next case. Room turnovers must be efficient both for the anesthesia provider (who will be busy with the patients in the recovery and preoperative areas) and for the AT. The AT's responsibilities may include

- Proper disposal of materials from the last case, using proper routes
- Cleaning and disinfection of surfaces and cables, using proper methods
- Placement of a new circuit, EKG pads, and suction
- Testing the new circuit for leaks
- Checking the CO2 absorbent
- Restocking the cart with any depleted supplies
- Bringing any requested special equipment for the next case

1.9.5 Resource and Supply Management

Resource planning is a significant part of the job of an AT. It deals with analyzing available resources and making certain that the anesthesia team is fully prepared for the day's cases as well as for emergencies or unanticipated needs. The AT should be involved on a daily basis in making sure adequate supplies are available. This may entail direct ordering or communication of needs to a purchasing department. It is important that there be a process in place that ensures products are continually checked for expiration dates.

1.9.6 Equipment Sterilization

Non-disposable devices used by anesthesia need to be cleaned between uses. The level of cleaning required depends on the device and its use. Critical items are ones that come in contact with the bloodstream or sterile body tissues, like surgical instruments. These must be sterilized between use. Sterilization kills all microbial life. The AT may be required to complete the cleaning or the contaminated items may be sent to a Sterile Processing Department (SPD).

1.9.7 Covering Multiple Areas

ATs work in all areas where the anesthesia team is needed. These can include holding areas, ORs, PACUs, emergency department (ED), block rooms, obstetrics rooms, magnetic resonance imaging (MRI)/CT scan rooms, nuclear medicine suites, interventional radiology suites (IR), cardiac procedure suites, gastrointestinal (GI) procedure areas, special procedure rooms, ICUs, and many more. With advances in modern-day medicine and technology, the areas covered by the anesthesia team are constantly growing; therefore, the areas covered by the AT are also growing.

Chapter 2

PATIENT TRANSPORT

IMPORTANT TERMS:

SPONTANEOUS BREATHING : patient is breathing on its own
MANUAL BREATHING : when someone else is giving artificial breaths
CAPNOGRAPHY : it is the measurement of carbon dioxide during breaths
PULSE OXIMETER : It helps in measuring the level of oxygen in blood

2.1 INTRODUCTION

With more anesthetics being delivered outside the operating room, the frequency in which patients are being transferred from one location to the next before, during, and after an anesthetic is also increasing. It is often the responsibility of the anesthesia provider to accompany [follow] these patients and to ensure their continued medical treatment during these critical transfers. Anesthesia technicians are called upon to assist [help] with transfers, which can be quite challenging due to the medical condition of the patient and the amount of equipment that may need to be managed during the transfer.

2.2 MONITORING DURING TRANSPORT

Monitoring during an anesthetic includes assessment [understanding] of the patient's oxygenation, ventilation, and circulation. It is important to monitor these same physiologic parameters during a transfer. How they are monitored will depend upon the medical condition of the patient.

2.2.1 Ventilation and Oxygenation

Patients transferred to and from the operating room may be spontaneously breathing or require manual ventilation. In either case, the delivery of oxygen to the tissues must be continually evaluated [checked]. Patients who are awake and alert may require only visual inspection [checking] of respiration.

2.2.2 Pulse oximeter

Pulse oximeter helps in determining the level of oxygen in the blood.

During transport, Pulse oximeter is used in patients who are deeply sedated, or have significant medical problems. It continuously measures the percentage of hemoglobin saturated with oxygen (SpO2) in the patient's blood.

2.2.3 Factors affecting pulse oximetry during transport

It has proven a reliable method and is readily available on all transport monitors; however, it does have some limitations. Pulse oximetry readings can be affected by

- excessive movement during patient transport and
- low-perfusion states.
- a drop in saturation is often a late sign of problems with ventilation

It is important to assess the accuracy of the readings and waveform when abnormal readings are encountered. If the accuracy is in doubt, other assessments of the patient's ventilation and perfusion should be immediately undertaken. Pulse oximetry assesses only the amount of hemoglobin saturated with oxygen, a key component of oxygen delivery to the tissues.

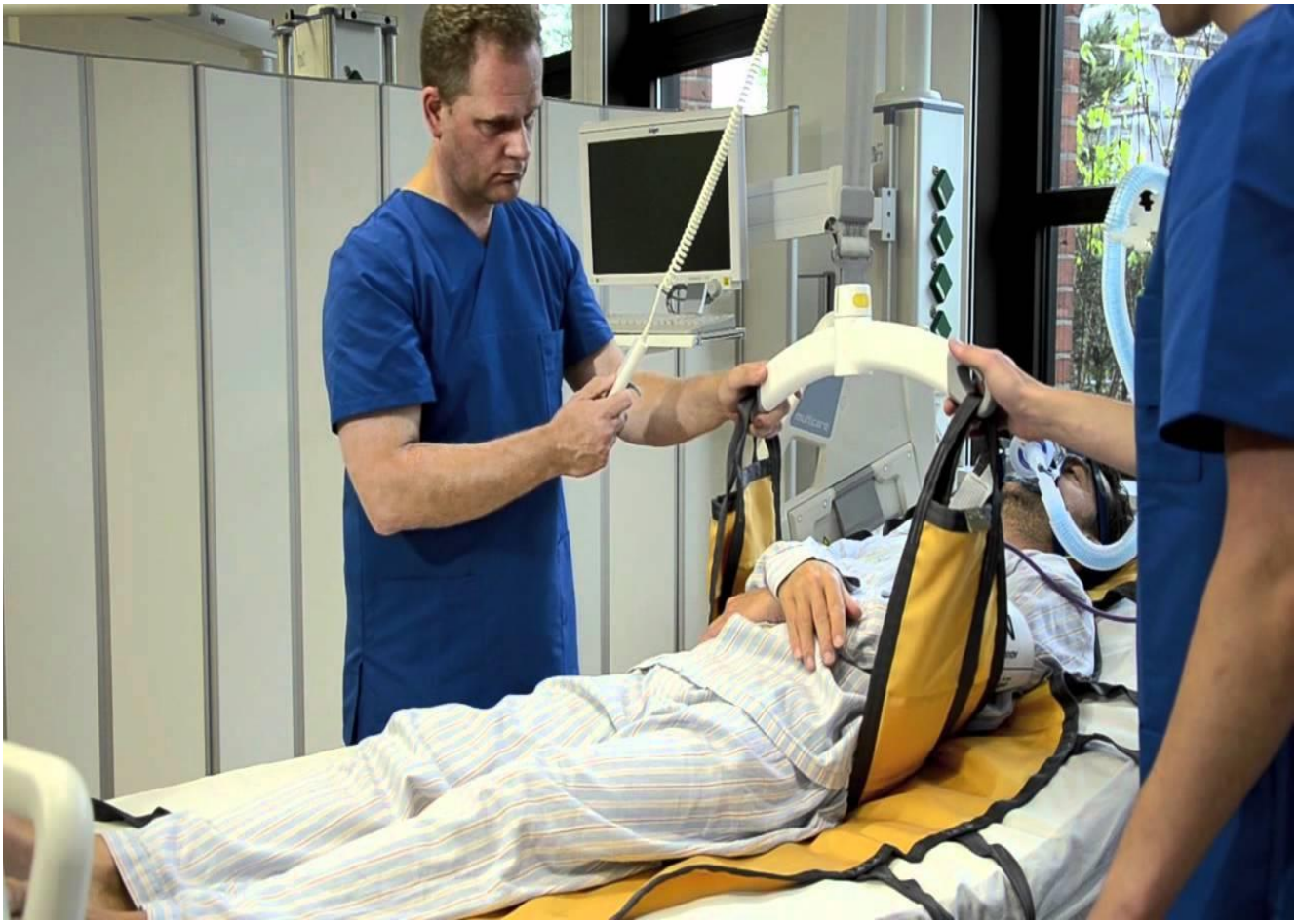
2.2.4 Capnography

Capnography measures the level of CO2 at the end of a breath

End-tidal CO2 (EtCO2) monitoring provides a more complete assessment of the adequacy of ventilation. . The majority of CO2 monitors display a continuous graph of exhaled CO2 throughout the respiratory cycle, along with a numeric value for exhaled CO2 levels. Capnography is available on many transport monitors and is an important adjunct to pulse oximetry. The provider can use capnography to adjust ventilation to maintain CO2 at desired levels (e.g., maintain hyperventilation in a patient with increased intracranial pressure), as well as to alert the provider to an endotracheal tube (ETT) dislodgement or breathing circuit disconnect.

2.2.5 Transport of intubated patients

During the transport of intubated patients, the provider should monitor EtCO2, chest excursion [movement] through direct visualization, or continuous auscultation of breath sounds. In spontaneously breathing patients, CO2 monitoring may be important to detect apnea [loss of breathing] or hypoventilation [slow breathing] during transport. Unfortunately, the availability of capnography on transport monitors is highly dependent on the individual institution. In the absence of EtCO2 monitoring, the practitioner must be able to continuously visualize chest excursion or continuously auscultate breath sounds through the use of a precordial stethoscope. Visualization of chest wall movement requires that the provider have a direct line of sight to the chest, and blankets should not obscure the view of the chest. Unfortunately, chest excursion is not always a reliable sign of ventilation. In the case of a completely obstructed airway, the patient may make respiratory efforts that include chest wall movements, but he or she is not able to inhale or exhale. In this case, there will be an absence of exhaled CO2 or absence of breath sounds on auscultation of the upper airway with a precordial stethoscope



2.2.6 Cardiovascular Monitoring

The monitoring of blood pressure and electrocardiogram (ECG) are simple and reliable methods of assessing circulation during transport.

2.2.7 Electrocardiography (ECG)

A standard three-lead or five-lead ECG is available on most transport monitors. Most transport monitors are simplified versions of the more comprehensive monitors used in fixed locations and will not have all of the functionality that the fixed monitors have. For example, a transport monitor may only allow a single lead to be displayed on the monitor at any given time. While ECG monitoring is easy to perform during transport, the provider must be aware that the leads are easily displaced and the waveform is subject to artifact with even minimal movement during transport. Because artifact [error] is common, any possible abnormalities on the ECG waveform should be correlated with other monitors, such as pulse oximetry waveform or an arterial waveform to confirm the presence of an arrhythmia [abnormal heart rhythm]

2.2.8 Blood pressure monitoring

Blood pressure is typically monitored through noninvasive or invasive techniques.

Noninvasive blood pressure (NIBP) cuffs are readily available on all transport monitors. The NIBP should be set to automatically measure the patient's blood pressure during transport at least every 3-5 minutes or more frequently depending on the stability of the patient. Inconsistent blood pressure readings may develop during transport due to excessive movement, or compression of pressure on any part of the NIBP system. Should an aberrant [abnormal] reading be observed, the NIBP should be recycled immediately, but this can often take a minute before the new reading is complete. During that time, the patient should be assessed for signs of adequate circulation, including the presence of a strong distal pulse.

2.2.9 Compatibility of monitors

It is important to check if the transport monitors and cables are compatible with the fixed monitors (intensive care unit, operating room, and post anesthesia care unit) in use at your institution. If the cabling systems are compatible, the cables can be unhooked from the fixed system and hooked to the transport monitor without detaching the blood pressure cuff, ECG lead wires, or pulse oximeter from the patient. Be careful to return all cables and monitoring equipment (e.g., blood pressure cuff or pulse oximeter probes) to the proper medical unit after transport.

2.2.10 Invasive arterial monitoring

Many patients require continuous assessment of their blood pressure and will have an invasive arterial line that can be monitored during transport. In preparation for transport, the arterial line transducer cable will be detached from a fixed monitor (e.g., operating room monitor) and reattached to the transport monitor. The vast majority of transport monitors will require "zeroing" once the new cable is attached. The arterial line transducer must be affixed [attached] to the bed or stretcher at the level of the right atrium and then zeroed to room air prior to beginning transport. After the transducer has been zeroed, the anesthesia technician should confirm that a waveform is present and the transport monitor is providing numeric values for blood pressure. Even if an arterial line will be used to monitor blood pressure during transport, an NIBP cuff should be attached to the patient and the transport monitor as a backup.

2.2.11 Troubleshooting during invasive arterial monitoring

It is common during transport for the arterial waveform to be altered due to changes in position of the extremity containing the arterial catheter or due to repeated movement of the bed. Due to these factors, providers must have a high index of suspicion about the accuracy of abnormal arterial line readings.

How to assess troubleshooting

Always consider the following things while troubleshooting abnormal arterial line readings during transport:

- assess the patient (clinical signs of perfusion, NIBP, etc.).
- check the patency of the line beginning with the catheter in the patient and following back to the transducer and the pressure bag
- ensure that the catheter is not kinked or occluded, tubing is not kinked and does not contain bubbles
- connections are tight
- stopcocks are in proper position
- the transducer is intact
- the transducer cable has been properly attached to the monitor.
- check the pressure bag.

  The majority of transducers have a pressure bag to keep the arterial catheter (or other catheter) patent. If the pressure bag has insufficient pressure, the catheter can become occluded.
- Check the drip chamber of pressure bag, the drip chamber must be in the upright position and some of the air evacuated from the drip chamber when priming. During transport, particularly when transferring the patient from the operating room table to the bed, pressure bags can be placed on their side on the patient bed. This may allow air to enter the line, which will interfere with monitoring by entraining air into the arterial tubing or worse embolize into the patient's arterial circulation (Fig. 51.1). The pressure bag should be hung on an intravenous (IV) line pole or other post connected to the bed, with the drip chamber in the upright position. FIGURE 51.1. Drip chamber on its side allowing air to enter the monitoring line.

Additional Monitors

Additional pressure monitors such as intracerebral pressure monitors, central venous pressure monitors, and pulmonary artery catheters may be present but often are not observed continually during transport. The anesthesia technician should communicate directly with the anesthesia provider regarding what monitoring is necessary during transport. If any of these pressures are to be monitored during transport, most of the same issues discussed above regarding arterial lines will apply as well.

2.3 PATIENT CARE DURING TRANSPORT

2.3.1 Prevention of Hypothermia

The presence of hypothermia increases the incidence of postoperative wound infection and myocardial ischemia. While it is not common to continually monitor temperature during transport, it is important to limit heat loss and the effects of hypothermia during transport. Anesthetized or critically ill patients cannot regulate their own body temperature. The

patients must rely on the clinical staff to limit their loss of body heat through convection and evaporation.

The loss of heat can be limited during transport by

- Covering the patient adequately with blankets
- Being vigilant not to expose excess body surface to the air.
- For patients who are ventilated, the use of a humidified moisture exchanger (HME) can contribute to retention of heat and water vapor lost during mechanical ventilation.

2.3.2 Management of Ventilation

The management of ventilation is a crucial [difficult] aspect of patient transport.

2.3.3 Confirmation of proper placement of ETT

For those patients who will be transported with an ETT in place, the verification of proper placement of the ETT should take place prior to transport.

The ways of confirmation include:

- auscultation of bilateral breath sounds
- EtCO2 readings

2.3.4 Airway equipment checklist

Once proper placement is confirmed, following airway equipment for the transport should be checked

- oxygen tank with sufficient oxygen, bag-valve-mask or other device for manual ventilation
- face mask for possible manual ventilation, etc.

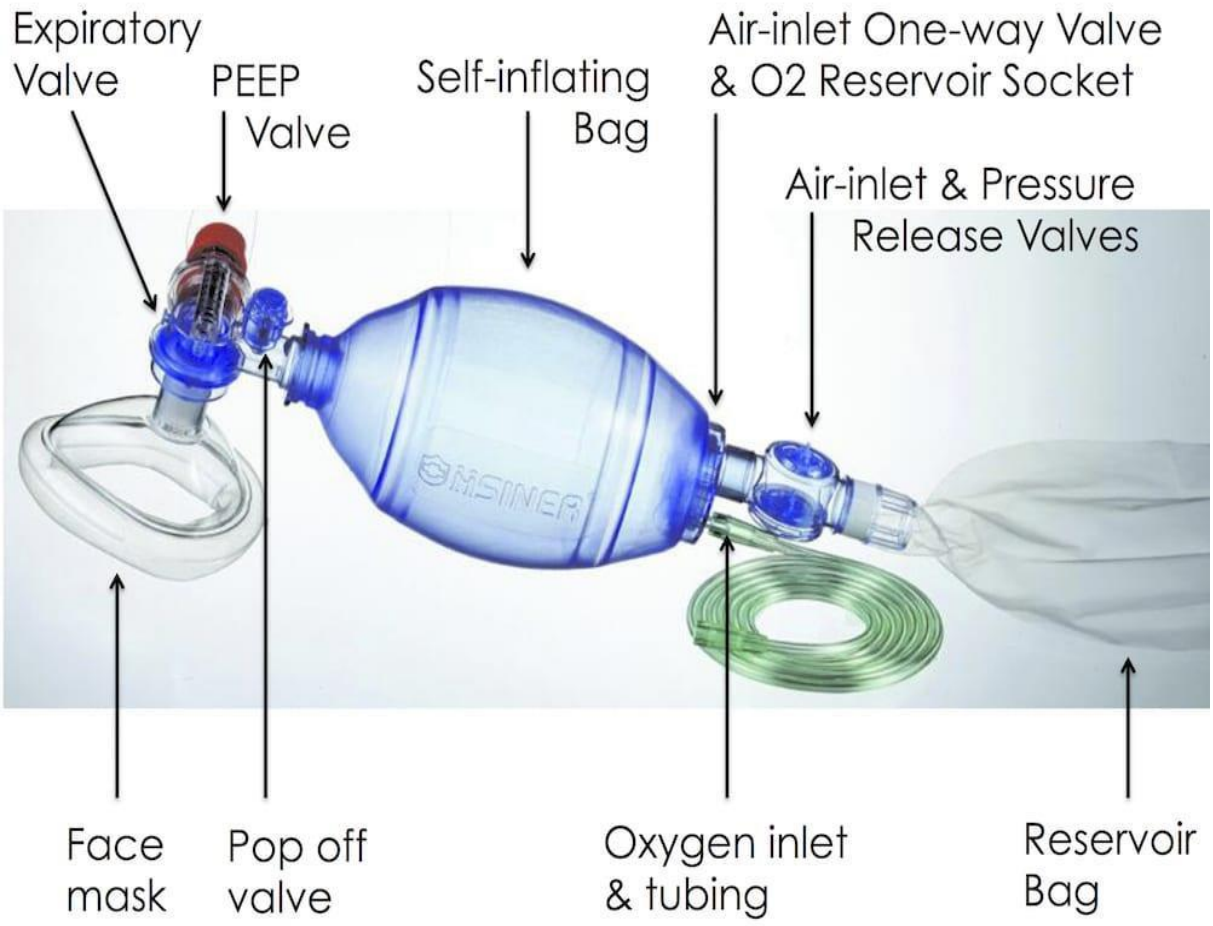
If the patient is transferred from one bed to another, the ETT position should be reconfirmed once the bed transfer is complete.

2.3.5 Bag-valve-mask system

Intubated patients will require manual ventilation during transport. Some facilities have transport ventilators, but this is the exception rather than the rule. The most common method of ventilating patients during transport is through the use of a manual breathing circuit such as a bag-valve-mask system.

Parts of bag-valve-mask system

- ventilation bag
- input for high-flow oxygen
- a pop off valve to prevent the over inflation of the patient’s lungs during ventilation · some have an adjustable positive end-expiratory pressure (PEEP) valve.
- Expiratory Valve
- Face mask



This type of breathing circuit may be used with either spontaneously breathing or ventilator-dependent patients. They do not allow for the delivery of mixed gases or of inhaled anesthetics. Patient transport can be a complicated process and requires coordination to push the bed, manage lines, and manage ventilation. The anesthesia technician may frequently be called upon to “squeeze the bag” and ventilate the patient during transport. The anesthesia technician should discuss the rate and depth of respirations to be delivered or EtCO2 goals during transport with the anesthesia provider. In some cases, the patient may be on advanced ventilator settings due to severe pulmonary disease, which would preclude the patient from being disconnected from the mechanical ventilator during transport. In these situations, the patient will be transported on a portable ventilator with the goal of preventing an interruption to the ventilatory support.

2.3.6 Difference between anesthesia machine ventilators and transport ventilators

There are many similarities between anesthesia machine ventilators and transport ventilators. They each have an O2 source, delivery tubing, and a control panel. They both are able to deliver high amounts of PEEP in a variety of ventilation modes; however, transport ventilators do not have the capability to deliver anesthetic gases. In addition,

transport ventilators generally rely [depend] on the oxygen source to drive the bellows of the ventilator as well as deliver oxygen into the circuit. This is important because transport ventilators will use more oxygen than manual ventilation circuits. During transport, you may not have additional oxygen tanks should you exhaust the initial oxygen tank. Verification of a full supply of oxygen and an adequate amount of battery life should be performed prior to transport (Fig. 2.2).

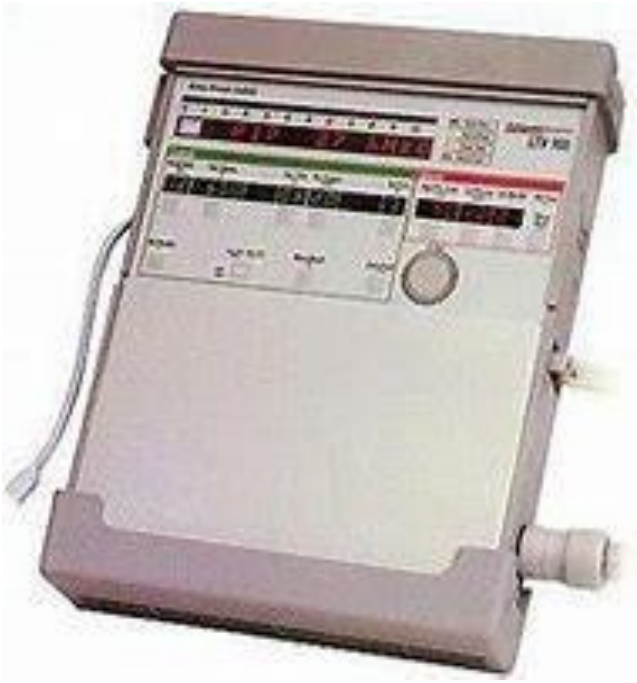


FIGURE 2.2. Transport ventilator that can be operated with tank oxygen

Oxygen supply and the availability of other necessary equipment should be communicated with the provider prior to transport.

2.3.7 Estimating the Duration of O2 Supply in a Cylinder

In the case of oxygen use, the anesthesia technician should have an understanding of how long a given supply of O2 will last. A typical e-cylinder of oxygen at capacity will hold 1,900 psi (660 L of O2). At a flow rate of 8 L/min, a full e-cylinder of oxygen will last about 78 minutes (660 L divided by 8 L/min).

The following formula can be used to calculate the remaining number of minutes of oxygen in a given e cylinder:

$$\frac{0.35 \times \text{psi on gauge}}{\text{L/ min of oxygen flow}} = \text{min to empty}$$

For example, if you have a fixed flow rate of 8 L/min to supply your bag valve-mask during transport and the O2 gauge is reading 1,800 psi

$$\frac{0.35 \times 1800}{\text{8L/ min of oxygen flow}} = 78 \text{ min to empty}$$

You will have approximately 78 minutes until the tank is empty. As mentioned above, if you are using a transport ventilator, the oxygen flow requirements can be much greater.

2.4 TRANSFER TO AND FROM THE TRANSPORT BED

Transferring the patient to and from the transport bed is a critical task that should not be taken lightly. It is important to ensure [make sure] that all lines are properly prepared prior to any patient movement. The anesthesia technician should ensure that all lines are free and clear and have sufficient slack [space] to allow the patient to be moved. ETTs, urinary catheters, IV lines, chest tubes, and arterial lines have all been pulled out when moving a patient from one bed to another. In addition, patients have sustained injuries during transfers because extremities or the head and neck were not properly supported during the transfer.

Required precautions

The anesthesia provider should always verify necessary precautions, such as cervical spine precautions, are in place prior to moving patients. Proper communication between all team members is essential to ensure a smooth transfer. The anesthesia provider has the final say as to when the patient is ready to be moved.

2.5 TRANSPORT CHECKLIST

The availability and necessity of additional equipment and pharmacologic therapy during transport will vary according to the patient's condition, but its selection should be based on the need to continue medical therapies and manage potential complication while en route. Because transportation of patients is a critical time in their care and is fraught with pitfalls, the transport team should consider the following items: • There should always be a manual ventilation bag with a face mask present. • Oxygen supply should be checked, and there should be sufficient oxygen for transport.

- In many cases, a laryngoscope and spare ETT for possible emergency intubation or reintubation should be transported with the patient.
- Will infusion pumps to deliver medications (vasopressors, sedatives, etc.) be necessary for the trip? If so, check the battery supply for all pumps prior to transport.

- Check with the anesthesia provider that all required medications are available for transport (vasopressors, muscle relaxants, sedatives, etc.)
- If the transport bed is motorized, check that the bed has sufficient battery power prior to transferring the patient onto the bed.
- Is sufficient help available to manage the transport (manage the bed, manage ventilation, manage lines and infusion pumps)?
- Monitors are set up and operational (ECG, pulse oximetry, capnography), and the monitor has sufficient battery power.
- Pressure lines are connected securely and operational. The pressure bag drip chamber is in an upright position. All lines have been zeroed, have good waveforms, and numeric readings are visible to the provider. The transducer is at the appropriate level.
- IV access is readily available and patent.
- Are there sufficient amounts of fluids available to deliver medications and give fluid boluses en route if needed?
- The patient is properly padded and secured to the transport bed with all bed rails up, locked, and secured.
- The patient is covered to prevent heat loss and to maintain privacy and dignity.
- If an elevator is needed, arrange for its availability in advance.
- Has the destination team been notified that the patient is ready for transport (intensive care unit, radiology suite, etc.)?

Chapter 3

ELECTRICAL SAFETY

3.1 INTRODUCTION

Electricity is used in the operating room (OR) to power many pieces of equipment, ranging from items associated with direct patient care to lighting, computers, and electronic devices that support patient care. Electrical power is essential [necessary] for the performance of contemporary anesthesia and surgery, as well as nearly all functions throughout the hospital, yet remains mysterious and poorly understood by many users. Despite an excellent safety record, electricity is hazardous and poses a variety of risks. In order for electrical equipment to be used safely, it is necessary to understand the ways in which electricity can cause harm. This chapter reviews the risks associated with the use of electricity in the OR and methods for ensuring safety. Harm related to the use of electricity can occur in four distinct ways. Electrical currents flowing through the body can cause an electrical shock or result in skin or other tissues being burned. Electricity can also ignite fires. The loss of electrical power can imperil [harm] patients if life-support equipment fails to function. Finally, electricity can interfere with the function of implanted devices such as pacemakers or defibrillators.

A framework for understanding the potentially harmful effects related to the use of electrical power in the operating room.

While patient safety is a primary concern when considering electrical hazards, OR staff are also at risk. As users of electrical equipment, anesthesiologists, surgeons, and other personnel can experience an electrical shock. For example, many surgeons have received an unpleasant jolt while using an electrosurgical device. Considerations for protection from shock apply equally well to the OR staff.

3.2 ELECTRICAL SHOCK

A shock is experienced when electric current passes through the body. The amount of current that flows will be a function of the voltage difference across the body and the resistance to current flow presented by the body. There must be a complete circuit for current to flow. In other words, there must be a continuous, unbroken path for current to flow from its point of origin through a circuit and back to its point of origin. The primary objective in electrical safety is to prevent patients or staff from becoming a part of that complete circuit. Two points of contact must exist for current to flow through the body. Oftentimes, one of these contacts is established as a result of being grounded (e.g., by standing on the ground), so only one other point of contact needs to be made in order for current to flow and a shock to occur. For the purposes of this chapter, anything that is

grounded, whether intentionally (e.g., an equipment case or the OR bed) or unintentionally (e.g., a patient or staff person in contact with a source of electrical power) will provide a pathway for current to return to its origin. Ideally, patients (and other individuals) should never be grounded, thus removing any possibility of becoming part of the electrical circuit. However, this is difficult and impractical to accomplish, so instead the OR power supply itself is kept isolated from ground. Conversely, electrical equipment should always be grounded, to provide a low-resistance pathway for current to return to its source, rather than through some alternate pathway, such as a human being. For example, if a piece of equipment was not grounded, but it had a fault such that electrical power was in contact with the case, an individual coming into contact with that case would then serve as the sole pathway for the fault current to flow back to the source. By keeping the equipment grounded, the bulk of the fault current will be conducted by the equipment's ground connection and only a small portion will flow through the person, thus significantly reducing the risk of shock.

3.2.1 "Can't let go" current

Below roughly 1 milliamperes (mA), current is not perceptible [noticeable]. At current levels between roughly 1 and 10 mA, current may be perceived as a tingling, warm sensation. Currents in the range of 10-20 mA produce muscle spasm, and the individual cannot let go of the conductor. This is known as the "can't let go" current. As current reaches 100 mA in magnitude, ventricular fibrillation (VF) and death occur.

3.2.2 Injuries from electrical shock

Injuries that result from electric shock include burns and tissue damage, VF, and death. The injury that occurs will depend on the magnitude and duration of current flow through the body, as well as the cross-sectional area through which it flows. This is embodied in the concept known as current density, which is defined as the amount of current flowing through a given cross-sectional area, and can be thought of as a measure of how "concentrated" the current is.

3.2.3 Macroshock vs Microshock

Macroshock refers to currents on the order of 1 mA or larger that are applied externally to the skin and are perceptible. There is a second phenomenon known as microshock that involves currents below the threshold of perception. Microshock occurs in the electrically susceptible patient, that is, a patient with a direct conductive connection to the heart that bypasses the skin (e.g., a temporary pacemaker wire or a saline-filled catheter). This is important as the skin is normally a source of considerable resistance. Not only does the direct connection provide a low-resistance pathway to current flow, the connection contacts the heart in a very small area. As a result, despite the low current levels flowing (as low as 10-100 microamperes [μA]), the resulting current density is sufficient to cause VF. Because the current levels associated with microshock are below the threshold of perception, normal methods to detect hazardous situations and prevent shock don't work.

3.2.4 Isolated power supplies

Isolated power supplies provide electrical power through two leads, line 1 and line 2, neither of which is connected to ground. The two lines are electrically isolated from ground by having power supplied by an isolation transformer located in the OR. Electrical equipment is still grounded through a third conductor; however, there is no pathway for current to flow from either line 1 or line 2 back to its source via the ground. As a result, if a person in contact with ground comes into contact with either line 1 or line 2, there is no pathway for establishing a complete circuit, and no shock can result. Only when an individual comes into contact with both lines 1 and 2 does a complete circuit result that allows current to flow and a shock to occur. The use of isolated power supplies thus provides an added layer of protection against electrical shock. Isolation is not perfect, however, and leakage currents do exist. The leakage can become significant enough to defeat the isolation, in which case the power supply then functions as a grounded supply. This will not affect equipment function, nor does it cause a shock, but it does remove that extra layer of protection. Since equipment continues to function, such a change will go unnoticed.

If a person (who is typically going to be in contact with ground) should come into contact with the electric circuit, there is a potential for some current to flow from the point of contact through the individual to ground and thus back to its source. However, because electrical equipment is grounded, most of the current should flow along established grounding pathways and only a small fraction through the person. The power grid supplies grounded power, with the neutral lead physically connected to the ground conductor. In the OR, after passing through an isolation transformer, line 1 and line 2 supply electrical power, but there is no connection with ground. Consequently, contact with either line 1 or line 2 cannot result in current return via the ground conductor. In contrast, isolated power supplies provide electrical power through two leads, line 1 and line 2, neither of which is connected to ground. The two lines are electrically isolated from ground by having power supplied by an isolation transformer located in the OR.

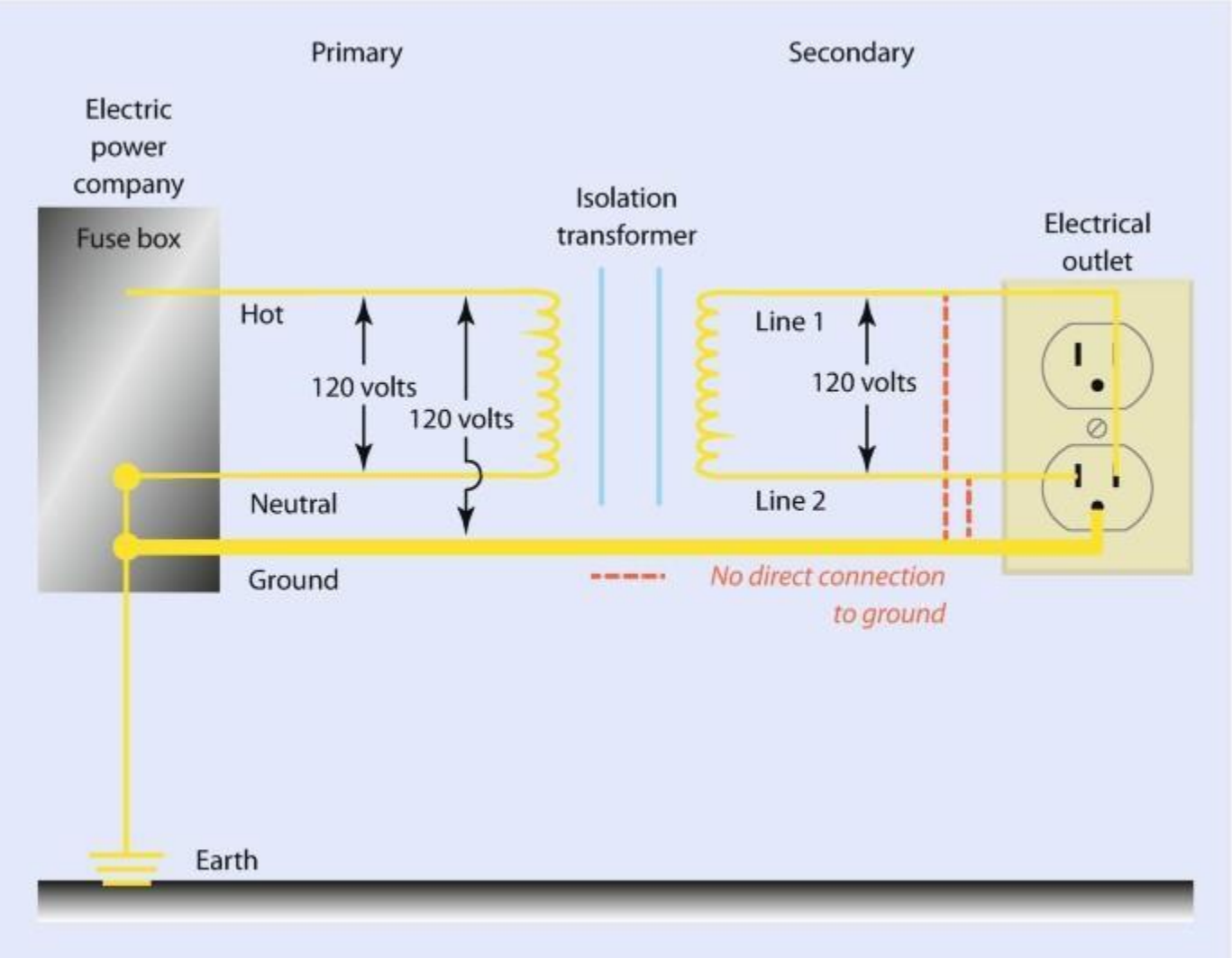


FIGURE 3.2. Schematic of the power supply. The power grid supplies grounded power, with the neutral lead physically connected to the ground conductor. In the OR, after passing through an isolation transformer, line 1 and line 2 supply electrical power, but there is no connection with ground. Consequently, contact with either line 1 or line 2 cannot result in current return via the ground conductor.

While patient safety is a primary concern when considering electrical hazards, OR staff are also at risk. As users of electrical equipment, anesthesiologists, surgeons, and other personnel can experience an electrical shock. For example, many surgeons have received an unpleasant jolt while using an electrosurgical device. Considerations for protection from shock apply equally well to the OR staff.

3.3 LOSS OF ELECTRICAL POWER

A loss of electrical power is a potentially catastrophic situation that requires prompt and effective management to minimize the risk to patients. It is a very different problem than electrical shock. Whereas shock will generally affect only a single patient, the loss of

electrical power can affect many patients. Electric shock has an immediate effect, such as VF, but the consequences of a power outage may extend over a long period of time. In the event of an outage, there is usually some form of backup electrical supply that allows critical equipment to continue functioning. This can take the form of a battery, such as in the anesthesia machine, or hospital generators. However, this does not ensure that equipment will continue to operate, since batteries have a limited duration and generators may fail.

The cause of an electrical power failure can be external to the institution and affect an entire facility, due to an interruption of the power company's supply, or arise from internal failures that may affect only a portion of the facility. Patients whose lives depend on critical life-support equipment are at risk from equipment that stops functioning. Power outages can also interrupt and interfere with surgery or other invasive procedures.

3.3.1 Important considerations regarding loss of power

Should there be a loss of power, several issues must be considered.

Patient status must be ascertained.

The status of the anesthetic and the surgery must be determined.

If the surgical procedure must continue, how will the anesthetic be provided? For example, it is possible to use portable battery powered monitors, intravenous infusion pumps to provide a total intravenous anesthetic, oxygen from tanks, and ventilation via a manually operated bag. Anesthesia technicians need to be prepared to make these items available, often rapidly to multiple ORs. Light can be provided from flashlights, laryngoscopes, and cell phones, although ORs may also have emergency lighting. All OR personnel should be familiar with the location of emergency light sources.

Equipment function needs to be evaluated. The status of the anesthetic machine, monitors, light sources, and any powered surgical equipment must be clarified, so decisions about whether or not to continue surgery can be made. If it appears that the power outage will be of significant duration, steps should be taken to conclude the surgical procedure.

The scope and duration of the outage must be determined. Is it confined to a single OR, to a number of ORs, or to some larger entity, such as one or more floors, the hospital or facility, or an entire community? The scope and expected duration of the interruption in power will significantly influence decision-making about what services can continue to be provided

In addition, it is important to realize that having backup power is no guarantee of continued operations. There have been several instances where backup generators have failed, resulting in the OR, or institution, being completely without power. Because a loss of power may occur, it is necessary to know which items of equipment have internal battery backup. It is important to keep batteries fully charged and to know how long the backup batteries will last; what functions will continue on backup power; how to provide light, computer, phone, and paging services; and how to provide alternatives to primary equipment and functions (e.g., portable monitors in place of normal physiologic monitors, or intravenous anesthesia via infusion pumps in place of inhaled anesthetics delivered by the anesthesia machine).

Anesthesia technicians have a critical role in providing the equipment for many of these functions. Practicing what to do in the event of a power failure is an excellent simulation exercise.

3.4 BURNS AND FIRE

The amount of heat produced by current flow depends on the magnitude of the current and the resistance through which it flows. A given current flowing through a small area will produce more heating than the same current flowing through a large area. The situation most commonly associated with burns in the OR is related to the use of an electrosurgical device (the Bovie or cautery). Electric current passes from a handheld electrode (sometimes known as the “pencil”) through the patient to a dispersive pad (often incorrectly called “the grounding pad”). Because the pencil tip is small, a high current density exists and significant heating occurs. However, the dispersive pad occupies a much larger surface area, resulting in much lower current density, effectively protecting against skin burns. However, if the conductive gel is dried out, the pad is incorrectly applied so it does not make good contact with the skin throughout its entire surface, or it is removed and reapplied, current can be concentrated at the point(s) of contact, resulting in skin burns. Ideally, the pad will be applied over well-muscled areas, such as the thigh, arm, or buttocks. It should not be placed over hairy areas (it won’t stick well) or over bony prominences or metal prostheses (the current can be concentrated at these points), and it should not be reapplied if it is removed (insufficient gel may remain). Otherwise, current may seek other pathways, such as through electrocardiographic electrodes, again resulting in a high enough current density to cause burns.

Under certain conditions, fires can be ignited as a result of using electricity in the OR. As is true of any fire, three elements must coexist to have a fire: something to ignite the fire, a fuel, and an oxidizing agent. A common way for fires to ignite is by use of electrosurgical devices in the presence of an oxygen-enriched [filled] atmosphere. A

typical scenario is the ignition of surgical drapes by the electrosurgical handheld electrode in a patient who is not intubated, but instead receiving supplemental oxygen via nasal cannula or a face mask. In such a situation, oxygen can accumulate under the drapes, and when the handheld electrode comes in contact with the drapes and is energized, fire can occur. Another common scenario is the patient undergoing a tracheostomy, and the handheld electrode is used to enter the airway, in the presence of elevated oxygen concentrations. In this circumstance, an airway fire is the result, with the endotracheal tube as the fuel. Fuller discussion of fire prevention and management can be found in Chapter 4

3.5 IMPLANTED DEVICES

The final category considered in this chapter has to do with patients who have implanted electronic devices, such as pacemakers, implantable cardioverter defibrillators (ICDs), cochlear implants, and spinal cord or other stimulators. The risk is that these devices may be damaged or malfunction as a result of exposure to electrical currents, usually from an electrosurgical device, and may result in harm or death.

Of all the implantable devices, the malfunction of pacemakers and ICDs due to electromagnetic interference from electrosurgical devices poses the greatest risk to patients. A healthy heart is an electrical organ and a pacemaker is a critical electrical appliance. Any patient with an electrical problem in the heart, who depends on an external electrical appliance for basic life functions, is exquisitely vulnerable to electrical injury in the OR. For this reason, many anesthesiologists are knowledgeable about pacemaker function.

3.5.1 Malfunctioning and its prevention

The typical reason for malfunction is that electrical currents from the electrosurgical unit pass in proximity to the implanted device or the leads emanating [arising] from it, resulting in a change to the device's mode of operation (reprogramming), accidental firing of an ICD or stimulator, or damage to the device, causing it to stop functioning. Simple steps can usually prevent this from being a problem. The dispersive pad should be placed so the current does not cross the device, but instead travels away from it. For example, if a patient has a pacemaker on the left side of the chest, and surgery is being conducted on the right shoulder, the dispersive pad should not be placed on the left shoulder, or anywhere on the left side. Bipolar electrosurgical devices can be considered as an alternative to the usual monopolar device, as this will confine the current between the tips of the bipolar device. ICDs should be programmed OFF for the duration of surgery. Depending on the patient and the pacemaker, magnets or reprogramming can be used to convert pacemakers to an asynchronous mode of function.

3.6 THE ROLE OF THE ANESTHESIA TECHNICIAN

In general, in situations involving electrical safety issues, the anesthesia technician is an important resource for providing support to the anesthesia provider and operative team.

The AT ensures that equipment is kept in good working condition to minimize the possibility that it will malfunction and pose a shock hazard. For example, electrical power cords where the external insulation has been damaged so that the inner wiring is exposed should be replaced or repaired. In the event of a power failure, the technician will need to provide the backup equipment needed to support patient care, as well as help with tasks during this busy time. In addition, by ensuring that equipment is routinely plugged into the proper sources of electrical power (essential equipment into emergency sockets, nonessential equipment into white sockets), operations will be better able to continue if a power failure occurs. Finally, as with many other situations, recognizing potentially unsafe situations and identifying them to the appropriate individual (e.g., improper application or use of the dispersive pad for electrosurgical devices) can be an important step in preventing patient harm.

Chapter 4

FIRE SAFETY

IMPORTANT TERMS

FLAMMABLE; Burnable

OXYGEN ENRICHED: filled with oxygen

EXTINGUISHED: To put an end to or cease.

4.1 INTRODUCTION

A fire that occurs in the operating room (OR) area is an obvious emergency with potentially devastating [lethal] consequences. It poses [can cause] a threat to all who are present in the OR, including patients, surgeons, anesthesiologists, nurses, and other staff. Patients are especially vulnerable [in danger] because they are unable to flee, seek shelter, or take any steps to protect themselves. Prevention is arguably the single most important step to ensure fire safety. Fire prevention and the response, should a fire occur, are everyone's responsibility. This chapter reviews fire prevention strategies, including an overview of how OR fires start and steps to reduce or eliminate the possibility that a fire will occur, the consequences of a fire in the OR, and actions to take in the event a fire should occur in the OR. Several different types of fires can occur in the OR. These are broadly classified as airway fires, surgical fires, and OR fires. Fires can also occur elsewhere in the facility.

Airway fires occur in the airway, surgical fires occur elsewhere on the patient's body, and OR fires take place elsewhere in the OR and do not directly involve the patient. Current estimates indicate that approximately 600 fires occur in the OR each year. However, this is likely to be an underestimate, since reporting requirements vary from state to state and many fires are unreported. About a third of fires occur in the airway, with ignition of an endotracheal tube (ETT), usually by electrosurgical instruments or a laser. Another quarter of fires involve the face, often during head and neck, ophthalmic, or plastic surgical procedures on the face or nearby areas; another quarter occur on other parts of the body. These commonly result from ignition of OR materials, such as surgical drapes. About 15% of fires occur inside the body, the result of igniting intestinal gases, for example, when the bowel is entered using an electrosurgical device. OR fires can result in thermal injuries (burns) that cause direct injury to skin and underlying tissues and smoke inhalation that results in lung injury and respiratory compromise.

Table 4.1 TERMINOLOGY RELATED TO FIRE SAFETY AND PREVENTION

Term	Definition
OR fire	A fire occurring in an operating room; it may not involve a patient.
Surgical fire	Burning materials on, in, or near a patient.
Surface fiber flame propagation	Flame that spreads swiftly through hair on a patient's skin or fine nap fibers on a textile's surface; it requires an oxygen-enriched atmosphere.
Oxidizer-enriched atmosphere	Atmosphere that promotes ignition and enhances combustion because of the presence of an oxidizing agent. Oxygen (O_2) and nitrous oxide (N_2O) are common oxidizing agents in the OR.
Oxygen index	The O_2 concentration at which a material will sustain a candle-like flame.
Electrocautery	Cauterizing tissue by using electric current to heat a conductor that is then applied to tissues.
Electrosurgery	Cutting, cauterizing, or desiccating tissues by passing an electric current through the tissues. An important distinction from electrocautery is that the patient is part of the electric circuit, i.e., electrical current passes through the patient.

4.2 PREVENTING AND RESPONDING TO FIRES: GENERAL PRINCIPLES

4.2.1 The Fire Triangle

Fires in the OR can arise from a variety of sources, but all fires share one common characteristic: three elements must be present for a fire to occur. This is known as the fire triangle (Fig. 4.1). For a fire to occur, there must be a fuel, an ignition source, and an oxidizer (Table 4.2). Preventing OR fires essentially comes down to eliminating one or more elements from the fire triangle. For example, limiting the amount of oxygen (and nitrous oxide) will eliminate the risk of combustion in many circumstances. Alternatively, eliminating the fuel, such as removing an ETT from the airway during laser surgery, or the source of heat, such as ensuring that fiberoptic light sources are not placed on surgical drapes, will also prevent a fire from occurring

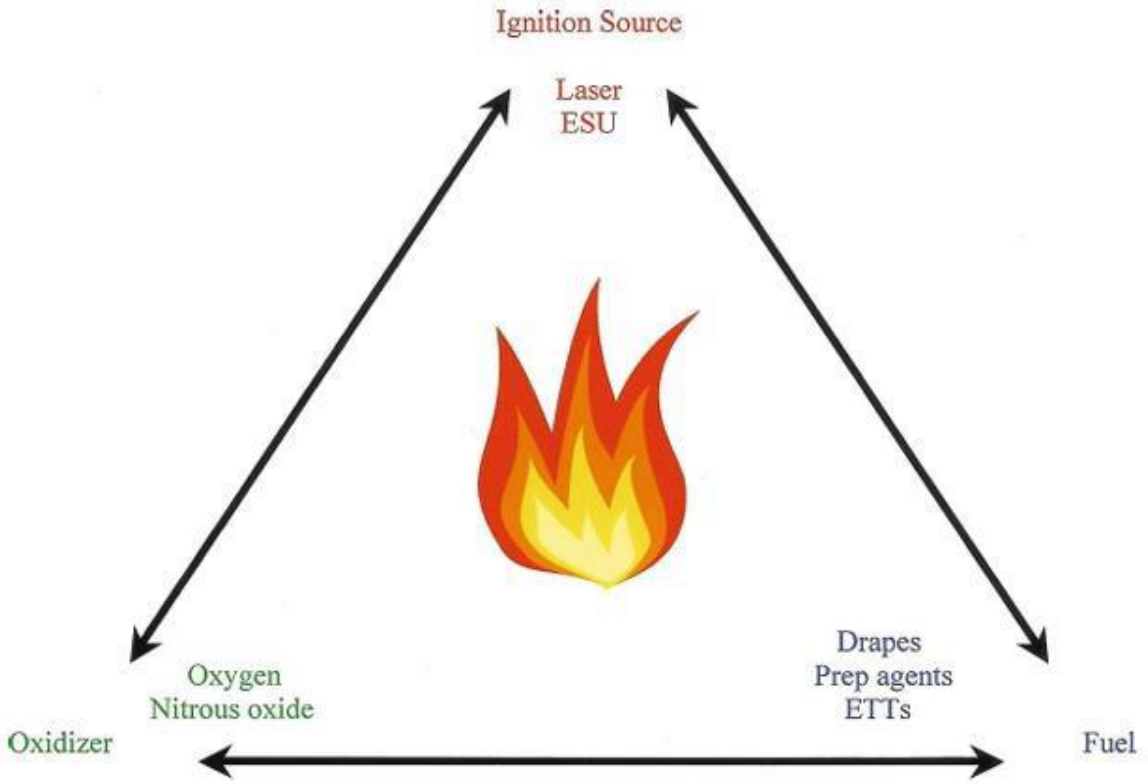


FIGURE 4.1. The fire triangle (also known as the fire triad). All three elements of the triangle must be present for combustion to occur. ESU, electrosurgical unit; ETT, endotracheal tube

Table 4.2 The Three Elements of the Fire Triangle, with Examples of Each That Are Present in the Operating Room

Fire Triangle Elements	Examples in the Operating Room
Ignition sources	Electrocautery devices Electrosurgical units Lasers Fiberoptic light sources Defibrillators Argon beam coagulators Sparks from high-speed dental and orthopedic burs Electroconvulsive therapy (ECT) devices Malfunctioning electrical equipment Static discharges
Fuels	Common OR materials (OR table mattress, sheets, blankets, pillows, towels, gowns, caps, gloves, booties, drapes, bandages, dressings, sponges) Volatile organic compounds (alcohol, acetone, ether) Body hair Intestinal gases Endotracheal tubes Desiccated body tissues Other miscellaneous materials (flexible bronchoscopes, face masks, breathing systems, petroleum jelly, adhesives, blood pressure cuffs, laser fiber sheaths)
Oxidizers	Oxygen Nitrous oxide

4.2.2 Fire Prevention

Preventing an OR fire depends on the specific type of fire being considered. For example, preventing an airway fire involves different factors than preventing ignition [burning] of surgical drapes. Nonetheless, they all share some common factors, relating to the roles of the different parts of the fire triangle. Removing any element of the fire triangle will successfully eliminate [remove] the risk of a fire. For example, by not creating an oxygen-enriched atmosphere under surgical drapes, a fire can be prevented by eliminating the oxidizing agent. Similarly, safe practices involving the use of ignition sources, such as lasers, or taking steps to keep fuels wet, such as soaking gauze pads used in the pharynx, markedly reduce the risk of a fire in the airway. Each element of the fire triangle is linked with all the working staff of OR and requires that everyone who is in the OR assumes [shares] responsibility for any and all aspects of fire prevention. Surgeons are usually the ones involved in the use of ignition sources, while anesthesia providers are typically in control of oxidizing agents and nursing staff are primarily concerned with the fuel sources in the OR. There is some overlap of responsibilities, however. For example, certain fuel sources, such as ETTs, are the anesthesia provider’s responsibility, surgeons sometimes

apply prep agents, and nurses often participate in controlling lasers and electrosurgical units. As such, good communication practices and teamwork are essential aspects of fire prevention

4.3.3 Responding to a Fire

The generic response to a hospital fire is encapsulated in the acronym RACE:

- Rescue
- Alarm
- Contain
- Evacuate (or Extinguish).

Rescue: The first priority is to rescue the patient, removing him or her from the dangerous situation. Several rescuers will likely be needed. However, it is not recommended that rescuers place themselves at severe risk.

Alarm: Sound the alarm; alert others as to what is happening. Nearby staff should be aware of what is happening and kept informed in case they will need to evacuate their patients. In addition, fire alarm systems should be activated. Often, these will summon assistance from within the facility and may also call the fire department.

Contain: Next, efforts should be made to contain and control the situation, such as by closing fire doors. Medical gas valves should be shut off, and air duct dampers can help to prevent the spread of smoke. Central smoke evacuator systems (used to remove surgical smoke) should also be shut off. Also, electrical power should be shut off at the circuit breaker panel, as this will prevent electrical fires from being sustained and reduce the risk of an electrical shock.

Evacuate/ Extinguish: Finally, an attempt may be made to extinguish the fire; however, it may be necessary instead to first evacuate patients and any personnel from the area. The evacuation should be orderly and patients taken to a preplanned area. Note that these steps may occur nearly simultaneously.

In the OR, the response depends on the specific type of fire. It will also depend on the extent of the fire.

4.4 Damages due to Fire

There are several consequences [outcomes] to a fire in the OR e.g.

- The risk of injury to pt. o pt.
- Costs due to damage from the fire, for example damaged equipment and facilities.

- The impact on OR operations, including whether they can continue on that day or not as a result of the damaged

The response to a fire in the OR will depend on the type of fire. Each of these will be considered separately below, although it may not be possible to specify every possible type of fire that can occur in the OR. Regardless, if any type of fire occurs, it should be quickly announced so that the entire surgical team is aware that there is a fire. The easiest fire to deal with is one that is small and confined[limited] to a specific area, for example, a gauze pad that has been ignited. If the fire is not on the head or neck, and the full extent of the fire is easily seen, it is reasonable to put t it out or smother it with a gloved hand or towel, thus extinguishing it. It is still important to check for embers or smoldering materials that could reignite, especially if there is a possibility of an enriched oxygen atmosphere.

4.5 PREVENTING AND RESPONDING TO FIRES: SPECIFIC SITUATIONS

4.5.1 Airway Fires

An airway fire is one of the most concerning, and most common, fires that can occur in the OR. Airway fires start when an ignition source, usually a laser or electrosurgical device, is used to perform surgery in the airway in the presence of an ETT (fuel source) and an enriched oxygen (or oxygen/nitrous oxide) atmosphere. Typical situations in which an airway fire will occur include laser surgery of airway lesions or tracheostomy. Several methods for minimizing the risk of igniting an airway fire have been promulgated[postulated] and are listed in Table 4.3. One of the most important is the use of a laser-resistant ETT with the cuff filled with saline, rather than air. Airway fires produce a thermal injury from the blowtorch-like flame that comes out from the end of the ETT and injury to the lungs from the toxic products of combustion of the ETT

Table 4.3 Recommended Practices to Help Prevent an Airway Fire, Grouped According to the Cause of Ignition

Recommended Practices to Help Prevent an Airway Fire, Grouped According to the Cause of Ignition

When Using Electrosurgical Devices	When Performing Laser Surgery
During tracheostomy, remove electrosurgical units from the surgical field prior to opening the trachea. This can effectively prevent inadvertent or reflexive use of the electrosurgical device.	Limit the laser output power density and pulse duration to the lowest clinically acceptable value. Place the laser in standby mode when not in use. Before removing a laser from the surgical site, deactivate it and place it in standby mode.
Do not allow use of an electrosurgical device to cut tracheal rings or enter the airway.	Allow only the person wielding the laser to activate it, thus minimizing the risk of inadvertent activation.
Do not use red rubber sheathing as an insulator during use of long electrosurgical probes or electrodes, such as during tonsillectomy. Red rubber will ignite even at room air concentrations (it has a low oxygen index).	Use appropriate laser-resistant ETTs during airway surgery. Follow recommended practices, such as inflating cuffs with saline to prevent ignition, or a dye-impregnated liquid to indicate cuff puncture.
Scavenge airway gases with suction to remove oxygen or nitrous oxide that could be leaking around the ETT.	Keep the laser tip in view during lower-airway surgery, making sure it is clear of the bronchoscope or ETT.
Soak gauzes or sponges, such as when using uncuffed ETTs, as this will minimize leakage of gas into the oropharynx, as well as reduce the risk of combustion by keeping them wet.	Place wetted gauze or sponges next to the ETT cuff to protect it from laser damage—and keep them wet.

FIGURE 4.2. Ignition of an ETT results in a fire that resembles a blowtorch. What cannot be appreciated from the photo are the acrid products of combustion, which can significantly impair respiratory function.

4.5.2 How to lessen injury from airway fires

Airway fires require immediate action to prevent or minimize patient injury. Most importantly, the supply of oxygen to the ETT must be removed. This can be accomplished [done] by disconnecting the breathing circuit or by turning off the flow of oxygen, such as at a flowmeter. This will immediately extinguish the fire. Simply dousing the ETT with water is not sufficient, as such fires can continue to burn underwater (Fig. 4.2). As soon as the oxygen supply is eliminated [disconnected] or, ideally, at the same time, the ETT must be removed from the airway. In addition, any other material in the airway should be removed. Any material removed from the airway should be extinguished with water or saline in a basin or sink or with a wet towel; otherwise, there is a risk of igniting drapes or other flammable matter. Care must be taken to not use a flammable liquid such as alcohol that might be present in or near the surgical field. A quick airway exam should then be performed to check for flaming sparks or other materials that could reignite once a new ETT is placed and oxygen flow resumes. Saline or water can be poured into the airway to extinguish any remaining burning material. Once this is done, a new ETT can be placed in the airway. Use room air until it is absolutely certain nothing is burning. As oxygen is reintroduced, [restarted] attention must be paid to whether any ignition takes place. As already mentioned, any embers or other ignition sources remaining in the airway can reignite the fire once oxygen begins to flow again. At this time, a more thorough inspection of the airway can be conducted, carefully assessing the extent of injury.

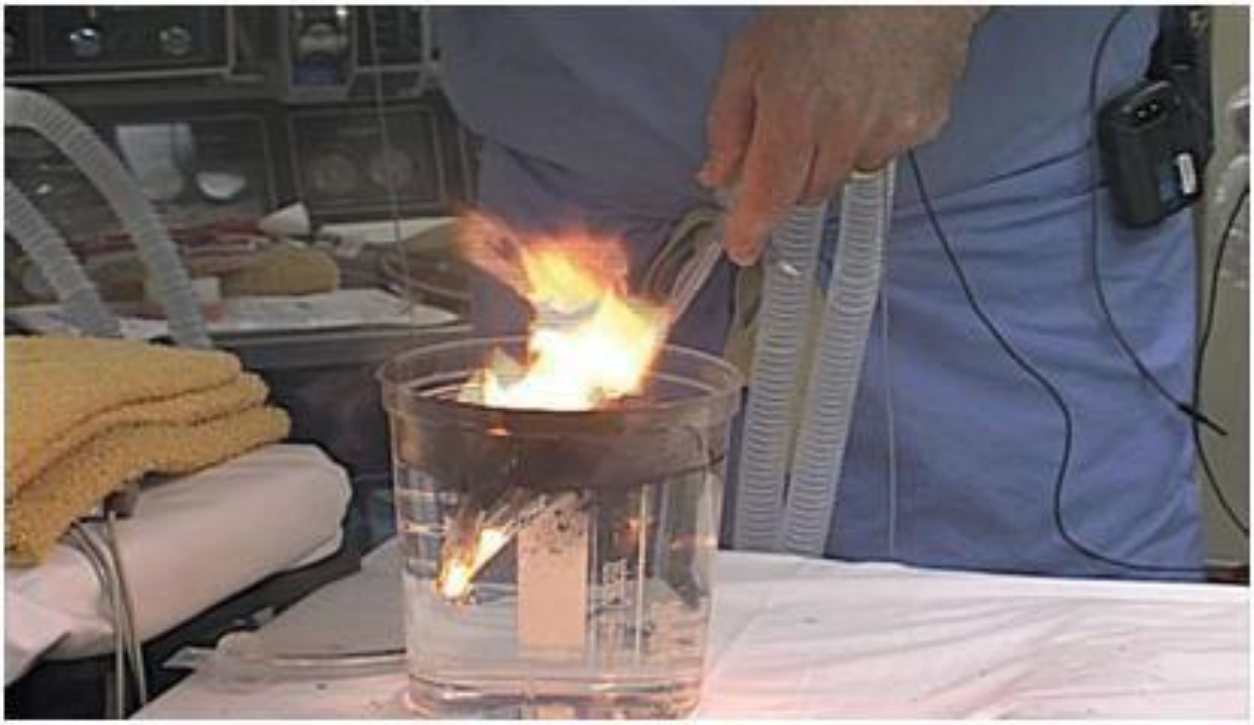


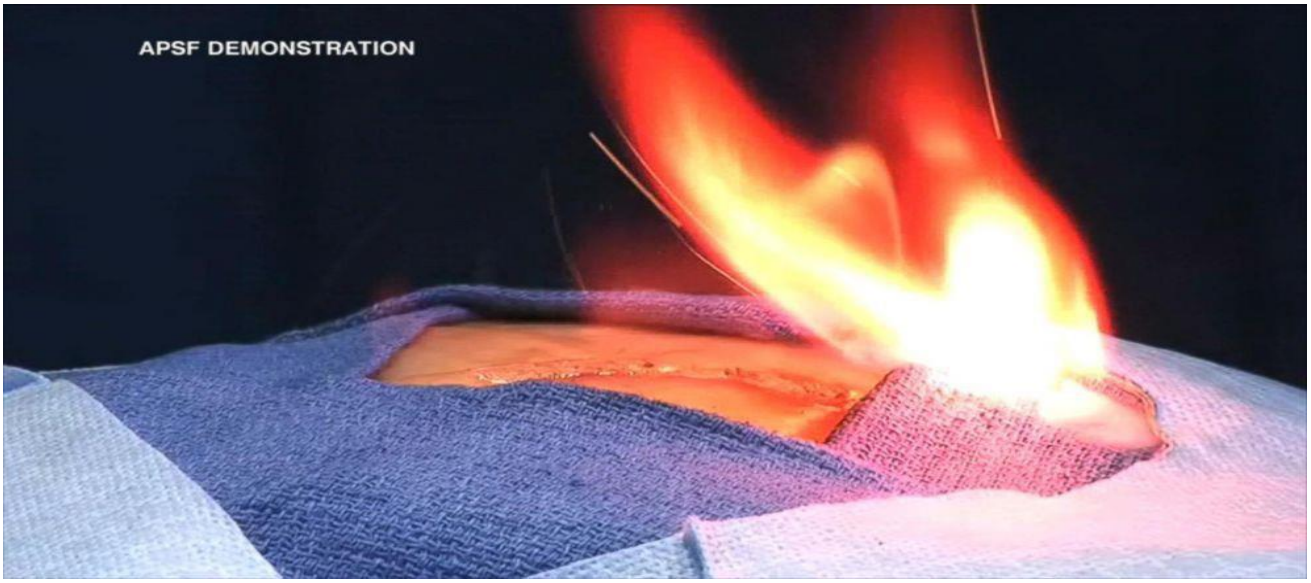
FIGURE 4.3. An ETT on fire continues to burn, despite being submerged underwater. Note the fire present within the portion of the tube that is below the surface of the water.

4.6 Surgical Fires

A surgical fire is defined as one that directly affects the patient and involves the ignition of surgical drapes or other flammable materials, such as gauze or towels. It can occur in a variety of situations and, once ignited, can spread rapidly to other areas of an OR. A surgical fire may then extend beyond the room in which it began. If not immediately managed, it poses a threat to all present. Lasers or electrosurgical devices can ignite a surgical fire. In addition, the tip of a light cord, such as from a headlamp or laparoscopic instrument, can be very hot. When placed on top of surgical drapes, it may also ignite a fire, usually in the presence of an oxygen-enriched atmosphere. Many operations are performed under sedation with supplemental oxygen provided by a face mask or nasal cannula. Because of the potential accumulation of oxygen under the drapes, these cases have a higher risk of a fire than those that do not use supplemental oxygen. This is particularly true when the surgery is on the face, near the supplemental oxygen supply. Finally, alcohol-based surgical prep solutions may remain on the patient and can ignite. Surgical fires can often be prevented through a combination of education and awareness on the part of OR staff, as well as implementation of recommended practices to reduce the likelihood of accidentally igniting a fire

4.6.1 What to do if surgical fire occurs

While a small, confined fire may be extinguished by the prompt action of a single person, for example, the surgeon or scrub nurse, oftentimes a surgical fire will generally require a coordinated response by numerous persons to control it, to keep it from spreading, and finally to extinguish it. In this situation, any staff present can contribute to successful management of this emergency.



As with an airway fire, the first step is to immediately stop the flow of all airway gases to the patient. At the same time, immediately remove any burning material from the patient. Stopping the flow of airway gases will often cause the fire to go out or at least burn less intensely. Rapidly removing the burning material is the only way to protect the patient from the fire. In addition, the fire could reignite if oxidizers are reintroduced. A team member should be ready to extinguish the burning materials. If needed, a carbon dioxide (CO_2) extinguisher should be used. It is important to note that surgical fires can spread extremely rapidly, and usually there will not be time to retrieve and use an extinguisher. Therefore, getting a fire extinguisher should not be an initial response, and one should be used only after other steps have been taken. The next step is to care for the patient, with resumption of ventilation, control of bleeding, and examination and treatment of any injuries. This should be done swiftly [quickly], as the patient may not be spontaneously breathing, may have severe bleeding, and may still be in contact with other burning materials.

4.7 OR Fires

An OR fire involves the ignition of material in the OR, but it does not necessarily immediately involve the patient. For example, an OR fire can be caused by improper disposal of an electrocautery device that ignites flammable material in a trash container.

Even if an OR fire does not initially involve the patient, if it is not quickly contained and extinguished, it may well spread rapidly and threaten patients and staff. The response to an OR fire should be similar to that of a surgical fire. It may be necessary to halt the flow of oxygen and nitrous oxide. Preparations should begin to remove the patient from the room, if the fire cannot be promptly contained and extinguished. A CO2 fire extinguisher should be used to extinguish the fire, OR suite staff should be notified of the fire, and steps should be taken to limit the spread of the fire and smoke.

4.8 Fires Elsewhere in the Facility

A fire that exists outside the OR area, but within or near the facility, may not pose an immediate threat, but the danger is still imminent. It may still be necessary to halt operations or transfer patients. Smoke may enter the OR area and interfere with procedures, for example, or there may be a risk that the fire will spread into the OR. Making sure that fire doors are closed will help limit the risk, at the very least slowing the progression of the fire into new areas. If patient evacuation is necessary, the same steps as noted above will need to be taken.

4.9 THE ROLE OF THE ANESTHESIA TECHNICIAN

Fire prevention is the responsibility of every individual working in the OR. It is a team work and the most important role for an anesthesia technician in fire safety is to participate as a member of an alert OR team in identifying safety hazards and helping institute steps to rectify them. For example, if it is observed that oxygen is being provided by nasal cannula in such a way that it can accumulate [gather] under drapes during facial surgery, and without regulating the delivered concentration of oxygen (i.e., open delivery of 100% supplemental oxygen), a gentle reminder to point out recommended best practice (delivered oxygen concentration should be kept below 30%) would be reasonable and might avert [prevent] a catastrophe. In addition, there are a number of specific ways in which an anesthesia technician can be involved and help to reduce the risk of an OR fire. Understand the fire triangle and appreciate what constitutes a fuel, a source of ignition, and an oxidizing agent and recognize risky situations. Maintenance of equipment, for example, replacing or repairing frayed electrical cables, may prevent a stray spark that could ignite a fire. Placing signs and notices about hazards and recommended practices can provide important information regarding fire safety. Lastly, ensure that appropriate supplies are available, such as laser-resistant ETTs for laser airway surgery.

The following is a brief checklist for the anesthesia technician responding to a fire:

- Be prepared to transport an anesthetized patient.
- Gurney (wheeled chair)
    - Airway supplies including self-inflating bag-valve-mask ventilation, oxygen supply, and reintubation supplies and equipment.
    - Remember that it may not be appropriate to use supplemental oxygen in the

presence of any potential embers or burning material; you will need an Ambu-style self-inflating system that can operate without supplemental gas flow until you are free of any fire area and can use an oxygen tank.

    - Infusion pumps and anesthetic agents (e.g., propofol) to maintain anesthesia during transport
    - Transport monitors
- Prepare to shut off oxygen to the room. Alert additional technicians to be prepared to transport multiple patients.

- Bring a CO2 fire extinguisher. Fire extinguishers are rarely needed to extinguish a surgical fire. Historically, they have been needed in the rare instance when a fire engulfs [catches] a patient, has migrated off a patient, involves materials that continue to burn after being removed from a patient, or involves equipment. Nonetheless, it is essential to know where extinguishers are kept, as well as the different types of extinguishers (and how to use them. While water-based, CO2, and dry powder extinguishers are all commonly available in the OR, the recommended extinguisher is a CO2 type.

Chapter 5

LASER SAFETY

IMPORTANT TERMS

LASER: light amplification through simulated emission of radiations

ELECTROMAGNETIC: the energy that travels in waves at speed of light.

WAVELENGTH: The distance over which the wave's shape repeats.

5.1 INTRODUCTION

Lasers have been used for surgery since the 1960s to cut, coagulate, and ablate tissue. Lasers provide several advantages compared to other surgical techniques, including the ability to target difficult-to-reach regions of the body as well as to deliver high amounts of energy to very small areas. The result is precise heating of surgical targets, often to the point of vaporization, with minimal swelling and trauma to surrounding tissues. This may minimize bleeding, reduce postoperative pain, and destroy small blood vessels at the target area. Lasers are used by many surgical specialties. For example, otolaryngologists often use lasers to target areas such as the larynx (voice box) and trachea (windpipe), while urologists use a different type of laser to destroy kidney stones. The use of lasers continues to expand throughout health care.

Laser use is not without risks. Anesthesia technicians will work throughout areas where lasers are in use and need familiarity with the various types of lasers, as well as the particular risks and protective measures that are unique to each.

5.2 LASER TECHNOLOGY

Laser is an acronym for "Light Amplification by Stimulated Emission of Radiation," a process of producing and amplifying light energy. Laser light, like all forms of electromagnetic energy, travels in waves and may be either visible with a distinct color or lie outside the visible spectrum (Fig. 5.1). The length of each wave (wavelength) determines each laser's unique properties, such as energy, color, and ability to affect certain tissues in the body.

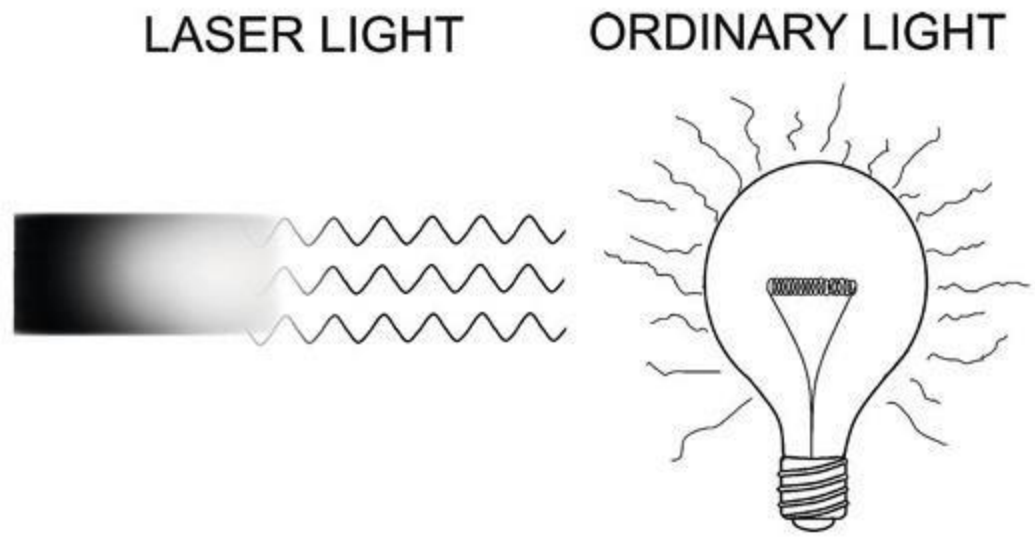


FIGURE 5.1 Laser beam energy travels in waves that are identical (monochromatic), line up perfectly (in phase), and travel together in the same direction (don't diverge), in contrast to ordinary light.

5.3 LASER PHYSICS

5.3.1 Properties of laser light

Unlike other forms of light, laser light has special properties which make it significantly more effective and dangerous than conventional light of the same power. The laser light particles (photons) are usually:

- **Monochromatic**: consisting of a single wavelength or colour
- **Coherent**: photons are in phase (like marching soldiers)
- **Collimated**: photons are almost in parallel (aligned), with little divergence from the point of origin

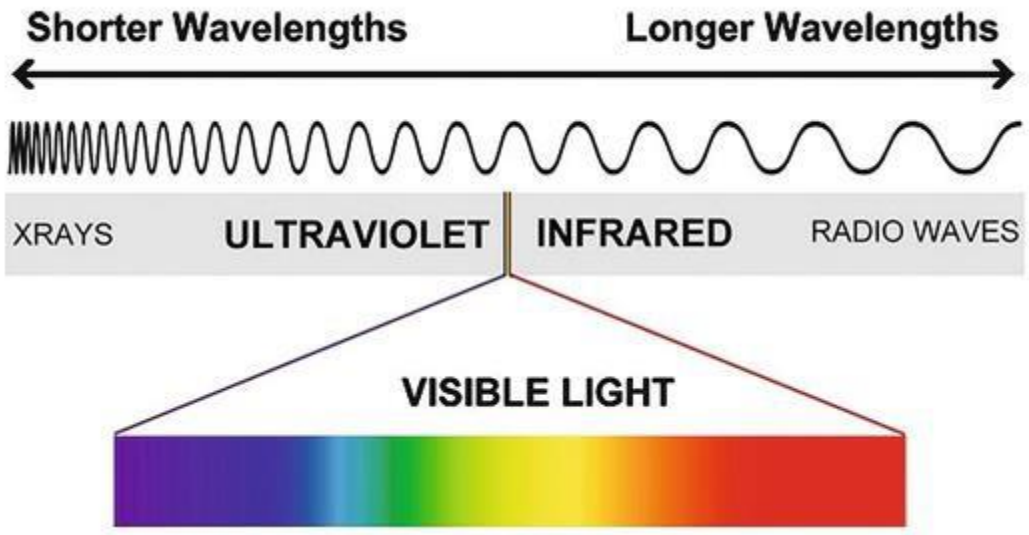


FIGURE 5.2. The wavelength of a laser beam determines whether it is invisible (infrared or ultraviolet) or visible, with a distinct color.

5.3.2 Components of a laser

A laser consists of 3 basic components:

1. **A lasing medium or "gain medium":**

May be a solid (crystals, glasses), liquid (dyes or organic solvents), gas (helium, CO2) or semiconductors

2. **An energy source or "pump":**

May be a high voltage discharge, a chemical reaction, diode, flash lamp or another laser

3. **An optical resonator or "optical cavity":**

Consists of a cavity containing the lasing medium, with 2 parallel mirrors on either side. One mirror is highly reflective and the other mirror is partially reflective, allowing some of the light to leave the cavity to produce the laser's output beam – this is called the output coupler.The laser is usually named according to the type of lasing medium. This also determines the type of pump required and the wavelength of the laser light which is produced.

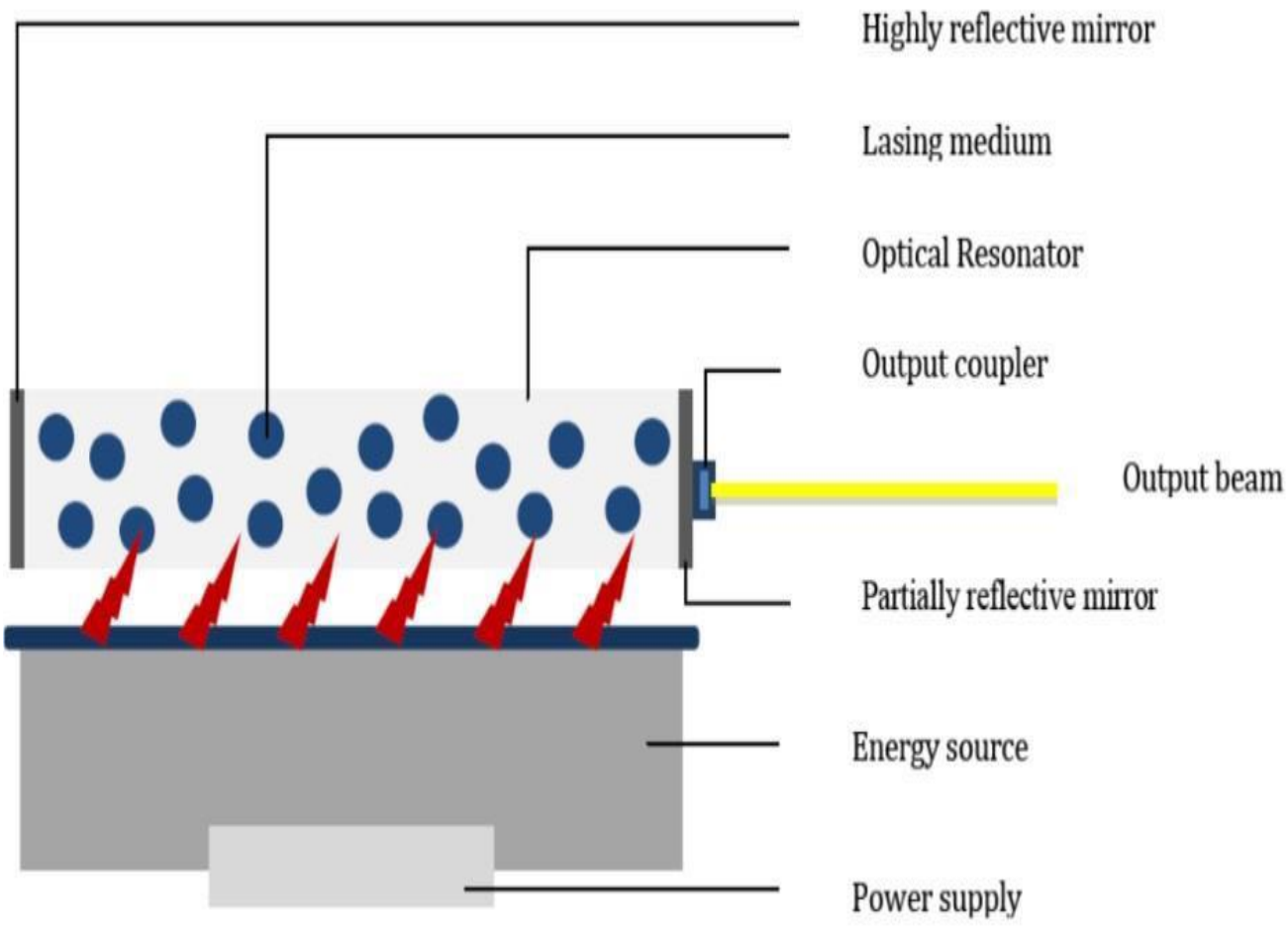


FIGURE 5.3. The 3 Components of a laser

5.4 MEDICAL LASERS

Medical lasers may be operated in continuous wave or pulsed wave modes. The output of continuous wave lasers is measured as **power** in watts, and for pulsed lasers the output is measured as **energy** in joules.

Irradiance, or power density, refers to laser power per unit area (W/cm2)

Fluence, or energy density, is irradiance multiplied by exposure time (J/cm2)

The interaction between the laser beam and the tissue is determined by the wavelength (figure 4), power density and exposure time.

It is the monochromatic nature of laser light that is responsible for its selective effect on biological tissues. When the light comes into contact with the tissues, it can be transmitted, scattered, reflected or absorbed. This depends on the nature of the tissue and the wavelength of the light. The laser light has to be **absorbed** by the tissue in order to exert biological effects. Examples of the main absorbing components in tissues are:

- Water – absorbs infrared light
- Hemoglobin – absorbs visible light, especially green
- Melanin – absorbs visible and ultraviolet light

The wavelength also determines the depth of penetration. As the wavelength decreases towards the ultraviolet spectrum more scattering occurs which limits the depth of penetration within the tissues. Hence the Argon laser is used for retinal surgery and port-wine birthmarks. The Nd:YAG laser operates at the near infrared spectrum, which has a greater depth of penetration and is therefore used for the cutting and coagulation of tissues.

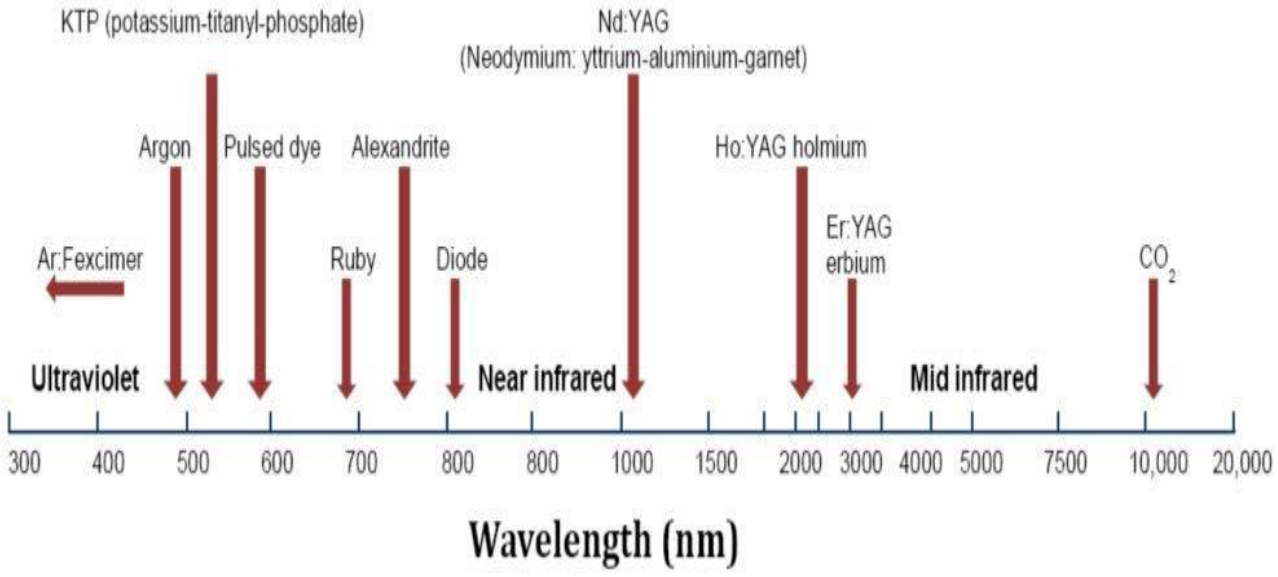


FIGURE 5.4. Wavelength of medical laser

Examples of lasers in medical practice

CO2 laser:

Used for cutting and coagulation of soft tissue, which consists primarily of water, e.g. laryngeal surgery. It creates a **photo-thermal effect,** rapidly heating the tissues. Depending on the exposure time, tissue vaporization (ablation), coagulation, or both may occur. Pulsing the laser exposure can minimize thermal conduction that may cause collateral tissue damage.

Holmium:YAG laser:

Used for tissue ablation or lithotripsy via a **photo-mechanical effect**. An extremely intense, but very brief, pulse of laser causes an explosive expansion of the tissue or water within the renal calculi, causing photoacoustic disruption.

Excimer (Argon:Florine) laser:

Used for corneal reshaping. The laser breaks down the covalent bonds in the protein molecules **(photodissociation),** resulting in non-thermal ablation.

LASER MEDIUM	TYPE	PUMP SOURCE	COLOUR/ WAVELENGTH	APPLICATIONS
CO2	Gas	Electrical discharge	Far infrared 10 600 nm	Cutting, coagulation, laser scalpel, skin resurfacing
Ho:YAG Holmium	Solid	Laser diode	Mid infrared 2070 nm	Tissue ablation, lithotripsy, endoscopic sinus surgery
Nd:YAG	Solid	Flash lamp, other laser	Near infrared 1064 nm	Cutting and coagulation, GI bleeding, black tattoo removal
Diode	Solid (Semiconductor)	Electric current	Red- infrared 630 - 900 nm	Laser pointer, hair removal, bar code scanners
Argon	Gas	Electrical discharge	Blue-green 500nm	Retinal surgery, AV malformations, thick port wine birthmarks
Eximer (Ar:F)	Gas	Electrical discharge	Ultraviolet 193 nm	Corneal vision correction
Ruby	Solid	Flash lamp	Red 694 nm	Hair removal, tattoo removal, holography
Pulsed dye	Liquid	Flash lamp, other laser	Yellow 390 - 640 nm	Birthmark removal, vascular skin lesions

FIGURE 5.5. Examples of medical lasers

5.5 LASER INTERACTIONS WITH TISSUES

Laser energy has a variable interaction with a target tissue depending on its wavelength and the composition of the target substance.
Laser energy may:

- Travel through a substance without affecting the substance
- Be absorbed by the substance at the point of impact [contact], generating heat
- Reflect off the target substance, either unchanged or with scattering [separating]

The goal when using a laser is to produce the desired effect by heating the target tissue without affecting adjacent [surrounding] tissues. Laser energy absorbed as heat can produce a plume of smoke and steam. At lower temperatures, protein remodeling and coagulation occur.

A laser's unique wavelength and characteristics are used to selectively treat a target tissue (Table 55.1). A particular laser is used because its wavelength is absorbed by certain colors (e.g., hemoglobin in vascular lesions such as port wine stains or a particular pigment in the skin during removal of a colored tattoo). Laser beams with longer wavelengths, such as the carbon dioxide laser, are readily absorbed by water in the superficial tissue layers. This minimizes deeper penetration, making it ideal for targeting only the surface of a tissue. Other lasers, depending on their wavelength, interact with other substances and, as a result, can target deeper structures.

The main factors determining the effect of a laser on a given tissue are listed below:

- Laser power (watts)
- Duration of exposure
- Surface area exposed (spot size)
- Wavelength
- Target tissue composition

5.6 SAFETY CONCERNS

Lasers have many hazards associated with their use, the most important being eye injury, fire, and air contamination. Other risks include damage to soft tissue, perforation of the trachea, venous gas embolism, and death. Laser usage must be limited to trained personnel in the operating room. Most lasers must be handled with care to avoid damage to the unit. Carbon dioxide lasers are the most susceptible to damage. The delivery system is composed of small mirrors necessary to carry the laser beam from the laser unit to a handpiece or scope. It is important to handle the machine carefully since the mirrors can easily be misaligned, resulting in a laser malfunction or a misdirected laser beam (Fig. 5.6).

FIGURE 5.6. A typical CO2 laser showing the articulated arm with mirrors located at each joint that are necessary to reflect the laser beam down the arm. These mirrors are easily knocked out of alignment [arrangement], which can seriously affect laser function

5.6.1 Anesthesia related risks

Injury or deaths resulting from the use of medical lasers have been mostly associated with upper airway surgery, especially airway fires. The effects of lasers on anesthetic agents and equipment, as well as on the shared airway, must be anticipated and methods for avoiding these complications should be employed.

Endo tracheal tubes:

Direct or reflected laser beams can ignite [burn] non-metallic endotracheal tubes. Laser resistant tracheal tubes are commercially available and are constructed of a flexible stainless steel spiral. These tubes are non-combustible, easily sterilized, gas tight and non-reactive with human tissue. Alternatively, conventional PVC tubes may be wrapped with self-adhesive non-reflective metal tape, which is adequate, but not without danger.

The cuff is also vulnerable to rupture by the laser beam. If a cuff inflated with air is ruptured, it allows a massive leak of anesthetic gasses, providing a richer environment for possible ignition. Filling the cuff with saline will acts as a heat sink and ensure that the heat from the laser beam is dissipated [dissolved]. Methylene blue may be added to the saline to provide a visible indication of inadvertent [accidental] rupture. An additional safety measure is to have twin distal cuffs.

Skin and eyes:

Combustible drapes should be avoided, and spirit-based solutions to clean the skin should either be avoided or allowed sufficient time for evaporation. Drapes must not create pockets for accumulation of oxidizing agents. Any exposed facial hair can be coated with aqueous lubricating jelly to make it non-combustible. The patient's eyes should be protected by taping them shut and covering with moist eye pads.

Gas mixtures:

Neither nitrous oxide nor oxygen are flammable, but as nitrous oxide is a better oxidizing agent than oxygen, it does support combustion at very high temperatures and should be avoided especially in open anesthetic systems. Provided adequate oxygenation occurs, an oxygen concentration of less than 30% in nitrogen or helium as a carrier gas is recommended.

FIGURE 5.7. Laser signs must list the laser type, wavelength, maximum power the unit is capable of emitting, and laser classification. This information suggests hazards and necessary protective measures. Laser eyewear is designed to protect the wearer from laser light of a specific wavelength and therefore a specific laser type. A: This sign is for a KTP type laser, wavelength 532 nm. B: This eyewear is used for a KTP laser with a wavelength of 532 nm. It can also be used with a laser wavelength of 1,064 nm. C: Enlarged view showing the wavelengths of 532 nm and 1,064 nm

Steps in the management of an airway fire:

The triad of fuel (tube, drapes, skin prep), oxidizing agent (oxygen) and heat (laser beam) may cause a theatre or airway fire. The following steps should be taken in this event;

- Discontinue laser surgery and make the surgeon aware

- Stop ventilation
- Disconnect the oxygen source
- Remove the burnt endotracheal tube
- Douse operating site in water
- Re-instate ventilation via a self-inflating bag or re-intubate and ventilate with room air
- Perform a rigid bronchoscopy to assess the extent of the thermal injury and remove foreign bodies / debris. Plan further management accordingly i.e. tracheostomy
- Commence a short course of steroid therapy if indicated to prevent inflammation
- Consider antibiotic therapy and transfer to critical care for ventilator support if concerned about upper airway swelling or injury to the lungs Theatre safety

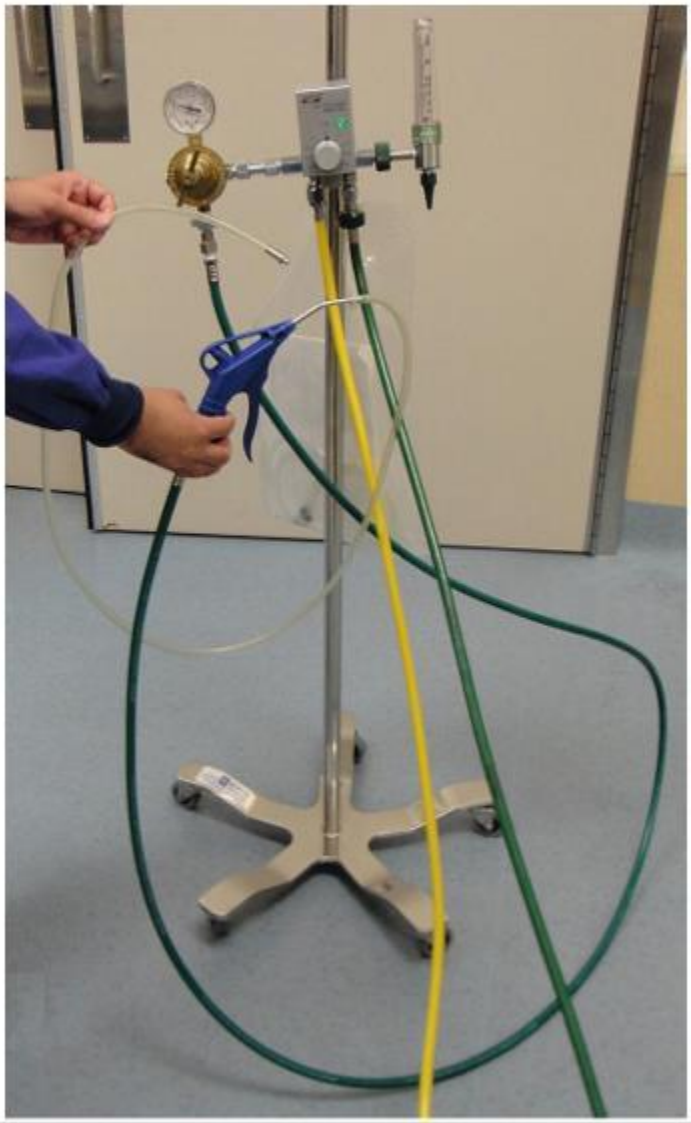
A formal safety program that defines the hazards of the laser to be used and the control of those hazards (including clinical aspects) should be instituted [installed] and a designated advisor should ensure that all the personnel are adequately trained. The hazard classification of the laser should be clearly marked on the outer casing. Laser should only be used by those trained to do so. Only the person using the laser must be able to activate it and it should be placed in the standby mode when not in active use. Regular servicing of the equipment and maintaining a log of laser use will minimize the risk of an accident. An appropriate non-water based fire extinguisher should be available in the clinical area.

All personnel in theatre should wear protective eyewear. The designated theatre must be clearly identified as a “laser-controlled area” and warning signs placed at all the entry points to restrict admission. Non-essential doors have to be locked and the windows covered to prevent injury to passers-by.

5.6.2 Airway Management during Laser Surgery

Several methods have been devised to allow laser surgery of the face, head, neck, and airway while decreasing the risk of fire. It is important that the anesthesia provider and surgeon collaborate to select the most optimal method of airway management. Techniques for airway management that avoid the use of an ETT altogether are spontaneous ventilation, intermittent apneic oxygenation (IAV), and jet ventilation. Alternatively, specialized laser-resistant ETTs can be used if a secured airway is desired for laser airway surgery. Spontaneous ventilation is normal, unassisted breathing. IAV involves providing 100% oxygen for short intervals in patients who are not breathing (apneic), usually via an ETT that is removed from the airway during laser use, and put back each time it is

necessary to oxygenate the patient; this is convenient during prolonged rigid laryngoscopy when the larynx is continuously in view. Oxygen can also be provided by intermittent mask ventilation. By eliminating the fuel from the airway, both spontaneous ventilation and IAV effectively minimize the risk of an airway fire. These techniques may require general anesthesia to be maintained with intravenous (IV) anesthetic agents since an ETT is not always present to deliver inhaled anesthetics. The patient's oxygenation must be monitored with pulse oximetry.



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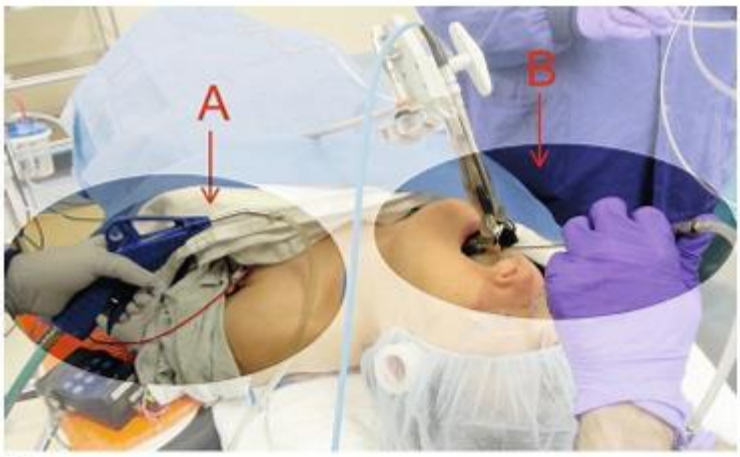


FIGURE 5.8. A: The setup for a jet ventilator. B: A jet ventilator in use. A points to the handle being squeezed to deliver oxygen, and B points to the long nozzle, which directs oxygen into the patient's airway

Chapter 6

PATIENT POSITIONING

IMPORTANT TERMS

COMPARTMENT SYNDROME: A painful condition that occurs when the pressure within muscles builds to dangerous levels.

COMPRESSION: the act of pressing something or putting pressure

NEUROPATHY: nerve damage leading to pain, weakness or tingling.

6.1 INTRODUCTION

Patients under anesthesia are at risk for injuries because they cannot protect themselves. The goal of intraoperative positioning is to place and secure the patient on the operating room table to allow adequate surgical exposure and access, without compromising physiologic function (e.g., ventilation) or injuring the patient. Patient positioning is a routine function of operating room nursing personnel and the anesthesia team; however, all members of the operating room team may be involved in positioning a patient, including the anesthesia technician

6.2 THE IMPORTANCE OF PATIENT POSITIONING

Patient positioning is vital to a safe and effective surgical procedure. Proper patient positioning in the operating room depends on the type and length of procedure, anesthesia access to the patient, devices required and other factors. Safely positioning the patient is a team effort. All members of the surgical team play a significant role in the process and share responsibility for establishing and maintaining the correct medical positions for patients.

6.3 TYPES OF POSITIONING

6.3.1 Supine position

Supine position, also known as Dorsal Decubitus, is the most frequently used position for procedures. In this reclining position, the patient is face-up. The patient's arms should be tucked at the patient's sides with a bedsheet, secured with arm guards to sleds.

6.3.2 Jackknife Position

Jackknife position, also known as Kraske, is similar to Knee-Chest or Kneeling positions and is often used for colorectal surgeries. This type of position places extreme pressure on the knees. While positioning, surgical staff should place extra padding for the knee area.

6.3.3 **Fowler's Position**

Fowler's position, also known as sitting position, is typically used for neurosurgery and shoulder surgeries. The beach chair position is often used for nasal surgeries, abdominoplasty, and breast reduction surgeries. When positioning a patient in Fowler's position, the surgical staff should minimize the degree of the patient's head elevation as much as possible and always maintain the head in a neutral position.

6.3.4 **Prone Position**

In Prone position, the patient is face-down with their head in a neutral position without excessive flexion, extension or rotation. A face positioner is used when the patient's head is in midline. Prone position is often used for spine and neck surgeries, neurosurgery, colorectal surgeries, vascular surgeries, and tendon repairs.

When a patient is in Prone, pressure should be kept off of the eyes, cheeks, ears, and breast. At a minimum, four members of the surgical staff should be available when turning a patient prone. Risks associated with Prone position include increased abdominal pressures, bleeding, compartment syndrome, nerve injuries, cardiovascular compromise, ocular injuries, and venous air embolism.

6.3.5 **Lithotomy Position**

In Lithotomy position, the patient can be placed in either a boot-style leg holder or stirrup-style position. Modifications to this type of position include low, standard, high, exaggerated or hemi. This position is typically used for gynecology, colorectal, urology, perineal, or pelvis procedures. The risks posed to a patient in a Lithotomy position for a procedure include fractures, nerve injuries, hip dislocation, muscle injuries, pressure injuries, and diminished lung capacity.

6.3.6 Trendelenburg Position

Trendelenburg position is typically used for lower abdominal, colorectal, gynecology, and genitourinary surgeries, cardioversion, and central venous catheter placement. In this type of position, the patient's arms should be tucked at their sides, and the patient must be secured to avoid sliding on the surgical table. The Trendelenburg position should be avoided for extremely obese patients. Risks to a patient while in this position include diminished lung capacity, diminished tidal volume and pulmonary compliance, venous pooling toward the patient's head, and sliding and shearing.

6.3.7 Lateral Position

A patient may be positioned in Lateral position during back, colorectal, kidney, and hip surgeries. It's also commonly used during thoracic and ENT surgeries, and neurosurgery.

6.4 GENERAL MECHANISMS OF INJURY

Patients can be injured in multiple ways due to positioning on the operating room table. Injuries attributable [relatable] to patient positioning include vision loss, abrasions, skin breakdown, pressure ulcers, hair loss, nerve damage, and joint damage.

The mechanisms by which patients sustain injuries include

- pressure
- friction
- Shear forces. Forces that compress the skin and underlying tissues can compromise blood flow to important structures, particularly nerves]

6.4.1 Pressure

Pressure injuries usually occur where tissue is compressed against a bony prominence or the tissue is at special risk (e.g., the eye).

Awake patients who do not have mobility problems change position frequently when they become uncomfortable, thus preventing pressure-related injuries. Unfortunately, patients with regional or general anesthesia do not become uncomfortable, nor can they

move. The procedure team must take great care to assure that undue pressure is not placed on any portion of the body. Even things as simple as face masks or intravenous (IV) poles can be placed in such a way as to place pressure on the body and injure a patient

6.4.2 Friction or shear forces

Friction or shear forces can also cause injury to patients. When skin rubs against a surface, it can sustain an abrasion or a burn-like injury that blisters. You might think that anesthetized patients are immobile, and most of the time, they are; however, the surgical team may move the patient. For example, during total knee replacement surgery, the operative knee is flexed and extended multiple times **Mechanism of injury caused by positioning**

A common mechanism of injury due to positioning involves the overextension of joints. Each individual joint in each individual patient has a range of motion through which the joint may comfortably move. Overextending a joint can damage the joint capsule and ligaments or tendons that surround the joint. Many common sports injuries like sprains involve the overextension of joints. When a joint is overextended, it is painful. In the operating room, an anesthetized patient will not be able to tell the operating room staff that a joint is overextended. As a patient is moved from one bed to another, positioned on the table, or moved during surgery to facilitate surgical exposure, the patient is at risk for a joint injury. During these movements, the operating room staff must take care to keep joints in a neutral position that is well within the joint's normal range of motion.

It is important to keep in mind that some patients, due to disease or previous injury, may have a reduced range of motion in a joint. These limitations should be identified preoperatively so that the operating room staff can avoid extending the joint beyond its reduced range of motion. For example, normal patients can tolerate an arm extended to the side up to 90 degrees. However, a patient with an old shoulder injury may not be able to tolerate having his or her arm moved more than 45 degrees away from his or her body.

6.4.3 Prevent the patient from falling off table

Even if joints are properly positioned at the beginning of surgery, their position may change during surgery while covered by drapes. The patient should be secured to the operating room table to prevent limbs or even the entire patient from falling off the table. Keep in mind that the restraints must be applied in such a way as to prevent movement but also to not improperly compress a body part.

6.5 Nerve injury during positioning

Nerves are at particular risk for positioning injury during surgery. Nerve injury in positioning is usually the result either of stretching the nerve or of prolonged compression, both of which compromise blood flow to the nerve. Both the amount of stretch or compression and the duration of the insult help determine the extent of injury.

6.5.1 Risk factors

- longer nerves seem to be more prone to injury.

- nerves with an existing problem or medical conditions that can compromise blood flow.
- Nerve injuries range widely in severity: minor injuries tend to resolve over time (<6 Months). However, some injuries are permanent and result in lifelong pain, altered sensation, or even paralysis.

6.6 Nerve compression

The most common source of nerve compression is inadequate padding of body parts that come into contact with the operating room table. Most operating room tables are covered with padded material to reduce the risk of pressure injuries. Even so, the majority of operating rooms apply additional padding to the arms, legs, heels, and head. Special care needs to be taken to ensure that any additional operating room equipment does not press on any part of the patient. It is easy for an improperly positioned Mayo stand, IV pole, or retractor support, or even the surgeon leaning against a body part, to cause nerve compression. As with nerve stretch, inadvertent [accidental] changes in patient position can lead to nerve compression that may go unrecognized for prolonged periods due to surgical draping. For example, a leg that has fallen partially off the table may be resting directly upon metal or some other unpadded portion of the table or operating room equipment. Nerve compression can also arise from excessive tissue pressure unrelated to positioning, as occurs when a crush injury or an infiltrated IV line leads to swelling of an extremity that compromises blood flow.

6.7 NEUROPATHIES

6.7.1 Ulnar Neuropathy

Nerve injuries are some of the most common and serious positioning injuries. Anesthesia providers focus routinely on their prevention, and anesthesia technicians should understand how they occur. Among perioperative nerve injuries, ulnar neuropathy is the most common.

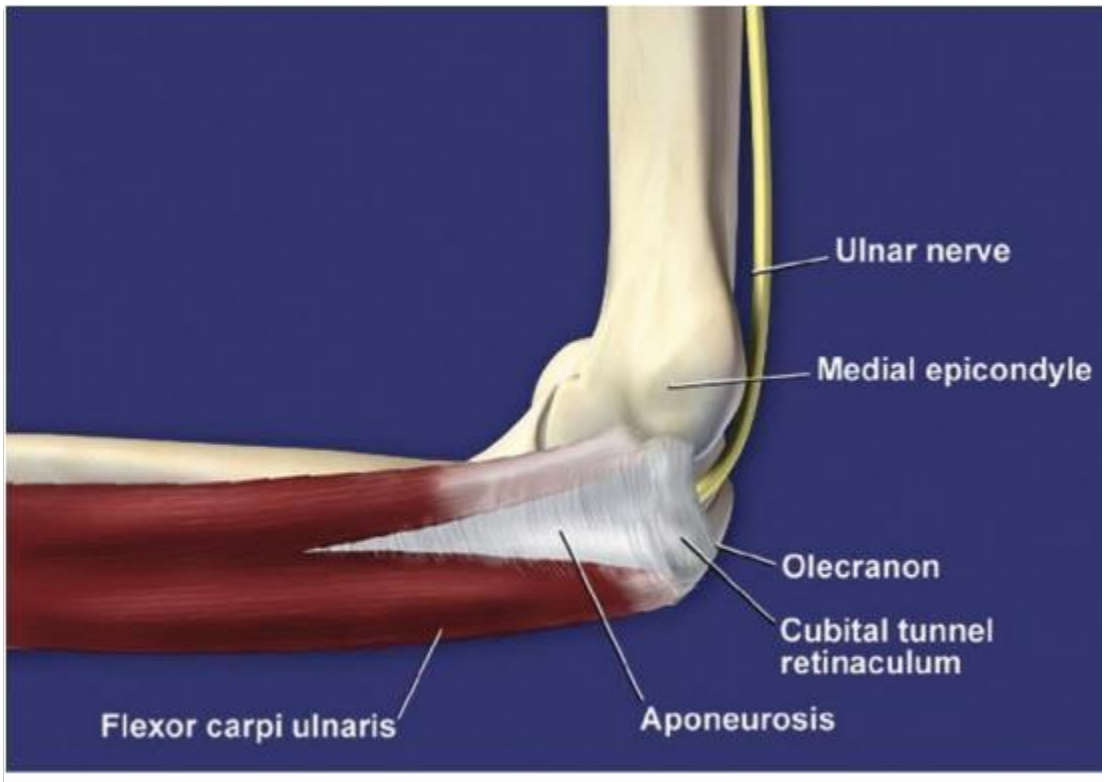
6.7.2 Factors associated with ulnar neuropathy

There are a number of factors that may be associated with ulnar neuropathy, including

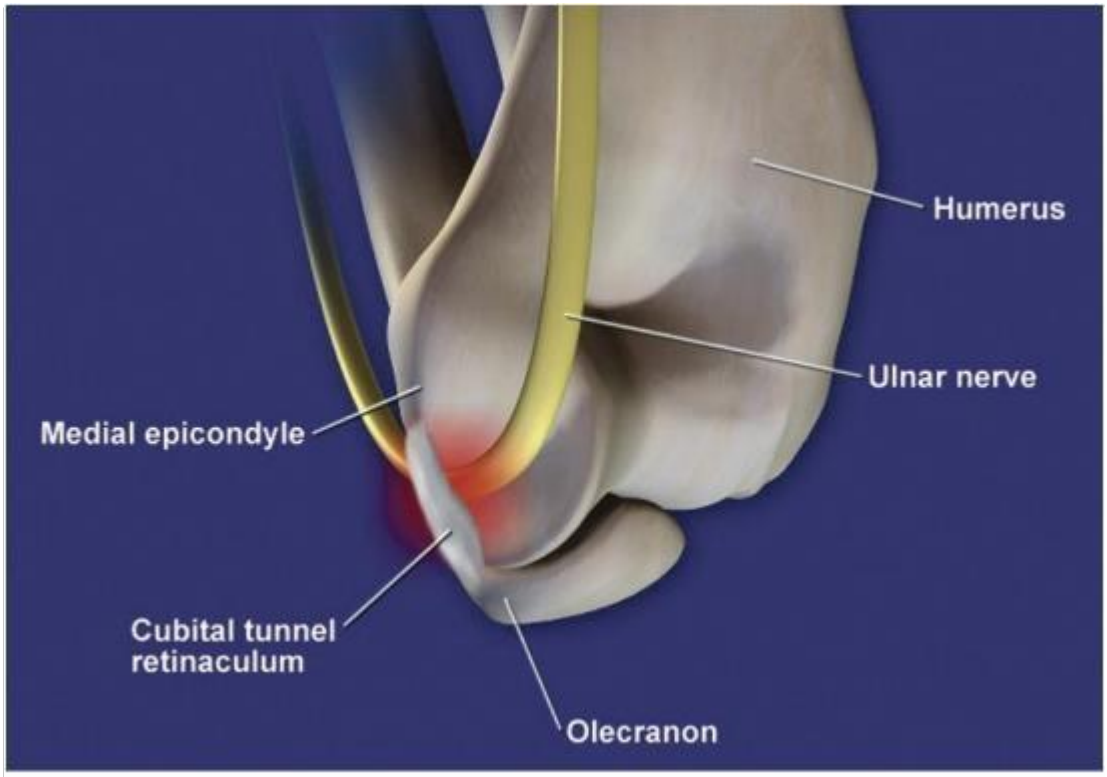
- direct compression from the outside on the nerve (which runs next to the bony point of the elbow, along its “medial” side, i.e., the side closest to the body)
- nerve compression from the inside (which happens during prolonged elbow flexion) · inflammation.

6.7.3 Key points of interest:

- Timing of postoperative symptoms: Most symptoms develop during the postoperative, not the intraoperative, period. There are good data that most surgical patients who develop ulnar neuropathy experience their first symptoms at least 24 hours postoperatively, suggesting that the mechanism of acute injury occurs primarily outside of the operating room setting (i.e., resting against a stretcher side rail for a prolonged period of time in the post-anesthesia care unit).
- Impact of elbow flexion: The ulnar nerve is the only major peripheral nerve in the body that always passes on the outside of a joint, in this case the elbow. All other major peripheral nerves primarily pass on the inner side of joints (e.g., median and femoral nerves). This difference in anatomy may play a role in some perioperative ulnar neuropathies.
- Anatomy and elbow flexion: Flexion of the elbow stretches the tendons around the bony elbow joint and generates high pressures within the nerve as it passes through (Fig. 6.1). This may be as important a factor as prolonged pressure on the outside of the elbow joint.
- Inflammation: In many instances, it is not possible to determine the cause of ulnar neuropathy. There are a growing number of studies that document a generalized inflammation of peripheral nerves after surgery, which may present with symptoms of ulnar neuropathy. Therefore, in a subset of patients, it may be appropriate to initiate [start] treatment with high dose steroids.
- Outcomes of ulnar neuropathy: Forty percent of sensory-only ulnar neuropathies resolve within 5 days; 80% resolve within 6 months. But if the ulnar neuropathy is both sensory and motor, it is unlikely to resolve [settle] within 5 days; only 20% resolve within 6 months, and most result in permanent motor dysfunction and pain. The motor fibers in the ulnar nerve are primarily located in the center of the nerve. Injury to those fibers likely is associated with a more significant ischemia [loss of blood supply] or pressure insult to all of the ulnar nerve fibers, and recovery may be prolonged or not possible.
- Prevention of ulnar neuropathy: Special attention should be given to padding the elbow and making sure it is not hyperextended or flexed greater than 90 degrees.


Ulnar nerve
Medial epicondyle
Olecranon
Cubital tunnel retinaculum
Flexor carpi ulnaris
Aponeurosis

A


Humerus
Ulnar nerve
Medial epicondyle
Cubital tunnel retinaculum
Olecranon

B

FIGURE 6.1. Ulnar nerve anatomy. **A:** The ulnar nerve of the right arm passes distally behind the medial epicondyle and underneath the aponeurosis that holds the two heads of the flexor carpi ulnaris together. The proximal edge of the aponeurosis is sufficiently thick in 80% of men and 20% of women to be distinct anatomically from the remainder of the tissue. It is commonly called the cubital tunnel retinaculum. **B:** Viewed from behind, the ulnar nerve is intrinsically compressed by the cubital tunnel retinaculum when the elbow is progressively flexed beyond 90 degrees and the distance between the olecranon and the medial epicondyle increases.

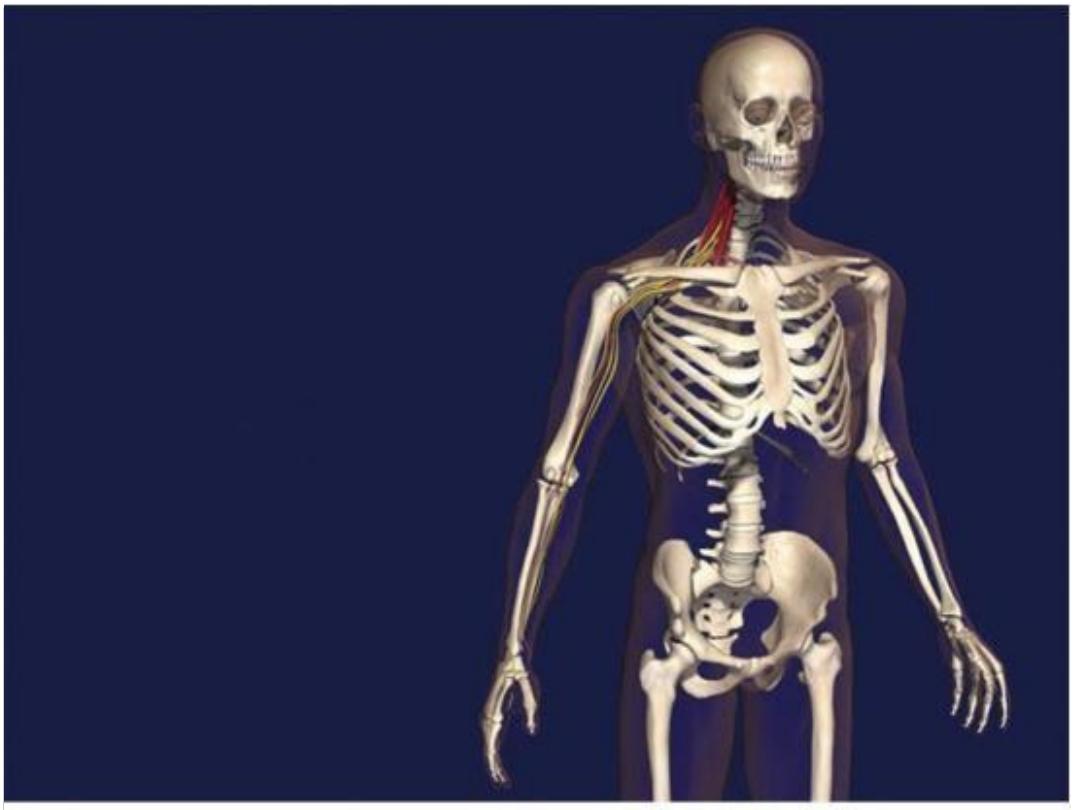
6.8 Brachial Plexopathies

The brachial plexus is the bundle of somatic nerves that originate in the neck and travel to the upper extremity.

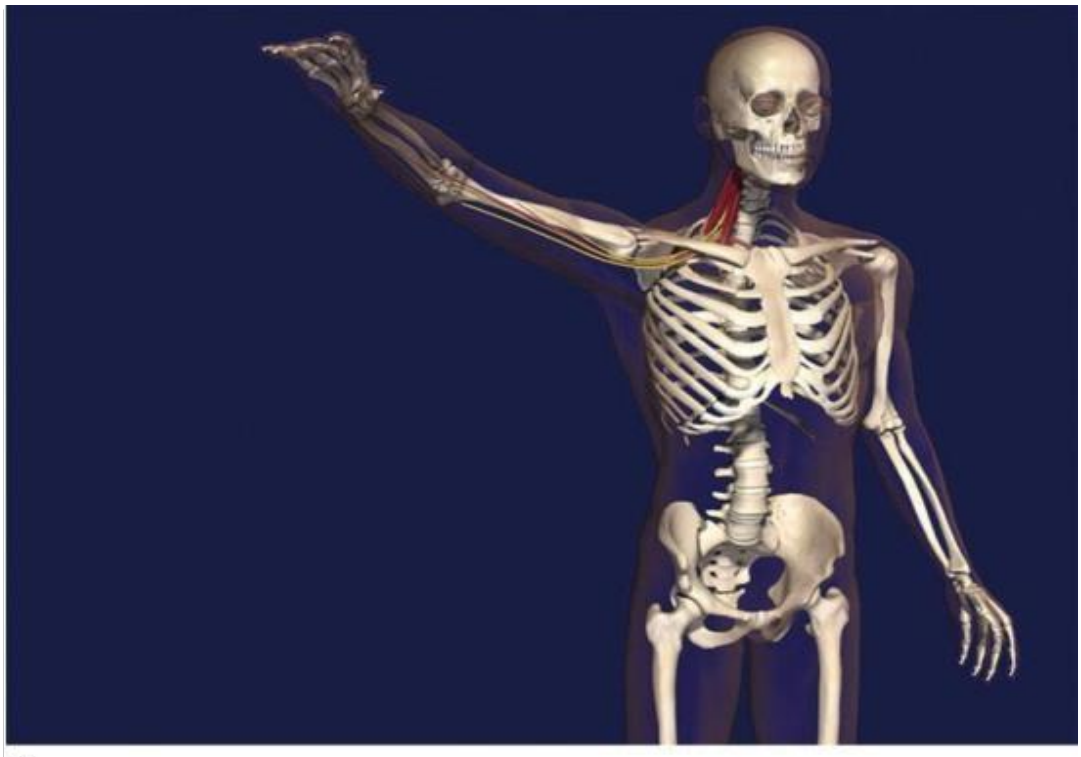
Brachial plexopathies (dysfunction of the brachial plexus) occur most often in patients undergoing sternotomies, usually for cardiac surgery. This finding is presumed to be associated with excessive retraction on the chest wall and potential compression of the nerves between the clavicle and the rib cage, or stretch of the nerves. Otherwise, patients in prone and lateral positions have a higher risk of developing this problem than those in supine positions. Finally, patients with their head secured to the operating room table and/or in the sitting position are at increased risk for brachial plexus injury. If the head is moved in the opposite direction of an arm, it can cause stretch of the brachial plexus. This can happen when the head is rotated too far to one side, the head falls off to one side, or an arm is pulled away from the body but the head is secured to the table.

6.8.1 Key points of interest:

- Brachial plexus entrapment: There are many problems that can occur in prone and laterally positioned patients. For example, the brachial plexus can become entrapped between compressed clavicles and the rib cage.
- Anatomy of shoulder abduction: Abduction of the shoulder (lifting the arm away from the side) more than 90 degrees potentially stretches the plexus (Fig. 6.2). Therefore, it is best to keep the arm at less than 90 degrees at the shoulder, especially for extended periods.
- Prone positioning: In the prone position, it may be prudent to tuck the arms to prevent brachial plexus stretch; nerve conduction testing can detect changes in some patients if the arms are at more than 90 degrees to the body with the hands beside the head (the so-called “surrender” or “Superman” position).



A



B

FIGURE 6.2. Stretching the brachial plexus. **A:** The neurovascular bundle to the upper extremity passes on the flexion side of the shoulder joint when the arm is at the side or abducted less than 90 degrees. **B:** Abduction of the arm beyond 90 degrees transitions the neurovascular bundle to where it now lies on the extension side of the shoulder joint. Progressive abduction greater than 90 degrees increases stretch on the nerves at the shoulder joint.

6.9 Median Neuropathies

Median neuropathies primarily occur in men aged 20-40 years. These men often have large biceps and reduced flexibility (think of weight lifters). The large biceps and reduced flexibility tend to prevent complete extension at the elbow. This chronic limitation in range of motion results in shortening of the median nerve over time. Median neuropathies typically involve motor dysfunction and do not resolve readily; up to 80% of median neuropathies are still present 2 years later.

6.9.1 Key points of interest:

- Stretch of a nerve: As mentioned in the section on ulnar neuropathy, nerves lose adequate blood flow when stretched more than 5% of their resting length.
- Arm support: When we subsequently anesthetize these men, we may fully extend their arms at the elbow and place them on arm boards or at the patient's sides. This full extension of the elbow stretches chronically contracted median nerves and promotes ischemia, often at the level of the elbow. Thus, it is important to support the forearm and hand to prevent full extension in men who have large, bulky biceps and who cannot fully extend their elbows because of a lack of flexibility.

6.10 Radial Neuropathies

Radial neuropathies occur more often than median neuropathies. The radial nerve appears to be injured by direct compression (in contrast to the median nerve being injured primarily by stretch). The important factor appears to be compression of the nerve in the middle of the upper arm where it wraps around behind the bone (Fig.
6.3). Radial neuropathies tend to have a better chance of recovery than ulnar or median neuropathies. Approximately half get better within 6 months, and 70% appear to resolve completely within 2 years.

6.10.1 Key points of interest:

- Surgical retractors: A case series reported several radial neuropathies associated with compression of the radial nerve by the vertical bars of upper abdominal retractor holders. The arms reportedly were impinged by these vertical support bars (Fig. 6.3A-C).

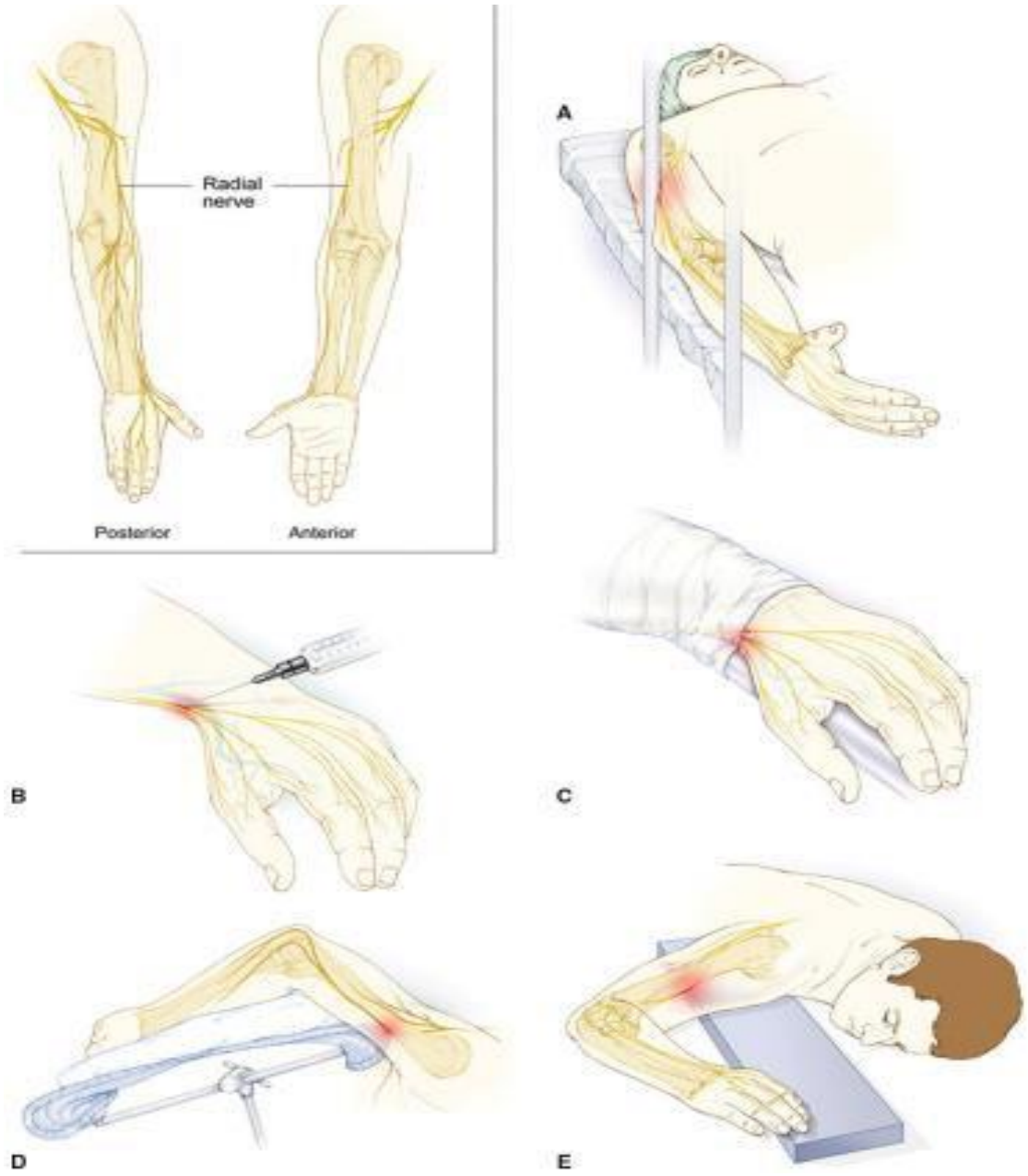


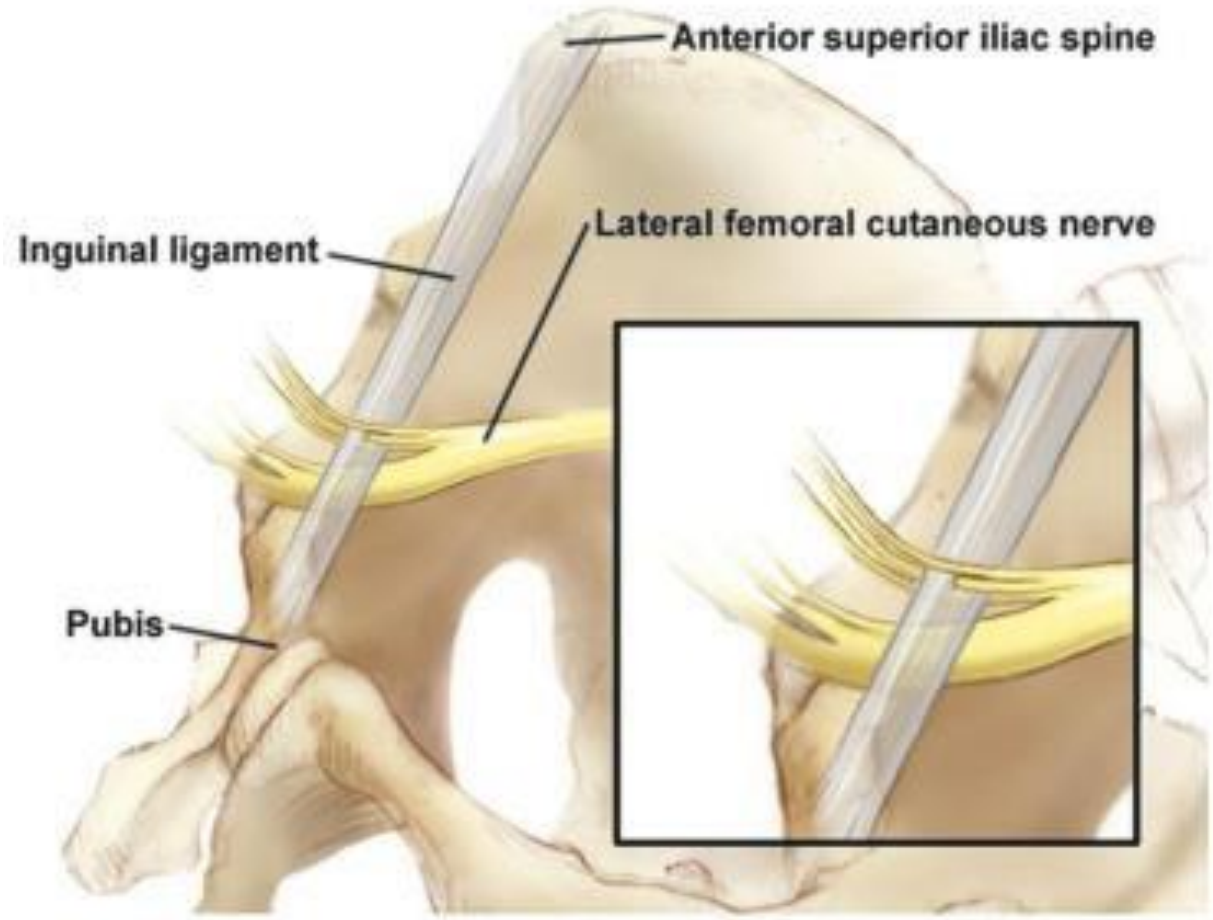
FIGURE 6.3. Potential radial nerve injuries: The anatomy of the radial nerve is shown in the **upper left** corner, illustrating how it wraps around the midhumerus. Reported mechanisms of perioperative injury include **(A)** compression by surgical retractor support bar, **(B)** direct needle trauma at the wrist, **(C)** compressive tourniquet effect by a draw sheet at the wrist, **(D)** impingement by an overhead arm board, and **(E)** compression in the midhumerus level as the arm supports much of the weight of the upper extremity.

- Surgical retractors: A case series reported several radial neuropathies associated with compression of the radial nerve by the vertical bars of upper abdominal retractor holders. The arms reportedly were impinged by these vertical support bars

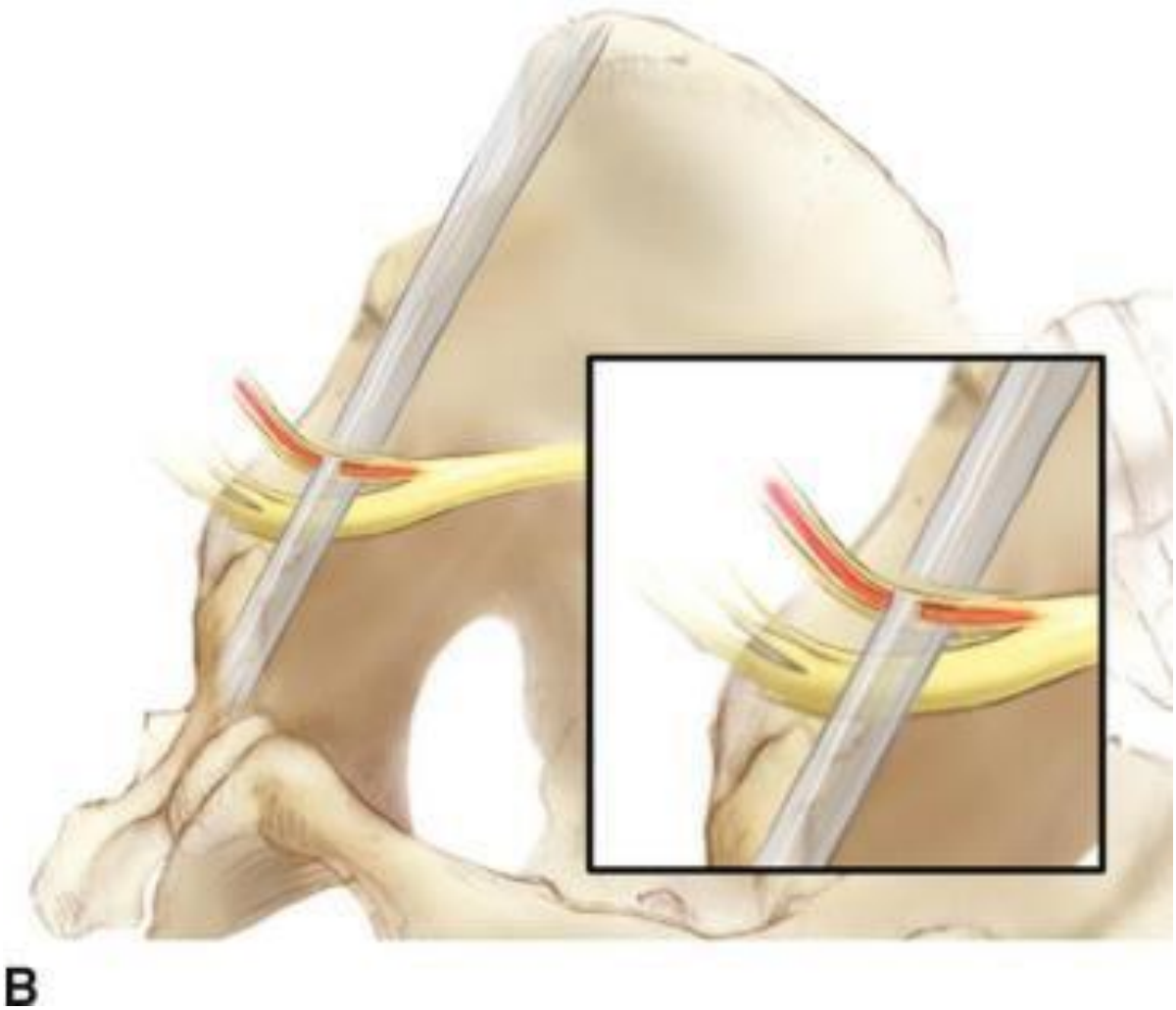
- Lateral positions: The radial nerve may be impinged by the upper arm board or sling when they protrude into the soft tissue of the mid upper arm.
- An unsupported arm: Anecdotal reports discuss compression on the nerve when the elbow of a fixated arm (at side or on an arm board) slips and loses support and the weight of the upper extremity is supported at the mid-upper arm.

6.11 LOWER EXTREMITY NEUROPATHIES

Although common peroneal and sciatic neuropathies have the most impact on walking, the most common perioperative neuropathies in the lower extremities involve the obturator and lateral femoral cutaneous nerves (see Fig. 6.4, which shows the arrangement of these nerves in the pelvis).



A



B

FIGURE 6.4. Anatomy of the lateral femoral cutaneous nerve. **A:** Approximately one third of the lateral femoral cutaneous nerve fibers penetrate the inguinal ligament as the nerve passes out of the pelvis and distally into the lateral thigh. **B:** Hip flexion, especially when greater than 90 degrees, leads to stretch of the inguinal ligament as the ilium is displaced laterally. This stretch causes the intra ligament pressure to increase and compresses the nerve fibers as they pass through the ligament.

6.12 PRACTICAL CONSIDERATIONS FOR PERIOPERATIVE PERIPHERAL NEUROPATHIES

A variety of different types of padding (e.g., foam) have been used to distribute compressive forces. Although there are few studies that demonstrate that padding impacts the frequency or severity of perioperative neuropathies, it makes sense to distribute point pressure. The use of padding has been found by juries to be important in medicolegal

actions. It is also prudent to position joints to avoid excessive stretching, recognizing that stretch of any nerve greater than 5% of its resting length over a prolonged period results in varying degrees of poor blood flow and dysfunction.

6.12.1 ASSESSMENT OF NEUROPATHY For patients who develop a peripheral neuropathy, it is important to first determine if the injury has primarily affected sensory or motor function. If the loss is sensory only, it is reasonable to monitor the patient daily for up to 5 days. Many sensory deficits in the immediate postoperative period will resolve during this time. If the deficit persists for more than 5 days, it is likely that the neuropathy will have an extended impact. If the loss is motor only or combined sensory and motor, it is more likely that these patients have a significant neuropathy and will need prolonged postoperative care.

6.12.2 SEQUELAE OF POOR POSITIONING

Poor positioning may result in excess pressure on skin and other soft tissues and cause severe tissue breakdown. For example, tissues in direct contact with rolls that extend from the shoulder girdle across the chest and to the pelvis may become ischemic with prolonged pressure (Fig. 6.5). There are multiple cases of women with large breasts who developed severe injury of one or both breasts when they were pushed in between chest rolls. The lateral pressure was sufficient to cause crushing, tissue death, and, in most, require mastectomy. Furthermore, in extreme situations, large amounts of tissue necrosis may occur due to pressure on skin and muscle (i.e., obese patients in the prone position during spine surgery) during prolonged surgery and result in release of muscle enzymes into the blood in high enough concentrations to cause permanent kidney damage.

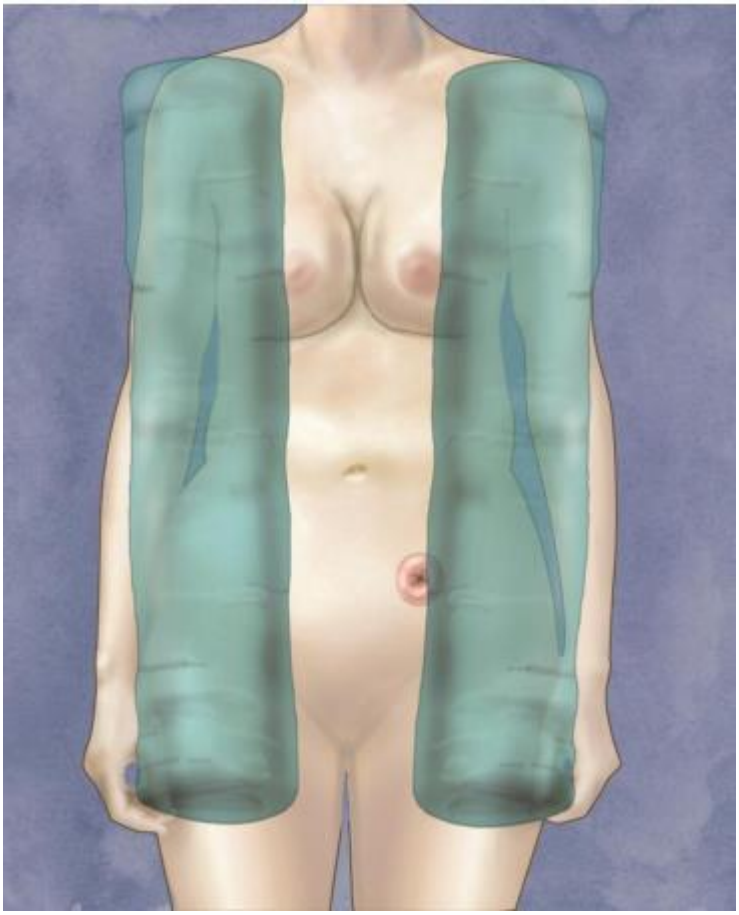


FIGURE 6.5. Chest rolls for prone positioning: soft tissues can be compressed and even become ischemic if there is too much pressure on them for long periods of time. This figure illustrates how chest rolls may compress the lateral aspects of large breasts or a stoma in prone-positioned patients

Skin is vulnerable to injury whenever skin is fragile and wherever a non-compressible object encounters the skin. Elderly patients, burn patients and patients with other severe skin diseases, patients with chronic edema, and neonates have particularly fragile skin, and the slightest injury can remove skin, exposing the patient to infection and creating permanent scarring. In these patients, adhesives must be used with caution and removed with even greater caution; an EKG lead carelessly pulled off can remove all the underlying skin. Any item remaining under any patient, or within a tight tucking position, can cause compression even on normal skin and lead to scarring. This is of particular concern in prone positioning and arm tucking, and the anesthesia technician should be particularly alert to removal of items that have been used for placement of IVs and monitoring, location of EKG cables (none of which should be compressed directly against the patient's skin), and padding of any items that may need to be wrapped within compressive tucking of arms such as IV or arterial lines. A small plastic cap inadvertently left under the arm for several hours can cause skin breakdown or scarring. When tucking arms, monitoring cables and IV lines should run outside tucking blankets, both to protect skin and for accessibility.

6.13 ANESTHESIA TECHNICIANS AND PATIENT POSITIONING

The anesthesia technician is not directly responsible for positioning safety but will frequently assist the anesthesia provider. The above discussion should illustrate the multiple details involved in positioning and the specific concerns and potential hazards. Every member of the operating room team assists with positioning, and every member of the team should speak up if they see a positioning hazard. Examples where the anesthesia technician might be directly involved with patient positioning include applying a blood pressure cuff and then positioning the arm on the arm board, extending the wrist and applying a wrist guard with tape for insertion of an arterial line, turning an anesthetized patient's head to the side in preparation for central venous access, taping of the patient's eyes prior to intubation, or transporting a patient. In addition, while assisting with the care of a patient, the anesthesia technician may recognize that the patient is positioned in such a way as to make an injury more likely. For example, while drawing a blood gas, the anesthesia technician may notice that the arm has fallen off the arm board, an IV line is infiltrated, or the shoulder is hyperextended because the arm board has been moved. An alert anesthesia technician would notify the anesthesia provider of the potential problem. In the out-of-operating room setting, additional positioning aids may need to be brought from the operating room (and returned at the end of the case). The anesthesia technician may have the most experience with the anesthetized patient in the out of OR setting and may need to provide more assistance. Every member of the team present, including the anesthesia technician, should observe the patient and equipment during motion of tables or large imaging devices and always speak up if a hazard approaches.

Section II

ANESTHESIA EQUIPMENT AND DEVICES

Chapter 7

Gas supply…cylinders and pipeline system

IMPORTANT TERMS

HYPOXIC MIXTURE: Mixture with a lower oxygen fraction than air.

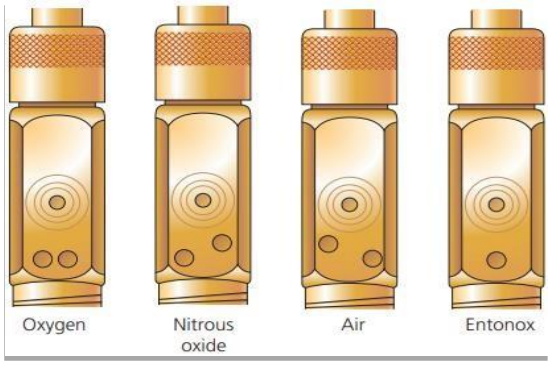
SAFETY INSTRUCTIONS: A Set of written instructions to ensure safety.

Medical gas supply takes the form of either **cylinders** or a **piped gas system**, depending on the requirements of the hospital.

7.1 CYLINDERS

- Cylinders are **made of** thin-walled seamless molybdenum steel in which gases and vapors are stored under pressure. They are designed to withstand considerable internal pressure.
- The **top end** of the cylinder is called the **neck**, and this ends in a tapered screw thread into which the valve is fitted. The thread is sealed with a material that melts if the cylinder is exposed to intense heat. This allows the gas to escape so reducing the risk of an explosion.
- There is a plastic disc around the neck of the cylinder. The year when the cylinder was last examined can be identified from the shape and color of the disc.
- **Lightweight cylinders** can be made from aluminium alloy with a fiberglass covering in epoxy resin matrix. These can be used to provide oxygen at home, during transport or in magnetic resonance scanners. They have a flat base to help in storage and handling.
- The gases and vapors should be free of water vapor when stored in cylinders. Water vapor freezes and blocks the exit port when the temperature of the cylinder decreases on opening.
- The outlet valve uses the **pin-index system** to make it almost impossible to connect a cylinder to the wrong yoke (Figure 7-0).

(A)



(B)

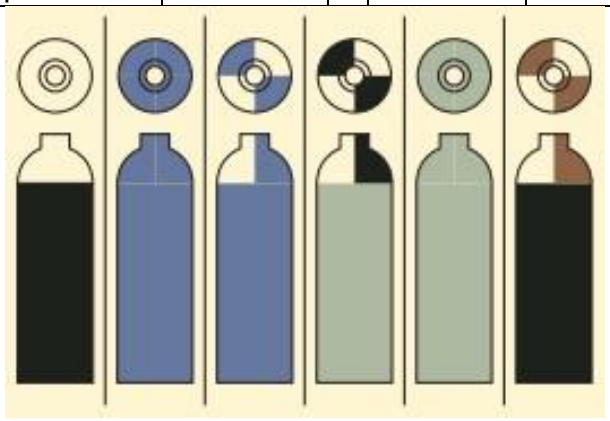
FIGURE 7-0 (A) Pin-index system. Note the different configuration for each gas. **(B)** Anesthetic machine cylinder yokes.

- Cylinders are **color-coded** to reduce accidental use of the wrong gas or vapor. In the UK, the color-coding is a two-part color, shoulder and body (Table 1.1). To improve safety, there are plans to change the colors of the bodies of cylinders using medical gas to white while keeping the colors of the shoulders according to the European Standard EN 1089-3.

TABLE 7-1 Color-coding of medical gas cylinders (old and new system), their pressure when full, their physical state in cylinder and pin index of cylinder for each medical gas

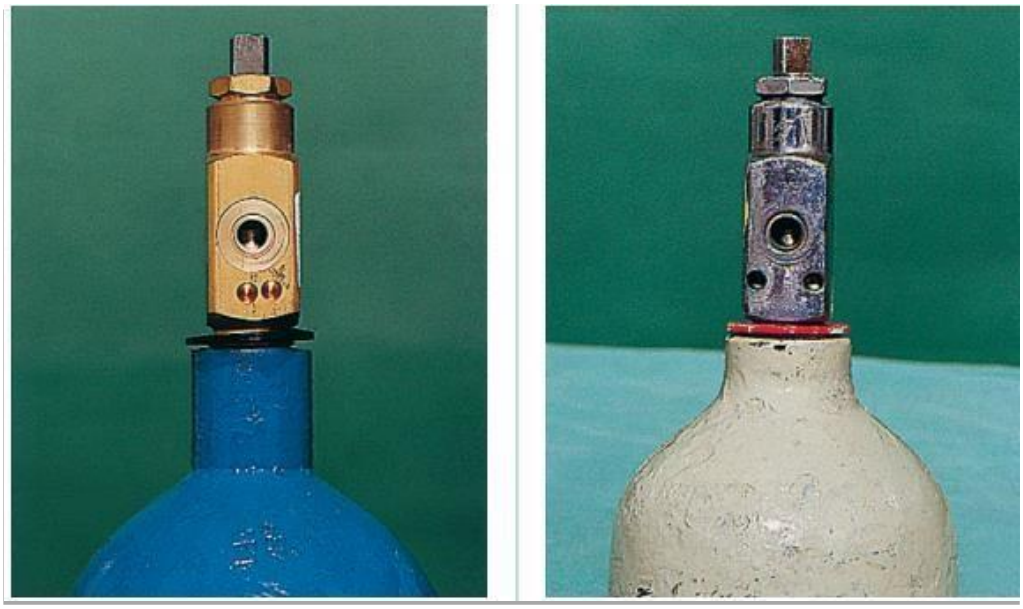
Medical gas	**Shoulder color**	**Body color (current/old system)**	**Body color (new system)**	**Pressure at room temperature (kPa)**	**Physical state in cylinder**	**Pin index**
Oxygen	White	Black (Green in USA)	White	13700	Gas	2, 5
Nitrous oxide	Blue	Blue	White	4400	Liquid/ Vapor	3, 5
Carbon dioxide	Grey	Grey	White	5000	Liquid/ Vapor	1, 6

Air	White/ Black quarters	Grey (Yellow USA)	in	White	13700	Gas	1, 5
Entonox (50% N_2O/50%O_2)	White/Blue quarters	Blue		White	13700	Gas	0 or 7
Heliox (79% He/21% O_2)	White/ Brown quarters	Black		White	13700	Gas	



7.1.1 Sizes of Cylinders

- Cylinders are manufactured in different sizes (**A to J**).
- Sizes A and H are not used for medical gases.
  - **Cylinders attached to the anesthetic machine are usually size E** (Figs 1.1–1.4).
- **Size J** cylinders are commonly used for cylinder manifolds.
- **Size E** oxygen cylinders contain 680 L, whereas size E nitrous oxide cylinders can release 1800 L.
- The smallest sized cylinder, **size C**, can hold 1.2 L of water, and size E can hold 4.7 L while the larger size J can hold 47.2 L of water.



7.1.2 Checking and testing of a cylinder

Cylinders in use are checked and tested by manufacturers at **regular intervals**, usually **5 years**. Test details are recorded on the plastic disc between the valve and the neck of the cylinder. They are also engraved on the cylinder:

- Internal endoscopic examination.
- Flattening, bend and impact tests are carried out on at least one cylinder in every 100.
- Pressure test: the cylinder is subjected to high pressures of about 22000 kPa, which is more than 50% above their normal working pressure.
- Tensile test where strips of the cylinder are cut and stretched. This test is carried out on at least one cylinder in every 100.

The marks engraved on the cylinders are:

- Test pressure.
- Dates of test performed.
- Chemical formula of the cylinder's content.
- Tare weight (weight of nitrous oxide cylinder when empty).

7.1.3 Labelling

The cylinder label includes the following details:

- Name, chemical symbol, pharmaceutical form, specification of the product, its license number and the proportion of the constituent gases in a gas mixture.
- Substance identification number and batch number.
- Hazard warnings and safety instructions.
- Cylinder size code.
- Nominal cylinder contents (litres).
- Maximum cylinder pressure (bars).
- Filling date, shelf life and expiry date.
- Directions for use.
- Storage and handling precautions.

7.1.4 Cylinder Valves

- They are mounted on the neck of the cylinder (Figure 7-1).

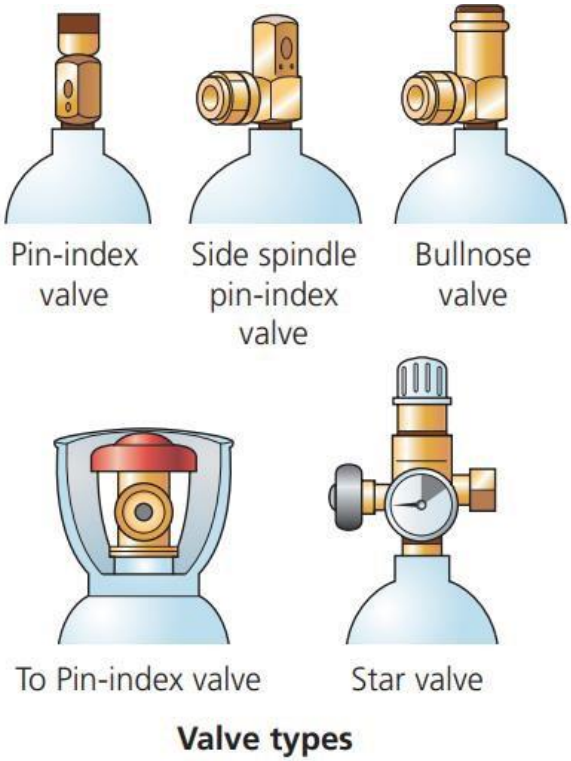


FIGURE 7-1 Cylinder valves

- Act as an on/off device for the discharge of cylinder contents.
- Pin-index system prevents cylinder identification errors.
- **Bodok sealing** washer must be placed between the valve and the yoke of the anesthetic machine (Figure 7-2).

(A)

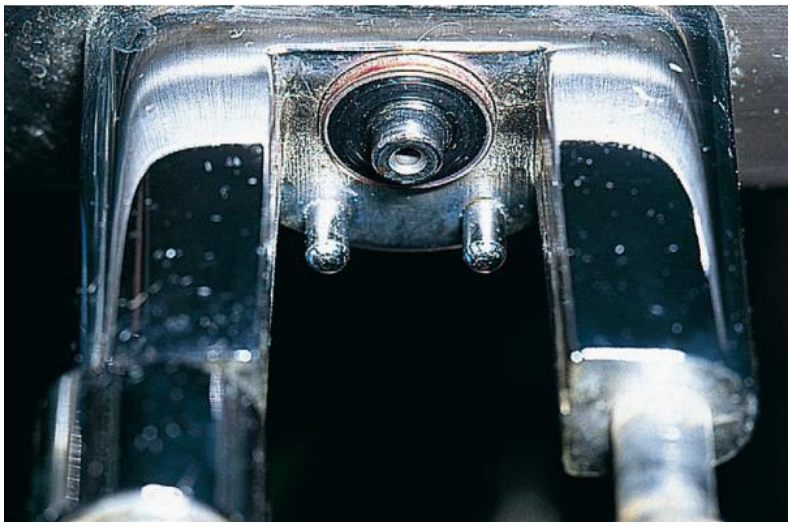


FIGURE 7-2 (A) A Bodok Seal. **(B)** A Cylinder yoke and Pin-index system. Note that a Bodok seal is in position.

- A newly designed valve allows keyless manual turning on and off (Figure 7-3).

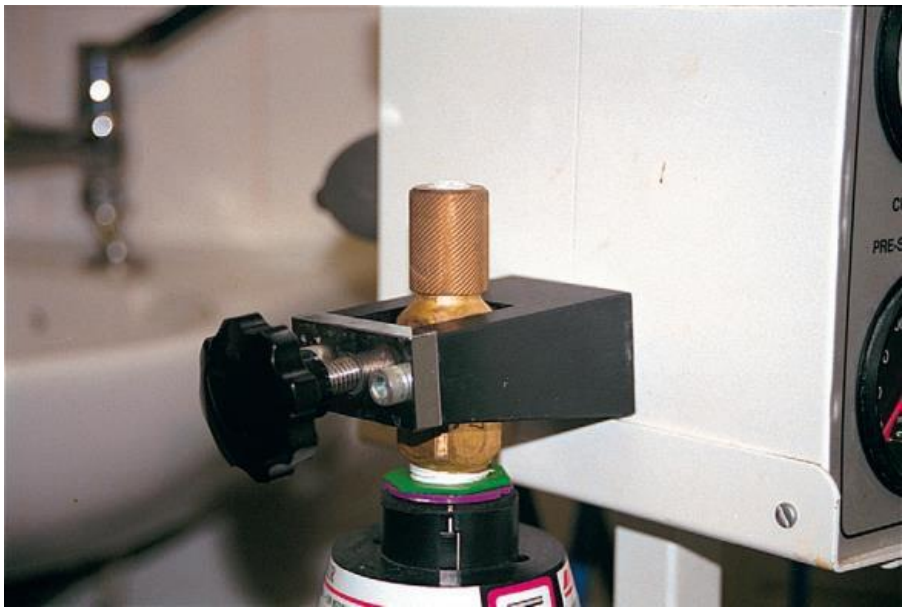


FIGURE 7-3 New cylinder valve which allows manual opening and closing.

7.1.5 Storage of Cylinders

- To avoid accidents, full cylinders should be stored separately from empty ones.
- F, G and J size cylinders are stored upright to avoid damage to the valves.
- C, D and E size cylinders can be stored horizontally on shelves made of a material that does not damage the surface of the cylinders.
- Over-pressurized cylinders are hazardous and should be reported to the manufacturer.

7.2 PIPELINE SYSTEM

PMGV (**piped medical gas** and **vacuum**) is a system where gases are delivered from central supply points to different sites in the hospital at a pressure of about **400 kPa** or 4 bars or 50 psig. Special outlet valves supply the various needs throughout the hospital.

Oxygen, nitrous oxide, Entonox, compressed air and medical vacuum are commonly supplied through the pipeline system.

7.2.1 Components

- Central supply points such as cylinder banks or liquid oxygen storage tank.
- Pipework made of special high-quality **copper alloy**, which both prevents degradation of the gases it contains and has bacteriostatic properties.
- The size of the pipes differs according to the demand that they carry. Pipes with a **42 mm diameter** are usually used for leaving the manifold. Smaller diameter tubes, such as 15 mm, are used after repeated branching.
- Outlets are identified by **gas color coding**, gas name and by shape (Figure 7-4). They accept matching quick connect/ disconnect probes, Schrader sockets (Figure 7-5), with an indexing collar specific for each gas (or gas mixture).

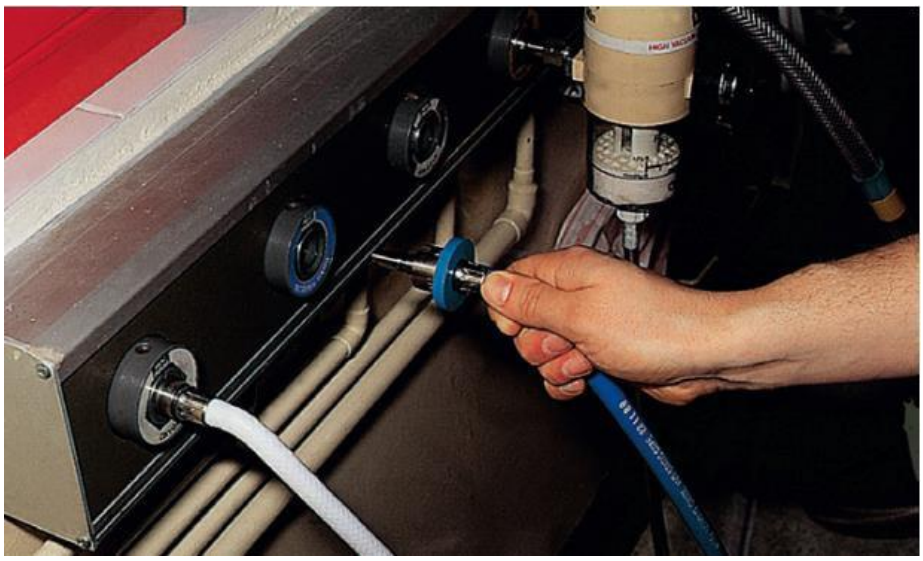


FIGURE 7-4 Inserting a remote probe into its matching wall-mounted outlet socket.

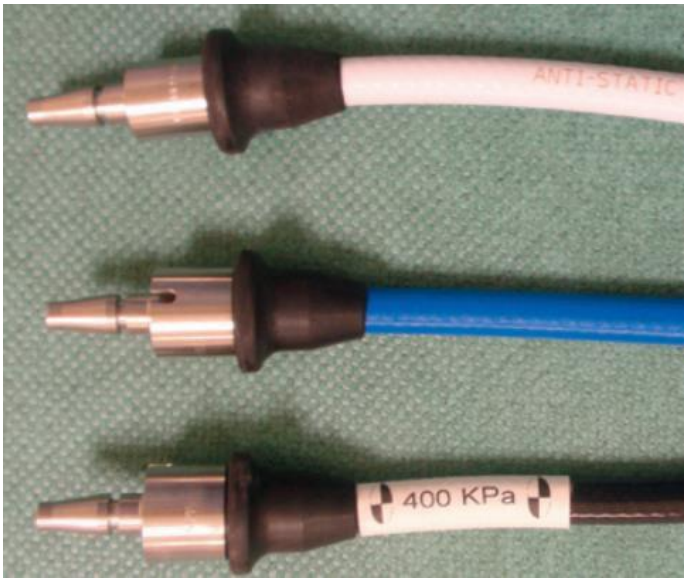


FIGURE 7-5 Gas probes for oxygen (top), nitrous oxide (middle) and air (bottom). Note the locking groove on the probe to ensure connectivity.

- **Outlets** can be installed as flush-fitting units, surface-fitting units, on booms or pendants, or suspended on a hose and gang mounted (Figure 7.6).

FIGURE 7-6 Outlet sockets mounted in a retractable ceiling unit.

- Flexible color-coded hoses connect the outlets to the anesthetic machine (Figure 7.7). The anesthetic machine end should be permanently fixed using a nut and liner union where the thread is gas specific and **non-interchangeable** (noninterchangeable screw thread, NIST, is the British Standard).

FIGURE 7-7 Color-coded hoses with NIST fittings attached to an anesthetic machine.

- **Isolating valves** behind break glass covers are positioned at strategic points throughout the pipeline network. They are also known as area valve service units (AVSUs) (Figure 7-8). They can be accessed to isolate the supply to an area in cases of fire or another emergency.

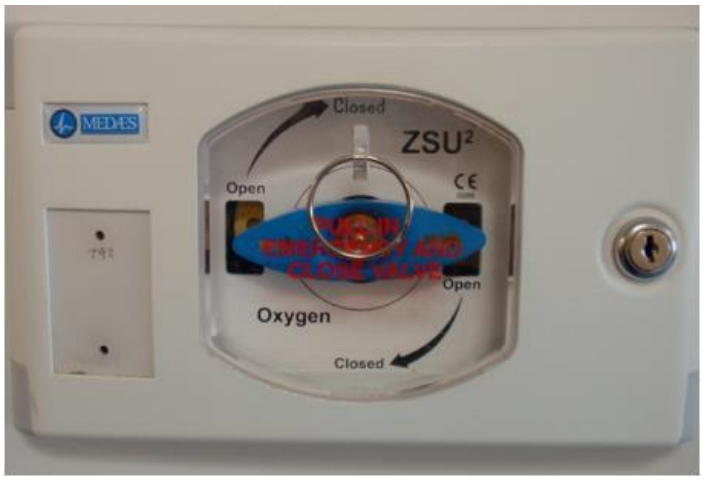


FIGURE 7-8 An area valve service unit (AVSU).

7.2.2 Problems in practice and safety features

- A reserve bank of cylinders is available should the primary supply fail. Low pressure alarms detect gas supply failure (Figure 7-9).

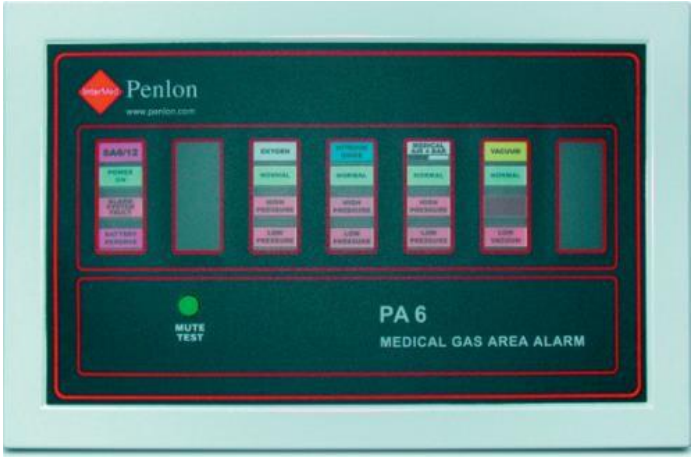


FIGURE 7-9 Medical gas alarm panel.

- **Single hose test** is performed to detect cross-connection.
- **Tug test** is performed to detect misconnection.
- Regulations for PMGV installation, repair and modification are enforced.
- Anesthetists are responsible for the gases supplied from the terminal outlet through to the anesthetic machine. Pharmacy, supplies and engineering departments share the responsibility for the gas pipelines ‘behind the wall’.
- There is a risk of fire from worn or damaged hoses that are designed to carry gases under pressure from a primary source such as a cylinder or wall-mounted terminal to medical devices such as ventilators and anesthetic machines. Because of heavy wear and tear, the risk of rupture is greatest in oxygen hoses used with transport devices. **Regular inspection and replacement, every 2–5 years, of all medical gas hoses is recommended.**

Chapter 8 The Anesthesia Machine

8.1 INTRODUCTION

The anesthetic machine receives medical gases (oxygen, nitrous oxide, air) under pressure and accurately controls the flow of each gas individually. A gas mixture of the desired composition at a defined flow rate is created before a known concentration of an inhalational agent vapour is added. Gas and vapour mixtures are continuously delivered to the common gas outlet of the machine, as fresh gas flow (FGF), and to the breathing system and patient (Figs 8.1 and 8.2). It consists of:

Fig. 8.1 The Datex-Ohmeda Aestiva S/5 anesthetic machine.

1. gas supplies
2. pressure gauges
3. pressure regulators (reducing valves)
4. flowmeters

5. vaporizers
6. common gas outlet
7. a variety of other features, e.g. high-flow oxygen flush, pressure relief valve and oxygen supply failure alarm and suction apparatus
8. most modern anesthetic machines or stations incorporate a circle breathing system (see Chapter 4) and a bag-in-bottle type ventilator (see Chapter 8). Safety features of a modern Anesthetic machine to ensure the delivery of a safe gas mixture should include the following:

- Colour-coded pressure gauges.
- Colour-coded flowmeters.
- An oxygen flowmeter controlled by a single touch-coded knob.
- Oxygen is the last gas to be added to the mixture.
- Oxygen concentration monitor or analyzer.
- Nitrous oxide is cut off when the oxygen pressure is low.
- Oxygen: nitrous oxide ratio monitors and controller.
- Pin index safety system for cylinders and non-interchangeable screw thread (NIST) for pipelines.
- Alarm for failure of oxygen supply.
- Ventilator disconnection alarm.
- At least one reserve oxygen cylinder should be available on machines that use pipeline supply.

8.2 Pressure gauge

This measures the pressure in the cylinder or pipeline. The pressure gauges for oxygen, nitrous oxide and medical air are mounted in a front-facing panel on the Anesthetic machine (Fig. 8.3). Some modern Anesthetic machine designs have a digital display of the gas supply pressures (Fig. 8.4)

8.2.1 Components

1. A robust, flexible and coiled tube which is oval in cross-section (Fig. 8.5). It should be able to withstand the sudden high pressure when the cylinder is switched on
2. The tube is sealed at its inner end and connected to a needle pointer which moves over a dial.
3. The other end of the tube is exposed to the gas supply. **Mechanism of action**

    1. The high-pressure gas causes the tube to uncoil (Bourdon gauge).

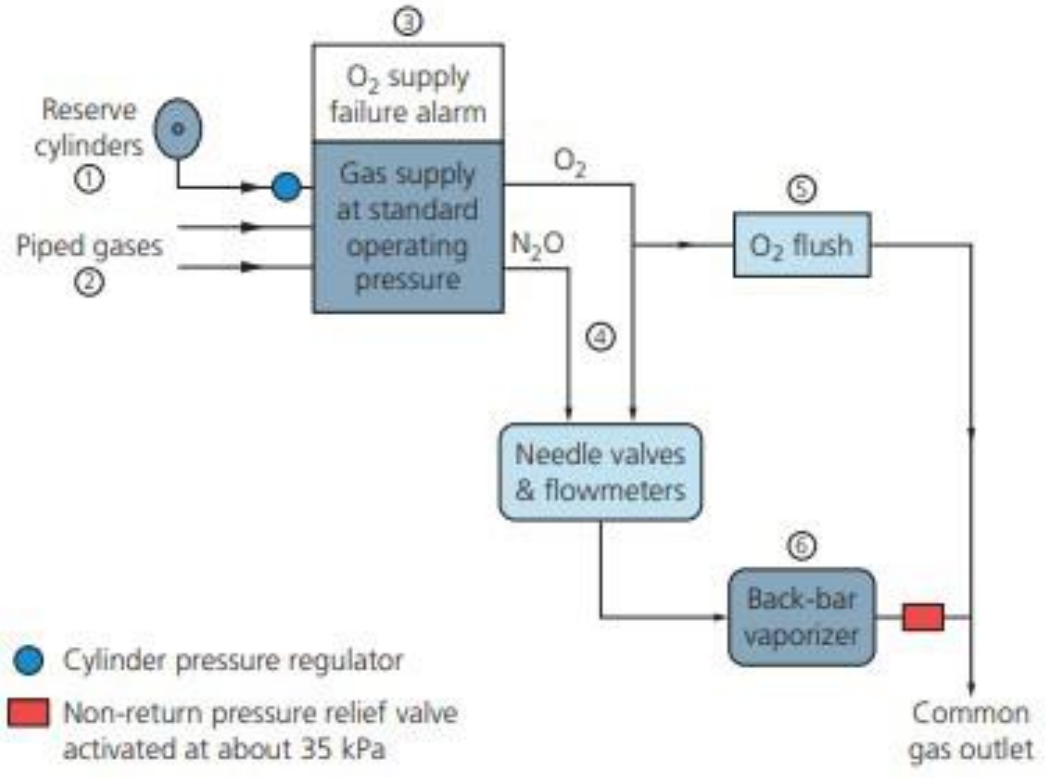


Fig. 8.2 Diagrammatic representation of a continuous flow Anesthetic machine. Pressures throughout the system: 1. O2: 13700 kPa, N2O: 4400 kPa; 2. pipeline: about 400 kPa; 3. O2 supply failure alarm activated at

2. The movement of the tube causes the needle pointer to move on the calibrated dial indicating the pressure.

8.2.2 Problems in practice and safety features

1. Each pressure gauge is colour-coded and calibrated for a particular gas or vapour. The pressure measured indicates the contents available in an oxygen cylinder. Oxygen is stored as a gas and obeys Boyle's gas law (pressure × volume = constant). This is not the case in a nitrous oxide cylinder since it is stored as a liquid and vapour.

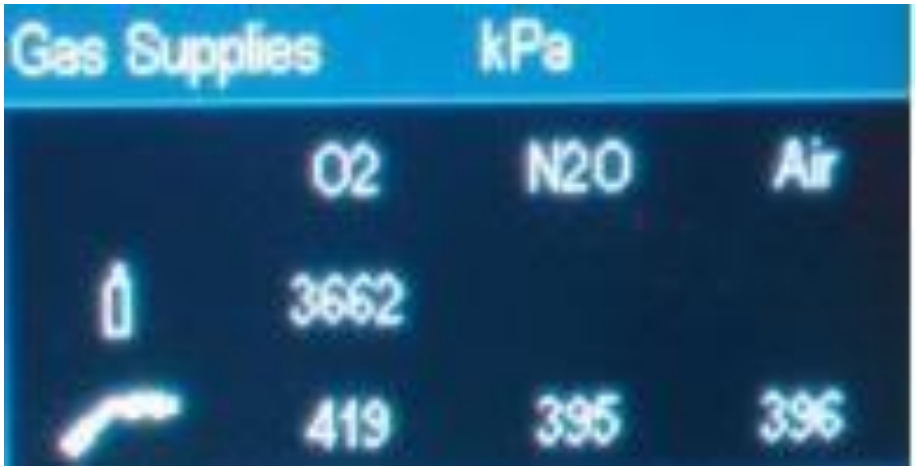


Fig. 8.4 Digital display of pressure gauges for oxygen (cylinder and pipeline), nitrous oxide (pipeline) and air (pipeline).

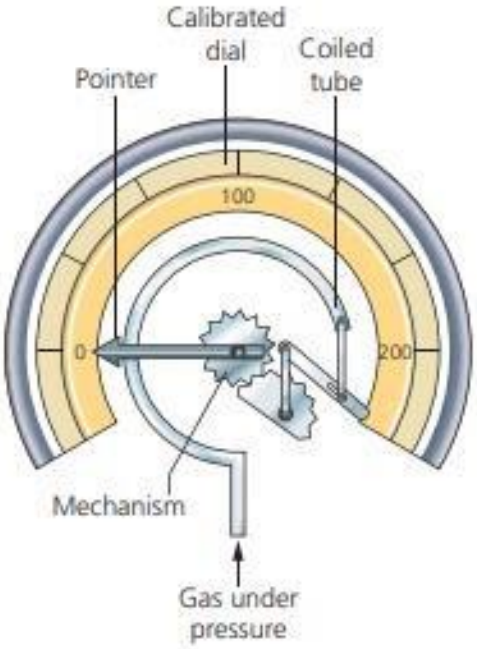


Fig. 8.5 The Bourdon pressure gauge.

Fig. 8.3 Pipeline pressure gauges for oxygen, nitrous oxide and air.

2. A pressure gauge designed for pipelines should not be used to measure cylinder pressure and vice versa. This leads to inaccuracies and/or damage to the pressure gauge.
3. Should the coiled tube rupture, the gas vents from the back of the pressure gauge casing. The face of the pressure gauge is made of heavy glass as an additional safety feature.

8.2.3 Pressure gauge

- Measures pressure in cylinder or pipeline.
- Pressure acts to straighten a coiled tube.
- Colour-coded and calibrated for a particular gas or vapour

8.3 Pressure regulator (reducing valve)

Pressure regulators are used because:

- Gas and vapour are stored under high pressure in cylinders. A regulator reduces the variable cylinder pressure to a constant safer operating pressure of about 400 kPa (just below the pipeline pressure) (Fig. 8.6).
- The temperature and pressure of the cylinder contents decrease with use. In order to maintain flow, constant adjustment is required in the absence of regulators.
- Regulators protect the components of the Anesthetic machine against pressure surges

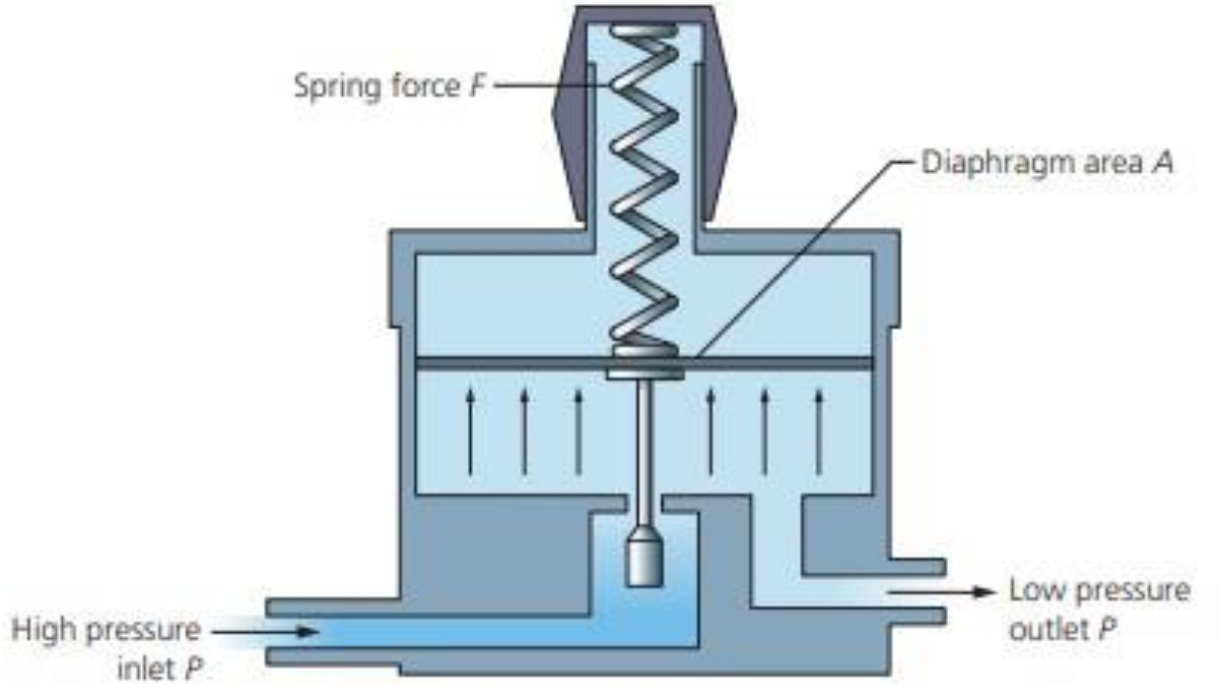


Fig. 8.6 The principles of a pressure regulator (reducing valve).

- The use of pressure regulators allows low-pressure piping and connectors to be used in the machine. This makes the consequences of any gas leak much less serious.
  They are positioned between the cylinders and the rest of the Anesthetic machine (Figs 8.7 and 8.8)

Fig. 8.7 Cylinder pressure regulators (black domes) positioned above the cylinder yokes in the Datex-Ohmeda Flexima Anesthetic machine

8.3.1 Components

1. An inlet, with a filter, leading to a high-pressure chamber with a valve.
2. This valve leads to a low-pressure chamber and outlet.
3. A diaphragm attached to a spring is situated in the low-pressure chamber.

Fig. 8.8 *Cylinder pressure regulator (the machine's tray has been removed)*

8.3.2 Mechanism of action

1. Gas enters the high-pressure chamber and passes into the low-pressure chamber via the valve.
2. The force exerted by the high-pressure gas tries to close the valve. The opposing force of the diaphragm and spring tries to open the valve. A balance is reached between the two opposing forces. This maintains a gas flow under a constant pressure of about 400 kPa.

8.3.3 Problems in practice and safety features

1. Formation of ice inside the regulator can occur. If the cylinder contains water vapour, this may condense and freeze as a result of the heat lost when gas expands on entry into the low-pressure chamber.
2. The diaphragm can rupture.
3. Relief valves (usually set at 700 kPa) are fitted downstream of the regulators and allow the escape of gas should the regulators fail.
4. A one-way valve is positioned within the cylinder supply line. This prevents backflow and loss of gas from the pipeline supplies should a cylinder not be connected. This one-way valve may be incorporated into the design of the pressure regulator.

8.3.4 Pressure regulator

- Reduces pressure of gases from cylinders to about 400 kPa (similar to pipeline pressure).
- Allows fine control of gas flow and protects the Anesthetic machine from high pressures.

- A balance between two opposing forces maintains a constant operating pressure.

8.4 Second-stage regulators and flow restrictors

The control of pipeline pressure surges can be achieved either by using a second-stage pressure regulator or a flow restrictor (Fig. 8.9) – a constriction, between the pipeline supply and the rest of the Anesthetic machine. A lower pressure (100–200 kPa) is achieved. If there are only flow restrictors and no regulators in the pipeline supply, adjustment of the flowmeter controls is usually necessary whenever there is change in pipeline pressure.

Flow restrictors may also be used downstream of vaporizers to prevent back pressure effect (see later).

8.4.1 One-way valve or backflow check valves

These valves are usually placed next to the inlet yoke. Their function is to prevent loss or leakage of gas from an empty yoke. They also prevent accidental transfilling between paired cylinders.

8.4.2 Flow control (needle) valves

These valves control the flow through the flowmeters by manual adjustment. They are positioned at the base of the associated flowmeter tube (Fig. 8.10). Increasing the flow of a gas is achieved by turning the valve in an anticlockwise direction.

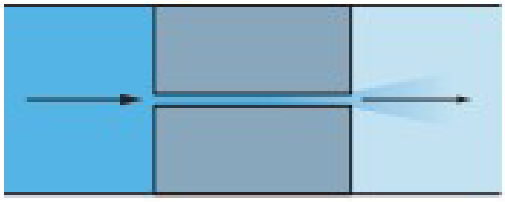


Fig. 8.9 A flow restrictor. The constriction causes a significant pressure drop when there is a high gas flow rate.

8.4.3 Components

1. The body, made of brass, screws into the base of the flowmeter.
2. The stem screws into the body and ends in a needle. It has screw threads allowing fine adjustment.
3. The flow control knobs are labelled and colour-coded.
4. A flow control knob guard is fitted in some designs to protect against accidental adjustment in the flowmeters.

8.5 Flowmeters

Flowmeters measure the flow rate of a gas passing through them. They are individually calibrated for each gas. Calibration occurs at room temperature and atmospheric pressure (sea level). They have an accuracy of about ±2.5%. For flows above 1 L/min, the units are L/min, and for flows below that, the units are 100 mL/min (Fig. 8.11).

8.5.1 Components

1. A flow control (needle) valve.
2. A tapered (wider at the top), transparent plastic or glass tube.
3. A lightweight rotating bobbin or ball. Bobbin-stops at either end of the tube ensure that it is always visible to the operator at extremes of flow.

8.5.2 Mechanism of action

1. When the needle valve is opened, gas is free to enter the tapered tube.

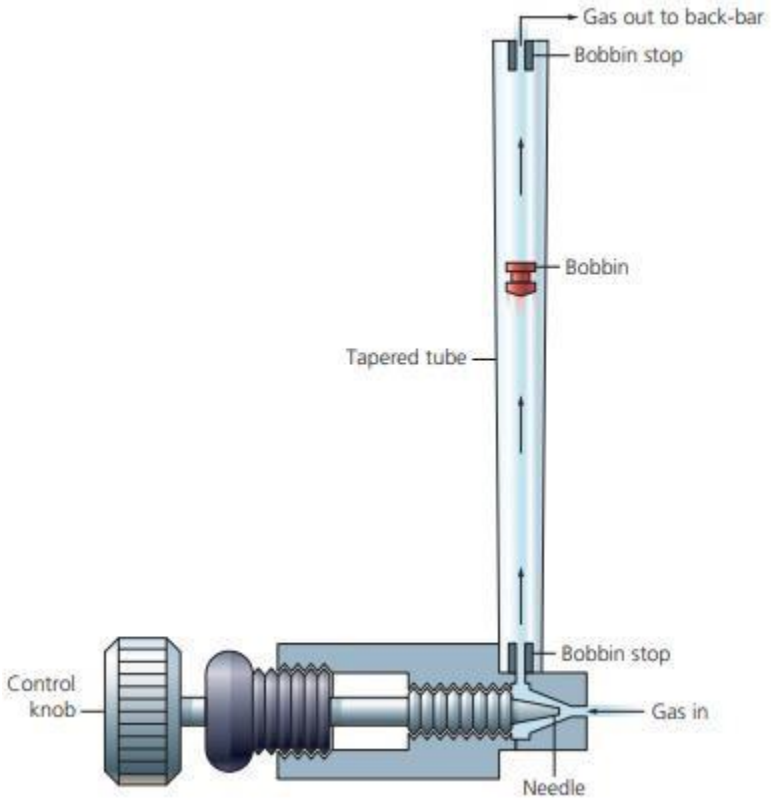


Fig. 8.10 A flow control (needle) valve and flowmeter.

2. The bobbin is held floating within the tube by the gas flow passing around it. The higher the flow rate, the higher the bobbin rises within the tube.
3. The effect of gravity on the bobbin is counteracted by the gas flow. A constant pressure difference across the bobbin exists as it floats.
4. The clearance between the bobbin and the tube wall widens as the gas flow increases (Fig. 8.12).
5. At low flow rates, the clearance is longer and narrower, thus acting as a tube. Under these circumstances, the flow is laminar and a function of gas viscosity (Poiseuille's law).
6. At high flow rates, the clearance is shorter and wider, thus acting as an orifice. Here, the flow is turbulent and a function of gas density.
7. The top of the bobbin has slits (flutes) cut into its side. As gas flows past it, the slits cause the bobbin to rotate. A dot on the bobbin indicates to the operator that the bobbin is rotating and not stuck.

8. The reading of the flowmeter is taken from the top of the bobbin (Fig. 8.13).
   When a ball is used, the reading is generally taken from the midpoint of the ball.
9. When very low flows are required, e.g. in the circle breathing system, an arrangement of two flowmeters in series is used. One flowmeter reads a maximum of 1 L/min allowing fine adjustment of the flow. One flow control per gas is needed for both flowmeters (Fig. 8.14)

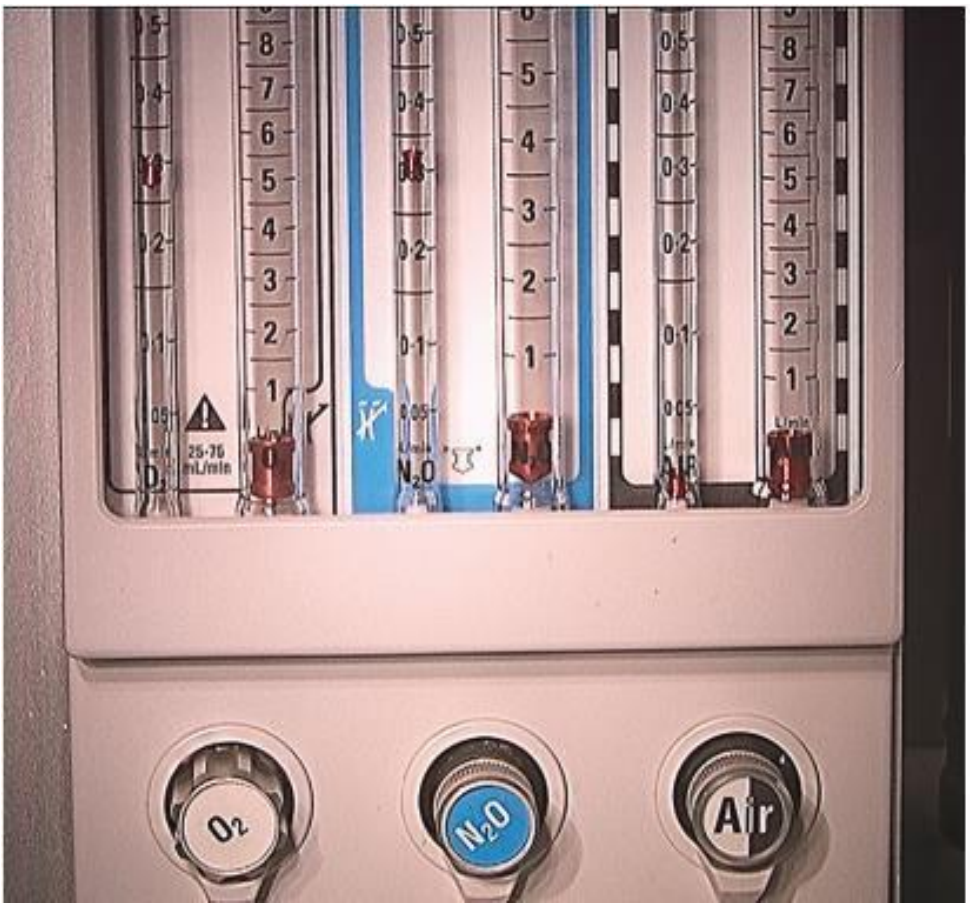


Fig. 8.11 *A flowmeter panel*

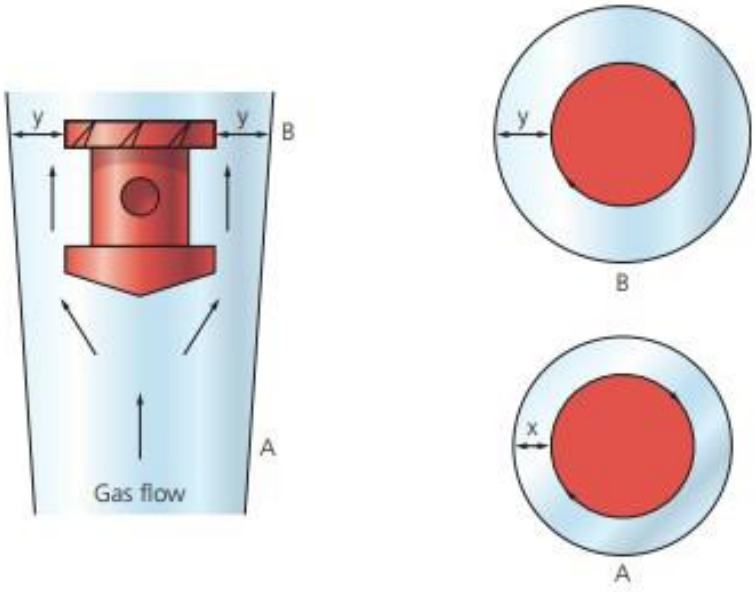


Fig. 8.12 *Mechanism of action of the flowmeter. As the bobbin rises from A to B, the clearance increases (from x to y).*

10. There is a stop on the oxygen flow control valve to ensure a minimum oxygen flow of 200–300 mL/min past the needle valve. This ensures that the oxygen flow cannot be discontinued completely.

8.5.3 Problems in practice and safety features

1. The flow control knobs are colour-coded for their respective gases. The oxygen control knob is situated to the left (in the UK) and, in some designs, is larger with larger ridges and has a longer stem than the other control knobs, making it easily recognizable (Fig. 8.15). In the USA and Canada, the oxygen control knob is situated to the right.
2. The European Standard for Anesthetic machines (EN 740) requires them to have the means to prevent the delivery of a gas mixture with an oxygen concentration below 25%. Current designs make it impossible for nitrous oxide to be delivered without the addition of a fixed percentage of oxygen. This is achieved by using interactive oxygen and nitrous oxide controls. This helps to prevent the possibility of delivering a hypoxic mixture to the patient. In the mechanical system, two gears are connected together by a precision stainless steel link chain. One gear with 14 teeth is fixed on the nitrous oxide flow control valve spindle. The other gear has 29 teeth and can rotate the oxygen flow control valve spindle, rather like a nut rotating on a bolt. For every 2.07 revolutions of the nitrous oxide flow control knob, the oxygen knob and spindle set to the lowest oxygen flow will rotate once. Because the gear on the oxygen flow control is mounted like a nut on a bolt, oxygen flow can be adjusted independently of nitrous oxide flow.
3. A crack in a flowmeter may result in a hypoxic mixture (Fig. 8.16). To avoid this, oxygen is the last gas to be added to the mixture delivered to the back bar.

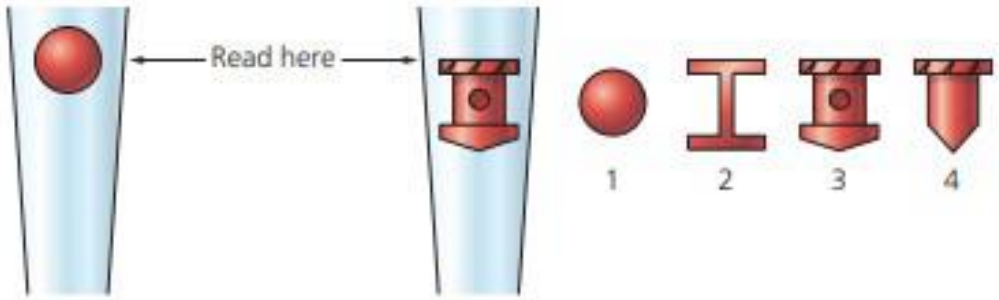


Fig. 8.13 Reading a flowmeter (top). Different types of bobbin: 1. ball; 2. non-rotating H float; 3. skirted; 4. non-skirted

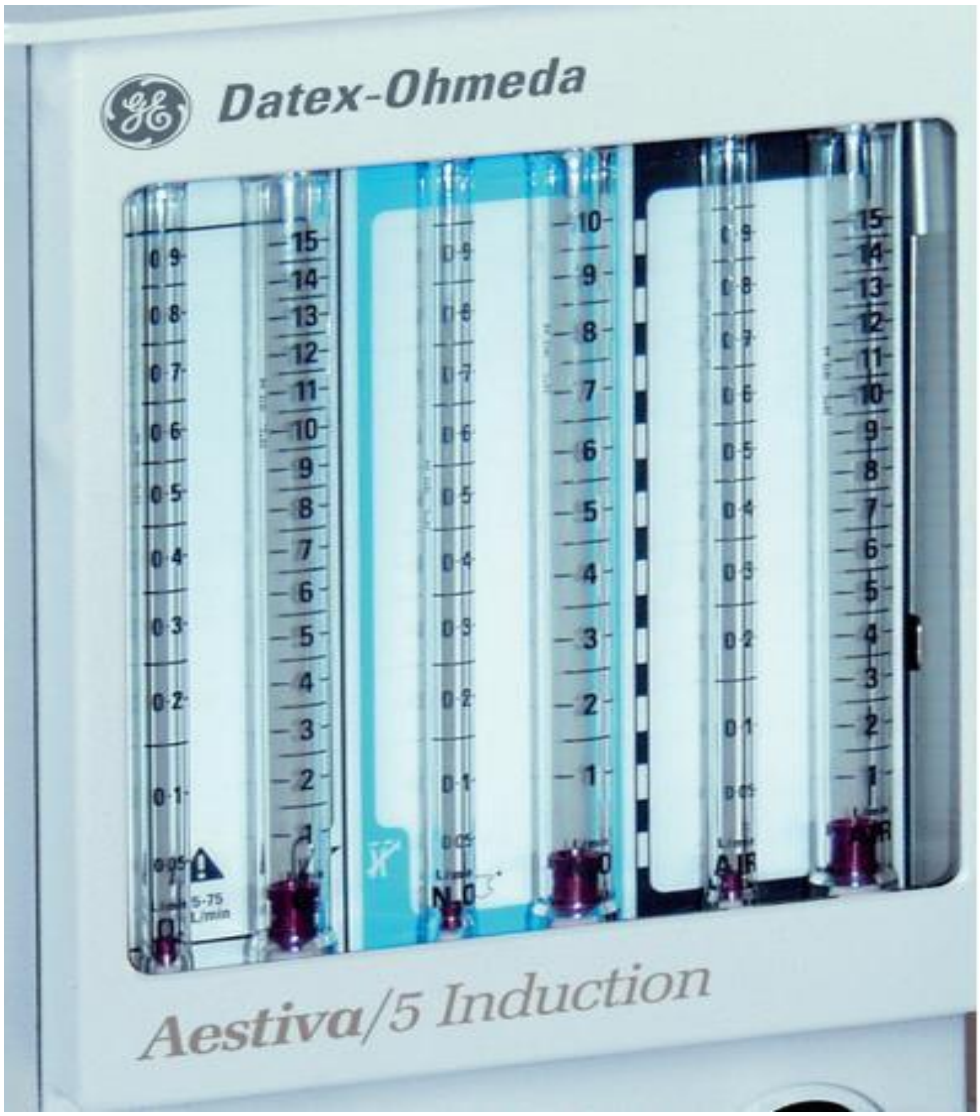


Fig. 8.14 *Two flowmeters in series.*

4. Flow measurements can become inaccurate if the bobbin sticks to the inside wall of the flowmeter. The commonest causes are:

a. dirt: this is a problem at low flow rates when the clearance is narrow. The source of the dirt is usually a contaminated gas supply. Filters, acting before gas enters the flowmeters, will remove the dirt
b. static electricity: the charge usually builds up over a period of time, leading to inaccuracies of up to 35%. Using antistatic materials in flowmeter construction helps to eliminate any build-up of charge. Application of antistatic spray removes any charge present.
5. Flowmeters are designed to be read in a vertical position, so any change in the position of the machine can affect the accuracy.
6. Pressure rises at the common gas outlet are transmitted back to the gas above the bobbin. This results in a drop in the level of the bobbin with an inaccurate reading. This can happen with minute volume divider ventilators as back pressure is exerted as they cycle with inaccuracies of up to 10%. A flow restrictor is fitted downstream of the flowmeters to prevent this occurring.
7. Accidents have resulted from failure to see the bobbin clearly at the extreme ends of the tube. This can be prevented by illuminating the flowmeter bank and installing a wire stop at the top to prevent the bobbin reaching the top of the tube.
8. If facilities for the use of carbon dioxide are fitted to the machine, the flowmeter is designed to allow a maximum of 500 mL/min to be added to the FGF. This ensures that dangerous levels of hypercarbia are avoided.
9. Highly accurate computer controlled gas mixers are available.

Fig. 8.15 *Flow control knobs. Note the colour-coding and the distinctive-shape oxygen control knob.*

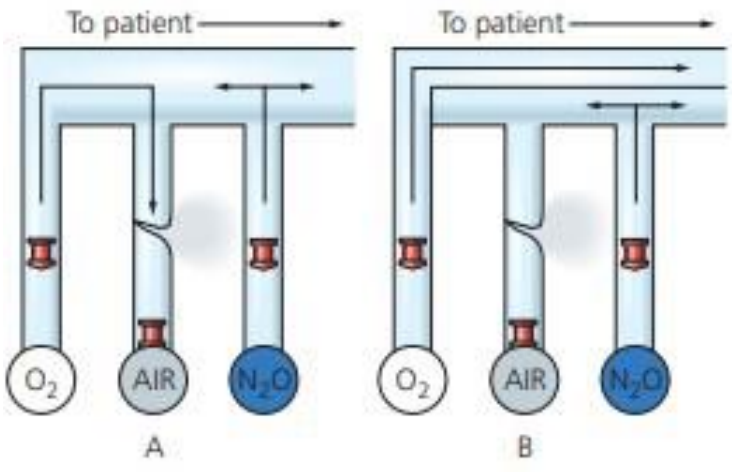


Fig. 8.16 *(A) A broken air flowmeter allows oxygen to escape and a hypoxic mixture to be delivered from the back bar. (B) A possible design measure to prevent this.*

8.5.4 Flowmeter

- Both laminar and turbulent flows are encountered, making both the viscosity and density of the gas relevant.
- The bobbin should not stick to the tapered tube.
- Oxygen is the last gas to be added to the mixture.
- It is very accurate with an error margin of ±2.5%.

8.6 Vaporizers

A vaporizer is designed to add a controlled amount of an inhalational agent, after changing it from liquid to vapour, to the FGF. This is normally expressed as a percentage of saturated vapour added to the gas flow. Characteristics of the ideal vaporizer

1. Its performance is not affected by changes in FGF, volume of the liquid agent, ambient temperature and pressure, decrease in temperature due to vaporization and pressure fluctuation due to the mode of respiration.
2. Low resistance to flow.
3. Light weight with small liquid requirement.
4. Economy and safety in use with minimal servicing requirements.
5. Corrosion- and solvent-resistant construction Vaporizers can be classified according to location:

1. Inside the breathing system. Gases pass through a very low resistance, draw over vaporizer due to the patient's respiratory efforts (e.g. Goldman, Oxford Miniature Vaporizer; OMV). Such vaporizers are simple in design, light in weight, agent non-specific, i.e. allowing the use of any volatile agent, small and inexpensive. For these reasons, they are used in the 'field' or in otherwise difficult environments. However, they are not as efficient as the plenum vaporizers as their performance is affected as the temperature of the Anesthetic agent decreases due to loss of latent heat during vaporization.
2. Outside the breathing system. Gases are driven through a plenum (high resistance, unidirectional and agent specific) vaporizer due to gas supply pressure.

8.6.1Plenum vaporizer

8.6.2 Components

1. The case with the filling level indicator and a port for the filling device.
2. Percentage control dial on top of the case.
3. The bypass channel and the vaporization chamber. The latter has wicks or baffles to increase the surface area available for vaporization (Fig. 8.18).
4. The splitting ratio is controlled by a temperature-sensitive valve utilizing a bimetallic strip (Fig. 8.19). The latter is made of two strips of metal with different coefficients of thermal

expansion bonded together. It is positioned inside the vaporization chamber in the Tec Mk 2 whereas in Tec Mk 3, 4 and 5, it is outside the vaporization chamber. An ether-filled bellows is the temperature compensating device in the M&IE Vapamasta Vaporizer 5 and 6. The bellows contracts as the temperature of the vaporizer decreases.

Fig. 8.17 Tec Mk 5 vaporizers mounted on the back bar of an Anesthetic machine.

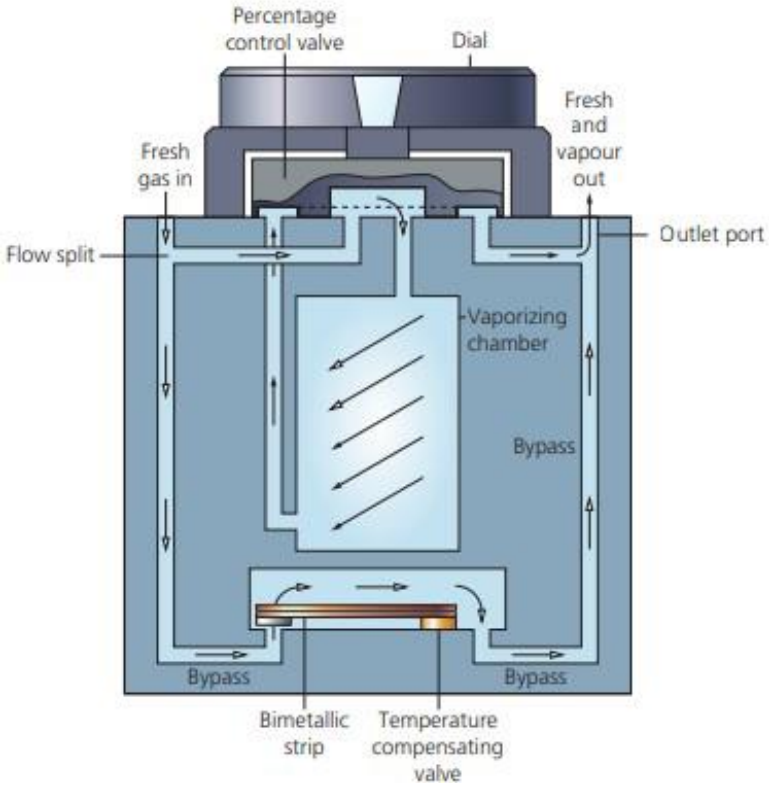


Fig. 8.18 *A schematic diagram of the Tec Mk 5, an example of a plenum vaporizer.*

5. The vaporizers are mounted on the back bar (Fig. 8.20) using the interlocking Selectatec system (Fig. 8.21). The percentage control dial cannot be moved unless the locking lever

of the system is engaged (in Mk 4 and 5). The interlocking extension rods prevent more than one vaporizer being used at any one time, preventing contamination of the one downstream (in Mk 4 and 5). The FGF only enters the vaporizer when it is switched on (Fig. 8.22).

8.6.3 Mechanism of action

1. The calibration of each vaporizer is agent-specific.
2. Fresh gas flow is split into two streams on entering the vaporizer. One stream flows through the bypass channel and the other, smaller stream, flows through the vaporizing chamber. The two gas streams reunite as the gas leaves the vaporizer.
3. The vaporization chamber is designed so that the gas leaving it is always fully saturated with vapour before it rejoins the bypass gas stream. This should be achieved despite changes in the FGF.
4. Full saturation with vapour is achieved by increasing the surface area of contact between the carrier gas and the Anesthetic agent. This is achieved by having wicks saturated by the inhalational agent, a series of baffles or by bubbling the gas through the liquid.
5. The desired concentration is obtained by adjusting the percentage control dial. This alters the amount of gas flowing through the bypass channel to that flowing through the vaporization chamber.
6. In the modern designs, the vapour concentration supplied by the vaporizer is virtually independent of the FGFs between 0.5 and 15 L/min.
7. During vaporization, cooling occurs due to the loss of latent heat of vaporization. Lowering the temperature of the agent makes it less volatile. In order to compensate for temperature changes:

a. the vaporizer is made of a material with high density and high specific heat capacity with a very high thermal conductivity, e.g. copper. Copper acts as a heat sink, readily giving heat to the Anesthetic agent and maintaining its temperature
b. a temperature sensitive valve (e.g. bimetallic strip or bellows) within the body of the vaporizer automatically adjusts the splitting ratio according to the temperature. It allows more flow into the vaporizing chamber as the temperature decreases.

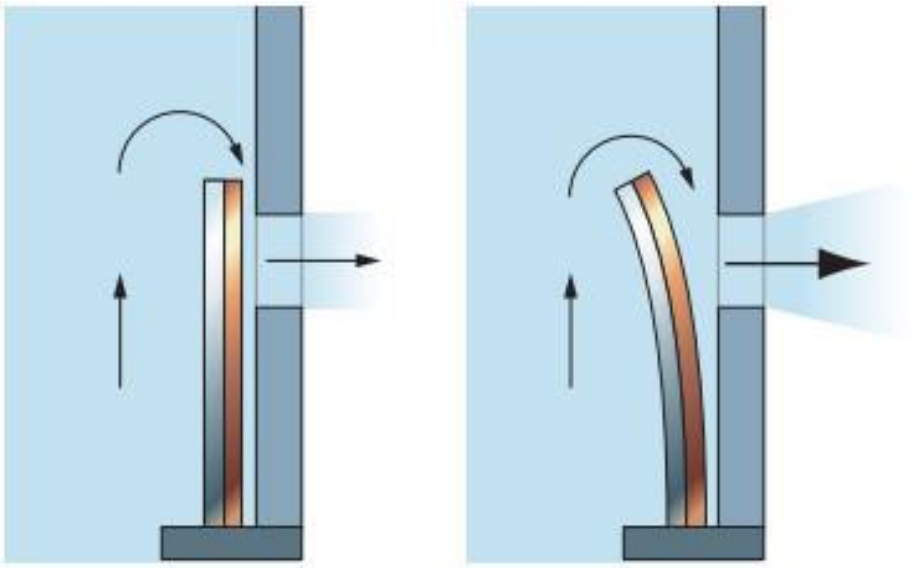


Fig. 8.19 *Mechanism of action of a bimetallic strip.*

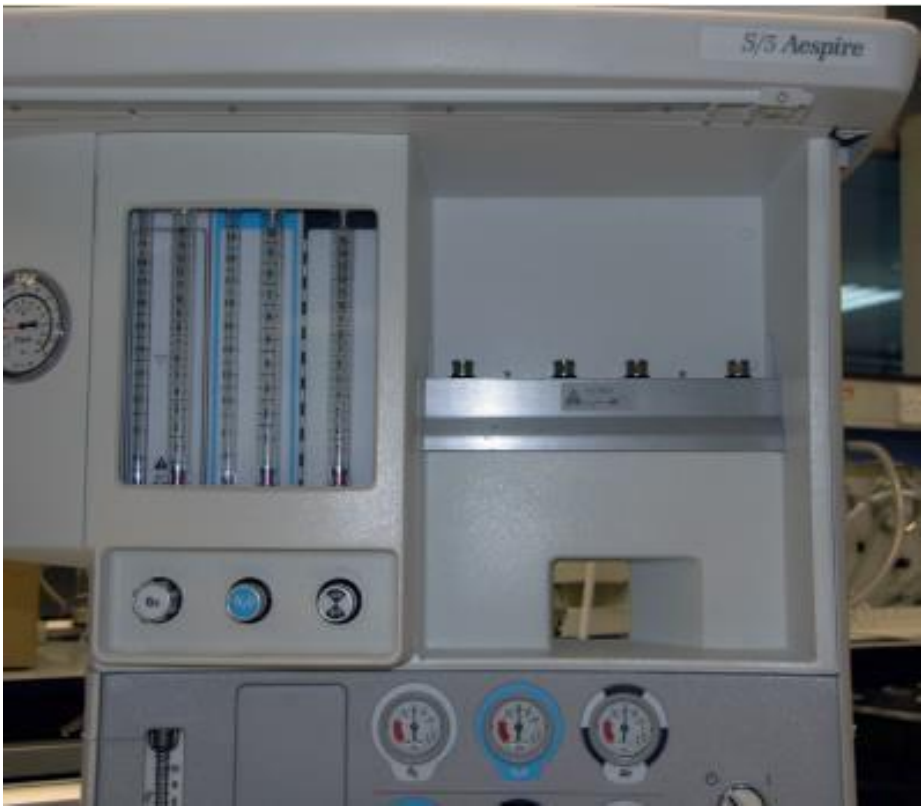


Fig. 8.20 *An empty Selectatec back bar of an Anesthetic machine.*

8. The amount of vapour carried by the FGF is a function of both the saturated vapour pressure (SVP) of the agent and the atmospheric pressure. At high altitudes, the atmospheric pressure is reduced whereas the SVP remains the same. This leads to an increased amount of vapour whereas the saturation of the agent remains the same. The opposite occurs in hyperbaric chambers. This is of no clinical relevance as it is the partial pressure of the agent in the alveoli that determines the clinical effect of the agent.

8.6.4 Problems in practice and safety features

1. In modern vaporizers (Tec Mk 5), the liquid Anesthetic agent does not enter the bypass channel even if the vaporizer is tipped upside down due to an anti-spill mechanism. In earlier designs, dangerously high concentrations of Anesthetic agent could be delivered to the patient in cases of agent spillage into the bypass channel. Despite that, it is recommended that the vaporizer is purged with a FGF of 5 L/min for 30 min with the percentage control dial set at 5%.
2. The Selectatec system increases the potential for leaks. This is due to the risk of accidental removal of the O-rings with changes of vaporizers.
3. Minute volume divider ventilators exert back pressure as they cycle. This pressure forces some of the gas exiting the outlet port back into the vaporizing chamber, where more vapour is added. Retrograde flow may also contaminate the bypass channel. These effects

cause an increase in the inspired concentration of the agent which may be toxic. These pressure fluctuations can be compensated for by:

a. long inlet port into the vaporizing chamber as in Tec Mk 3. This ensures that the bypass channel is not contaminated by retrograde flow from the vaporizing chamber
b. downstream flow restrictors: used to maintain the vaporizer at a pressure greater than any pressure required to operate commonly used ventilators
c. both the bypass channel and the vaporizing chamber are of equal volumes so gas expansion and compression are equal.

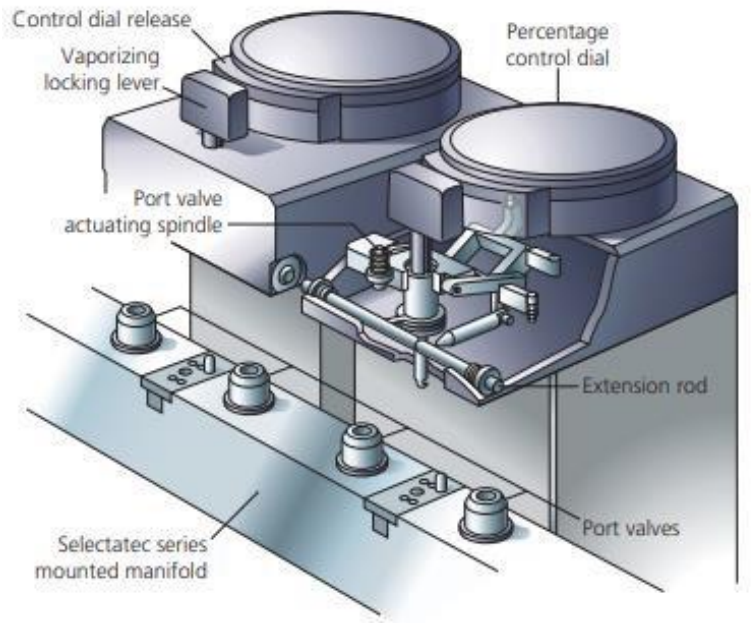


Fig. 8.21 *The Selectatec vaporizer interlock mechanism. See text for details. (Reproduced with permission from Datex-Ohmeda.)*

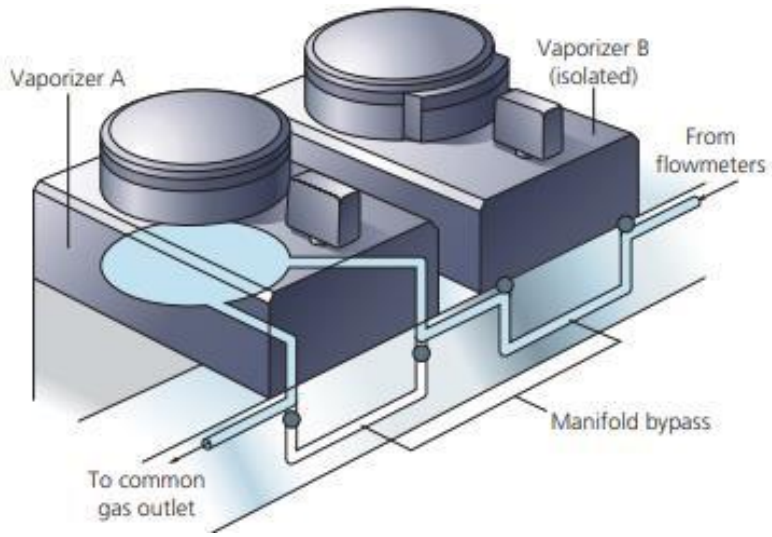


Fig. 8.22 *The Selectatec series mounted manifold bypass circuit. Only when a vaporizer is locked in position and turned on can fresh gas enter. Vaporizer B is turned off and is isolated from the fresh gas which only enters vaporizer A which is turned on. If no vaporizer is fitted, the port valves are closed. (Reproduced with permission from DatexOhmeda.)*

4. Preservatives, such as thymol in halothane, accumulate on the wicks of vaporizers with time. Large quantities may interfere with the function of the vaporizer. Thymol can also cause the bimetallic strip in the Tec Mk 2 to stick. Enflurane and isoflurane do not contain preservative.
5. A pressure relief valve downstream of the vaporizer opens at about 35 kPa. This prevents damage to flowmeters or vaporizers if the common gas outlet is blocked.
6. The bimetallic strip has been situated in the bypass channel since the Tec Mk 3. It is possible for the chemically active strip to corrode in a mixture of oxygen and the inhalational agent within the vaporizing chamber (Tec Mk 2).

8.7 Vaporizer filling devices

These are agent-specific being geometrically coded (keyed) to fit the safety filling port of the correct vaporizer and Anesthetic agent supply bottle (Fig. 8.23). They prevent the risk of adding the wrong agent to the wrong vaporizer and decrease the extent of spillage. The safety filling system, in addition, ensures that the vaporizer cannot overflow. Fillers used for desflurane and sevoflurane have valves that are only opened when fully inserted into their ports. This prevents spillage.

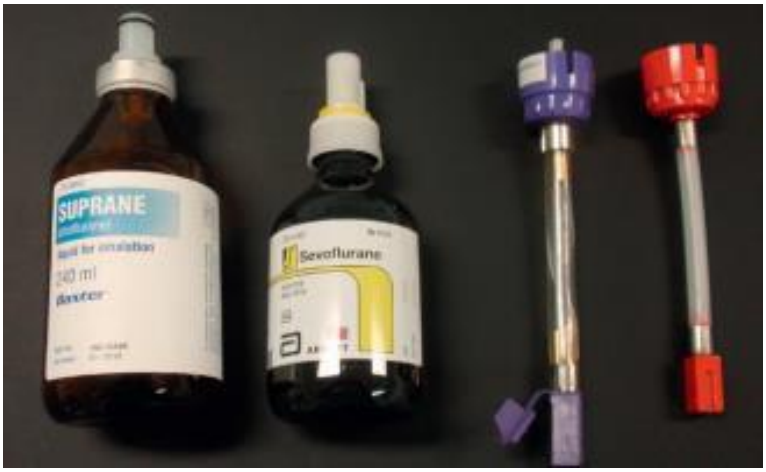


Fig. 8.23 *Agent-specific, colour-coded filling devices; (left to right) desflurane, sevoflourane, isoflurane and enflurane.*

The fillers are colour-coded:

Red	Halothane
Orange	Enflurane
Purple	Isoflurane
Yellow	Sevoflurane
Blue	Desflurane

A more recent design feature is the antipollution cap allowing the filler to be left fitted to the bottle between uses to prevent the agent from vaporizing. It also eliminates air locks, speeding up vaporizer filling, and ensures that the bottle is completely emptied, reducing wastage

8.8. Non-return pressure relief safety valve

This is situated downstream of the vaporizers either on the back bar itself or near the common gas outlet (Fig. 8.24).

1. Its non-return design helps to prevent back pressure effects commonly encountered using minute volume divider ventilators.
2. It opens when the pressure in the back bar exceeds about 35 kPa. Flowmeter and vaporizer components can be damaged at higher pressures.

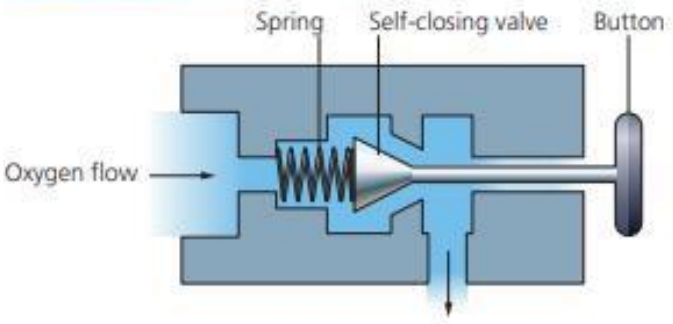


Fig. 8.25 *The emergency oxygen flush button (above); its mechanism of action (below).*

8.9 Emergency oxygen flush

This is usually activated by a non-locking button (Fig. 8.25).

When pressed, pure oxygen is supplied from the outlet of the Anesthetic machine. The flow bypasses the flowmeters and the vaporizers. A flow of about 35–75 L/min at a pressure of about 400 kPa is expected. The emergency oxygen flush is usually activated by a non-locking button and using a self-closing valve. It is designed to minimize unintended and accidental operation by staff or other equipment. The button is recessed in a housing to prevent accidental depression.

8.10 Problems in practice and safety features

1. The high operating pressure and flow of the oxygen flush puts the patient at a higher risk of barotrauma.
2. When the emergency oxygen flush is used inappropriately, it leads to dilution of the Anesthetic gases and possible awareness.
3. It should not be activated while ventilating a patient using a minute volume divider ventilator.

8.11 Compressed oxygen outlet(s)

One or more compressed oxygen outlets used to provide oxygen at about 400 kPa (Fig. 8.26). It can be used to drive ventilators or a manually controlled jet injector.

8.12 Oxygen supply failure alarm

There are many designs available (Fig. 8.27) but the characteristics of the ideal warning device are:

Fig. 8.26 *Compressed oxygen outlet*

Fig. 8.27 *The oxygen supply failure alarm in the Datex-Ohmeda Flexima Anesthetic machine.*

1. Activation depends on the pressure of oxygen itself.
2. It requires no batteries or mains power.
3. It gives an audible signal of a special character and of sufficient duration and volume to attract attention.
4. It should give a warning of impending failure and a further alarm that failure has occurred.
5. It should have pressure-linked controls which interrupt the flow of all other gases when it comes into operation. Atmospheric air is allowed to be delivered to the patient, without carbon dioxide accumulation. It should be impossible to resume Anesthesia until the oxygen supply has been restored.
6. The alarm should be positioned on the reduced pressure side of the oxygen supply line.
7. It should be tamper proof.
8. It is not affected by backpressure from the Anesthetic ventilator. In modern machines, if the oxygen supply pressure falls below 200 kPa, the low-pressure supply alarm sounds. With supply pressures below 137 kPa, the 'fail safe' valve will interrupt the flow of other gases to their flowmeters so that only oxygen can be delivered (Fig. 8.28). The oxygen flow set on the oxygen flowmeter will not decrease until the oxygen supply pressure falls below 100 kPa

8.13 Common gas outlet

(Fig. 8.29)

This is where the Anesthetic machine 'ends'. At the common gas outlet, the gas mixture made at the flowmeters, plus any inhaled Anesthetic agent added by the vaporizer, exits the machine and enters the fresh gas tubing that conducts it to the breathing system. The common gas outlet is a conically tapered pipe with a 22 mm male/15 mm female. It can be fixed or on a swivelling connector. The connector of the common gas outlet should be

strong enough to withstand a torque of up to 10 Nm because of the heavy equipment that may be attached.

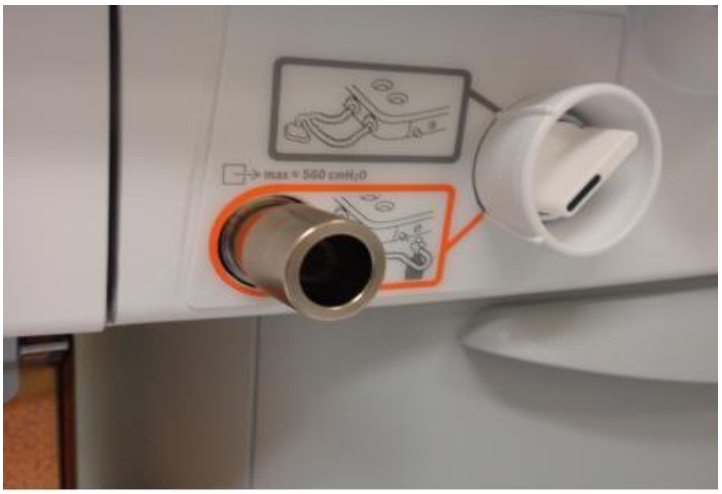


Fig. 8.29 *Common gas outlet*

Chapter 9

THE BREATHING CIRCUITS

9.1 INTRODUCTION

Breathing systems provide the final conduit for the delivery of anesthetic gases to the patient. Breathing circuits link a patient to an anesthesia machine (fig.9-1). Many different circuit designs have been developed, each with varying degrees of efficiency, convenience, and complexity. This chapter reviews the most important breathing systems: **Mapleson circuits** and the **circle system**.

Figure. 9-1. The relationship between patient breathing circuit and anesthesia machine

Breathing systems must fulfill **three objectives**:

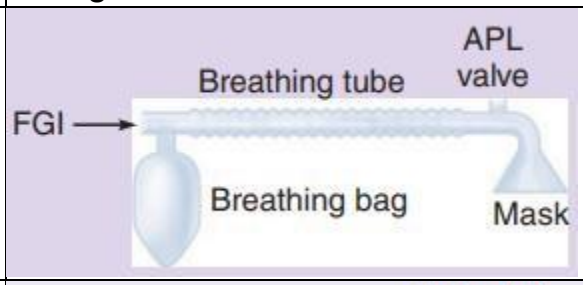
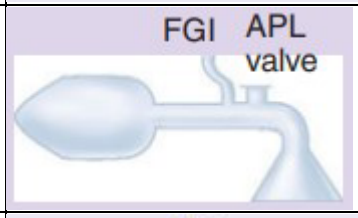
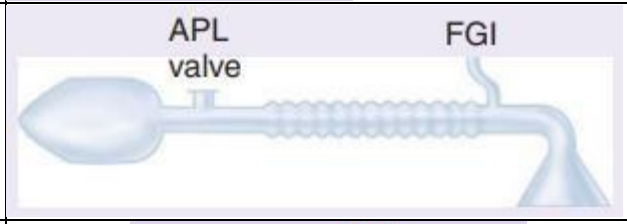
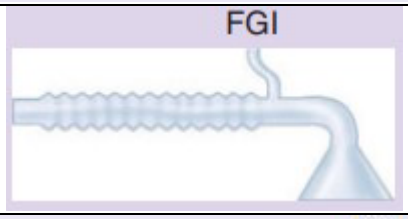
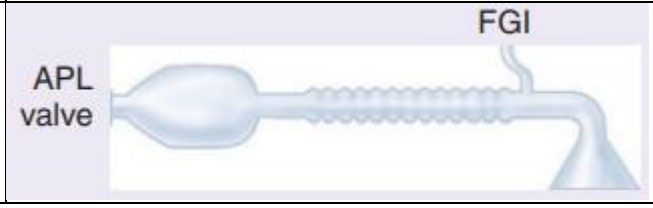
- Delivery of oxygen.
- Removal of carbon dioxide from the patient.
- Delivery of inhaled anesthetic agents. These agents are predominantly eliminated by the lungs, so the breathing system must be able to expel them as necessary.

9.2 MAPLESON CIRCUITS

9.2.1 Components of Mapleson Circuits

The Mapleson systems have some additional components like breathing tubes, fresh gas inlets, adjustable pressure-limiting (APL) valves, and reservoir bags in the breathing circuit. The relative location of these components determines circuit performance and is the basis of the Mapleson classification (Table 9-1).

TABLE 9-1 Classification of Mapleson Circuits.

Mapleson Class	Other Names	Configuration[1]
A	Magill attachment	
B		
C	Waters' to-and-fro	
D	Bain circuit	
E	Ayre's T-piece	
F	Jackson-Rees' modification	

[1] FGI, fresh gas inlet; APL, adjustable pressure-limiting

9.2.2 Breathing Tubes

- **Corrugated** tubes - made of rubber (reusable) or plastic (disposable) - connect the components of the Mapleson circuit to the patient (Figure 9–2).
- The size for **adults** is **22 mm** wide and **pediatric** tubing is **15 mm** wide.
- The large diameter of the tubes (22 mm) creates a low-resistance pathway and a potential reservoir for anesthetic gases.
- To minimize fresh gas flow requirements, the volume of gas within the breathing tubes in most Mapleson circuits should be at least as great as the patient's tidal volume.

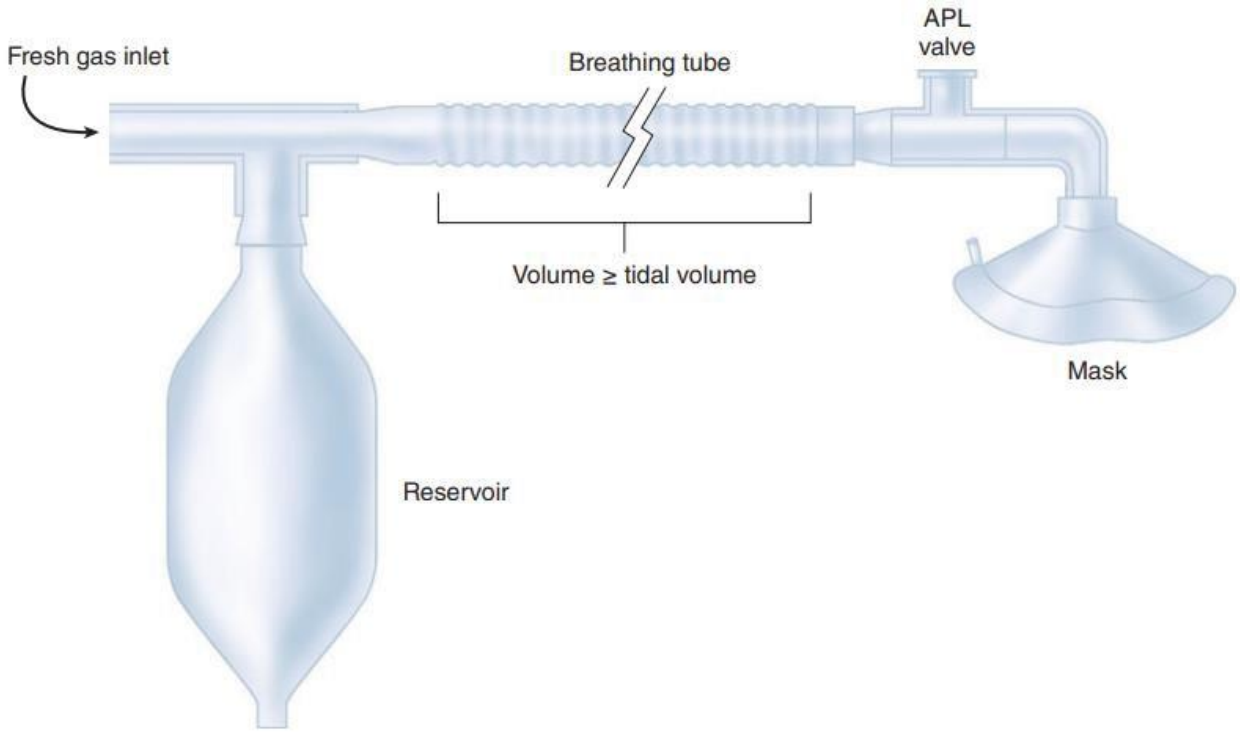


FIGURE 9-2 Components of a Mapleson Circuit. APL, Adjustable pressure-limiting (valve).

9.2.3 Fresh Gas Inlet

· Gases (anesthetics mixed with oxygen or air) from the anesthesia machine continuously enter the circuit through the fresh gas inlet.

9.2.4 Adjustable Pressure-Limiting Valve (Pressure-Relief Valve, Pop-Off Valve, Spill valve)

- This is a valve which allows the exhaled gases and excess FGF (fresh gas flow) to leave the breathing system to avoid pressure build up in the circuit.
- Exiting gases enter the operating room atmosphere or, preferably, a waste-gas scavenging system.

- It does not allow room air to enter the breathing system.
- All APL valves allow a variable pressure threshold for venting.
- The APL valve should be **fully open** during **spontaneous ventilation** so that circuit pressure remains negligible throughout inspiration and expiration.
- **Assisted** and **controlled ventilation** require positive pressure during inspiration to expand the lungs. **Partial closure** of the APL valve limits gas exit, permitting positive circuit pressures during reservoir bag compressions. **Reservoir Bag (Breathing Bag)**

- Reservoir bags function as a reservoir of anesthetic gas and a method of generating positive-pressure ventilation.
- They are designed to increase in compliance as their volume increases, hence it limits pressure build-up in the breathing system.
- It is made of rubber or plastic.
- Designs tend to be ellipsoidal in shape (Figure 9-3).
- The standard adult size is 2 L. The smallest size for pediatric use is 0.5 L.

FIGURE 9-3 A 0.5 L double ended reservoir bag.

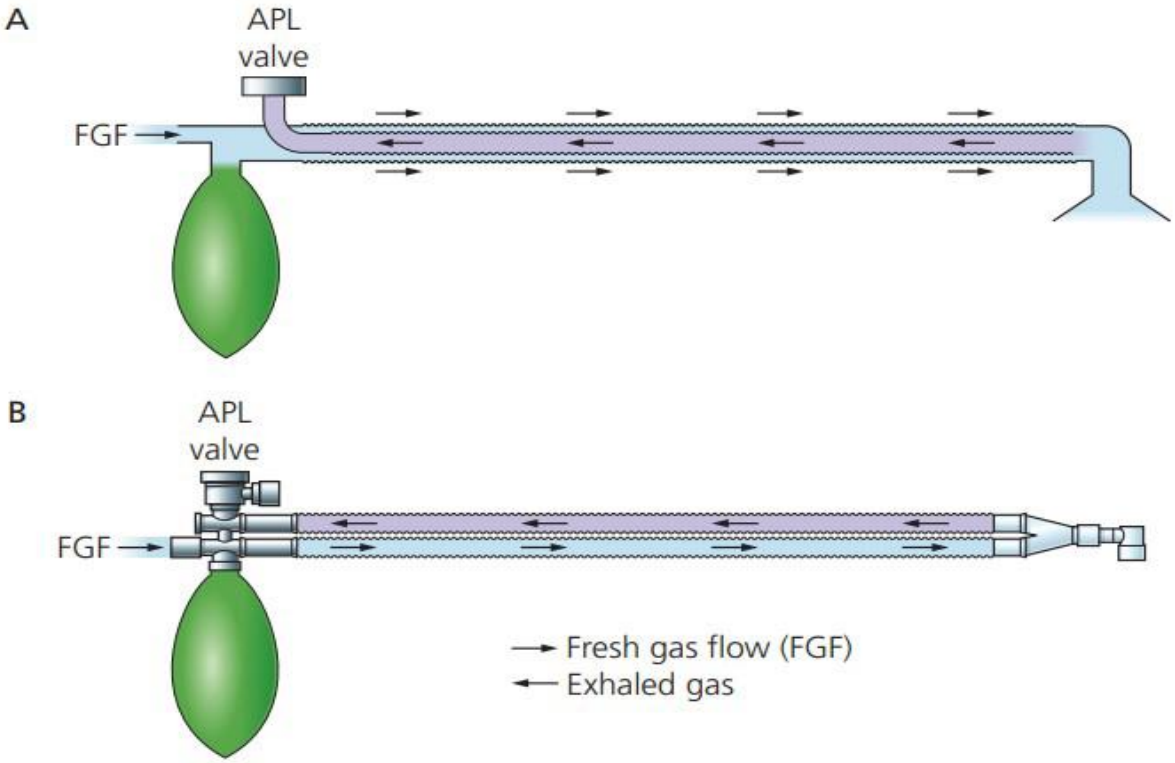
9.2.5 Performance Characteristics of Mapleson Circuits

- Mapleson circuits are lightweight, inexpensive, and simple.
- Breathing-circuit efficiency is measured by the fresh gas flow required to reduce CO_2 rebreathing to a negligible value. Because there are no unidirectional valves or CO_2 absorption in Mapleson circuits, rebreathing is prevented by adequate fresh gas flow into the circuit and venting exhaled gas through the APL valve before inspiration.
- There is usually some rebreathing in any Mapleson circuit. The total fresh gas flow into the circuit controls the amount.
- To reduce rebreathing, high fresh gas flows are required.

- The APL valve in Mapleson A, B, and C circuits is located near the face mask, and the reservoir bag is located at the opposite end of the circuit. **Mapleson A (Magill system)**
- **Efficient for spontaneous ventilation**. FGF required is equal to alveolar minute volume (about 70 mL/kg/min).
- Inefficient for controlled ventilation. FGF three times alveolar minute volume.
- APL valve is at the patient's end (Table 9-1). · Not suitable for pediatric practice.

Lack Breathing System

- **Coaxial version of Mapleson A**, making it efficient for spontaneous ventilation. FGF rate of about 70 mL/kg/min is required.
- FGF is delivered along the outside tube and the exhaled gases flow along the inner tube (Figure 9-4).
- APL valve is at the machine end (Table 9-1).
- Not suitable for controlled ventilation.



- **FIGURE 9-4 (A)** The coaxial Lack breathing system. (B) The parallel Lack breathing system.

9.2.6 Mapleson B and C systems

- B system has a tubing and bag reservoir.
- Both B and C systems are not efficient for spontaneous and controlled ventilation.

- B system is more efficient than A system during controlled ventilation. Fresh gas flows are conveniently available because the fresh gas inlet is in close proximity to the APL valve in a Mapleson B circuit (Table 9-1). **Mapleson D**
- Interchanging the position of the APL valve and the fresh gas inlet transforms a Mapleson A into a Mapleson D circuit (Table 9-1).
- The Mapleson D circuit is **efficient during controlled ventilation**, since fresh gas flow forces alveolar air away from the patient and toward the APL valve. Thus, simply moving components completely alters the fresh gas requirements of the Mapleson circuits.
- Not efficient for spontaneous ventilation.

9.2.7 Bain Circuit

- The Bain circuit is a **coaxial version of the Mapleson D** system that incorporates the fresh gas inlet tubing inside the breathing tube (Figure 9–5).
- This modification decreases the circuit's bulk and retains heat and humidity better than a conventional Mapleson D circuit as a result of partial warming of the inspiratory gas by countercurrent exchange with the warmer expired gases.
- A disadvantage of this coaxial circuit is the possibility of kinking or disconnection of the fresh gas inlet tubing.

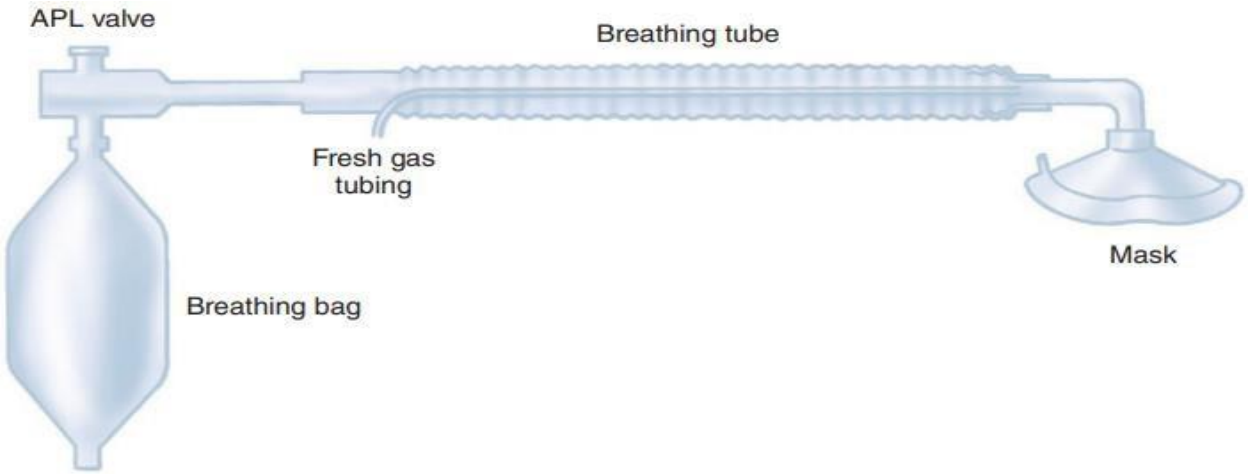


FIGURE 9-5 A Bain circuit is a Mapleson D circuit design with the fresh gas tubing inside the corrugated breathing tube. APL, adjustable pressure-limiting (valve).

9.2.8 Mapleson E and F (T-piece system)

- This is a valveless breathing system used in Anesthesia for children up to 25–30 kg body weight (Figure 9-6)
- It is suitable for both spontaneous and controlled ventilation.
- Requires a high FGF during spontaneous ventilation.
- Offers minimal resistance to expiration.
- Scavenging is difficult.

- A recent design with an APL valve and a closed-ended reservoir allows effective scavenging (Figure 9-7).

FIGURE 9-7 Inter-surgical T-piece incorporating an APL valve and closed reservoir bag to enable effective scavenging.

9.3 THE CIRCLE SYSTEM

The high fresh gas flows required to prevent rebreathing of CO_2 result in waste of anesthetic agent, pollution of the operating room environment, and loss of patient heat and humidity are featured in Mapleson circuits (Table 9-2). In an attempt to avoid these problems, the circle system adds more components to the breathing system.

TABLE 9-2 Characteristics of breathing circuits.

	MAPLESON	**CIRCLE**
Complexity	Simple	Complex
Control of anesthetic depth	Variable	Good
Ability to scavenge	Variable	Good
Conservation of heat and humidity	No	Yes[1]
Rebreathing of exhaled gases	No[1]	Yes[1]
[1] These properties depend on the rate of fresh gas flow.		

The components of a circle system (Figure 9-8) include:

- a CO_2 absorber containing CO_2 absorbent;
- a fresh gas inlet;
- an inspiratory unidirectional valve and inspiratory breathing tube;
- a Y-connector;
- an expiratory unidirectional valve and expiratory breathing tube; · an APL valve; and · a reservoir.

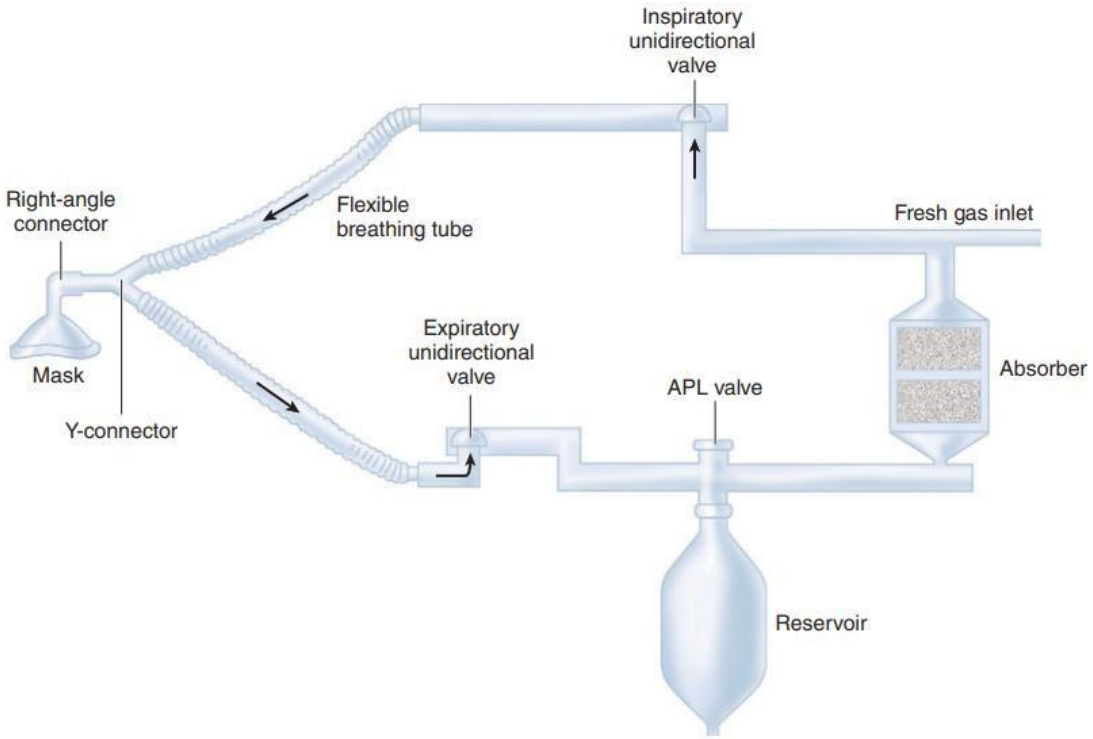


Figure. 9-8: The circle system Carbon Dioxide Absorber and the Absorbent

- Rebreathing alveolar gas conserves heat and humidity. However, the CO_2 in exhaled gas must be eliminated to prevent hypercapnia (increased concentration of CO_2).
- Soda lime, barium hydroxide lime and Amsorb are some examples of CO_2 absorbent.
- **Soda lime** is the more common absorbent and is capable of absorbing up to 23 L of CO_2 per 100 g of absorbent.
- It consists primarily of calcium hydroxide (80%), along with sodium hydroxide (15%), water (14% to 19%), and a small amount of potassium hydroxide (<0.1%). Silica is also added to increase the hardness of soda lime.
- A pH indicator dye (e. g, ethyl violet) changes color from white to purple as a consequence of increasing hydrogen ion concentration and absorbent exhaustion (Table 9-3).
- Absorbent should be replaced when 50% to 70% has changed color. Although exhausted granules may revert to their original color if rested, no significant recovery of absorptive capacity occurs.

TABLE 9-3 Indicator dye changes signaling absorbent exhaustion.

Indicator	Color when Fresh	Color when exhausted
Ethyl violet	White	Purple
Phenolphthalein	White	Pink
Clayton yellow	Red	Yellow
Ethyl orange	Orange	Yellow
Mimosa 2	Red	White

- **Granule size** is a compromise between the higher absorptive surface area of small granules and the lower resistance to gas flow of larger granules. The granules commonly used as CO_2 absorbent are between 4 and 8 mesh; the number of mesh corresponds to the number of holes per square inch of a screen.
- The granules of absorbent are contained within one or two canisters that fit snugly between a head and base plate. Together, this unit is called an **absorber** (Figure 9-9).
- Although bulky, double canisters permit more complete CO_2 absorption, less frequent absorbent changes, and lower gas flow resistance. · Indicator dye color is monitored through the absorber's transparent walls. Absorbent exhaustion typically occurs first where exhaled gas enters the absorber and along the canister's smooth inner walls.
- A trap at the base of the absorber collects dust and moisture.

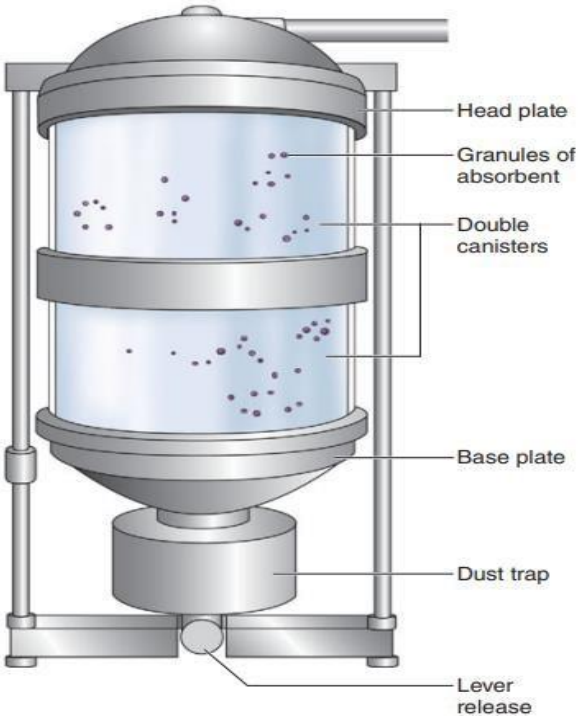


Figure. 3-9: A carbon dioxide absorber

Unidirectional Valves

- Unidirectional valves, which function as check valves, contain a ceramic or mica **disk** resting horizontally on an annular valve seat (Figure 9–10).

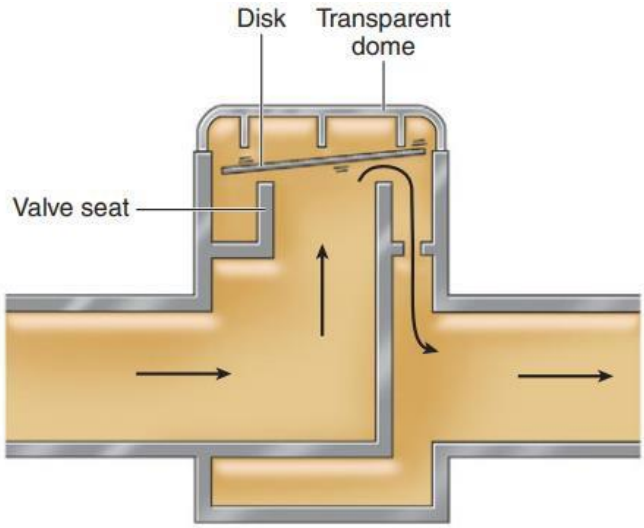


Figure 9-10: unidirectional valve

- Forward flow displaces the disk upward, permitting the gas to proceed through the circuit. Reverse flow pushes the disk against its seat, preventing reflux.
- **Inhalation** opens the inspiratory valve, allowing the patient to breathe a mixture of fresh and exhaled gas that has passed through the CO_2 absorber. Simultaneously, the expiratory valve closes to prevent rebreathing of exhaled gas that still contains CO_2.
- Th e subsequent flow of gas away from the patient during **exhalation** opens the expiratory valve. Th is gas is vented through the APL valve or rebreathed by the patient aft er passing through the absorber. Closure of the inspiratory valve during exhalation prevents expiratory gas from mixing with fresh gas in the inspiratory limb.
- **Malfunction** of either unidirectional valve may allow rebreathing of CO_2, resulting in hypercapnia.
- **Valve incompetence** is usually due to a warped disk or seat irregularities. The expiratory valve is exposed to the humidity of alveolar gas. Condensation and resultant moisture formation may prevent upward displacement of the disks, resulting in incomplete escape of expired gases and rebreathing.

9.3.1 Optimization of Circle System Design

Although the major components of the circle system (unidirectional valves, fresh gas inlet, APL valve, CO_2 absorber, and a reservoir bag) can be placed in several configurations, the following arrangement is preferred (Figure 9–8):

- **Unidirectional valves** are relatively **close to the patient** to prevent backflow into the inspiratory limb if a circuit leak develops. However, unidirectional valves are not placed in the Y-piece, as that makes it difficult to confirm proper orientation and intraoperative function.
- The **fresh gas inlet** is placed **between the absorber and the inspiratory valve**. Positioning it downstream from the inspiratory valve would allow fresh gas to bypass the patient during exhalation and be wasted.
- Th e **APL valve** is usually placed between the absorber and the expiratory valve and close to the reservoir bag.
- Resistance to exhalation is decreased by locating the **reservoir bag in the expiratory limb**. Bag compression during controlled ventilation will vent expired gas through the APL valve, conserving absorbent.

9.3.2 Performance Characteristics of the Circle System

9.3.3 Fresh Gas Requirement

- With an absorber, the circle system prevents rebreathing of CO_2 at reduced fresh gas flows (≤1 L).
- At fresh gas flows greater than 5 L/min, rebreathing is so minimal that a CO_2 absorber is usually unnecessary.
- Higher flows speed induction and recovery, compensate for leaks in the circuit, and decrease the risks of unanticipated gas mixtures. **Dead Space**
- That part of a tidal volume that does not undergo alveolar ventilation is referred to as dead space.
- Because of the unidirectional valves, apparatus dead space in a circle system is limited to the area distal to the point of inspiratory and expiratory gas mixing at the Y-piece.
- Unlike Mapleson circuits, the circle system tube length does not affect dead space. Like Mapleson circuits, length does affect circuit compliance and thus the amount of tidal volume lost to the circuit during positive-pressure ventilation.
- Pediatric circle systems may have both a septum dividing the inspiratory and expiratory gas in the Y-piece and low-compliance breathing tubes to further reduce dead space, and are lighter in weight. **Resistance**
- The unidirectional valves and absorber increase circle system resistance, especially at high respiratory rates and large tidal volumes.
- Nonetheless, even premature neonates can be successfully ventilated using a circle system.

9.3.4 Humidity and Heat Conservation

- Medical gas delivery systems supply dehumidified gases to the anesthesia circuit at room temperature.
- Exhaled gas, on the other hand, is saturated with water at body temperature.
- Therefore, the heat and humidity of inspired gas depend on the relative proportion of rebreathed gas to fresh gas.
- High flows are accompanied by low relative humidity, whereas low flows allow greater water saturation.
- Absorbent granules provide a significant source of heat and moisture in the circle system.

9.3.5 Bacterial Contamination

The minimal risk of microorganism retention in circle system components could theoretically lead to respiratory infections in subsequent patients. For this reason, **bacterial filters** are sometimes incorporated into the inspiratory or expiratory breathing tubes or at the Y-piece.

9.3.6 Disadvantages of the Circle System

Although most of the problems of Mapleson circuits are solved by the circle system (Figure 9-11), the improvements have led to other disadvantages:

- greater size and less portability
- increased complexity
- a higher risk of disconnection or malfunction
- complications related to use of absorbent
- the difficulty of predicting inspired gas concentrations during low fresh gas flows

FIGURE 9-11 The Circle Breathing System

Chapter 10

AIRWAY EQUIPMENT

10.1Introduction

Airway management is a crucial component of safe anesthesia practice. Patients under anesthesia commonly need assisted ventilation and oxygenation.

One of the most critical features of airway management emphasized throughout this text is the need for rapid responsiveness and flexibility in changing and urgent situations. Airway plans can change instantly, and every member of the anesthesia team must have detailed, on-the-spot knowledge of the full spectrum of possible outcomes, plans, and equipment in order to care for patient safely. Manufacturers have responded by producing a tremendous variety of devices and tools designed to address common and uncommon issues arising from the inherent complexity of airway management. The topic of airway equipment will be your area of expertise.

10.2 Face masks and angle pieces

The face mask is designed to fit the face anatomically. It comes in different sizes to fit patients of different age groups (from neonates to adults). It is connected to the breathing system via the angle piece.

10.2.1 Components

1. The body of the mask which rests on an air-filled cuff (Fig. 10.1). Some paediatric designs do not have a cuff, e.g. Rendell–Baker (Fig. 10.2).
2. The proximal end of the mask has a 22-mm inlet connection to the angle piece.
3. Some designs have clamps for a harness to be attached.
4. The angle piece has a 90° bend with a 22-mm end to fit into a catheter mount or a breathing system.

Fig. 10.1 *A range of sizes of transparent face masks with air-filled cuffs.*

10.3 Nasal masks (inhalers)

1. These masks are used during dental chair Anesthesia.
2. An example is the Goldman inhaler which has an inflatable cuff to fit the face and an adjustable pressure limiting (APL) valve at the proximal end. The mask is connected to tubing which delivers the fresh gas flow.
3. Other designs have an inlet for delivering the inspired fresh gas flow and an outlet connected to tubing with a unidirectional valve for expired gases.

Fig. 10.2 *Paediatric face masks. Ambu design (left) and Rendell–Baker design (right).*

Classification of the oxygen delivery systems

Variable performance devices	Fixed performance devices
Hudson face masks and partial rebreathing masks	Venturi-operated devices
Nasal cannulae (prongs or spectacles)	Anaesthetic breathing systems with a suitably large reservoir
Nasal catheters	

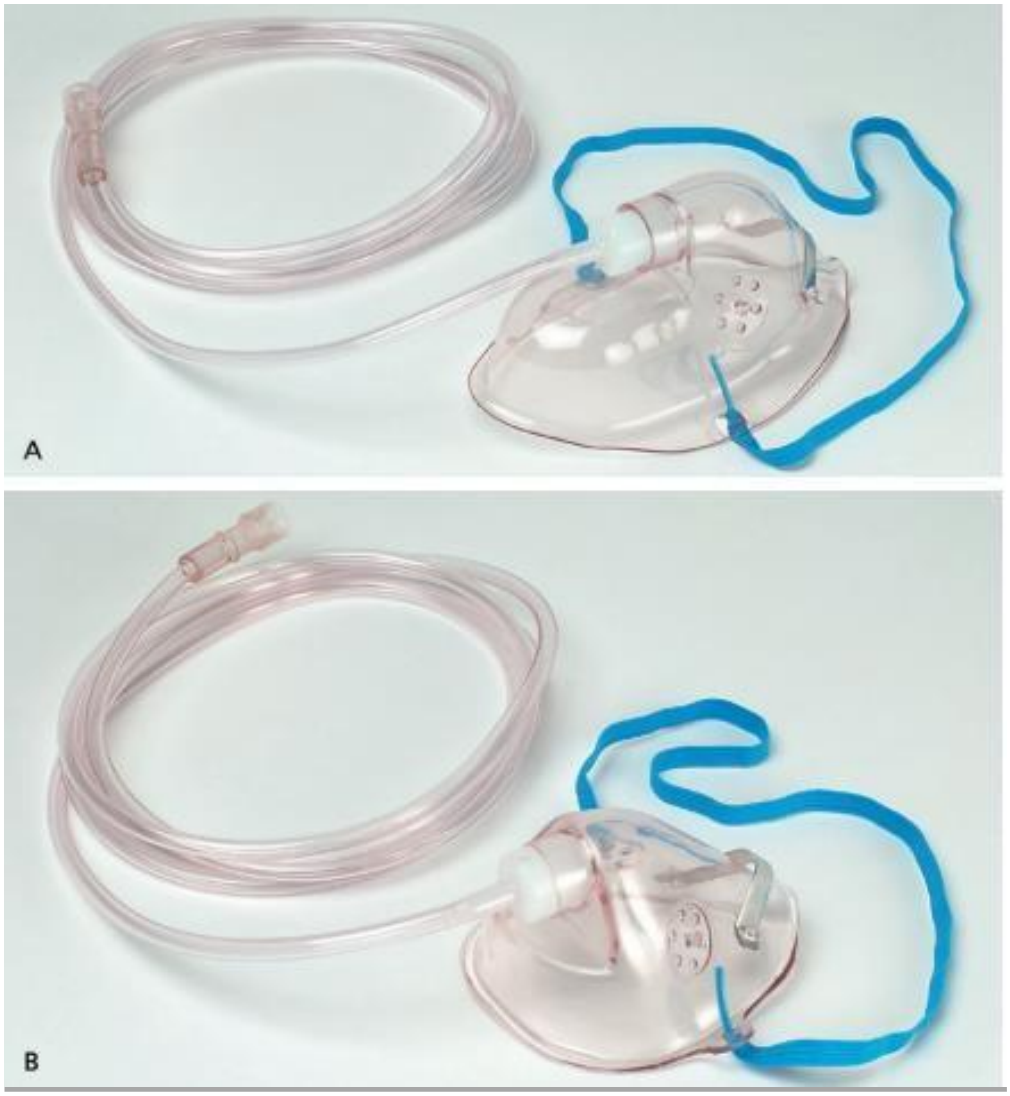


Fig. 10.3 *(A) Adult variable performance face mask. (B) Paediatric variable performance face mask.*

10.4 Tracheal tubes

Tracheal tubes provide a means of securing the patient's airway. These disposable plastic tubes are made of polyvinyl chloride (PVC) which could be clear, ivory or siliconized. As plastic is not radio-opaque, tracheal tubes have a radio-opaque line running along their length, which enables their position to be determined on chest X-rays. The siliconized PVC aids the passage of suction catheters through the tube. In the past, tracheal tubes used to be made of rubber allowing them to be reused after cleaning and autoclaving.

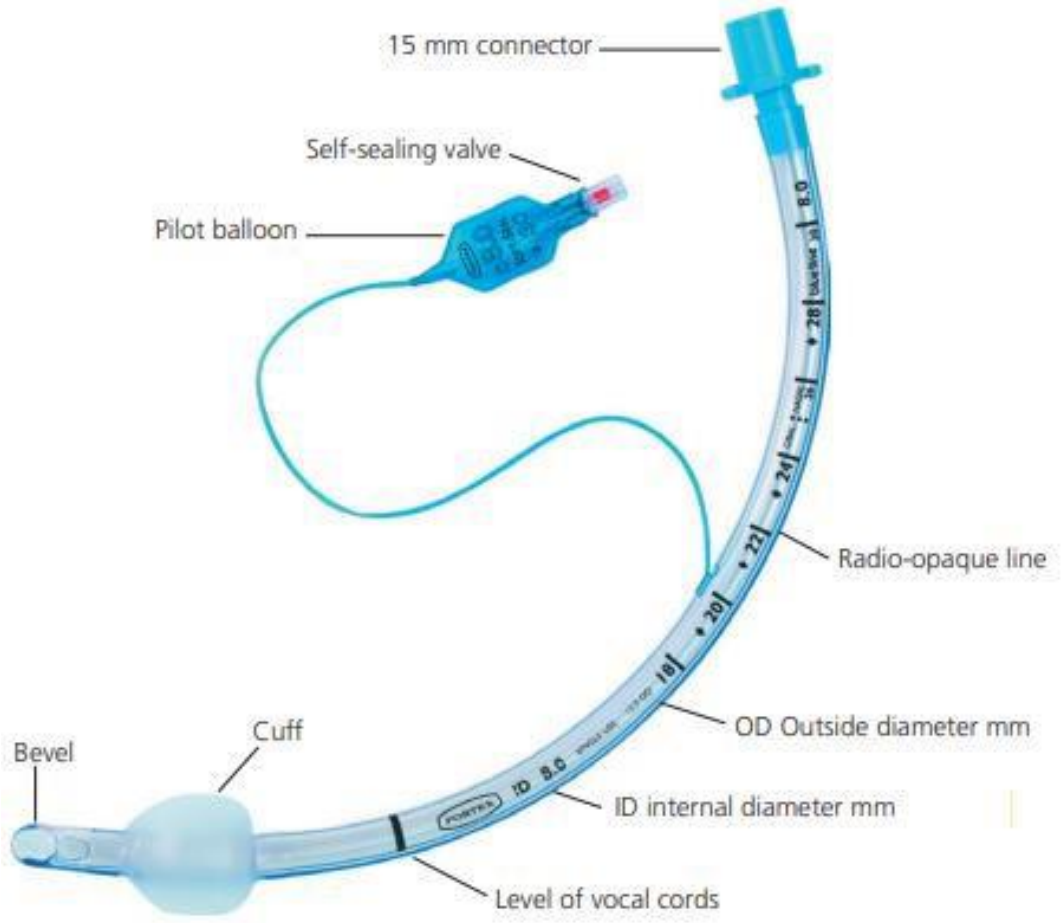


Fig. 10.4 *Features of a cuffed tracheal tube. Some designs have the markings of IT (implantation tested) and Z–79 stands (the Z–79 Committee of the American National Standards Institute). (Courtesy of Smiths Medical.)*

10.4.1 High-pressure/low-volume cuffs

1. These can prevent the passing of vomitus, secretions or blood into the lungs.
2. At the same time, they exert a high pressure on the tracheal wall. If left in position for long periods, they may cause necrosis of the tracheal mucosa (Fig. 10.5).

10.4.2 Low-pressure/high-volume cuffs

1. These exert minimal pressure on the tracheal wall as the pressure equilibrates over a wider area. This allows the cuff to remain inflated for longer periods.
2. They are less capable of preventing the aspiration of vomitus or secretions. This is due to the possibility of wrinkles forming in the cuff.

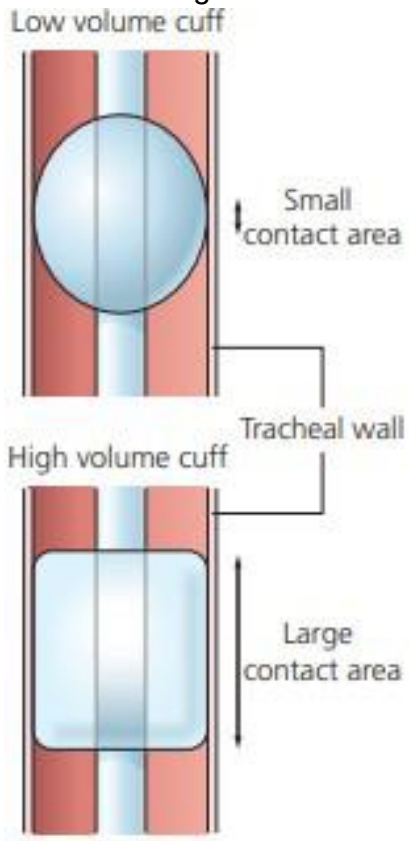


Fig. 10.5 *Diagram illustrating how a low-volume cuff (top) maintains a seal against a relatively small area of tracheal wall compared to a high-volume cuff (bottom)*

10.4.3 Specially designed tracheal tubes

- Oxford Tracheal Tube
- Armoured Tracheal Tube
- Polar And Rae Tracheal Tubes
- Laser Resistant Tracheal Tubes
- Micro-laryngeal Tube

Fig. 10.6 *Micro-laryngeal tracheal tube.*

10.4.4 Double lumen endobronchial tubes

During thoracic surgery, there is a need for one lung to be deflated. This offers the surgeon easier and better access within the designated hemithorax. In order to achieve this, double lumen tubes are used which allow the anesthetist to selectively deflate one lung while maintaining standard ventilation of the other.

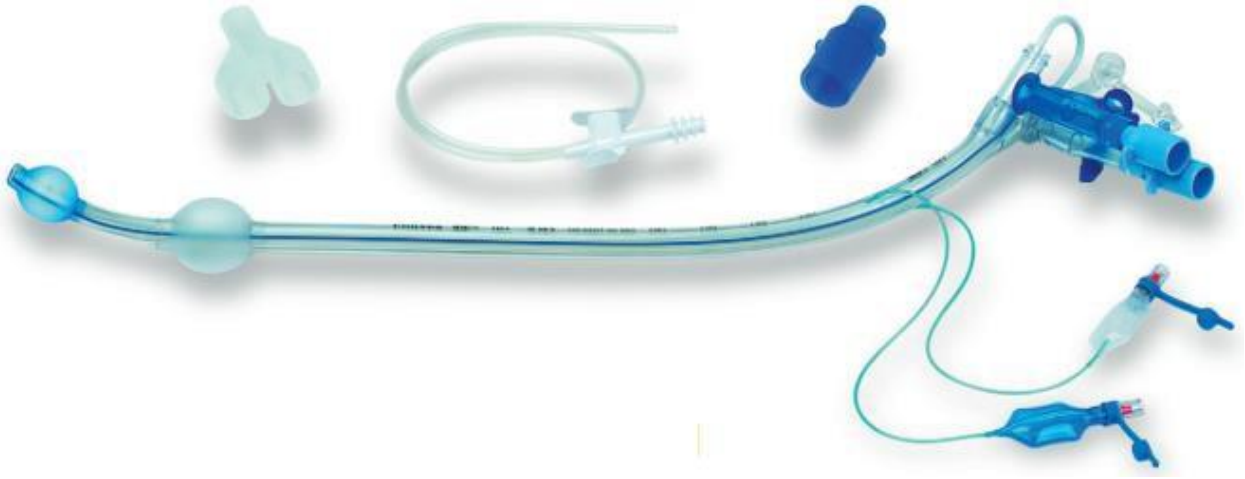


Fig. 10.7 *Double lumen endobronchial tube (left sided).*

10.5 Oropharyngeal airway

This anatomically shaped airway is inserted through the mouth into the oropharynx above the tongue to maintain the patency of the upper airway (Fig. 10.8) in cases of upper airway obstruction caused by a decreased level of consciousness in a patient. Decreased consciousness can lead to loss of pharyngeal tone that can result in airway obstruction by the tongue, epiglottis, soft palate or pharyngeal tissues. There are various regularly used types of oropharyngeal airway. The most common type is the Guedel airway, named after its developer Arthur Guedel, an American anesthetist who served in France during the First World War. It is available in up to nine sizes, which have a standardized number coding (the smallest '000' to the largest '6').

Fig. 10.8 *An oropharyngeal (Guedel) airway.*

10.5.1 Components

1. The curved body of the oropharyngeal airway contains the air channel. It is flattened antero-posteriorly and curved laterally.
2. There is a flange at the oral end to prevent the oropharyngeal airway from falling back into the mouth so avoiding further posterior displacement into the pharynx.
3. The bite portion is straight and fits between the teeth. It is made of hard plastic to prevent occlusion of the air channel should the patient bite the oropharyngeal airway.

10.5.2 Problems in practice and safety features

1. Trauma to the different tissues during insertion.
2. Trauma to the teeth, crowns/ caps if the patient bites on it.
3. If inserted in a patient whose pharyngeal reflexes are not depressed enough, the gag reflex can be induced that might lead to vomiting and laryngospasm.
4. They confer no protection against aspiration.

5. The degree to which airway patency has been increased after insertion of a Guedel airway should be assessed, not assumed. It should also always be remembered that a badly inserted Guedel airway can make airway patency worse rather than better.

10.6 Nasopharyngeal airway

This airway is inserted through the nose into the nasopharynx, bypassing the mouth and the oropharynx. The distal end is just above the epiglottis and below the base of the tongue (Fig. 5.36).

10.6.1 Components

1. The rounded curved body of the nasopharyngeal airway.
2. The bevel is left-facing.
3. The proximal end has a flange. A ‘safety pin’ is provided to prevent the airway from migrating into the nose.

10.6.2 Problems in practice and safety features

1. Its use is not recommended when the patient has a bleeding disorder, is on anticoagulants, has nasal deformities or sepsis.
2. Excess force should not be used during insertion as a false passage may be created.
3. An airway that is too large can result in pressure necrosis of the nasal mucosa, while an airway that is too small may be ineffective at relieving airway obstruction.

10.7 Laryngeal mask

This very useful device is frequently used as an alternative to either the face mask or tracheal tube during Anesthesia.

10.7.1 Components

1. A transparent tube of wide internal diameter. The proximal end is a standard 15mm connection.
2. An elliptical cuff at the distal end. The cuff resembles a small face mask to form an air-tight seal around the posterior perimeter of the larynx and is inflated via a pilot balloon with a self-sealing valve. A non-metallic self-sealing valve is available for use during magnetic resonance imaging (MRI) scans.
3. The original design (Intavent Classic LMA™) had two slits or bars at the junction between the tube and the cuff to prevent the epiglottis from obstructing the lumen of the laryngeal mask. Newer designs, such as Portex SoftSeal™ and Intersurgical Solus™, omit the bars with no adverse clinical effects.
4. A modified design (LMAProSeal™) has an additional lumen (drain tube) lateral to the airway tube and traverses the floor of the mask to open in the mask tip opposite the upper esophageal sphincter allowing blind passage of an

   orogastric tube and helps in the drainage of gastric air or secretions. Both tubes are contained within an integrated bite block. The cuff inflates in a three-dimensional manner with the elliptical cuff augmented by a second cuff behind the bowl, known as the rear boot or dorsal cuff. This design improves the seal pressure. A single-use

version, LMA Supreme™, is available which combines the best features of previous LMA versions, and contains an elliptical and anatomically shaped curve, which facilitates insertion success and provides a double seal. A first seal is important for adequacy of gas exchange, better known as the oropharyngeal seal. It also incorporates a second seal, designed to reduce the risk of stomach insufflation during ventilation, to provide a passive conduit for (unexpected) regurgitation or active suctioning of gastric content and enhances the effectiveness of the first seal.

5. Low-cost disposable laryngeal masks have been introduced and are widely used (Fig. 10.9).

Fig. 10.9 *Smith's Portex single-use Soft-Seal laryngeal mask.*

The recommended safety checks before the use of laryngeal masks

- Inflate the cuff and look for signs of herniation.
- Check that the lumen of the tube is patent.
- The tube can be bent to 180° without kinking or occlusion.
- Inspect the device for signs of dehiscence of the tube or mask aperture bars, and cuff separations. In the reusable devices, look for signs of damage or weakness where the teeth were in contact with the tube.
- The device should also be inspected after removal from the patient for signs of bleeding.

10.7.2 I-gel airway

The i-gel airway is a single-use extra-glottic airway that uses an anatomically designed mask to fit the peri-laryngeal and hypopharyngeal structures without the use of an inflatable cuff (Fig. 10.10). It also incorporates a second drain tube.

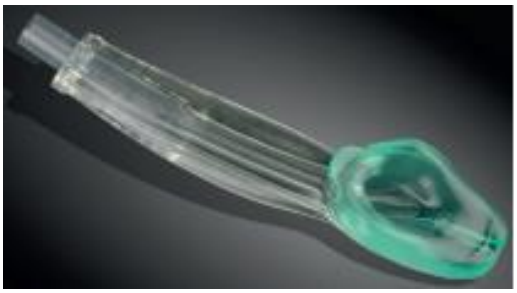


Fig. 10.10 *The i-gel airway. (Courtesy of Intersurgical.)*

10.8 Laryngoscopes

These devices are used to perform direct laryngoscopy and to aid in tracheal intubation

10.8.1 Components

1. The handle houses the power source (batteries) and is designed in different sizes.
2. The blade is fitted to the handle and can be either curved or straight. There is a wide range of designs for both curved and straight blades (Fig. 10.11).

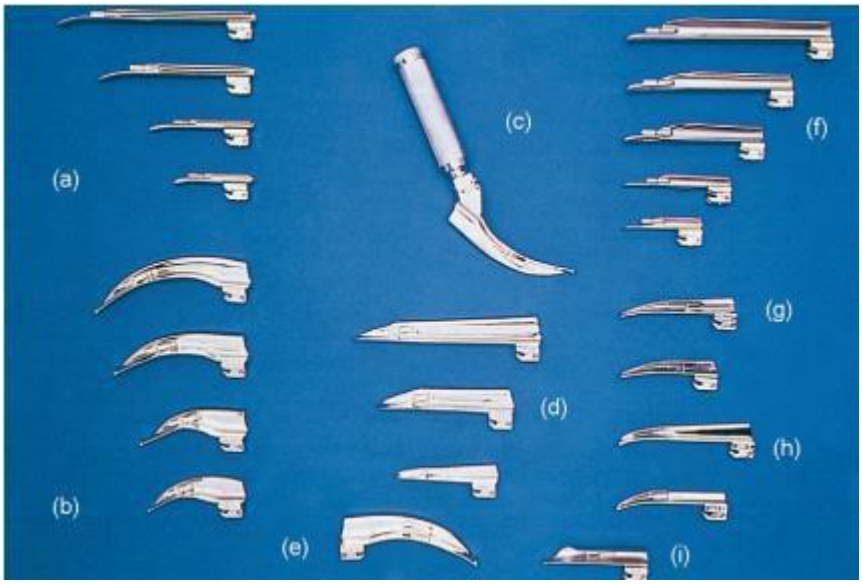


Fig. 10.11 *A wide range of laryngoscope blades. (A) Miller blades (large, adult, infant, premature); (B) Macintosh blades (large, adult, child, baby); (C) Macintosh polio blade; (D) Soper blades (adult, child, baby); (E) left-handed Macintosh blade; (F) Wisconsin blades (large, adult, child, baby, neonate); (G) Robertshaw's blades (infant, neonatal); (H) Seward blades (child, baby); (I) Oxford infant blade.*

10.9 Fibre-optic intubating laryngoscope

These devices have revolutionized airway management in Anesthesia and intensive care (Fig. 10.12). They are used to perform oral or nasal tracheal intubation to evaluate the airway in trauma, tumour, infection and inhalational injury, to confirm tube placement (tracheal, endobronchial, double lumen or tracheostomy tubes) and to perform tracheobronchial toilet.

Fig. 10.12 *Intubating fibre-optic scope.*

10.10 Magill forceps

These forceps are designed for ease of use within the mouth and oropharynx. Magill forceps come in small or large sizes (10.13). During tracheal intubation, they can be used to direct the tracheal tube towards the larynx and vocal cords. Care should be taken to protect the tracheal tube cuff from being damaged by the forceps. Other uses include the insertion and removal of throat packs and removal of foreign bodies in the oropharynx and larynx.

10.11 Introducer, bougie, bite guard, local Anesthetic spray, Endotrol tube and Nosworthy airway

1. A local Anesthetic spray is used to coat the laryngeal and tracheal mucosa, usually with lidocaine. This decreases the stimulus of intubation.

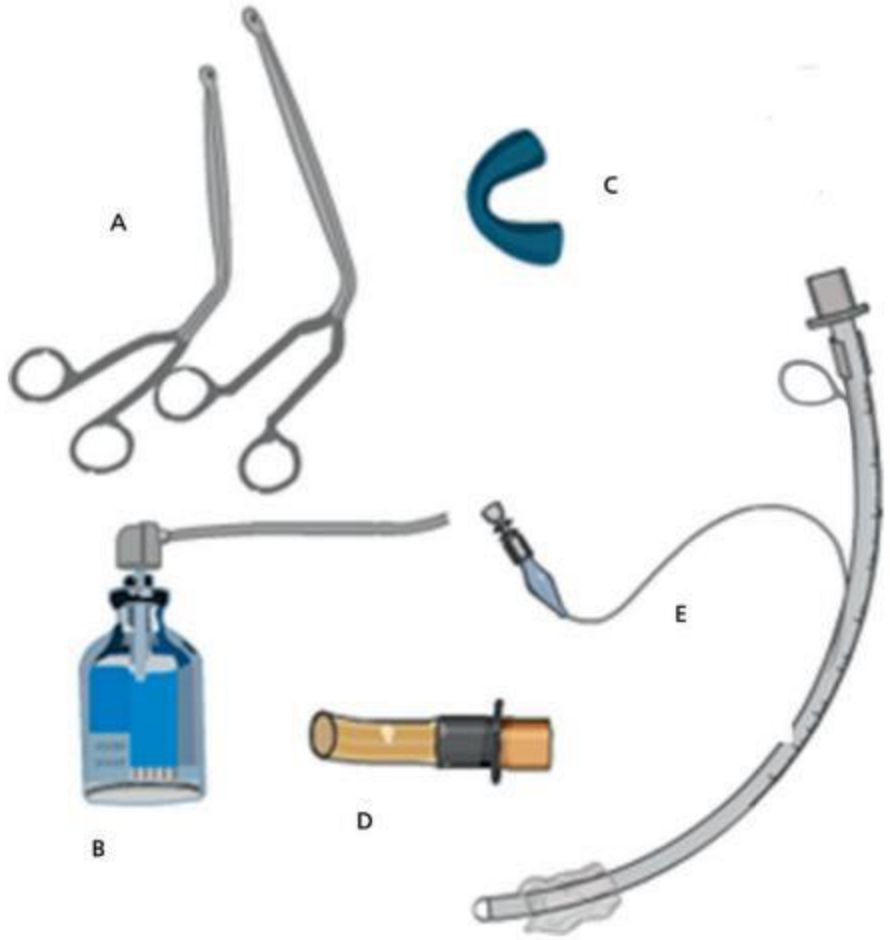


Fig. 10.13 *Intubation aids. (A) Magill forceps; (B) local Anesthetic spray; (C) bite guard; (D) Nosworthy airway; (E) Endotrol tube.*

Fig. 10.14 *Introducers or stylets.*

2. A bite guard protects the front upper teeth during direct laryngoscopy.

3. The Endotrol tube has a ring-pull on its inner curvature connected to the distal end of the tube. During intubation, the ring-pull can be used to adjust the curvature of the tube.
4. The Nosworthy airway is an example of the many modifications that exist in oropharyngeal airway design. This airway allows the connection of a catheter mount and a breathing system.
5. An introducer or stylet (Fig. 10.14) is used to adjust the curvature of a tracheal tube to help direct it through the vocal cords.
6. A gum elastic bougie is used when it is difficult to visualize the vocal cords. First, the bougie is inserted through the vocal cords, then the tracheal tube is railroaded over it. Single use intubating bougies are available.
7. The airway exchange catheter (AEC) allows the exchange of tracheal tubes. It is a long hollow tube that can be inserted through a tracheal tube. This can then be withdrawn and another tracheal tube is inserted over it. Specially designed detachable 15-mm male taper fit and Luer-Lok connectors can be used to provide temporary oxygenation.
8. The Aintree intubation catheter. This catheter is designed to be used with a fibrescope being passed through a laryngeal mask or other supraglottic airway device. It allows any appropriate size of tracheal tube to be inserted into the trachea which would otherwise be limited by the size of tube that could be passed through the supraglottic airway.

Chapter 11

NON-INVASIVE MONITORING EQUIPMENT

11.1 INTRODUCTION

This chapter covers basic monitors required for patient safety during an anesthetic administration, as defined by the American Society of Anesthesiologists (ASA) Standards for Basic Monitoring, and the role of the anesthesia technician in complying with these standards. The ASA standards were first approved in October 1986. The most recent update was completed in October 2015

11.2 ASA STANDARD I

“Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics, and monitored anesthesia care.”

11.3 ASA STANDARD II

Patient’s oxygenation, ventilation, circulation and temperature should be monitored throughout the conduct of all general anesthetics, regional anesthetics, and monitored anesthesia care.”

11.4 INTEGRATED MONITORING

Until recently, it was common to see the Anesthetic machine adorned with discrete, bulky monitoring devices. Significant advances in information technology have allowed an integrated monitoring approach to occur. Plug-in monitoring modules feed a single visual display on which selected values and waveforms can be arranged and colour coded (Figs 11.1–10.3). Although some would argue that such monitoring systems are complex and potentially confusing, their benefits in term of flexibility and ergonomics are undisputed. More recently, wireless monitoring systems are becoming available. An example is wireless invasive pressure monitoring systems (Fig. 11.4). This reduces the clutter of cables surrounding the patients.

Fig. 11***.1*** *Datex-Ohmeda plug-in monitoring modules mounted on the S/5 Advance Anesthetic machine.*

Fig. 11***.2*** *Datex-Ohmeda compact monitor.*

11.5 ELECTROCARDIOGRAM (ECG)

This monitors the electrical activity of the heart with electrical potentials of 0.5–2 mV at the skin surface. It is useful in determining the heart rate, ischemia, the presence of arrhythmias and conduction defects. It should be emphasized that it gives no assessment of cardiac output. The bipolar leads (I, II, III, AVR, AVL and AVF) measure voltage difference between two electrodes. The unipolar leads (V1–6) measure voltage at different electrodes relative to a zero point.

11.5.1 Components

1. Skin electrodes detect the electrical activity of the heart (Fig. 11.5). Silver and silver chloride form a stable electrode combination. Both are held in a cup and separated from the skin by a foam pad soaked in conducting gel.
2. Colour-coded cables to transmit the signal from electrodes to the monitor. Cables are available in 3- and 5-lead versions as snap or grabber design and with a

variety of lengths. All the cables of a particular set should have the same length to minimize the effect of electromagnetic interference.

3. The ECG signal is then boosted using an amplifier. The amplifier covers a frequency range of 0.05–150 Hz. It also filters out some of the frequencies considered to be noise. The amplifier has ECG filters that are used to remove the noise/ artifacts from ECG and produce a ‘clean’ signal.
4. An oscilloscope that displays the amplified ECG signal. A high-resolution monochrome or colour monitor is used.

Fig. 11***.3*** *Colour-coded values and waveforms displayed on the Zeus Dräger monitor. (Courtesy of Dräger.)*

Modern ECG monitors use multiple filters for signal processing. The filters used should be capable of removing the unwanted frequencies, leaving the signal intact (Fig. 11.6). Two types of filters are used for this purpose:

a. high-pass filters attenuate the frequency components of a signal below a certain frequency. They help to remove lower frequency noise from the signal. For example, the respiratory component from ECG can be removed by turning on a 1-Hz high pass filter on the amplifier. The filter will centre the signal around the zero isoline
b. low-pass filters attenuate the frequency components of a signal above a certain frequency. They are useful for removing noise from lower frequency signals. So an amplifier with a 35-Hz low-pass filter will remove/ attenuate signals above 35 Hz and help to ‘clean’ the ECG signal.

11.5.2 Modes of ECG monitors

The ECG monitor can have two modes:

- The monitoring mode has a limited frequency response of 0.5–50 Hz. Filters are used to narrow the bandwidth to reduce environmental artifacts. The high-frequency filters reduce distortions from muscle movement, mains current and electromagnetic interference from other equipment. The low-frequency filters help provide a stable baseline by reducing respiratory and body movement artifacts

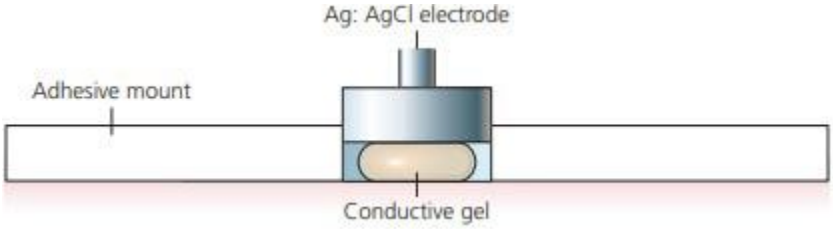


Fig. 11***.5*** *An ECG electrode.*

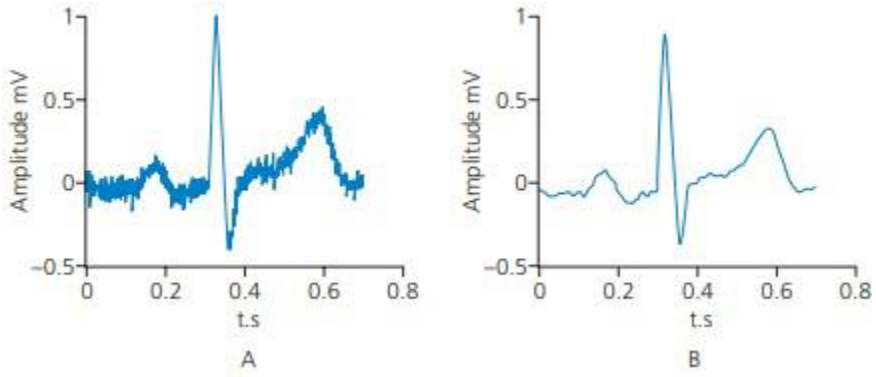


Fig. 11***.6*** *ECG filters. (A) Unfiltered signal with noise. (B) Filtered 'clean' signal.*

- The diagnostic mode has a wider frequency response of 0.05–150 Hz. The high-frequency limit allows the assessment of the ST segment, QRS morphology and tachyarrhythmias. The low-frequency limit allows representation of P and T wave morphology and ST-segment analysis.

11.5.3 ECG Electrodes

- There are many ECG electrode configurations. Usually during Anesthesia, three skin electrodes are used (right arm, left arm and indifferent leads). The three limb leads used include two that are 'active' and one that is 'inactive' (earth). Sometimes five electrodes are used. Lead II is ideal for detecting arrhythmias. CM5 configuration is able to detect 89% of ST-segment changes due to left ventricular ischemia. In CM5, the right arm electrode is positioned on the manubrium (chest lead from manubrium), the left arm electrode is on V5

position (fifth interspace in the left anterior axillary line) and the indifferent lead is on the left shoulder or any convenient position (Fig. 11.7).

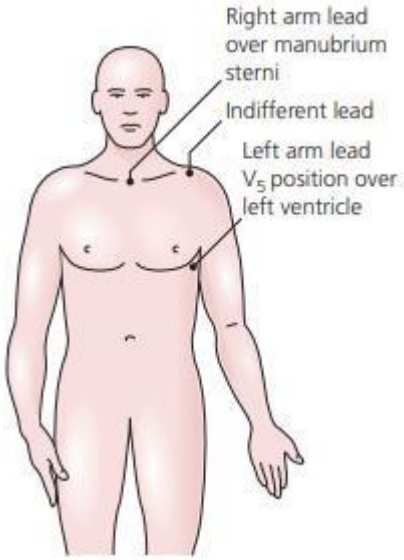


Fig. 11***.7*** *The CM5 ECG lead configuration.*

- The CB5 configuration is useful during thoracic Anesthesia. The right arm electrode is positioned over the centre of the right scapula and the left arm electrode is over V5.
- A display speed of 25 mm/s and a sensitivity of 1 mV/cm are standard in the UK

11.6 ARTERIAL BLOOD PRESSURE MONITORING

Oscillometry is the commonest method used to measure blood pressure non-invasively during Anesthesia. The systolic, diastolic and mean arterial pressures and pulse rate are measured, calculated and displayed. These devices give reliable trend information about the blood pressure. They are less reliable in circumstances where a sudden change in blood pressure is anticipated, or where a minimal change in blood pressure is clinically relevant. The term ‘device for indirect non-invasive automatic mean arterial pressure’ (DINAMAP) is used for such devices.

11.6.1 Components

1. A cuff with a tube used for inflation and deflation. Some designs have an extra tube for transmitting pressure fluctuations to the pressure transducer.
2. The case where the microprocessor, pressure transducer and a solenoid valve which controls the deflation of the arm cuff are housed. It contains the display and a timing mechanism which adjusts the frequency of measurements. Alarm limits can be set for both high and low values.

11.6.2 Mechanism of action

1. The microprocessor is set to control the sequence of inflation and deflation.
2. The cuff is inflated to a pressure above the previous systolic pressure, then it is deflated incrementally. The return of blood flow causes oscillation in cuff pressure (Fig. 11.9).
3. The transducer senses the pressure changes which are interpreted by the microprocessor. This transducer has an accuracy of ±2%.

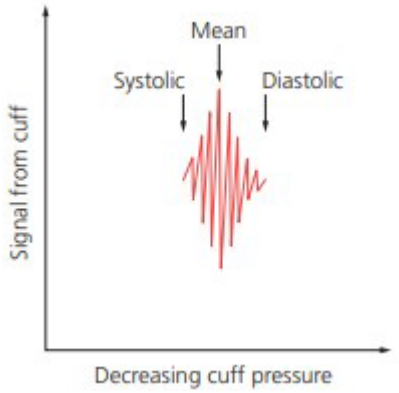


Fig. 11***.9*** *Diagram showing how oscillations in cuff pressure correspond to mean, systolic and diastolic pressures.*

4. The output signal from the transducer passes through a filter to an amplifier that amplifies the oscillations. The output from the amplifier passes to the microprocessor through the analogue digital converter (ADC). The microprocessor controls the pneumatic pump for inflation of the cuff and the solenoid valve for deflation of the cuff.
5. The mean arterial blood pressure corresponds to the maximum oscillation at the lowest cuff pressure. The systolic pressure corresponds to the onset of rapidly increasing oscillations.
6. The diastolic pressure corresponds to the onset of rapidly decreasing oscillations. In addition, it is mathematically computed from the systolic and mean pressure values (mean blood pressure = diastolic blood pressure + 1/3 pulse pressure).
7. The cuff must be of the correct size (Table 10.2). It should cover at least two-thirds of the upper arm. The width of the cuff's bladder should be 40% of the mid circumference of the limb. The middle of the cuff's bladder should be positioned over the brachial artery.

Table 10.2 A guide to the correct blood pressure cuff size

3 cm	Infant
5 cm	Infant
6 cm	Child
9 cm	Small adult
12 cm	Standard adult
15 cm	Large adult

8. Some designs have the ability to apply venous stasis to facilitate intravenous cannulation.

11.7 PULSE OXIMETRY

This is a non-invasive measurement of the arterial blood oxygen saturation at the level of the arterioles. A continuous display of the oxygenation is achieved by a simple, accurate and rapid method (Fig. 11.11).

Pulse oximetry has proved to be a powerful monitoring tool in the operating theatre, recovery wards, intensive care units, general wards and during the transport of critically ill patients. It is considered to be the greatest technical advance in monitoring of the last decade. It enables the detection of incipient and unsuspected arterial hypoxemia, allowing treatment before tissue damage.

11.7.1 Components

1. A probe is positioned on the finger, toe, ear lobe or nose (Fig. 11.12). Two light emitting diodes (LEDs) produce beams at red and infrared frequencies (660 nm and 940 nm respectively) on one side and there is a sensitive photodetector on the other side. The LEDs operate in sequence at a rate of about 30 times per second (Fig. 11.13).
2. The case houses the microprocessor. There is a display of the oxygen saturation, pulse rate and a plethysmographic waveform of the pulse. Alarm limits can be set for a low saturation value and for both high and low pulse rates.

Fig. 11***.11*** *Smiths Medical Finger Print oximeter.*

Fig. 11***.12*** *Pulse oximeter probes. Finger probe (top) and ear probe (bottom).*

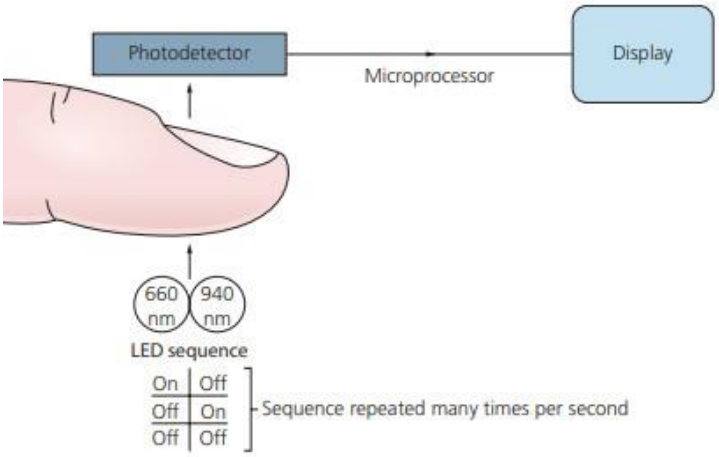


Fig. 11***.13*** *Working principles of the pulse oximeter. The LEDs operate in sequence and when both are off the photodetector measures the background level of ambient light.*

11.7.2 Mechanism of action

1. The oxygen saturation is estimated by measuring the transmission of light, through a pulsatile vascular tissue bed (e.g. finger). This is based on Beer's law (the relation between the light absorbed and the concentration of solute in the solution) and Lambert's law (relation between absorption of light and the thickness of the absorbing layer).
2. The amount of light transmitted depends on many factors. The light absorbed by non-pulsatile tissues (e.g. skin, soft tissues, bone and venous blood) is constant (DC). The non-constant absorption (AC) is the result of arterial blood pulsations (Fig. 11.14). The sensitive photodetector generates a voltage proportional to the transmitted light. The AC component of the wave is about 1–5% of the total signal.
3. The high frequency of the LEDs allows the absorption to be sampled many times during each pulse beat. This is used to enable running averages of saturation to be calculated many times per second. This decreases the 'noise' (e.g. movement) effect on the signal.

4. The microprocessor is programmed to mathematically analyze both the DC and AC components at 660 and 940 nm calculating the ratio of absorption at these two frequencies (R/IR ratio). The result is related to the arterial saturation. The absorption of oxyhaemoglobin and deoxyhaemoglobin at these two wavelengths is very different. This allows these two wavelengths to provide good sensitivity.

   805 nm is one of the isobestic points of oxyhaemoglobin and deoxyhaemoglobin.

   The OFF part allows a baseline measurement for any changes in ambient light.
5. A more recent design uses multiple wavelengths to eradicate false readings from carboxy haemoglobin and methaemoglobinaemia. Advanced oximeters use more than seven light wavelengths. This has enabled the measurement of haemoglobin value, oxygen content, carboxyhaemoglobin and methaemoglobin concentrations.
6. A variable pitch beep provides an audible signal of changes in saturation.

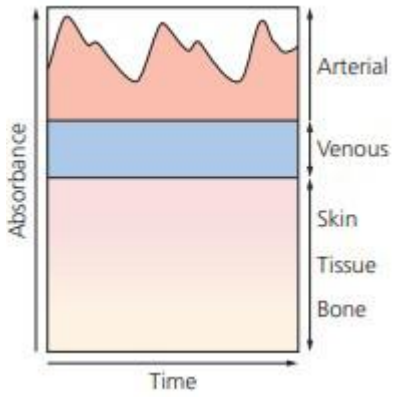


Fig. 11***.14*** *Schematic representation of the contribution of various body components to the absorbance of light.*

11.8 END-TIDAL CARBON DIOXIDE ANALYZER (CAPNOGRAPHS)

Gases with molecules that contain at least two dissimilar atoms absorb radiation in the infrared region of the spectrum. Using this property, both inspired and exhaled carbon dioxide concentration can be measured directly and continuously throughout the respiratory cycle (Fig. 11.15).

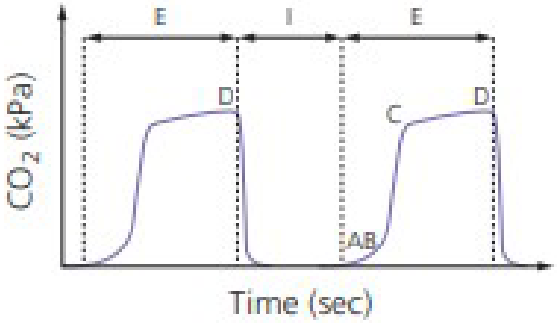


Fig. 11***.15*** *Diagram of an end-tidal carbon dioxide waveform. I = inspiration; E = expiration; A–B represents the emptying of the upper dead space of the airways. As this*

has not undergone gas exchange, the CO2 concentration is zero. B–C represents the gas mixture from the upper airways and the CO2-rich alveolar gas. The CO2 concentration rises continuously. C–D represents the alveolar gas and is described as the 'alveolar plateau'. The curve rises very slowly. D is the end-tidal CO2 partial pressure where the highest possible concentration of exhaled CO2 is achieved at the end of expiration. It represents the final portion of gas which was involved in the gas exchange in the alveoli. Under certain conditions (see text) it represents a reliable index of the arterial CO2 partial pressure. D–A represents inspiration where the fresh gas contains no CO2

The end-tidal CO2 is less than alveolar CO2 because the end-tidal CO2 is always diluted with alveolar dead space gas from un-perfused alveoli. These alveoli do not take part in gas exchange and so contain no CO2. Alveolar CO2 is less than arterial CO2 as the blood from unventilated alveoli and lung parenchyma (both have higher CO2 contents) mixes with the blood from ventilated alveoli. In healthy adults with normal lungs, end-tidal CO2 is 0.3–0.6 kPa less than arterial CO2. This difference is reduced if the lungs are ventilated with large tidal volumes. The Greek root kapnos, meaning 'smoke', give us the term capnography (CO2 can be thought as the 'smoke' of cellular metabolism).

End-tidal CO alveolar CO aCO 2 2 2 < < P

In reality, the devices used cannot determine the different phases of respiration but simply report the minimum and maximum CO2 concentrations during each respiratory cycle.

11.8.1Components

1. The sampling chamber can either be positioned within the patient's gas stream (mainstream version, Fig. 11.16) or connected to the distal end of the breathing system via a sampling tube (side-stream version, Fig. 11.17).
2. A photodetector measures light reaching it from a light source at the correct infrared wavelength (using optical filters) after passing through two chambers. One acts as a reference whereas the other one is the sampling chamber (Fig. 11.18).

11.8.2 Mechanism of action

1. Carbon dioxide absorbs the infrared radiation particularly at a wavelength of 4.3 µm.
2. The amount of infrared radiation absorbed is proportional to the number of carbon dioxide molecules (partial pressure of carbon dioxide) present in the chamber.
3. The remaining infrared radiation falls on the thermopile detector, which in turn produces heat. The heat is measured by a temperature sensor and is proportional to the partial pressure of carbon dioxide gas present in the mixture in the sample chamber. This produces an electrical output. This means that the amount of gas present is inversely proportional to the amount of infrared light present at the detector in the sample chamber .
4. In the same way, a beam of light passes through the reference chamber which contains room air. The absorption detected from the sample chamber is compared to that in the reference chamber. This allows the calculation of carbon dioxide values.

5. The inspired and exhaled carbon dioxide forms a square wave, with a zero baseline unless there is rebreathing.
6. A microprocessor-controlled infrared lamp is used. This produces a stable infrared source with a constant output. The current is measured with a current sensing resistor, the voltage across which is proportional to the current flowing through it. The supply to the light source is controlled by the feedback from the sensing resistor maintaining a constant current of 150 mA.

Fig. 11***.17*** *The Penlon PM9000 Express which measures end-tidal CO2, oximetry and inhalational agent concentration using a side-stream method.*

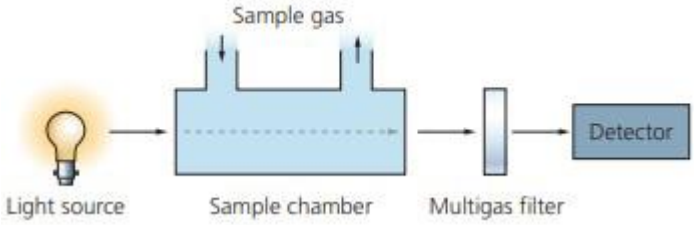


Fig. 11***.18*** *Components of a gas analyzer using an infrared light source suitable for endtidal carbon dioxide measurement. The reference chamber has been omitted for the sake of clarity*

7. Using the rise and fall of the carbon dioxide during the respiratory cycle, monitors are designed to measure the respiratory rate.
8. Alarm limits can be set for both high and low values.
9. To avoid drift, the monitor should be calibrated regularly with known concentrations of CO2 to ensure accurate measurement.

Photo-acoustic spectroscopy: in these infrared absorption devices, the sample gas is irradiated with pulsatile infrared radiation of a suitable wavelength. The periodic expansion and contraction produces a pressure fluctuation of audible frequency that can be detected by a microphone.

The advantages of photo-acoustic spectrometry over conventional infrared absorption spectrometry are:

1. The photo-acoustic technique is extremely stable and its calibration remains constant over much longer periods of time.
2. The very fast rise and fall times give a much more accurate representation of any change in CO2 concentration.

Carbon dioxide analyzers can be either side-stream or main-stream analyzer.

Increased end-tidal carbon dioxide	Decreased end-tidal carbon dioxide
Hypoventilation	Hyperventilation
Rebreathing	Pulmonary embolism
Sepsis	Hypoperfusion
Malignant hyperpyrexia	Hypometabolism
Hyperthermia	Hypothermia
Skeletal muscle activity	Hypovolaemia
Hypermetabolism	Hypotension

11.8.3 Problems in practice and safety features

1. In patients with chronic obstructive airways disease, the waveform shows a sloping trace and does not accurately reflect the end-tidal carbon dioxide (see Fig. 11.20B). An ascending plateau usually indicates impairment of ventilation: perfusion ratio because of uneven emptying of the alveoli.
2. During paediatric Anesthesia, it can be difficult to produce and interpret end-tidal carbon dioxide because of the high respiratory rates and small tidal volumes. The patient's tidal breath can be diluted with fresh gas.
3. During a prolonged expiration or end-expiratory pause, the gas flow exiting the trachea approaches zero. The sampling line may aspirate gas from the trachea and the inspiratory limb, causing ripples on the expired CO2 trace (cardiogenic oscillations). They appear

during the alveolar plateau in synchrony with the heart beat. It is thought to be due to mechanical agitation of deep lung regions that expel CO2-rich gas. Such fluctuations can be smoothed over by increasing lung volume using positive end expiratory pressure (PEEP).

4. Dilution of the end-tidal carbon dioxide can occur whenever there are loose connections and system leaks.
5. Nitrous oxide (may be present in the sample for analysis) absorbs infrared light with an absorption spectrum partly overlapping that of carbon dioxide. This causes inaccuracy of the detector, nitrous oxide being interpreted as carbon dioxide. By careful choice of the wavelength using special filters, this can be avoided. This is not a problem in most modern analyzer.
6. Collision broadening or pressure broadening is a cause of error. The absorption of carbon dioxide is increased because of the presence of nitrous oxide or nitrogen. Calibration with a gas mixture that contains the same background gases as the sample solves this problem.

11.9 NEUROMUSCULAR MONITORING

There are various methods for monitoring the neuromuscular transmission using a nerve stimulator (Fig. 11.37).

1. Twitch: a short duration (0.1–0.2 ms) square wave stimulus of a frequency of 0.1–1 Hz (one stimulus every 10 seconds to one stimulus every 1 second) is applied to a peripheral nerve. When used on its own, it is of limited use. It is the least precise method of assessing partial neuromuscular block.

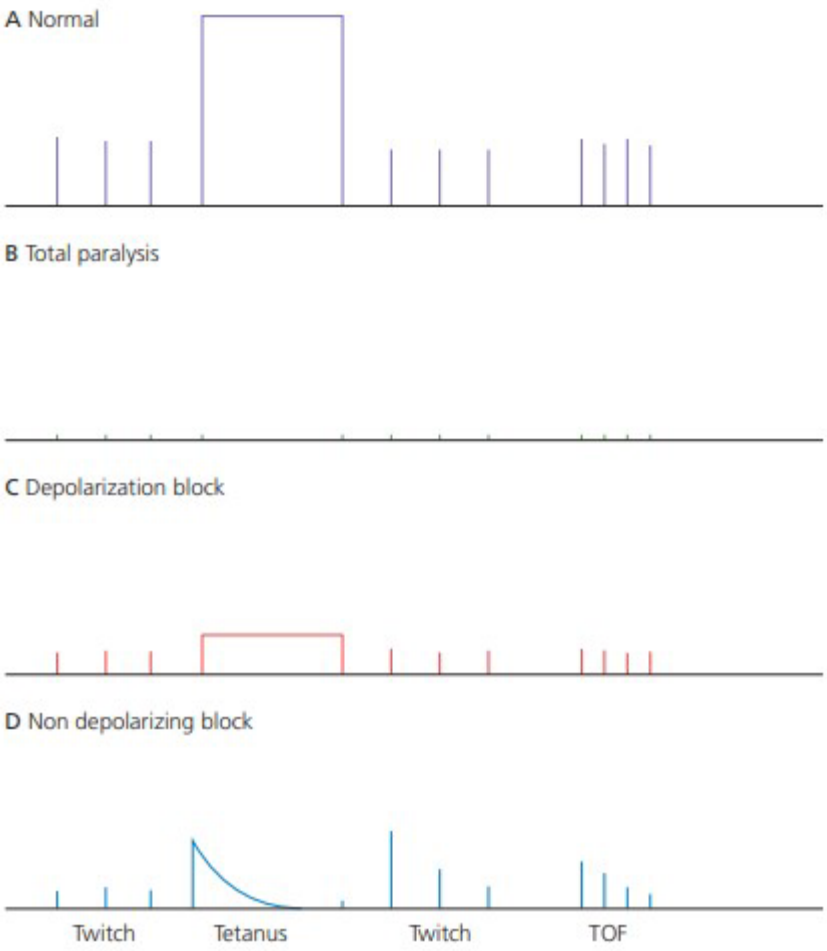


Fig. 11***.37*** *Effects of a single twitch, tetanus and train-of-four (TOF) assessed by a force transducer recording contraction of the adductor pollicis muscle.*

Fig. 11***.38*** *The pattern of double-burst stimulation. Three impulses of 50 Hz tetanus, at 20-ms intervals, every 750 ms is shown.*

2. Tetanic stimulation: a tetanus of 50–100 Hz is used to detect any residual neuromuscular block. Fade will be apparent even with normal response to a twitch. Tetanus is usually applied to anaesthetized patients because of the discomfort caused.
3. Train-of-four (TOF): used to monitor the degree of the neuromuscular block clinically. The ratio of the fourth to the first twitch is called the TOF ratio:

a. Four twitches of 2 Hz each applied over 2 s. A gap of 10 s between each TOF

b. As the muscle relaxant is administered, fade is noticed first, followed by the disappearance of the fourth twitch. This is followed by the disappearance of the third then the second and last by the first twitch
c. On recovery, the first twitch appears first then the second followed by the third and fourth; reversal of the neuromuscular block is easier if the second twitch is visible
d. For upper abdominal surgery, at least three twitches must be absent to achieve adequate surgical conditions
e. The TOF ratio can be estimated using visible or tactile means. Electrical recording of the response is more accurate.

4. Post-tetanic facilitation or potentiation: this is used to assess more profound degrees of neuromuscular block.

   Double burst stimulation (Fig. 11.38): this allows a more accurate visual assessment than TOF for residual neuromuscular blockade. Two short bursts of 50 Hz tetanus are applied with a 750-ms interval. Each burst comprises two or three square wave impulses lasting for 0.2 ms.

Section III

STERILIZATION AND INFECTION CONTROL

Chapter 12

DEFINITIONS

12.1 INTRODUCTION

The purpose of sterilization and disinfection procedures is to prevent transmission of microbes to patients. In addition to sterilization and disinfection, other important measures to prevent transmission are included in the protocol of "**standard precautions**" (previously known as Universal Precautions). These standard precautions should be used in interaction with *all* patients because it is unknown whether any particular patient may be the reservoir of transmissible bacteria, viruses, or other microbes.

12.1.1 Standard Precautions

Standard precautions include:

1. hand hygiene
2. respiratory hygiene and cough etiquette
3. safe injection practices
4. proper disposal of needles and scalpels.

Further, if exposure to body fluids or aerosols is likely, **personal protective equipment** (PPE) such as masks or face shields, gloves, gowns, and protective eyewear should be used. The precautions taken should be specific for the task rather than for the particular patient.

12.1.2 Transmission-Based Precautions

In addition, there are transmission-based precautions that supplement the standard precautions and should be employed when the patient is infected (or suspected to be infected) with a highly transmissible organism. The three categories of transmission based precautions are **contact, droplet,** and **airborne**.

12.2 KEY TERMS

12.2.1 Aerobic

Microorganism that requires air or the presence of oxygen for maintenance of life. **12.2.2 .Anaerobic**

Microorganism that grows best in an oxygen-free environment or one that cannot tolerate oxygen (e.g., Clostridium species that causes gas gangrene).

12.2.3 Antibiotics

Substances, natural or synthetic, that inhibit growth of or destroy microorganisms. Used as therapeutic agents against infectious diseases; some are selective for a specific organism; some are broad-spectrum antibiotics.

12.2.4 Antimicrobial agent

Chemical or pharmaceutical agent that destroys or inhibits growth of microorganisms.

12.2.5 Biofilm

Three-dimensional layers of living bacteria embedded in a sticky matrix that persists on the surface of tissues and implanted medical devices. Commonly the cause of chronic infections, such as otitis media and rhinitis.

12.2.6 Community-acquired infection

Infectious disease process that developed or was incubating before the patient entered the health care facility.

12.2.7 Cross-contamination Transmission of microorganisms from patient to patient and from inanimate objects to patients and vice versa

12.2.8 Florae

Bacteria and fungi normally inhabiting the body, resident or transient.

12.2.9 Hospital-acquired infection (HAI)

An infection that was not present when the patient was admitted to the health care facility. Infection may occur at the surgical site or as a complication unrelated to the surgical site (formerly known as nosocomial infection).

12.2.10 Infection

Invasion of the body by pathogenic microorganisms and the reaction of tissues to their presence and to toxins generated by the organisms.

12.2.11 Microorganisms

Living organisms, invisible to the naked eye, including bacteria, fungi, viruses, protozoa, yeasts, and molds.

12.3 Sterilization

Sterilization is the killing or removal of all microorganisms, including bacterial spores, which are highly resistant.

Sterilization is usually carried out by **autoclaving,** which consists of exposure to steam at 121°C under a pressure of 15 lb/in^2 for 15 minutes.

Surgical instruments that can be damaged by moist heat are usually sterilized by exposure to ethylene oxide gas, and most intravenous solutions are sterilized by filtration.

12.4 Disinfection

Disinfection is the killing of many, but not all, microorganisms.

For adequate disinfection, pathogens (disease-causing microorganisms) must be killed, but some organisms and bacterial spores may survive.

12.4.1 Disinfectants vary in their tissue-damaging properties from the corrosive phenol containing compounds, which should be used only on inanimate objects, to less toxic materials such as ethanol and iodine, which can be used on skin surfaces.

12.4.2 Antiseptics

Chemicals used to inhibit the growth of microorganisms (without necessarily killing them) on the surface of skin and mucous membranes are called antiseptics.

12.4.3 Aseptic and Sterile techniques

Sterile means free of living microorganisms, including all spores.

The terms aseptic and sterile are not same, although aspects of both are closely related. An object can be aseptic without being sterile.

Asepsis literally means “without dirt,” and it implies the absence of pathogenic microorganisms that cause infection.

12.5 Decontamination

Cleaning and disinfecting or sterilizing processes carried out to make **contaminated** (infected by microorganisms) items safe to handle.

12.5.1 Clean, disinfect or sterilize instruments?

As there is no need to sterilize all clinical items and some items can’t be sterilized, healthcare policies must identify whether cleaning, disinfection or sterilization is indicated based primarily on the items’ intended use.

Earle H Spaulding devised a classification system where instruments and items used for patient care are divided into **three categories** based on the degree of risk of infection involved in the use of the items:

Table. Spaulding classification

Critical	Semi-critical	Non-critical

• Items which enter normally sterile tissue or the vascular system or through which blood flows • They have **a high risk of infection** • These items should be **sterile**	• Items that touch the mucous membranes or skin that is not intact • They require a **high-level disinfection process** as intact mucous membranes are generally resistant to infection, • such items pose an **intermediate risk** • Such devices should ideally be sterilized but chemical disinfection is usually reserved for those that are intolerant of heat sterilization	• Items that touch only intact skin require low-level disinfection as skin is an effective barrier to microorganisms, • such items pose a **low risk of infection**
Examples: surgical instruments and needles	**Example:** laryngoscopes	**Examples:** bedpans and blood pressure cuffs.

12.6 Cleaning

Cleaning is the removal of visible soil (e.g., organic and inorganic material) from objects and surfaces.

It is normally accomplished by manual or mechanical means using water with detergents or enzymatic products.

Chapter 13

STERILIZATION AND DISINFECTION METHODS

13.1 CLEANING

Involves physical removal of the infectious material or organic matter on which microorganisms thrive.

The critical parameters for cleaning are the following:

1. Temperature
2. Chemicals
3. Energy
4. Time

13.1.1 Temperature

Initial wash temperatures must be below 45°C to prevent coagulation of tissue/blood residues.

13.1.2 Chemicals

Detergents used are a complex formulation of chemicals designed to remove soil (proteins, carbohydrates, lipids, etc.) from instruments. Detergents have an optimal concentration and pH to work effectively.

13.1.3 Energy

This may take the form of manual washing, ultrasonic energy or water jets/sprays in automated washer disinfectors.

13.1.4 Time

The cleaning cycle requires a suitable time period to achieve its desired effect.

13.2 Methods of Cleaning

Cleaning can be achieved either by:

13.2.1 Manual cleaning

- Immersion in a diluted detergent at 35°C.
- Non-immersion techniques involve a cloth soaked in cleaning solution and used to wipe the items. This can be used for electrical equipment.

12.2.2 Mechanical cleaning

It uses thermal disinfection, chemical disinfection (see later) or ultrasonic cleaners.

13.2.3 Ultrasonic cleaning

It is used in areas that are difficult to access. The ultrasonic waves create small bubbles on the surfaces of the instruments.

13.3 MATERIAL USED FOR STERILIZATION AND DISINFECTION

13.3.1 Chemical Agents

Chemicals vary greatly in their ability to kill microorganisms. Chemical agents act primarily by one of the three mechanisms:

1. disruption of the lipid-containing cell membrane
2. modification of proteins
3. modification of DNA

Each of the following chemical agents has been classified into one of the three categories, but some of the chemicals act by more than one mechanism.

AGENT	PROPERTIES	USES
	Disruption of cell membrane	
Alcohol	• It acts mainly by disorganizing the lipid structure in membranes, but it denatures proteins as well. • Ethanol requires the presence of water for maximal activity (i.e., it is far more effective at 70% than at 100%). • Ethanol will not kill bacterial spores and therefore cannot be used for sterilization.	**Seventy percent ethanol** is often used as an antiseptic to clean the skin prior to venipuncture.

Detergents	• Detergents are “surface active” agents. • These surfactants interact with the lipid in the cell membrane and disrupt it.	• Quaternary ammonium compounds (e.g., benzalkonium chloride) are widely used for skin antisepsis. • **Benzalkonium** chloride is the active ingredient in Lysol, a commonly used disinfectant for floors and other surfaces.
Phenols	· Phenol was the first disinfectant used in the operating room (by Lister in the 1860s), but it is rarely used as a disinfectant today because it is **too caustic**.	· **Chlorhexidine** is a chlorinated phenol that is widely used as a hand disinfectant prior to surgery (“surgical scrub”) and in the

	· Phenols not only damage membranes, but also denature proteins.	cleansing of wounds.
Modification of proteins		
Chlorine	Chlorine is a powerful oxidizing agent that kills by cross-linking essential sulfhydryl groups in enzymes to form the inactive.	• Chlorine is used as a disinfectant to purify the water supply and to treat swimming pools. • It is also the active component of **hypochlorite** (bleach, Clorox), which is used as a disinfectant in the home and in hospitals.

Iodine	• Iodine is the most effective skin antiseptic used in medical practice and should be used prior to obtaining a blood culture and installing intravenous catheters. • Iodine, like chlorine, is an oxidant that inactivates sulfhydryl-containing enzymes. • It also binds specifically to tyrosine residues in proteins.	Iodine is supplied in two forms: • **Tincture of iodine** (2% solution of iodine and potassium iodide in ethanol) is used to prepare the skin prior to blood culture. Because tincture of iodine can be irritating to the skin, it should be removed with alcohol. • **Iodophors** are complexes of iodine with detergents that are frequently used to prepare the skin prior to surgery because they are less irritating than tincture of iodine. **Povidone-iodine** is an iodophor

			commonly used as an antiseptic.

Heavy metals	·	**Mercury** and **silver** have the greatest antibacterial activity of the heavy metals and are the most widely used in medicine.	• **Thimerosal** (Merthiolate) and **merbromin** (Mercurochrome), which contain mercury, are used as skin antiseptics.
	·	They act by binding to sulfhydryl groups, thereby blocking enzymatic activity.	• **Silver nitrate drops** are effective in preventing gonococcal neonatal conjunctivitis (ophthalmia neonatorum, eye infection in neonates).
			• **Silver sulfadiazine** is used to prevent infection of burn wounds.
Hydrogen peroxide	·	Hydrogen peroxide is an oxidizing agent that attacks sulfhydryl groups, thereby inhibiting enzymatic activity.	Hydrogen peroxide is used as an antiseptic to clean wounds.
	·	Its effectiveness is limited by the organism's ability to produce catalase, an enzyme that degrades H_2O_2. (The bubbles produced when peroxide is used on wounds are formed by oxygen arising from the breakdown of H_2O_2 by tissue catalase.)	
Formaldehyde & Glutaraldehyde	·	**Formaldehyde,** which is available as a 37% solution in water (formalin), denatures proteins and nucleic acids.	In hospitals, it is used to sterilize respiratory therapy equipment, endoscopes, and hemodialysis equipment.
	·	**Glutaraldehyde**, which has two reactive aldehyde groups, is 10 times more effective than formaldehyde and is less toxic.	

Ethylene Oxide	• Ethylene oxide kills by alkylating both proteins and nucleic acids. • It is classified as a **mutagen** (cause mutations in DNA) and a **carcinogen** (cancer causing agent).	**Ethylene oxide gas** is used extensively in hospitals for the sterilization of heat-sensitive materials such as surgical instruments and plastics.
Acids & Alkalis	• Strong acids and alkalis kill by denaturing proteins. • Although most bacteria are susceptible, it is important to note that Mycobacterium tuberculosis and other mycobacteria are relatively resistant to 2% NaOH.	• **2% NaOH** is used in the clinical laboratory to liquefy sputum prior to culturing the organism. • Weak acids, such as **benzoic, propionic,** and **citric acids**, are frequently used as food preservatives because they are bacteriostatic (stops the growth of bacteria).
	Modification of Nucleic Acids	
Crytal violet dye	A variety of dyes not only stain microorganisms, but also inhibit their growth.	Crystal violet (gentian violet), is an antiseptic used to treat fungal infections of the skin
Malachite green dye		Malachite green, a triphenylamine dye like crystal violet, is a component of Löwenstein-Jensen's medium, which is used to grow *M. tuberculosis*. The dye inhibits the growth of unwanted organisms in the sputum during the 6-week incubation period.

13.3.2 Physical Agents

The physical agents act either by imparting energy in the form of **heat** or **radiation** or by removing organisms through **filtration**.

13.4 HEAT

In general, heat kills by denaturing proteins, but membrane damage and enzymatic cleavage of DNA may also be involved. Heat energy can be applied in three ways:

1. in the form of moist heat (either boiling or autoclaving)
2. dry heat
3. pasteurization

13.4.1 Moist Heat

Moist heat sterilizes at a lower temperature than dry heat**.** Moist heat sterilization, usually **autoclaving**, is the most frequently used method of sterilization. Because bacterial spores are resistant to boiling (100°C at sea level), they must be exposed to a higher temperature; this cannot be achieved unless the pressure is increased. For this purpose, an autoclave chamber is used in which steam, at a pressure of 15 lb/in^2, reaches a temperature of 121°C and is held at that temperature for 15 to 20 minutes. This kills even the highly heat-resistant spores.

13.4.2 Dry Heat

Sterilization by dry heat, on the other hand, requires temperatures in the range of 180°C for 2 hours. This process is used primarily for glassware and is used less frequently than autoclaving.

13.4.3 Pasteurization

Pasteurization, which is used primarily for milk, consists of heating the milk to 62°C for 30 minutes followed by rapid cooling. ("**Flash**" **pasteurization** at 72°C for 15 seconds is often used.) This is sufficient to kill the vegetative cells of the milk-borne pathogens, but not to sterilize the milk.

13.5 RADIATION

The two types of radiation used to kill microorganisms are **ultraviolet** (UV) **light** and **Xrays**.

13.5.1 Ultraviolet Light

The greatest antimicrobial activity of UV light occurs at **250 to 260 nm wavelength**. DNA replication is inhibited and the organism cannot grow. Cells have repair mechanisms against UV-induced damage. Because UV radiation can damage the cornea and skin, the

use of UV irradiation in medicine is limited. However, it is used in hospitals to kill air-borne organisms, especially in operating rooms when they are not in use. Bacterial spores are quite resistant and require a dose up to 10 times greater than do the vegetative bacteria.

13.5.2 X-Rays

X-rays have higher energy and penetrating power than UV radiation and kill mainly by the **production of free radicals**. These highly reactive radicals can break covalent bonds in DNA, thereby killing the organism. Another mechanism is a direct hit on a covalent bond in DNA, resulting in chain breakage, but this is probably less important than the mechanism involving free radicals.

X-rays kill vegetative cells readily, but spores are remarkably resistant, probably because of their lower water content. X-rays are used in medicine for sterilization of heat-sensitive items, such as sutures and surgical gloves, and plastic items, such as syringes.

13.6 FILTERATION

Filtration is the preferred method of sterilizing certain solutions (e.g., those with heatsensitive components). The most commonly used filter is composed of nitrocellulose and has a pore size of **0.22 mm**. This size will retain all bacteria and spores. Filters work by physically trapping particles larger than the pore size and by retaining somewhat smaller particles via electrostatic attraction of the particles to the filters.

13.7 DISINFECTION

Involves reduction of microorganisms on devices.

13.7.1. Thermal washer disinfectors

It combines cleaning and disinfection. Powerful water and detergent jets heated to about 80°C are used. Most organisms are inactivated except for bacterial spores, some heat resistant viruses.

13.7.2. Chemical disinfection

It is the destruction of micro-organisms by chemical or physiochemical means. It is frequently used for devices that are heat sensitive in the semi-critical category such as endoscopes.

Examples are glutaraldehyde 2% for 20 min, hydrogen peroxide 6–7.5% for 20–30 min, peracetic acid 0.2–0.35% for 5 min and ortho-phthalaldehyde (OPA) for 5–12 min.

13.7.3. Pasteurization (heat disinfection)

It is heating to 60– 100°C for approximately 30 min to reduce the number of pathogens by killing a significant number of them.

The higher the temperature, the shorter the time needed.

13.8 STERILIZATION

The complete destruction of all micro-organisms.

13.8.1 Sterility assurance level (SAL)

Sterility is the probability of complete sterilization. This probability is known as the sterility assurance level (SAL). A sterile device has a SAL of 10^{-6}, which means that the probability of an organism surviving on that device is one in a million using a validated process.

The **methods** used to achieve sterility include the following:

1. Steam sterilization
2. Ionizing radiation
3. Dry heat sterilization (hot air oven):
4. Ethylene oxide

13.8.2 Steam sterilization

Steam sterilization is currently the gold standard method. It is reliable, easy to monitor, non-toxic, inexpensive, sporicidal and has high lethality, rapid heating and good penetration of fabrics. The temperature and pressure reached determine the time to sterilization. Usually, a temperature of 134°C maintained for a period of 3 min under a pressure of 2.25bars is used.

13.8.3 Ionizing radiation

Ionizing radiation using γ rays to produce sterility. It is ideal for prepacked heat-labile single-use items such as IV cannula and syringes. This technique of sterilization is widely used in industry.

13.8.4 Dry heat sterilization (hot air oven)

A constant supply of electricity is needed. Used for reusable glass, metal instruments, oil, ointments and powders.

13.8.5 Ethylene oxide

It can effectively sterilize most equipment that can withstand temperatures of 50–60°C. However, it is used under carefully controlled conditions because it is extremely toxic, carcinogenic, flammable and an explosion risk. Although it is very versatile and can be used for heat-sensitive equipment, fluids and rubber, a long period of aeration is necessary to remove all traces of gas before the equipment can be distributed. The processing time ranges from 2 to 24 h and is a very costly process.

13.9 SINGLE-USE ITEMS

The use of single-use items should be encouraged when possible. This practice ensures the sterility of the equipment and prevents cross-infection. The quality of such devices must be the same as the reusable ones. As a large proportion of these devices are made from PVC plastic materials, a balance should be struck between the reduction in infection risk and effect on the environment.

Chapter 14

ANESTHESIA SUPPLY AND EQUIPMENT: CONTAMINATION, SANITATION AND WASTE MANAGEMENT

14.1 INTRODUCTION

All health care workers share the responsibility of preventing the transmission of infectious diseases. Anesthesia technicians are on the frontlines in the battle against infectious diseases in the operating room. Multiple pathogens present in our working environment can cause serious illness or death in our patients or coworkers, as the anesthesia machine and associated equipment are potential vectors in the spread of infection. Improper handling and cleaning of anesthesia apparatus can increase the transmission of pathogens, causing postoperative wound infections, respiratory system infections like pneumonia, or infections that invade the bloodstream and entire body. Both patients and health care workers are at risk. Anesthesia equipment and personnel are in close contact with patients' blood, mucous membranes (i.e., mouth, nose), and secretions. The Centers for Disease Control and Prevention (CDC) call these "potentially infectious materials" (PIMs). Blood and secretions create a moist environment for growth and survival of pathogens such as fungi, yeast, viruses, and bacteria.

14.2 STERILE OPERATIVE TERMINOLOGY

14.2.1 Contamination: This is the state of actually or potentially having been in contact with microorganisms. It may also refer to the presence of pathogens or unwanted foreign material on an object. Contamination may occur via contact with patients, handling by staff, splashing, or contact with already contaminated objects.

14.2.2 Bioburden (bioload, microbial load): This is the number and types of viable organisms contaminating an object. The level of bioburden is related to the anatomic site where the device was used (Fig. 14.1).

FIGURE 14.1. Video laryngoscope blade with bioburden.

14.2.3 Cross-contamination:

The transmission of microorganisms. Cross contamination can occur via contaminated medical equipment or through health care workers (e.g., child's toy, baby doll use on multiple patients without cleaning). Other terms are already

14.3 ANESTHESIA TURNOVER

All anesthesia practitioners and technicians should be concerned with the cleanliness of their equipment, both to prevent the spread of infections between patients and to ensure that they themselves do not contract infections. Nosocomial infections (infections acquired in a health care facility) continue to be a significant drain on human and economic resources, producing suffering and higher health care costs. Infection control has become an important focus of The Joint Commission (TJC) (formerly called the Joint Commission on Accreditation of Healthcare Organizations [JCAHO]). It is important to follow the cleaning and maintenance policies of individual machine manufacturers. Doing so can be a challenge, as recommendations vary among manufacturers.

14.3.1 Anesthesia Breathing Circuits Most institutions in the United States use single-use breathing circuits that are disposed of and replaced between cases. However, in many other parts of the world, reusable circuits are used with a single-use filter to prevent cross contamination. When reusable circuits are used, there is a risk that microorganisms may be retained in components of a circular system that could cause respiratory infections in subsequent patients. Because of this risk, bacterial filters are incorporated between the

expiratory valve and the expiratory limb or between the endotracheal tube and the Ypiece. When the filter is placed between the endotracheal tube and the Y-piece, the anesthesia technician may replace the filter and leave the circuit to be reused on the next case if this practice has been approved by local institutional policy. When the filter is placed between the expiratory valve and the expiratory limb, both the circuit and the filter need to be discarded at the end of the case. Placement of a filter in the expiratory limb of the breathing circuit is commonly used to prevent contamination of the anesthesia machine. Many filters are commercially available; the two major types are pleated hydrophobic filters and electrostatic filtersdefined in chapter 12 and 13

14.3.2 Anesthesia Machine Cleaning

Machine surfaces should be decontaminated between cases. It is not necessary to regularly decontaminate the internal components of the anesthesia machine, including the vaporizers, flowmeters, gas outlets, and valves. However, components of the ventilator, including ventilator tubing, unidirectional valves, and bellows, should be cleaned or changed according to manufacturer specifications.

14.3.3 Anesthesia Equipment Cleaning

To prevent cross-contamination between cases, all reusable equipment must be decontaminated, and all single-use items should be disposed of after use. Single use items may include oral and nasal airways, endotracheal tubes, supraglottic airways, face masks, oxygen tubing, and breathing circuits. Always refer to the manufacturer instruction for guidance in determining the intended use of an item.

14.3.4 Anesthesia Work Area and Auxiliary Part Cleaning

All surfaces of monitors, ventilator controls, flowmeter knobs, vaporizer controls, blood and fluid warmers, machines, carts, cabinets, drawers, handles, touch screens, and any other work areas should be decontaminated between cases. Because porous surfaces are difficult to properly disinfect, surfaces in the operating room should be nonporous.

Reusable monitors and probes, and anything that could come in contact with a patient’s skin, respiratory tract, or bloodstream must be disinfected between patients. These include, but are not limited to, blood pressure cuffs, ECG cables and leads, pulse oximeters, temperature probes, stethoscopes, and all noninvasive cables. When cleaning electronic equipment and computers, manufacturer instructions should be followed, as exposure to certain chemicals (even water) may damage these devices

14.4 ANESTHESIA DRUG MANAGEMENT

Vials and syringes of medications are intended for use in only one patient and should not be used for multiple patients. Several incidents of serious infections transmitted between patients have been traced to the use of medication vials that were inappropriately used for multiple patients. Dispose of any opened vials or syringes of medications between cases. Each hospital will have a unique policy for disposal of controlled substances such as

opioids, benzodiazepines, ketamine, and others. Because these medications have high potential for abuse, their use is closely tracked. These drugs usually need to be disposed of by the anesthesia provider who checked them out from the pharmacy, and they are often placed in a closed container.

14.5 HANDLING AND DISPOSAL OF SHARPS

A sharp is any object that could cut or puncture the skin, such as a scalpel, needle, or broken glass. Health care workers should keep handling of sharps to a minimum. Anesthesia personnel are at risk of occupational exposure to blood borne pathogens, such as human immunodeficiency virus (HIV), hepatitis B virus, and hepatitis C virus, by accidental injury from a contaminated needle or other sharps. All anesthesia personnel should use alternative needleless systems whenever possible and use devices with safety features when available. Some safety features include retractable needles, selfresheathing needles, and hinged recap needles. When sharps must be used, it is imperative to follow safety precautions in order to prevent needle stick injuries. Needles should never be recapped. Always be aware of the location of other staff members in the area to avoid injuries to a coworker. Be sure to use clear communication when using or transporting sharps. If a sharp is dropped on the floor, an instrument should be used to recover the sharp rather than simply using one's hand. Anesthesia technicians may be asked to assist with looking for an object that has been placed in the trash inappropriately. Extreme care should always be exercised whenever handling trash, as a sharp may have been inadvertently placed in the wrong container. Many recommend using an instrument, such as disposable forceps, for sorting through the trash. The anesthesia technician often also assists with or participates in disposing of equipment and trays that contain sharps. Sharps are to be disposed of in leak-proof, punctureresistant containers that are accessible to all personnel. Containers should be sealed and disposed of when two-thirds full. Be sure that the container is properly sealed before handling or transporting it.

14.6 WASTE MANAGEMENT AND DISPOSAL (SOLID WASTE, MEDICAL WASTE, RECYCLING, AND REPROCESSING)

It is estimated that operating rooms are responsible for 20%-30% of total hospital waste. The increasing use of disposable, single-use equipment accounts for a large portion of the waste, as does packaging material used to maintain the sterility of equipment. Several different types of waste are generated in operating rooms, including solid waste, medical waste, recyclable waste, medications, and sharps. Properly segregating waste into the appropriate bins can result in cost savings and environmental benefits. For example, the disposal costs for sharps bins can be several times the disposal cost for general trash. Similarly, it is up to 10 times more costly to dispose of biohazard waste than it is to dispose of noninfectious waste. Consequently, filling sharps bins and biohazard waste containers with inappropriate trash drives up the cost of waste management.

Recycling bins are being placed in operating rooms and other perioperative areas as space allows. Bins for recycling glass are placed near anesthesia carts so that providers are able to recycle intact glass vials instead of placing them in sharps containers. Some institutions

have programs to recycle uninfected paper, polypropylene, polyethylene, and polyvinyl chloride, which account for much of the packing material for anesthesia and surgical equipment. Posting signage in the operating room to remind staff of the appropriate container for different kinds of waste helps compliance. Regulated medical waste, also known as “infectious medical” waste or “biohazardous” waste, must be separated from general waste and discarded in an appropriately labeled biohazardous waste container. Regulated waste includes intravenous tubing used to administer blood products, contaminated PPE, syringes, and objects that are soiled with blood, body fluids.

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