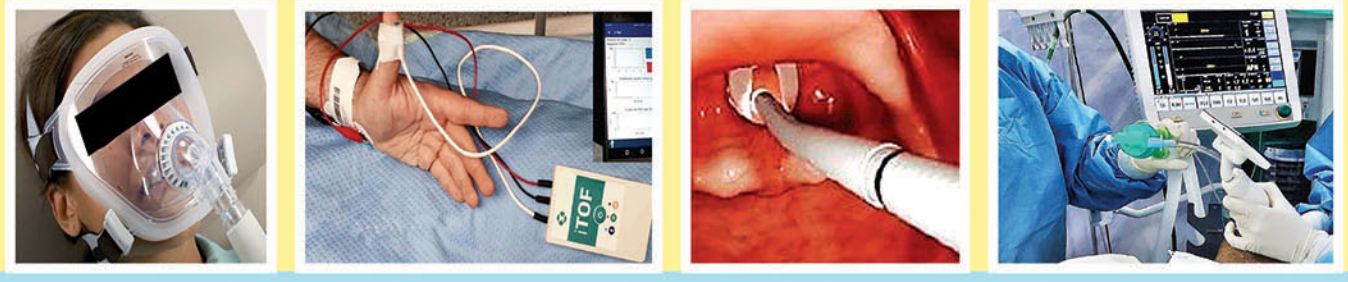
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UNDERSTANDING ANESTHETIC EQUIPMENT & PROCEDURES

A Practical Approach

Revised and Updated with Chapter on Applications of AI in Anesthesia



Editors
Dwarkadas K Baheti
Vandana V Laheri

Foreword
Dipankar Das Gupta

4th Edition

JAYPEE

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CHAPTER 50

Anesthesia: Safety and Prevention of Hazards and Accidents

Pradnya C Kulkarni

ABSTRACT

The anesthesiologist's prime concern is safety of patient and personnel working in operation room areas. The concerns regarding safety of patients are equipment malfunctions, errors of medications, errors in performance of anesthesiologist's, or any other member of the team. Environmental safety issues like electricity hazards, fire and explosions, transmission of diseases, accidents, and radiation affect both.

The higher incidence of chemical dependence, addictions, and performance errors due to chronic fatigue, stress, and chronic exposure to anesthetic gases are causes of concern for healthcare professionals. The hospital administration should focus on improving safety and try to strike a golden mean between cost and safety.

INTRODUCTION

Anesthesiologists have always performed a key role in achieving high standards of safety for patients in perioperative period. About 6–7 decades ago, death under anesthesia was considered inevitable in certain situations. In 1949, this view was challenged by Robert Macintosh, "deaths due to anesthesia can frequently (many times) be attributed to failure of anesthetist (or his equipment)".[1]

Since then, increasingly anesthesiologists have substantially contributed toward patient safety, major share of it is due to advancements in engineering, technology, and pharmaceutical progresses. Addressing the problem of human error[2] and emphasis on continued medical education plays a vital role. To minimize the gap between best practice and actual care offered to patients, lies the continuous process of identifying problems and analyzing failures.

It is very important for anesthesiologist to realize that knowledge about safety is as relevant to anesthesia practice as understanding of basic medical subjects like anatomy, physiology, and pharmacology, etc.[2] The anesthesia safety has widened its spectrum to patients, anesthesiologist, surgeons, assistants, nursing staff, other medical professionals, technical staff, and other nonmedical staff [healthcare professionals (HCPs)]. The area for which anesthesiologist is concerned regarding safety is extended to not only operative rooms, but also recovery rooms, intensive care, emergency medicine department (casualty), pain clinics, magnetic resonance imaging (MRI) suit, computed tomography (CT) scan, radiation therapy department, cardiac catheterization laboratories, endoscopy department, etc.

It is the right of the patient to expect safety and protection from harm in perioperative period. The goal should be as an anesthesiologist, to identify potential hazards, source of accidents so as to reduce the occurrence of adverse incidents in perioperative period.

Safety issues can be considered as:

- Pertaining to patients
- Pertaining to HCP
- Common in both (patients and HCP)

Patients Safety

- Equipment malfunction
- Errors
- Medication errors
- Performance errors
- Team work failure

Healthcare Professional Safety

- Theater pollution—control of trace gas levels
- Radiation hazard

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- Chemical dependence
- Stress and chronic fatigue

Patient and Healthcare Professionals Both

- Electricity hazards
- Fire and explosion hazards
- Laser hazards
- Magnetic resonance imaging suit hazards
- Transmission of diseases
- Accidents and injuries

DEFINITIONS

Accident

It is an unfortunate incident that happens unexpectedly and unintentionally typically resulting in damage or injury.

Hazard

It is a potential source of danger or risk.

Adverse Incident

It is an event that causes or has the potential to cause unexpected or unwanted effects involving the safety of patients, users, or other persons.

Critical Incident

It is a reporting technique. It is applied in medicine to identify the causes of errors. First reported its use in anesthesia is by Cooper et al.[3] in 1978. They examined errors and equipment failure in anesthesia practice. In last 3 decades, critical incident reporting has been widely adopted in anesthesia to identify causes of adverse outcomes. Many departments and institutes collect the data and analyze, which can be used to modify guidelines, protocols, and for judging performances. This can also be used for training purposes. In the original report critical incident was defined as an occurrence that could have led (if not corrected or discovered in time) or did lead to an undesirable outcome ranging from increased length of hospital stay to death, it must also involve error by a member of anesthetic team or failure of anesthetic equipment to function, occur while patient is under anesthetic care, be described in clear detail by an observer or member of anesthetic team and be clearly preventable. Some authors include nonpreventable causes or nonanesthetic causes or some may include only the incidents which have adverse outcome to make the definition confusing. Therefore, unambiguous and self-explanatory term "real or potential adverse effect" has been proposed.[4]

Analyzing critical incidents has a very important role in identifying risks, potential source of damages, and help forming base for improving safety.[5] Noticing the cause that is occurring very frequently can point to the defect in functioning or designing of an equipment.[6]

Reporting and analysis of critical incident has two major disadvantages:

1. Conscientious and sincere reporter may be labeled as poor performer; this in due course of time can lead to underreporting.
2. Apathy and underreporter may be fallaciously labeled as good performer which result in continuation of faulty or risky practices and failure of improvement in safety.

SAFETY ISSUES: PATIENT

Equipment Malfunction

Many studies have shown that human errors are more common than equipment failures but equipment failure still forms a major share of critical incidents. These are failure of breathing circuits, oxygen (O_2) delivery problems, misconnections, disconnections, development of high or low pressures in breathing circuits, major or minor leaks in circuits, delivery of hypoxic mixtures, carbon dioxide (CO_2) retention (hypercapnia), incorrect delivery of inhaled anesthetic agents, inhalation of foreign substances, malfunction of monitoring devices, suction apparatus, monitoring alarms malfunction, physical damage to patient due to machine, and falling of heavy equipment's on patient are all reported. The constant breakthroughs in engineering and technology enable manufacturers to incorporate many safety features in modern anesthesia machines and monitors. The electromagnetic interference due to devices such as cell phones, papers, and internet can cause interference in working of monitors and alarm systems, etc.

Medication Error

The medication error has proved to be a constant problem despite considerable efforts has consistently resisted improvement.[7-9] The standardize technical advances in delivery systems, color-coding of labels, checking of medication using barcodes, and conforming to key principles

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of safe drug administration is the only factor that has proven to be beneficial in reduction of medication errors.[10] The formal checking and rechecking of medication to be administered is the most recommended and highly safe practice.

Error

By definition, it means unintentional action causing harm or unintentional use of a wrong plan to achieve aim or failure to carry out a planned action as intended. The chances of error are greatly increased by violation of norms.[11,12]

Violation

A deliberate but not necessarily reprehensive deviation from those practices appreciated by the individual as being required by regulations or necessary or advisable to achieve an appropriate objective while maintaining safety and the ongoing operation of the device or system.[7,8] The violation leads to errors or violations magnify damage due to errors, e.g., violating speed limit by a vehicle increases its chance of driver to make error that may lead to accident. The high speed may be the cause of accident and magnified damage.

Teamwork Failure—Error

The failure of team in communication and/or suboptimal performance of any team member may cause wastage of time, waste of resources, tension, procedural errors and adverse incidences, or critical error can lead to unfavorable outcome or even death.[13,14] The failure to communicate has led to grave consequences, e.g., operation on wrong patient, wrong side, and wrong operation, etc. The administration of medication to patient with known allergy is the most common communication failure error. Anesthesiologist performs an important task of coordinating the team comprising of diverse professional groups.

HEALTHCARE PROFESSIONALS

Control of Trace Gas Levels

Healthcare professionals working in operating room (OR) and anesthesia areas are constantly exposed to low concentrations or trace levels of anesthetic gases/vapors. Some of the feared health problems are:

- Spontaneous abortions in HCPs
- Spontaneous abortions in spouses of HCPs
- Birth defects in babies born to HCPs
- Infertility
- Cancer—various
- Impaired performance
- Liver disease
- Kidney diseases
- Hematological abnormalities (leukemia)
- Alteration in immune responses (change in immunological profile)
- Neurological problems (polyneuropathy causing tingling numbness, muscle weakness)
- Cardiac diseases (hypertension, arrhythmias)
- Suicidal tendencies
- Substance abuse causing morbidity and mortality
- *Miscellaneous:* Bone and joint diseases, ulcers, ulcerative colitis, gallbladder diseases, migraine headache, fatigue, asthma, laryngitis, ophthalmic hypersensitivity, conjunctivitis, exacerbation of myasthenia gravis, and skin ulcers, etc.

The evidence that is currently available that exposure to trace gases can be harmful to personnel working in OR areas is inconclusive.[15] There are many epidemiological prospective and retrospective studies, studies on human volunteers, and large number of animal studies have failed to prove cause-effect relationship.[16] It is important to know all the pertinent information on the supposed and proposed risks of prolonged exposure and many ways of reducing the exposure risks.[17] The department of occupational health can educate the HCPs and provide guidelines, which may prove useful in minimizing occupational exposure risks,[18] due to constant concern and persistent controversy of this issue. The American Society of Anesthesiologists (ASAs) Committee on occupational health of OR personnel convened a task force on trace anesthetic gases. After analyzing all the available data at the time, ASA task force concluded that there was no proof of an association between occupational exposure to waste anesthetic gases and adverse health effects.[19] Many anesthesiologists have modified their techniques or anesthesia practice to minimize the exposure to trace gas levels. There is continuous debate on this issue that has got a considerable impact on the decision making of anesthesiologists about their anesthesia practices.[20]

The focus lies on four main areas to minimize concentration of waste anesthetic gases to minimum, with reasonable cost and efforts:

1. Leaks in equipment's breathing systems
2. Operating room ventilation systems

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3. Various techniques of gas administration and anesthesia
4. Scavenging systems

Leaks in Breathing Systems and Equipment

The minor leaks are unavoidable, but major leaks should be identified and corrected. Regular servicing of anesthesia machine equipment will minimize leaks and systematic checking of anesthesia machine (high pressure, intermediate pressure, and low-pressure system) at the beginning of the day, and quick general checkup in between cases is advised.

Room Ventilation System

The room ventilation systems which recirculate the same air are not effective in removing waste anesthetic gases and do not reduce OR pollution, the noncirculating systems are efficient in reducing OR pollution.

A turnover of 20 exchanges per hour is recommended to prevent bacteria from setting on OR surfaces. At the time of planning and construction of operation theater the placement of anesthesia machine should be near room ventilation system and provision for scavenging system for evacuation of waste anesthetic gases.

Work Practices

The work practices adopted by anesthesiologists can help in reducing OR pollution with anesthetic waste gases. These are:

- Checking of anesthesia machines thoroughly prior to induction of each case
- Efficient and correct use of scavenging system
- Holding tightly a properly fitting face mask, will reduce risk of leaks and lessen the escape of anesthetic gases to ambient air
- Meticulous filling and emptying of vaporizers to avoid spillage
- Use of low-flow anesthesia techniques
- Use of cuffed endotracheal tubes versus supraglottic airway, which have higher portion of leaks
- Use of techniques, such as total intravenous anesthesia/regional anesthesia, complete avoidance of nitric oxide (N_2O), etc.
- Do not use N_2O and inhalational agents to check machine. N_2O and anesthetic agents are started only when breathing circuit is connected to cuffed endotracheal tube.

Scavenging Systems

The scavenging by definition, mean the collection and removal of waste or expired anesthetic gases from OR. As the supplied anesthetic gases are far more than that are necessary for patient to remain anesthetized and to reduce waste anesthetic gases polluting OR, the scavenging is a very efficient mean.

Scavenging systems are of two types:

1. *Active:* In this, suction is applied to actively suck gases, however, it has danger of low or high pressure being transmitted to patient circuit.
2. *Passive:* In this, waste anesthetic gases flow passively from valves on expired tubing through room ventilation, through exhaust grill in OR.

Passive scavenging has possibility of only positive pressure buildup due to some obstruction to flow of exhaust gases.

There are two distinctly different scavenger interfaces: (i) open and (ii) closed. Open interfaces are safe for patient and hence are incorporated in many newer anesthesia machines.

The components of scavenging systems are:

- Gas collection assembly [tubes connected to adjustable pressure-limiting (APL) valve and vent relief valve]
- Transfer tubing 19 mm or 30 mm (mostly in yellow color codes)
- Scavenging interface
- Tubing for gas disposal (carries gas from interface to disposable assembly)
- Gas disposable assembly (active or passive, active is common)

The open interface has no valves and is open to atmosphere (there is provision for allowing both positive and negative pressure relief). These should be used only with active systems. The open interfaces are safe for patient as no pressure is applied to the airway of patient in case of failure of scavenger but they are inferior in controlling trace gas levels and increases risk of occupational exposure to trace gases and this risk increases further by their incorrect use. Closed interface has valves and require appropriate vacuum adjustments to keep reservoir bag adequately filled (neither flat nor over distended) as needed.

Hazards of scavenging system are:

- *Pressure alteration of breathing systems:*
  - *Excess positive (high) pressure buildup:* Barotraumas occurs due to resistance to transfer or occlusion of

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gas disposable tubing. Occlusion can be caused by equipment's pressing on it like anesthesia machine, trolleys, etc., from outside. Occlusion can occur from inside by water, foreign materials or insects, etc., blocking it
    - Negative pressure applied to breathing circuits is a possibility when active disposal system is used with fully open APL valve
- *Misassemble or misconnection:* It can happen, although scavenging system has connectors of 19 mm or 30 mm as against to 15 mm or 22 mm connections (universal connections) of breathing circuits, misconnection can happen by using adaptors or sticking tapes. These mistakes which mostly occur due to ignorance lead to serious complications
- The accidental administration of high concentration of inhaled anesthetic agent may get unnoticed as strong smell (odor) may get masked due to efficient scavenging system. Monitoring of inspired and expired concentration of volatile anesthetic agents will offer protection against these mishaps
- Occasionally, low minute volume or disconnection alarms may become inactive as atmospheric air can get sucked into the breathing circuits when scavenging is in use.

Monitoring of Exposure to Trace Gases

It is necessary as anesthesiologists are usually most vulnerable personnel for exposure to waste anesthesia gases is maximum in terms of time and intensity.[21]

Places of Monitoring

These are OR, air-condition exhausts, grills, and area just outside OR door are frequent sites for sampling air. The instantaneous, time weighted, or continuous are three methods of sampling of ambient atmosphere of operation theater, for estimation of intensity of exposure to trace gases of theater personnel. The education of HCP, meticulous maintenance of anesthesia machine, proper use of scavenging system, and focus on correct anesthesia practices are principle ways to reduce exposure.

RADIATION

The radiations to which HCPs are exposed are of two types:
1. Ionizing radiation (X-rays, radioactive isotopes, etc.)
2. Nonionizing radiation (lasers)

Ionizing Radiation[22]

It is vital to know the harmful effects of exposure to ionizing radiation and their stringent preventive measures. Areas in which anesthesiologists work routinely, has risk of radiation exposure, such as urological, orthopedic operations. Cardiac catheterization laboratory, interventional procedures in radiology department, radiation therapy department, department of nuclear medicine, and interventional pain treatment procedures need anesthesiologist's services. The exposure of HCPs to radiation comes from scattered X-rays from patients and equipment's. The continuous fluoroscopy has more radiation than single exposure X-ray and radiation exposure from scattered rays depends on distance from the source and is inversely proportional to square of the distance.

As Low as Reasonably Achievable

As no amount of radiation is safe, minimizing radiation exposure is the goal of as low as reasonably achievable (ALARA) concept.[23] The safe limit of maximum yearly occupational radiation exposure is 5 rem (Roentgen equivalent man; rem is a unit of measurement of radiation exposure). Limits are different in pregnancy. Rem is essentially a measure of the biologic damage from radiation, adjusted to apply to all tissues. It is difficult to quantitatively determine ALARA concept.

As low as reasonably achievable concept is considered under three basic divisions:
1. Planning and installation of protective measures at the time of construction of radiation areas
2. Training, teaching, and promoting awareness in the personnel regarding necessity and importance of minimizing radiation exposure. The written guidelines and policies should be available to all
3. Protective measures like lead apron, shields, thyroid shield, protective goggles, and lead gloves should be easily available. Their use should be strictly imposed and encouraged.

Protection of Personnel from Radiation Exposure

- Radiation monitoring
- Understanding harmful effects of radiation exposure
- Protective measures taken to shield from harmful effects of radiation

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Radiation monitoring: Devices available are—

- *Pocket dosimeter:* It is most sensitive instrument, easily damageable, which can be inaccurate in inexperienced hands and this dosimeter does not give permanent record of levels of exposure
- *Film badge:* These are most convenient and can be worn on neck or apron, etc.
- *Thermoluminescent dosimeters* ***(Fig. 1)****:* They are cheap, are seated in teflon to avoid damage, small, and hence could be easily incorporated in jewelry, etc. They can be read directly and are accurate. They have wide range of exposure and resemble human tissue. These are the most commonly used monitoring devices currently.

It is important to note that badges should never be exchanged among personnel and clearly marked for identification. They are returned to laboratory at regular intervals (mostly 3 monthly) for processing under standard conditions.

Harmful effects of radiation exposure: As no radiation is safe, it is always harmful to tissues. The amount and nature of any damage depends on radiation quality, the dose quantity that is absorbed, area of tissue exposed, duration (acute/chronic), or time period of exposure.

The radiation damage or injury is of three types:

1. *Local effects:* Small occupational exposures do not have local skin changes, but exposure of many years can cause chronic skin changes like skin erythema, dry skin, cracking or ulceration, and very rarely cancer induction. A highly radiosensitive structure is optic lens and can cause lens opacities (focal or general, premature cataract formation)
2. *General effects:* Chromosomal abnormalities, blood dyscrasias like changes in lymphocytes, leukocytes, and platelets, etc., increase chances of causing leukemia, shortening of life span are few of many proposed general effects of radiation
3. *Pregnancy:* Radiation exposure during pregnancy is hazardous to conceptus (embryo + fetus). In animal studies with large radiation dose gestational exposure can cause malformation of baby (microcephaly, anencephaly, heart defects, etc.) but human equivalents are not conclusive.



Fig. 1: Thermoluminescent dosimeter badge—with user name.

For patients, day 10 rule is followed. From 1st day of menstruation to 10 days is considered to be safe period for elective (planned) radiological studies as the chance of pregnancy is minimal. The recommended exposure limits for pregnant personnel are 0.5 rem (5 mSv) for entire gestation and not more than 0.05 rem (0.5 mSv) in any 1 month.[24] Complete avoidance of radiation, if possible, is desired during pregnancy.

The genetic hazard is most serious problem of radiation exposure, genes particularly in the chromosomes of sex cells are extremely vulnerable. The radiation damage to the genetic material is expressed as chromosomal aberration and gene mutation.

Protective measures: Three general principles are—

1. *Exposure time:* As minimum as possible
2. *Distance:* As much as possible
3. *Lead barrier:* As many as available

Emphasis on importance of protective measures and frequent revisions of safety precautions ensures maximum cooperation of personnel.

For personnel working in radiation areas:

- Minimize the period, like by avoiding repeat studies[25]
- Anesthesiologist may stand in control room or behind protective drape/glass barrier or behind operator as away as possible from fluoroscopy
- Adopt anesthesia techniques which will allow anesthesiologist to maintain distance from patient (avoid manual ventilation techniques, bag mask anesthesia, etc.)
- Use protection, e.g., lead protective apron, special lead shield for gonads, protective goggles, lead protective thyroid collar, gloves, etc.

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- Do not hold patient for radiological examination or procedures. Restrainers, straps, and safety belts can be used for that purpose
- When working in radiology department, always wear a film badge or thermoluminescent dosimeter. If female HCP is planning pregnancy, avoid radiation completely.

For departments:

- On all doors, having access to radiographic and fluoroscopic rooms, an official yellow warning sign reading "caution, radiation area" should be prominently displayed **(Figs. 2 and 3)**.
- All equipment concerned with radiation and personal protective devices should be regularly checked and serviced. They should be always kept in optimum working condition
- Name and emergency contact details of person concerned with radiation safety should be prominently displayed in radiation areas
- Regular teaching, training of personnel, and carrying out continuous educational activities in department with emphasis on minimizing radiation exposure and improving radiation safety are of great benefit.

The danger of ionizing radiation in the well-controlled radiological procedure is nil, if all the personnel make full use of the all protective devices, equipment's, and constantly bear in mind ALARA principle.



Fig. 2: Official yellow radiation warning sign.



Fig. 3: Radiation warning sign in regional language.

CHEMICAL DEPENDENCE

The prevalence of drug abuse among anesthesiologists is estimated to be roughly 1–2%,[26-28] and commonly cited causes are high levels of stress, easy availability or access to drugs, and knowledge of pharmacology of drugs.[29] Identification of problem is generally delayed due to medical knowledge used to hide it. The death may be the first symptom and early identification, appropriate intervention, and proper treatment are important. Along with treatment and strict adherence to follow-up many can continue to practice their profession.[30]

STRESS AND FATIGUE

Being workaholic is a virtue in medical practice and doctors take pride in working long hours. The factors such as long working hours, working constantly in odd shifts, working without proper breaks, inadequate sleep, and inadequate recreation leads to stress and fatigue. The incidence is high among anesthesiologist and the shortage of personnel is perpetual problem. The period between 2 AM and 7 AM and late afternoon are identified as maximum vulnerable period for sleep[31] and are vulnerable for maximum human errors. It is strongly recommended to enforce work hour regulations.

Some factors that have constantly proven to cause stress are difficult anesthesia cases, frequent night calls, strained professional relationships, and noncooperation from peers, etc. In addition, the domestic problems like divorce, bereavement add to the stress. The effective and adequate communication, interactive sessions, adequate time and proper access for recreational facilities, and adjustments in work hours will help in reducing stress and fatigue.[32] The effective management of stress, at times

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psychological counseling will improve performance and minimize human errors in some.

LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION

The use of light amplification by stimulated emission of radiation (LASER) is well established in ophthalmic surgery, plastic surgery, urology, head and neck surgery, airway surgery, neurosurgery, gastrointestinal surgery, and major vascular surgery. The laser causes nonionizing electromagnetic radiation. LASER produces ultraviolet light, visible light, or infrared light. The commonly used lasers in medical practice are CO_2, neodymium-doped yttrium aluminum garnet (Nd:YAG), potassium titanyl phosphate, and argon.

Light amplification by stimulated emission of radiation equipment's are classified in four groups **(Table 1)**.

The commonly used in surgical practice are classes III and IV.

Hazards of Laser

Patient

- Misdirected laser beam can cause perforation of viscous or blood vessels causing bleeding
- Venous air embolism—known with Nd:YAG lasers
- Inadvertent injury to patient's eye
- Burns due to heat generated locally

Healthcare Professionals

- *Eye injury:* Eye injuries, such as eye damage in form of corneal burns, retinal burns, destruction of macula, optic nerve cataract, etc., seen in HCP due to direct exposure or reflected radiation. The suitable protective eyewear (goggles) must be worn **(Fig. 4)**. The type of protection provided by the filter is marked on the frame of the goggles and must be checked for specificity of the type of laser being used. Laser protective eyewear should be worn by all personnel present in OR as scattered laser beams are equally damaging to eyes. Intensity of scattered laser beams does not significantly reduce for long distances. The visibility of monitors and anesthesia machine should be checked preoperatively as some goggles diminish or blur vision. Do not use broken or shattered goggles
- *Plume:* The vapor and cellular debris caused by laser is called plume.[32] It is harmful when inhaled. Human immunodeficiency virus (HIV)/human papillomavirus (HPV) is found in plume. Although no case of transmission of infection is reported and damage to lungs of operator is very rare, the smoke (plume) should be actively removed by suction or scavenged out of operation theater[33]
- *Fire:* Airway and OR fire is the most dreaded complication of lasers.[34,35] The incidence of airway fire or anesthetic mixture catching fire is approximately 0.5%; however, fire can result from either direct laser illumination and ignition or reflected laser rays. Sometimes tissue particles bloom from surgical site or cottonoids or gauze pieces used can catch fire. If accidently laser beam strikes unprotected endotracheal tube carrying high O_2 concentration anesthesia gas mixture, tube can ignite and fire can start intraluminal. It is called "blowtorch fire".

Following measures are taken to minimize complication of airway fire:

- Inspired concentration of O_2 should be as low as possible preferably less than 30%, avoid N_2O and inhalational agents in high concentration

TABLE 1: Classification of light amplification by stimulated emission of radiation equipment's.

Class I	Totally enclosed with extremely low output
Class II	Low risk—minimal risk to eye
Class III	• Power 1–5 mw—moderate risk to eye • Power 5–500 mw—potentially hazardous to eyes and skin
Class IV	• Continuous mode and power output >500 mw • Great risk to eye, skin, and fire hazard



Fig. 4: Laser protective eyewear (goggles), the type of protection provided by the filter is marked on the frame (see inset).

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- Endotracheal tube cuff may be filled with cold saline, tinged blue with methylene blue to keep temperatures at the operation site low, dissipate heat, and detect cuff rupture
- Electrosurgical forceps should be kept away from patient as much as possible. Remove from surgical site when not in use
- Laser safe endotracheal tubes should be used
- Instruments should be matt finish and avoid instruments with bright shining surfaces
- Laser plumes from surgical area should be removed by strong active suction

Laser safe endotracheal tubes are available like Bivona® (Foam cuff®), Xomed laser shield tube, and flexometallic stainless steel double cuff endotracheal tube (Mallinckrodt), red rubber tubes are wrapped with aluminum or copper tapes. The silicon endotracheal tubes, Sheridan® laser tracheal tube, Oswal–Hunton tube, Merocel® laser guard, and laser tubes silicon tubes are safe. The polyvinyl chloride endotracheal tubes are not safe for laser surgery. All available tubes are reasonably safe to use in airway laser surgery, but none have been specially recommended.

Airway fire: In case of airway fire, all personnel in OR must act in quick and orderly manner. Each person must know what to do and this practice drill should have been practiced earlier and revised at regular intervals.

- Operator/surgeon should promptly detect and remove source of fire and inform OR personnel
- Anesthesiologist should instantly stop ventilation and disconnect circuit and stop O_2 supply to breathing circuit
- The flaming tube should be removed and immersed in bucket of water to extinguish fire. As precaution bucket of water must always be kept ready in OR when laser airway surgery is performed
- After confirming fire inside has completely extinguished, anesthesia should be continued with intravenous agents, and patient ventilated by bag and mask
- Damage should be assessed by direct laryngoscopy, rigid or flexible laryngoscopy, or bronchoscopy and further treatment carried on.

International safety norms for use of lasers in OR are formulated.

Precautions that are followed universally:

- Personnel working in OR should be educated about safe use and side effects of lasers

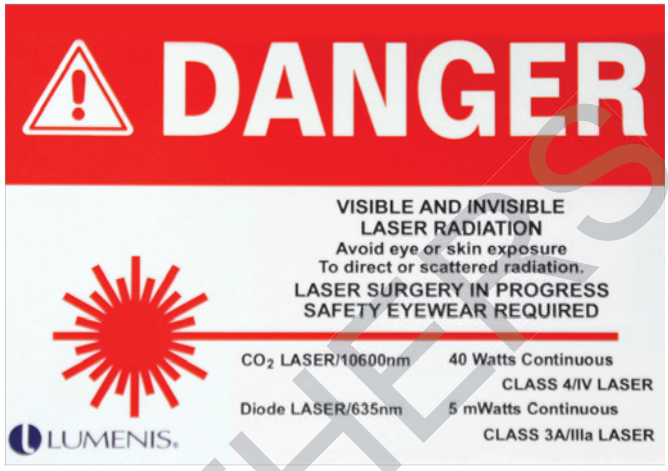


Fig. 5: Laser warning sign.

- A sign board stating use of lasers in OR should be displayed prominently on OR door **(Fig. 5)**
- Provide adequate protection for eyes to all personnel and patient
- Operator/surgeon must be trained in safe use of lasers
- Regular checks to keep laser machines, fibers, and personnel protective devices in optimum working conditions
- Safety officer who is incharge of lasers should be available in case of any troubleshooting

Anesthesiologist should choose utmost safe anesthesia techniques, follow safety norms, and keep continuous vigilance on laser use.

MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging is used to obtain superior images without ionizing radiation. Majority of patients cooperate for the study but in few like children, critically ill intensive care unit (ICU) patients, patients with involuntary movements, claustrophobic patients, etc., sedation or general anesthesia may be required. As MRI study is not painful and immobile patient is the only requirement and sedation technique generally suffices. But rarely patients may need general anesthesia.

Magnetic Resonance Imaging Hazards

Patient

Ferromagnetic substances are the ones which contain iron, iron oxide, iron coating alloys, nickel, and cobalt. Depending on site, size of object, and position in respect

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Fig. 6: Accidental collision of full oxygen cylinder to magnetic resonance imaging machine.

to magnetic field rotational (torque) and/or translational (attraction) forces act on them.[36]

- *Ferromagnetic substances outside patient's body:* Freely moving objects get pulled toward the magnet with alarming speed (missile or projectile effect). This can injure patient, personnel, or may damage equipment's **(Fig. 6)**. Common ones are watches, scissors from nurse's pockets, keys, hairpins, mobile phones, loose coins, jewelry, stethoscopes, etc.
  - All persons entering MRI scan room must be thoroughly checked for internal and external ferromagnetic substances
  - Warning signs should be clearly displayed in prominent areas
  - An extensive list of all possible items and clear guidelines about their safety inside MRI suit should be available in department to avoid confusion and mistakes regarding ferromagnetic nature of objects.
- *Ferromagnetic substances inside patient's body:* These are implanted or inserted ferromagnetic objects, such as aneurysm clips, cardiac pacemakers, and foreign bodies embedded in vital organs like eye, indwelling catheters, etc. The newer implants and pacemakers are safe, as they are made up of nonferromagnetic substances. Some cochlear implants and cardioverters may be safe. The equipment malfunction due to MR interference can pose problem to patients and compromise their safety
- Electrocardiography (ECG) leads, cables, sensors, wires, surface, coils, skin staples, etc., can get heated during MR study and cause burns
- Hypothermia can occur especially in small children undergoing long studies.

Patient's safety in MRI can get compromised because of inaccessibility of patient.[37] It may cause problems in airway management, monitoring of patient, intravenous access, etc. Loud noise may interfere with detection of audible alarms.

Note: Powerful magnetic field keeping the oxygen cylinder suspended horizontally in air.

Healthcare Professionals

Since the availability of MRI, the anesthesiologist's work in MRI is infrequent and data regarding hazards due to prolonged exposure are insufficient. Although there is no known evidence and it is advisable for females to avoid MR area, for the 1st trimester. The continuous and prolonged exposure to loud noise of MRI machine can cause hypertension and can damage hearing.

The demonstrated noise level in MRI suit on an average is about 92 decibels. The use of earplugs or headphones by all present will minimize the effect of noise pollution. As MR suits are not equipped with scavenging, trace gas levels may be high. Very rarely, liquid helium which surrounds the superconducting solenoid escapes in MRI suit, at that time atmosphere may contain low O_2 levels leading to hypoxia. This problem can be detected early if O_2 sensors are installed in MRI suits. The detailed understanding of limitations, risks involved, and problems encountered are mandatory for safe anesthesia practice in MR suite.

ELECTRICITY

Electrical Hazards in Operating Room

It is vital for all personnel to understand principles of electrical supply to OR and its inherent hazards. As almost all equipment's used in ORs have electric supply such as anesthesia machine, ventilators, monitors, drug delivery systems (syringe pumps), body warming devices, overhead theater lights, electrosurgical cautery, and suction apparatus, etc.

There are four major ways in which mains electrical supply can be hazardous to patient and/or HCP:

1. Electrocution—shock
2. Electric burns
3. Electrochemical effects
4. Fire and explosions

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Electrocution or Shock (Macroshock)

The effect of shock on humans depends on tissue resistance (R), current (I), potential difference (V), current frequency, current pathway and time (duration), and also on current density.

The thermal energy delivered to the body tissues depends on the power (P) dissipated.

$$V \times I = I2R$$

Where V: potential difference, I: current, and R: tissue resistance.

The electrical resistance of mucous membrane is the least and is highest in skin of sole or very hard callus of hands and soles. The water or moisture or sweat on skin reduces the resistance of skin markedly, i.e., by approximately 10 times than dry skin. The pathological effect of electric shock is directly proportional to the current. At 50 Hz frequency, current of 1 mA causes tingling sensation; pain is caused at roughly 5 mA; 15 mA can cause severe joint and muscle contractions. The "let go threshold" for 50 Hz frequency is about 30 mA, currents above 30 mA cause respiratory muscle contractions, which leads to asphyxia and death. The higher currents about 70–100 mA cause multifocal premature ventricular contraction, cardiac failure, local burns, and ventricular fibrillations. Any current above 1,000 mA causes extensive burns and charring.

The sudden death due to ventricular fibrillation is more likely if current passes through heart horizontally and damage to cardiac muscles is more likely if current passes through heart vertically **(Fig. 7)**.[38]



Fig. 7: Possibility of macroshock faulty technique. Ventricular fibrillation: Current passing through heart horizontally.

Microshock

A very small amount of electric current passing through the body also can interfere with normal functioning of muscles and nerves and minimum of 50 mA current is needed to cause ventricular fibrillation. The modern surgical, medical, and critical care procedures, such as pulmonary artery catheterization, central venous catheter placements using "P" wave guidance, dialysis catheter insertion, etc., involves placement of electrodes within or very near heart. Due to this proximity of placement of leads from the heart, extremely small current can cause ventricular arrhythmias, fibrillation. This is called microshock, even stray potential or inductive small currents can cause microshocks.

Capacitative coupling can occur when the electrosurgical current induces stray currents on the other nearby conductions. This phenomenon happens only in alternating current (AC). Although this is generally insignificant, in certain unusual circumstance it can cause severe burns. For example, use of non-MRI compatible pulse oximeter in MRI can cause finger burns.[39] In laparoscopic surgeries if active electrode of electrosurgical cautery is in contact with a noninsulated metal instrument, e.g., laparoscope and if this laparoscope is passed through a metal cannula (electrically energized), current can flow to patient's abdominal wall. If laparoscope is passed through a nonconductive cannula, current can pass to any piece of bowel or abdominal organs which may cause burns. The capacitative coupling can be minimized but cannot be eliminated.

Electric Burns

As current passes through body or skin, heat is generated, depending on the amount of heat generated and area, burns may result.

Enormous heat generated by electric currents can cause two harmful effects:

1. Electric burns
2. Fire and explosion in OR

Electrical burns are most common with electrosurgical units (ESUs) (diathermy/cautery).

- Unipolar/monopolar electrosurgery (UPES) (unipolar cautery/diathermy/monopolar cautery)
- *Bipolar electrosurgery (bipolar cautery/diathermy):* The difference in unipolar and bipolar electrosurgery is path taken by the electric current. In electrosurgery,

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electric current is applied by the operator via electrode to body tissues that burn and cut or burn and coagulate the tissues.

In UPES, this current passes through entire body of patient and is collected outside surgical field by a wide, large area to which a well-lubricated and properly gelled grounding pad is applied. This pad is also called dispersing electrode or cautery plate.

In bipolar electrosurgery (BPES) or bipolar cautery, this current from one electrode passes to the tissues for a very small distance and returns back through another electrode only few millimeters away. Bipolar electrosurgery has two pencil point electrodes which resemble forceps. These can be used in patients with cardiac pacemakers, automatic implantable cardioverter defibrillators (AICDs) with reasonable safety, with due caution.

In unipolar/monopolar electrosurgery if grounding pad (dispersing electrode) is small, not gelled well, applied over small area, or contact is minimum due to bony prominence the current has to pass through small area. This increases resistance and heat is generated, which causes burns. If grounding pad is not applied properly or is defective or not applied at all, current will pass through alternate pathway like ECG leads, monitoring cables, etc., and cause local burns in that area. Unipolar/monopolar electrosurgery is unsafe for use in neurosurgery and patients with pacemaker, therefore, should be avoided.

Protection of patient from shock: This can be done by installing small isolating transformer whose output is isolated carefully from the earth in the circuit of equipment running on electricity that is connected to patient. This can enhance patient safety. In this case, patient circuit is completely earth free or fully floating and equipment enclosure can be earthed.

The other method is to install a current operated earth leakage circuit breaker. It operates at low earth leakage currents; its action is very fast and is cheap. Their use has greatly diminished the risk of serious electric shock to patients. The use of equipment working on battery is safe and batteries may be charged by electricity between patients.

The equipment used in medical practice is classified to make sure electrical safely norms are appropriately applied.

- *Class I:* Common household equipment with single insulation
- *Class II:* Equipment with double insulation
- *Class III:* Work at power source less than 24V AC. Less chances of micro- and macroshock.

All three types of equipment are subdivided into type B, type BF, and type CF with increasing safety measures.

The most common source of electric burns is electrosurgery or diathermy or cautery.

The electric burns due to electrosurgery can occur due to:

- Accidental pressing of paddle or footswitch
- Inadequate contact of grounding pad/plate to surface of body
- Any organ or part of it can infarct if vascular supply of the organ is compromised by monopolar electrosurgery, e.g., testes elevated from body on the spermatic cord by monopolar electrosurgery during surgery generates unintentional areas of high current density and compromise blood supply to testes
- *Absent grounding plate:* In case of absent grounding plate electric current is completed via OR table, ECG leads, monitoring cables, temperature probes, and Doppler probes causing severe burns.

Precautions during Use of Electrosurgical Unit

- Avoid using ESU in areas where high concentration of O_2 is present, e.g., during tracheostomy
- Should be in standby mode when not in use
- Preferable to use bipolar ESU as it requires less voltage compared to unipolar ESU
- Electrosurgical unit should be activated by operator, only when its tip is in direct vision
- Minimum power setting that is required must be used, if higher than standard power settings are required. Electrosurgical unit should be sent for checking for faults
- Minimize clutter at foot spaces to reduce chances of accidentally pressing footpad of ESU
- Electrosurgical unit should be used very cautiously with metallic cannulas in laparoscopic surgeries
- Electrosurgical unit probe should be safely kept away when not in use and its tip cleaned regularly.

Precautions for Use of Prejellied Dispersing Electrode (Cautery Pad/Cautery Plate)

- It should be checked prior to application of jelly
- It should be applied to clear, dry, and nonhairy area with good contact to large skin surface as near surgical area as possible

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