6th edition

Morgan & Mikhail's CLINICAL ANESTHESIOLOGY

John F. Butterworth • David C. Mackey • John D. Wasnick

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Morgan & Mikhail's Clinical Anesthesiology

SIXTH EDITION

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Foreword

When a new residency training program in anesthesia was beginning in Rwanda in 2006, we were looking for a suitable textbook to recommend to the trainees. We chose Clinical Anesthesiology by Morgan and Mikhail. I am happy to state that today, 12 years later, the residents are still making the same choice. Over one third of all copies of the last edition were sold outside of North America thus underlining the popularity of this textbook around the world.

A major change in editors and authors occurred with the 5th edition and it is clear that they stayed true to the ideals of the original editors. Now in 2018, the 6th edition is presented to us. The text continues to be simple, concise, and easily readable. The use of Key Concepts at the beginning of each chapter is very useful and focuses the reader's attention on the important points. The authors have worked hard not to increase the size of the book but to update the material. Expanded chapters on critical care, on enhanced recovery after anesthesia, and on the use of ultrasound will be very useful to readers. This textbook continues to provide a comprehensive introduction to the art and science of anesthesia.

Congratulations to the authors and editors on their fine work.

Angela Enright MB, FRCPC
Past President, World Federation of Societies of Anaesthesiologists (WFSA)

Preface

My, how time flies! Can half a decade already have passed since we last edited this textbook? Yet, the time has passed and our field has undergone many changes. We are grateful to the readers of the fifth edition of our textbook. The widespread use of this work have ensured that the time and effort required to produce a sixth edition are justified.

As was true for the fifth edition, the sixth edition represents a significant revision. A few examples are worth noting:

- Those familiar with the sequence and grouping of content in the fifth edition will notice that chapters have been reordered and content broken out or consolidated to improve the flow of information and eliminate redundancy.
- The alert reader will note that the section on **critical care medicine** has been expanded, reflecting the increasing number of very sick patients for whom we care.
- Enhanced recovery after surgery has progressed from an important concept to a commonly used acronym (**ERAS**), a specialty society, and (soon) standard of care.
- **Ultrasound** has never been more important in anesthesia practice, and its use in various procedures is emphasized throughout the textbook.

Some things remain unchanged:

- We have not burdened our readers with large numbers of unnecessary **references**. We hope that long lists of references at the end of textbook chapters will soon go the way of the library card catalog and long-distance telephone charges. We assume that our readers are as fond of (and likely as facile with) Google Scholar and PubMed as are we, and can generate their own lists of references whenever they like. We continue to provide URLs for societies, guidelines, and practice advisories.
- We continue to emphasize **Key Concepts** at the beginning of each chapter that link to the chapter discussion, and **case discussions** at the end.

- We have tried to provide **illustrations and images** whenever they improve the flow and understanding of the text.

Once again, the goal expressed in the first edition remains unchanged: “to provide a concise, consistent presentation of the basic principles essential to the modern practice of anesthesia.” And, once again, despite our best intentions, we fear that errors will be found in our text. We are grateful to the many readers who helped improve the last edition. Please email us at mm6edition@gmail.com when you find errors. This enables us to make corrections in reprints and future editions.

John F. Butterworth, IV, MD
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CHAPTER
1

The Practice of Anesthesiology

KEY CONCEPTS

1. Oliver Wendell Holmes in 1846 was the first to propose use of the term *anesthesia* to denote the state that incorporates amnesia, analgesia, and narcosis to make painless surgery possible.
2. Ether was used for frivolous purposes ("ether frolics") and was not used as an anesthetic agent in humans until 1842, when Crawford W. Long and William E. Clark independently used it on patients. On October 16, 1846, William T.G. Morton conducted the first publicized demonstration of general anesthesia for surgical operation using ether.
3. The original application of modern local anesthesia is credited to Carl Koller, at the time a house officer in ophthalmology, who demonstrated topical anesthesia of the eye with cocaine in 1884.
4. Curare greatly facilitated tracheal intubation and muscle relaxation during surgery. For the first time, operations could be performed on patients without the requirement that relatively deep levels of inhaled general anesthetic be used to produce muscle relaxation.
5. John Snow, often considered the father of the anesthesia specialty, was the first to scientifically investigate ether and the physiology of general anesthesia.
6. The "captain of the ship" doctrine, which held the surgeon responsible for every aspect of the patient's perioperative care (including anesthesia), is no longer a valid notion when an anesthesiologist is present.

The Greek philosopher Dioscorides first used the term *anesthesia* in the first century AD to describe the narcotic-like effects of the plant *mandragora*. The term subsequently was defined in Bailey's *An Universal Etymological English*

Dictionary (1721) as “a defect of sensation” and again in the *Encyclopedia Britannica* (1771) as “privation of the senses.” Oliver Wendell Holmes in 1846 was the first to propose use of the term to denote the state that incorporates amnesia, analgesia, and narcosis to make painless surgery possible. In the United States, use of the term *anesthesiology* to denote the practice or study of anesthesia was first proposed in the second decade of the twentieth century to emphasize the growing scientific basis of the specialty.

Although anesthesia now rests on scientific foundations comparable to those of other specialties, the practice of anesthesia remains very much a mixture of science and art. Moreover, the practice has expanded well beyond rendering patients insensible to pain during surgery or obstetric delivery (**Table 1–1**). Anesthesiologists require a working familiarity with a long list of other specialties, including surgery and its subspecialties, internal medicine, pediatrics, palliative care, and obstetrics, as well as imaging techniques (particularly ultrasound), clinical pharmacology, applied physiology, safety science, process improvement, and biomedical technology. Advances in scientific underpinnings of anesthesia make it an intellectually stimulating and rapidly evolving specialty. Many physicians entering residency positions in anesthesiology will already have multiple years of graduate medical education and perhaps certification in other medical specialties.

TABLE 1–1 Aspects of the practice of medicine that are included within the scope of anesthesiology.[1]

Assessment of, consultation for, and preparation of patients for anesthesia.
Relief and prevention of pain during and following surgical, obstetric, therapeutic, and diagnostic procedures.
Monitoring and maintenance of normal physiology during the perioperative or periprocedural period.
Management of critically ill patients.
Diagnosis and treatment of acute, chronic, and cancer-related pain.
Management of hospice and palliative care.
Clinical management and teaching of cardiac, pulmonary, and neurological resuscitation.
Evaluation of respiratory function and application of respiratory therapy.
Conduct of clinical, translational, and basic science research.
Supervision, teaching, and evaluation of performance of both medical and allied health personnel involved in perioperative or periprocedural care, hospice and palliative care, critical care, and pain management.
Administrative involvement in health care facilities and organizations, and medical schools, as appropriate to the American Board of Anesthesiology's mission.

[1]Data from the American Board of Anesthesiology Primary Certification Policy Book (Booklet of Information), 2017.

This chapter reviews the history of anesthesia, emphasizing its British and American roots, and considers the current scope of the specialty.

The History of Anesthesia

The specialty of anesthesia began in the mid-nineteenth century and became firmly established in the following century. Ancient civilizations had used opium poppy, coca leaves, mandrake root, alcohol, and even phlebotomy (to the point of unconsciousness) to allow surgeons to operate. Ancient Egyptians used the combination of opium poppy (containing morphine) and hyoscyamus (containing scopolamine) for this purpose. A similar combination, morphine and

scopolamine, was widely used for premedication until recent times. What passed for regional anesthesia in ancient times consisted of compression of nerve trunks (nerve ischemia) or the application of cold (cryoanalgesia). The Incas may have practiced local anesthesia as their surgeons chewed coca leaves and applied them to operative wounds, particularly prior to trephining for headache.

The evolution of modern surgery was hampered not only by a poor understanding of disease processes, anatomy, and surgical asepsis but also by the lack of reliable and safe anesthetic techniques. These techniques evolved first with inhalation anesthesia, followed by local and regional anesthesia, intravenous anesthesia, and neuromuscular blockers. The development of surgical anesthesia is considered one of the most important discoveries in human history, and it was introduced to practice without a supporting randomized clinical trial.

INHALATION ANESTHESIA

Because the hypodermic needle was not invented until 1855, the first general anesthetics were destined to be inhalation agents. Diethyl ether (known at the time as “sulfuric ether” because it was produced by a simple chemical reaction between ethyl alcohol and sulfuric acid) was originally prepared in 1540 by Valerius Cordus. Ether was used for frivolous purposes (“ether frolics”), but not as an anesthetic agent in humans until 1842, when Crawford W. Long and William E. Clark independently used it on patients for surgery and dental extraction, respectively. However, neither Long nor Clark publicized his discovery. Four years later, in Boston, on October 16, 1846, William T.G. Morton conducted the first publicized demonstration of general anesthesia for surgical operation using ether. The dramatic success of that exhibition led the operating surgeon to exclaim to a skeptical audience: “Gentlemen, this is no humbug!”

Chloroform was independently prepared by Moldenhawer, von Liebig, Guthrie, and Soubeiran around 1831. Although first used by Holmes Coote in 1847, chloroform was introduced into clinical practice by the Scot Sir James Simpson, who administered it to his patients to relieve the pain of labor. Ironically, Simpson had almost abandoned his medical practice after witnessing the terrible despair and agony of patients undergoing operations without anesthesia.

Joseph Priestley produced nitrous oxide in 1772, and Humphry Davy first noted its analgesic properties in 1800. Gardner Colton and Horace Wells are

credited with having first used nitrous oxide as an anesthetic for dental extractions in humans in 1844. Nitrous oxide's lack of potency (an 80% nitrous oxide concentration results in analgesia but not surgical anesthesia) led to clinical demonstrations that were less convincing than those with ether.

Nitrous oxide was the least popular of the three early inhalation anesthetics because of its low potency and its tendency to cause asphyxia when used alone (see Chapter 8). Interest in nitrous oxide was revived in 1868 when Edmund Andrews administered it in 20% oxygen; its use was, however, overshadowed by the popularity of ether and chloroform. Ironically, nitrous oxide is the only one of these three agents still in use today. Chloroform superseded ether in popularity in many areas (particularly in the United Kingdom), but reports of chloroform-related cardiac arrhythmias, respiratory depression, and hepatotoxicity eventually caused practitioners to abandon it in favor of ether, particularly in North America.

Even after the introduction of other inhalation anesthetics (ethyl chloride, ethylene, divinyl ether, cyclopropane, trichloroethylene, and fluroxene), ether remained the standard inhaled anesthetic until the early 1960s. The only inhalation agent that rivaled ether's safety and popularity was cyclopropane (introduced in 1934). However, both are highly combustible and both have since been replaced by a succession of nonflammable potent fluorinated hydrocarbons: halothane (developed in 1951; released in 1956), methoxyflurane (developed in 1958; released in 1960), enflurane (developed in 1963; released in 1973), and isoflurane (developed in 1965; released in 1981).

Currently, sevoflurane is by far the most popular inhaled agent in developed countries. It is far less pungent than isoflurane and has low blood solubility. Ill-founded concerns about the potential toxicity of its degradation products delayed its release in the United States until 1994 (see Chapter 8). These concerns have proved to be theoretical. Sevoflurane is very suitable for inhaled inductions and has largely replaced halothane in pediatric practice. Desflurane (released in 1992) has many of the desirable properties of isoflurane as well as more rapid uptake and elimination (nearly as fast as nitrous oxide). Sevoflurane, desflurane, and isoflurane are the most commonly used inhaled agents in developed countries worldwide.

LOCAL & REGIONAL ANESTHESIA

The medicinal qualities of coca had been recognized by the Incas for centuries before its actions were first observed by Europeans. Cocaine was isolated from

coca leaves in 1855 by Gaedicke and was purified in 1860 by Albert Niemann. Sigmund Freud performed seminal work with cocaine. Nevertheless, the original application of cocaine for anesthesia is credited to Carl Koller, at the time a house officer in ophthalmology, who demonstrated topical anesthesia of the eye in 1884. Later in 1884 William Halsted used cocaine for intradermal infiltration and nerve blocks (including blocks of the facial nerve, brachial plexus, pudendal nerve, and posterior tibial nerve). August Bier is credited with administering the first spinal anesthetic in 1898. He was also the first to describe intravenous regional anesthesia (Bier block) in 1908. Procaine was synthesized in 1904 by Alfred Einhorn and within a year was used clinically as a local anesthetic by Heinrich Braun. Braun was also the first to add epinephrine to prolong the duration of local anesthetics. Ferdinand Cathelin and Jean Sicard introduced caudal epidural anesthesia in 1901. Lumbar epidural anesthesia was described first in 1921 by Fidel Pages and again (independently) in 1931 by Achille Dogliotti. Additional local anesthetics subsequently introduced include dibucaine (1930), tetracaine (1932), lidocaine (1947), chloroprocaine (1955), mepivacaine (1957), prilocaine (1960), bupivacaine (1963), and etidocaine (1972). The most recent additions, ropivacaine (1996) and levobupivacaine (1999), have durations of action similar to bupivacaine but less cardiac toxicity (see Chapter 16). Another, chemically dissimilar local anesthetic, articaine, has been widely applied for dental anesthesia.

INTRAVENOUS ANESTHESIA

Induction Agents

Intravenous anesthesia required the invention of the hypodermic syringe and needle by Alexander Wood in 1855. Early attempts at intravenous anesthesia included the use of chloral hydrate (by Oré in 1872), chloroform and ether (Burkhardt in 1909), and the combination of morphine and scopolamine (Bredenfeld in 1916). Barbiturates were first synthesized in 1903 by Fischer and von Mering. The first barbiturate used for induction of anesthesia was diethylbarbituric acid (barbital), but it was not until the introduction of hexobarbital in 1927 that barbiturate induction became popular. Thiopental, synthesized in 1932 by Volwiler and Tabern, was first used clinically by John Lundy and Ralph Waters in 1934 and for many years it remained the most common agent for intravenous induction of anesthesia. Methohexital was first used clinically in 1957 by V.K. Stoelting. Methohexital continues to be very popular for brief general anesthetics for electroconvulsive therapy. After

chlordiazepoxide was discovered in 1955 and released for clinical use in 1960, other benzodiazepines—diazepam, lorazepam, and midazolam—came to be used extensively for premedication, conscious sedation, and induction of general anesthesia. Ketamine was synthesized in 1962 by Stevens and first used clinically in 1965 by Corssen and Domino; it was released in 1970 and continues to be popular today, particular when administered in combination with other agents for general anesthesia or when infused in low doses to awake patients for painful conditions. Etomidate was synthesized in 1964 and released in 1972. Initial enthusiasm over its relative lack of circulatory and respiratory effects was tempered by evidence of adrenal suppression, reported after even a single dose. The release of propofol in 1986 (1989 in the United States) was a major advance in outpatient anesthesia because of its short duration of action (see Chapter 9). Propofol is currently the most popular agent for intravenous induction worldwide.

Neuromuscular Blocking Agents

The introduction of curare by Harold Griffith and Enid Johnson in 1942 was a milestone in anesthesia. Curare greatly facilitated tracheal intubation and muscle relaxation during surgery. For the first time, operations could be performed on patients without the requirement for relatively deep planes of inhaled general anesthetic to produce muscle relaxation. Such deep planes of general anesthesia often resulted in excessive cardiovascular and respiratory depression as well as prolonged emergence. Moreover, deep planes of inhalation anesthesia often were not tolerated by frail patients.

Succinylcholine was synthesized by Bovet in 1949 and released in 1951; it remains a standard agent for facilitating tracheal intubation during rapid sequence induction. Until recently, succinylcholine remained unchallenged in its rapid onset of profound muscle relaxation, but its side effects prompted the search for a comparable substitute. Other neuromuscular blockers (NMBs; discussed in Chapter 11)—gallamine, decamethonium, metocurine, alcuronium, and pancuronium—were subsequently introduced. Unfortunately, these agents were often associated with side effects (see Chapter 11), and the search for the ideal NMB continued. Recently introduced agents that more closely resemble an ideal NMB include vecuronium, atracurium, rocuronium, mivacurium, and *cis*-atracurium.

Opioids

Morphine, first isolated from opium in between 1803 and 1805 by Sertürner, was also tried as an intravenous anesthetic. The adverse events associated with opioids in early reports caused many anesthetists to favor pure inhalation anesthesia. Interest in opioids in anesthesia returned following the synthesis and introduction of meperidine in 1939. The concept of *balanced anesthesia* was introduced in 1926 by Lundy and others and evolved to include thiopental for induction, nitrous oxide for amnesia, an opioid for analgesia, and curare for muscle relaxation. In 1969, Lowenstein rekindled interest in "pure" opioid anesthesia by reintroducing the concept of large doses of opioids as complete anesthetics. Morphine was the first agent so employed, but fentanyl and sufentanil have been preferred by a large margin as sole agents. As experience grew with this technique, its multiple limitations—unreliably preventing patient awareness, incompletely suppressing autonomic responses during surgery, and prolonged respiratory depression—were realized. Remifentanil, an opioid subject to rapid degradation by nonspecific plasma and tissue esterases, permits profound levels of opioid analgesia to be employed without concerns regarding the need for postoperative ventilation, albeit with an increased risk of acute opioid tolerance.

EVOLUTION OF THE SPECIALTY

British Origins

Following its first public demonstration in the United States, ether anesthesia quickly was adopted in England. John Snow, often considered the father of the anesthesia specialty, was the first physician to take a full-time interest in this new anesthetic. He was the first to scientifically investigate ether and the physiology of general anesthesia. Of course, Snow was also a pioneer in epidemiology who helped stop a cholera epidemic in London by proving that the causative agent was transmitted by ingestion of contaminated well water rather than by inhalation. In 1847, Snow published the first book on general anesthesia, *On the Inhalation of Ether*. When the anesthetic properties of chloroform were made known, he quickly investigated and developed an inhaler for that agent as well. He believed that an inhaler should be used in administering ether or chloroform to control the dose of the anesthetic. His second book, *On Chloroform and Other Anaesthetics*, was published posthumously in 1858.

After Snow's death, Dr. Joseph T. Clover took his place as England's leading anesthetist. Clover emphasized continuously monitoring the patient's pulse during anesthesia, a practice that was not yet standard at the time. He was the

first to use the jaw-thrust maneuver for relieving airway obstruction, the first to insist that resuscitation equipment always be available during anesthesia, and the first to use a cricothyroid cannula (to save a patient with an oral tumor who developed complete airway obstruction). After Clover, Sir Frederic Hewitt became England's foremost anesthetist in the 1890s. He was responsible for many inventions, including the oral airway. Hewitt also wrote what many consider to be the first true textbook of anesthesia, which went through five editions. Snow, Clover, and Hewitt established the tradition of physician anesthetists in England, but it was Hewitt who made the most sustained and strongest arguments for educating specialists in anesthesia. In 1893, the first organization of physician specialists in anesthesia, the London Society of Anaesthetists, was formed in England by J.F. Silk.

The first elective tracheal intubations during anesthesia were performed in the late nineteenth century by surgeons Sir William MacEwen in Scotland, Joseph O'Dwyer in the United States, and Franz Kuhn in Germany. Tracheal intubation during anesthesia was popularized in England by Sir Ivan Magill and Stanley Rowbotham in the 1920s.

North American Origins

In the United States, only a few physicians had specialized in anesthesia by 1900. The task of providing general anesthesia was often delegated to junior surgical house officers, medical students, or general practitioners.

The first organization of physician anesthetists in the United States was the Long Island Society of Anesthetists, formed in 1905, which, as it grew, was renamed the New York Society of Anesthetists in 1911. The group now known as the International Anesthesia Research Society (IARS) was founded in 1922, and in that same year the IARS-sponsored scientific journal *Current Researches in Anesthesia and Analgesia* (now called *Anesthesia and Analgesia*) began publication. In 1936, the New York Society of Anesthetists became the American Society of Anesthetists, and later, in 1945, the American Society of Anesthesiologists (ASA). The scientific journal *Anesthesiology* was first published in 1940.

Harold Griffith and others founded the Canadian Anesthetists Society in 1943, and Griffith (now better known for introducing curare) served as its first president. Twelve years later the journal now known as the *Canadian Journal of Anesthesia* was first published. Five physicians stand out in the early development of anesthesia in the United States after 1900: James Tayloe

Gwathmey, F.H. McMechan, Arthur E. Guedel, Ralph M. Waters, and John S. Lundy. Gwathmey was the author (with Charles Baskerville) of the first major American textbook of anesthesia in 1914 and was the highly influential first president of the New York State Society of Anesthetists. McMechan, assisted by his wife, was the driving force behind both the IARS and *Current Researches in Anesthesia and Analgesia*, and until his death in 1939 tirelessly organized physicians specializing in anesthesia into national and international organizations. Guedel was the first to describe the signs and four stages of general anesthesia. He advocated cuffed tracheal tubes and introduced artificial ventilation during ether anesthesia (later termed *controlled respiration* by Waters). Ralph Waters made a long list of contributions to the specialty, probably the most important of which was his insistence on the proper education of specialists in anesthesia. Waters developed the first academic department of anesthesiology at the University of Wisconsin in Madison. Lundy, working at the Mayo Clinic in Minnesota, was instrumental in the formation of the American Board of Anesthesiology (1937) and chaired the American Medical Association's Section on Anesthesiology for 17 years.

Because of the scarcity of physicians specializing in anesthesia in the United States, surgeons at both the Mayo Clinic and Cleveland Clinic began training and employing nurses as anesthetists in the early 1900s. As the numbers of nurse anesthetists increased, a national organization (now called the American Association of Nurse Anesthetists [AANA]) was incorporated in 1932. The AANA first offered a certification examination in 1945. In 1969 two Anesthesiology Assistant programs began accepting students, and in 1989 the first certification examinations for anesthesiologist assistants were administered. Certified registered nurse anesthetists and anesthesiologist assistants represent important members of the anesthesia workforce in the United States and in other countries.

Official Recognition

In 1889 Henry Isaiah Dorr, a dentist, was appointed Professor of the Practice of Dentistry, Anaesthetics and Anaesthesia at the Philadelphia College of Dentistry. Thus he was the first known professor of anesthesia worldwide. Thomas D. Buchanan, of the New York Medical College, was the first physician to be appointed Professor of Anesthesia (in 1905). When the American Board of Anesthesiology was established in 1938, Dr. Buchanan served as its first president. Certification of specialists in anesthesia was first available in Canada in 1946. In England, the first examination for the Diploma in Anaesthetics took

place in 1935, and the first Chair in Anaesthetics was awarded to Sir Robert Macintosh in 1937 at Oxford University. Anesthesia became an officially recognized specialty in England only in 1947, when the Royal College of Surgeons established its Faculty of Anaesthetists. In 1992 an independent Royal College of Anaesthetists was granted its charter. Momentous changes occurred in Germany during the 1950s, progress likely having been delayed by the isolation of German medical specialists from their colleagues in other countries that began with World War I and continued until the resolution of World War II. First the journal *Der Anaesthetist* began publication in 1952. The following year, requirements for specialist training in anesthesia were approved and the German Society of Anesthetists was founded.

The Scope of Anesthesiology

The practice of anesthesia has changed dramatically since the days of John Snow. The modern anesthesiologist must be both a perioperative consultant and a deliverer of care to patients. In general, anesthesiologists are responsible for nearly all "noncutting" aspects of the patient's medical care in the immediate perioperative period. The "captain of the ship" doctrine, which held the surgeon responsible for every aspect of the patient's perioperative care (including anesthesia), is no longer a valid notion when an anesthesiologist is present. The surgeon and anesthesiologist must function together as an effective team, and both are ultimately answerable to the patient rather than to each other.

The modern practice of anesthesia is not confined to rendering patients insensible to pain (Table 1–1). Anesthesiologists monitor, sedate, and provide general or regional anesthesia outside the operating room for various imaging procedures, endoscopy, electroconvulsive therapy, and cardiac catheterization. Anesthesiologists such as Peter Safar have been pioneers in cardiopulmonary resuscitation, and anesthesiologists continue to be integral members of resuscitation teams.

An increasing number of practitioners pursue subspecialty fellowships in anesthesia for cardiothoracic surgery (see Chapter 22), critical care (see Chapter 57), neuroanesthesia (see Chapter 27), obstetric anesthesia (see Chapter 41), pediatric anesthesia (see Chapter 42), palliative care, regional anesthesia, and acute pain management (see Chapters 45, 46, 48) or chronic pain medicine (see Chapter 47). Certification requirements for special competence in critical care, pediatric anesthesia, and pain medicine already exist in the United States. Fellowship programs in Adult Cardiothoracic Anesthesia, Critical Care

Medicine, Pediatric Anesthesiology, Obstetric Anesthesiology, Regional Anesthesia and Acute Pain Management, Sleep Medicine, Palliative Care, and Interventional Pain have specific accreditation requirements. Education and certification in anesthesiology can also be used as the basis for certification in Sleep Medicine or in Palliative Medicine.

Anesthesiologists are actively involved in the administration and medical direction of many ambulatory surgery facilities, operating room suites, intensive care units, and respiratory therapy departments. They have also assumed administrative and leadership positions on the medical staffs of many hospitals and ambulatory care facilities. They serve as deans of medical schools and chief executives of health systems. In the United States they have served in state legislatures, in the U.S. Congress, and as the Surgeon General. The future of the specialty has never looked brighter.

SUGGESTED READINGS

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SECTION I

Anesthetic Equipment & Monitors

CHAPTER

2

The Operating Room Environment

Charles E. Cowles, Jr., MD, MBA, FASA

KEY CONCEPTS

1. A pressure of 1000 psig indicates an E-cylinder that is approximately half full and represents 330 L of oxygen.
2. The only reliable way to determine residual volume of nitrous oxide is to weigh the cylinder.
3. To discourage incorrect cylinder attachments, cylinder manufacturers have adopted a pin index safety system.
4. A basic principle of radiation safety is to keep exposure "as low as reasonably practical" (ALARP). The principles of ALARP optimize protection from radiation exposure by the use of *time*, *distance*, and *shielding*.
5. The magnitude of a leakage current is normally imperceptible to touch (<1 mA, and well below the fibrillation threshold of 100 mA). If the current bypasses the high resistance offered by skin, however, and is applied directly to the heart (microshock), current as low as 100 µA may be fatal. The maximum leakage allowed in operating room equipment is 10 µA.
6. To reduce the chance of two coexisting faults, a line isolation monitor measures the potential for current flow from the isolated power supply to the ground. Basically, the line isolation monitor determines the degree of isolation between the two power wires and the ground and predicts the amount of current that *could* flow if a second short circuit were to develop.
7. Almost all surgical fires can be prevented. Unlike medical complications, fires are a product of simple physical and chemistry properties. Occurrence is guaranteed given the proper combination of

factors, but can be almost entirely eliminated through understanding the basic principles of fire risk.

8. The most common risk factor for surgical fire relates to the open delivery of oxygen.
9. Administration of oxygen in concentrations of greater than 30% should be guided by the clinical presentation of the patient and not solely by protocols or habits.
10. The sequence of stopping gas flow and removal of the endotracheal tube when fire occurs in the airway is not as important as ensuring that both actions are performed immediately.
11. Before beginning laser surgery, the laser device should be in the operating room, warning signs should be posted on the doors, and protective eyewear should be issued. The anesthesia provider should ensure that the warning signs and eyewear match the labeling on the device, as laser protection is specific to the type of laser.

Anesthesiologists, who spend more time in operating rooms than any other physician specialty, are responsible for protecting patients and operating room personnel from a multitude of dangers during surgery. Some of these threats are unique to the operating room. As a result, the anesthesiologist may be responsible for ensuring proper functioning of the operating room's medical gases, fire prevention and management, environmental factors (eg, temperature, humidity, ventilation, and noise), and electrical safety. Anesthesiologists often coordinate, or assist with, layout and design of surgical and procedural suites, including workflow enhancements. This chapter describes the major operating room features that are of special interest to anesthesiologists and the potential hazards associated with these systems.

Culture of Safety

Patients often think of the operating room as a safe place where the care given is centered around protecting the patient. Anesthesia providers, surgeons, nurses, and other medical personnel are responsible for carrying out critical tasks safely and efficiently. Unless members of the operating room team remain vigilant, errors can occur that may result in harm to the patient or to members of the operating room team. The best way of preventing serious harm to the patient or to the operating room team is by creating a *culture of safety*, which identifies and

stops unsafe acts before harm occurs.

One tool that fosters the safety culture is the use of a surgical safety checklist. Such checklists must be used prior to incision on every case and include components agreed upon by the facility as crucial. Many surgical checklists are derived from the surgical safety checklist published by the World Health Organization (WHO). For checklists to be effective, they must first be used; second, all members of the surgical team must be focused on the checklist when it is being used. Checklists are most effective when performed in an interactive fashion. An example of a suboptimally executed checklist is one that is read in entirety, after which the surgeon asks whether everyone agrees. This format makes it difficult to identify possible problems. A better method is one that elicits a response after each point; eg, “Does everyone agree this patient is John Doe?”, followed by “Does everyone agree we are performing a removal of the left kidney?”, and so forth. Optimal checklists do not attempt to cover every possibility, but address only key components, allowing them to be completed in less than 90 seconds.

Some practitioners argue that checklists waste too much time; they fail to realize that cutting corners to save time often leads to problems later, resulting in a net loss of time and harm to the patient. If safety checklists were followed in every case, significant reductions would be seen in the incidence of preventable surgical complications such as wrong-site surgery, procedures on the wrong patient, retained foreign objects, and administration of a medication to a patient with a known allergy to that medication. Anesthesia providers are leaders in patient safety initiatives and should take a proactive role to utilize checklists and other activities that foster the culture of safety.

Medical Gas Systems

The medical gases commonly used in operating rooms are oxygen, nitrous oxide, air, and nitrogen. Although technically not a gas, vacuum exhaust for disposal or scavenging of waste anesthetic gas and surgical suction must also be provided, and these are considered integral parts of the medical gas system. Patients are endangered if medical gas systems, particularly oxygen, are misconfigured or malfunction. The anesthesiologist must understand the sources of the gases and the means of their delivery to the operating room to prevent or detect medical gas depletion or supply line misconnection. Estimates of a particular hospital’s peak demand determine the type of medical gas supply system required. Design and standards follow National Fire Protection Association (NFPA) 99 in the

United States and HTM 2022 in the United Kingdom.

SOURCES OF MEDICAL GASES

Oxygen

A reliable supply of oxygen is a critical requirement in any surgical area. Medical grade oxygen (99% or 99.5% pure) is manufactured by fractional distillation of liquefied air. Oxygen is stored as a compressed gas at room temperature or refrigerated as a liquid. Most small hospitals store oxygen in two separate banks of high-pressure cylinders (H-cylinders) connected by a manifold (**Figure 2–1**). Only one bank is utilized at a time. The number of cylinders in each bank depends on anticipated daily demand. The manifold contains valves that reduce the *cylinder pressure* (approximately 2000 pounds per square inch [psig]) to *line pressure* (55 ± 5 psig) and automatically switch banks when one group of cylinders is exhausted.

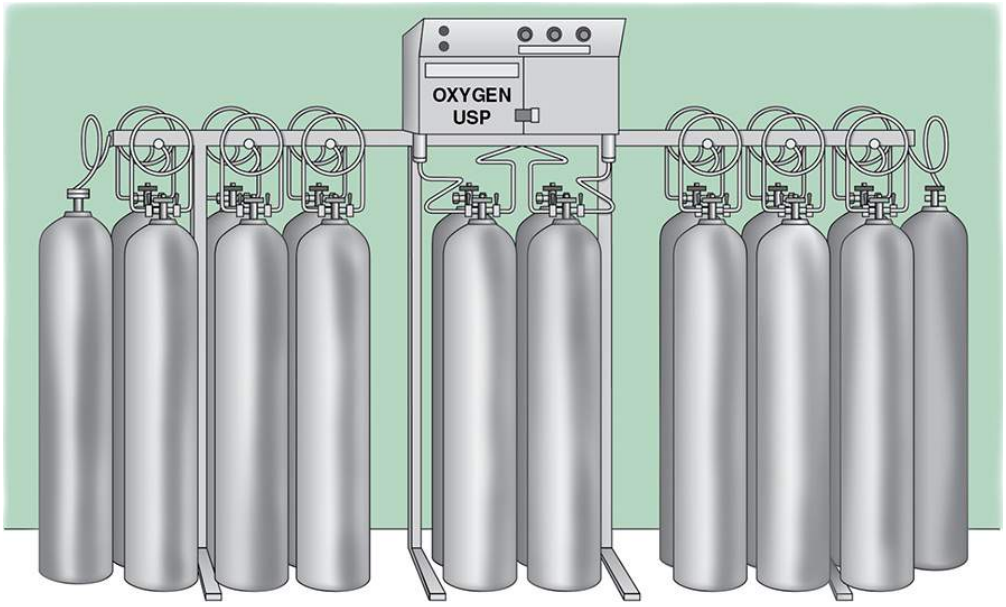

FIGURE 2–1 A bank of oxygen H-cylinders connected by a manifold.

A liquid oxygen storage system (**Figure 2–2**) is more economical for large hospitals. Liquid oxygen must be stored well below its critical temperature of –119°C because gases can be liquefied by pressure *only* if stored below their critical temperature. A large hospital may have a smaller liquid oxygen supply or a bank of compressed gas cylinders that can provide one day's oxygen requirements as a reserve. To guard against a hospital gas-system failure, the

anesthesiologist must always have an emergency (E-cylinder) supply of oxygen available during anesthesia.

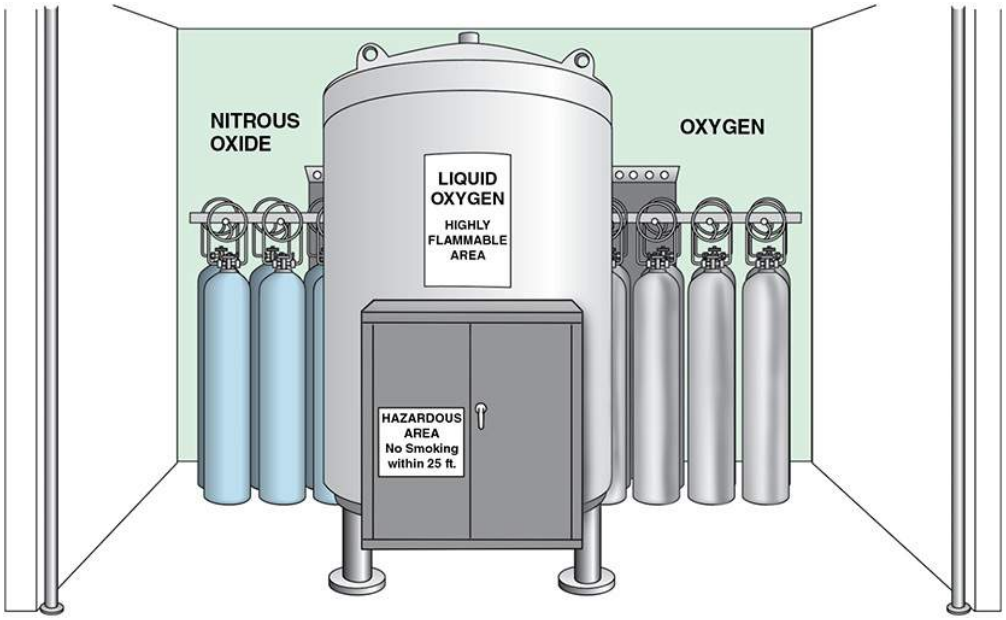

FIGURE 2–2 A liquid storage tank with reserve oxygen tanks in the background.

Most anesthesia machines accommodate E-cylinders of oxygen (**Table 2–1**). As oxygen is expended, the cylinder's pressure falls in proportion to its content. A pressure of 1000 psig indicates an E-cylinder that is approximately half full and represents 330 L of oxygen at atmospheric pressure and a temperature of 20°C. If the oxygen is exhausted at a rate of 3 L/min, a cylinder that is half full will be empty in 110 min. Oxygen cylinder pressure should be assessed prior to use and periodically during use. Anesthesia machines usually also accommodate E-cylinders for medical air and nitrous oxide, and may accept cylinders of helium. Compressed medical gases utilize a pin index safety system for these cylinders to prevent inadvertent crossover and connections for different gas types. As a safety feature, oxygen E-cylinders have a "plug" made from *Wood's metal*. This metallurgic alloy has a low melting point, allowing dissipation of pressure in a fire that might otherwise heat the cylinder to the point of explosion. This pressure-relief "valve" is designed to rupture at 3300 psig, well below the pressure E-cylinder walls should be able to withstand (more than 5000 psig), preventing "overfilling" of the cylinder.

TABLE 2–1 Characteristics of medical gas cylinders.

Gas	E-Cylinder Capacity[1] (L)	H-Cylinder Capacity[1] (L)	Pressure[1] (psig at 20°C)	Color (USA)	Color (International)	Form
O_2	625–700	6000–8000	1800–2200	Green	White	Gas
Air	625–700	6000–8000	1800–2200	Yellow	White and black	Gas
N_2O	1590	15,900	745	Blue	Blue	Liquid
N_2	625–700	6000–8000	1800–2200	Black	Black	Gas

[1]Depending on the manufacturer.

Nitrous Oxide

Nitrous oxide is almost always stored by hospitals in large H-cylinders connected by a manifold with an automatic crossover feature. Bulk liquid storage of nitrous oxide is economical only in very large institutions.

Because the critical temperature of nitrous oxide (36.5°C) is above room temperature, it can be kept liquefied without an elaborate refrigeration system. If the liquefied nitrous oxide rises above its critical temperature, it will revert to its gaseous phase. Because nitrous oxide is not an ideal gas and is easily compressible, this transformation into a gaseous phase is not accompanied by a great rise in tank pressure. Nonetheless, as with oxygen cylinders, all nitrous oxide E-cylinders are equipped with a Wood's metal plug to prevent explosion under conditions of unexpectedly high gas pressure (eg, unintentional overfilling or during a fire).

Although a disruption in supply is usually not catastrophic, most anesthesia machines have reserve nitrous oxide E-cylinders. Because these smaller cylinders also contain nitrous oxide in its liquid state, the volume remaining in a cylinder is *not* proportional to cylinder pressure. By the time the liquid nitrous oxide is expended and the tank pressure begins to fall, only about 400 L of nitrous oxide remains. **If liquid nitrous oxide is kept at a constant temperature (20°C), it will vaporize at the same rate at which it is consumed and will maintain a constant pressure (745 psig) until the liquid is exhausted**.

The only reliable way to determine residual volume of nitrous oxide is to weigh the cylinder. For this reason, the tare weight (TW), or empty weight, of cylinders containing a liquefied compressed gas (eg, nitrous oxide) is often stamped on the shoulder of the cylinder. The pressure gauge of a nitrous oxide cylinder should not exceed 745 psig at 20°C. A higher reading implies gauge malfunction, tank overfill (liquid fill), or a cylinder containing a gas other than nitrous oxide.

Because energy is consumed in the conversion of a liquid to a gas (the latent heat of vaporization), liquid nitrous oxide cools during this process. The drop in

temperature results in a lower vapor pressure and lower cylinder pressure. The cooling is so pronounced at high flow rates that there is often frost on the tank, and the pressure regulator may freeze in such circumstances.

Medical Air

The use of air is becoming more frequent in anesthesiology as the popularity of nitrous oxide and unnecessarily high concentrations of oxygen has declined. Cylinder air is medical grade and is obtained by blending oxygen and nitrogen. Dehumidified (but unsterile) air is provided to the hospital pipeline system by compression pumps. The inlets of these pumps must be distant from vacuum exhaust vents and machinery to minimize contamination. Because the critical temperature of air is –140.6°C, it exists as a gas in cylinders whose pressures fall in proportion to their content.

Nitrogen

Although compressed nitrogen is not administered to patients, it may be used to drive operating room equipment, such as saws, drills, and surgical handpieces. Nitrogen supply systems incorporate either the use of H-cylinders connected by a manifold or a wall system supplied by a compressor-driven central supply.

Vacuum

A central hospital vacuum system usually consists of independent suction pumps, each capable of handling peak requirements. Traps at every user location prevent contamination of the system with foreign matter. The medical-surgical vacuum system may be used for waste anesthetic gas disposal (WAGD) as long as it does not affect performance of the system. Medical vacuum receptacles are usually black in color with white lettering. A dedicated WAGD vacuum system is required with modern anesthesia machines. The WAGD outlet may incorporate the use of a suction regulator with a float indicator that should be maintained between the designated markings. Excess suction may result in inadequate patient ventilation, and insufficient suction levels may result in the failure to evacuate waste anesthetic gases. WAGD receptacles and tubing are usually lavender in color.

Carbon Dioxide

Many surgical procedures are performed using laparoscopic or robotic-assisted techniques requiring insufflation of body cavities with carbon dioxide, an odorless, colorless, nonflammable and slightly acidic gas. Large cylinders containing carbon dioxide, such as M-cylinders or LK-cylinders, are frequently found in the operating room; these cylinders share a common size orifice and thread with oxygen cylinders and can be inadvertently interchanged.

DELIVERY OF MEDICAL GASES

Medical gases are delivered from their central supply source to the operating room through a network of pipes that are sized such that the pressure drop across the whole system never exceeds 5 psig. Gas pipes are usually constructed of seamless copper tubing using a special welding technique. Internal contamination of the pipelines with dust, grease, or water must be avoided. The hospital's gas delivery system appears in the operating room as hose drops, gas columns, or elaborate articulating arms (**Figure 2–3**). Operating room equipment, including the anesthesia machine, connects to pipeline system outlets by color-coded hoses. Quick-coupler mechanisms, which vary in design with different manufacturers, connect one end of the hose to the appropriate gas outlet. The other end connects to the anesthesia machine through a non-interchangeable diameter index safety system fitting that prevents incorrect hose attachment.

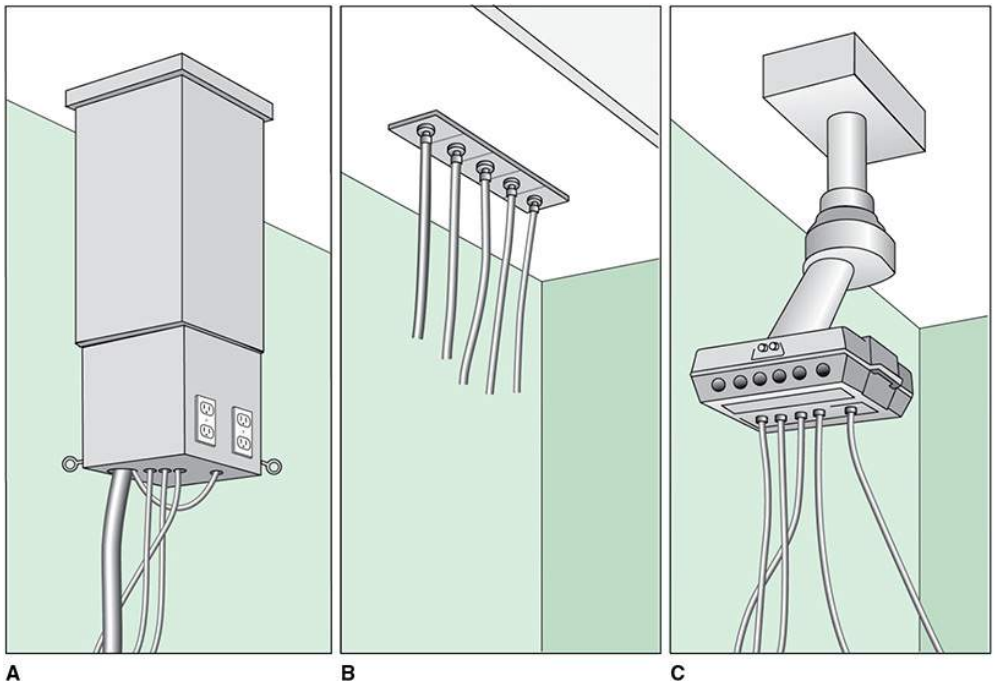

FIGURE 2–3 Typical examples of **A:** gas columns, **B:** ceiling hose drops, and **C:** articulating arms. One end of a color-coded hose connects to the hospital medical gas supply system by way of a quick-coupler mechanism. The other end connects to the anesthesia machine through the diameter index safety system.

E-cylinders of oxygen, nitrous oxide, and air attach directly to the anesthesia machine. To discourage incorrect cylinder attachments, cylinder manufacturers have adopted a *pin index safety system*. Each gas cylinder (sizes A–E) has two holes in its cylinder valve that mate with corresponding pins in the yoke of the anesthesia machine (**Figure 2–4**). The relative positioning of the pins and holes is unique for each gas. Multiple washers placed between the cylinder and yoke, which prevent proper engagement of the pins and holes, have unintentionally defeated this system and thus must not be used. The pin index safety system is also ineffective if yoke pins are damaged or if the cylinder is filled with the incorrect gas.

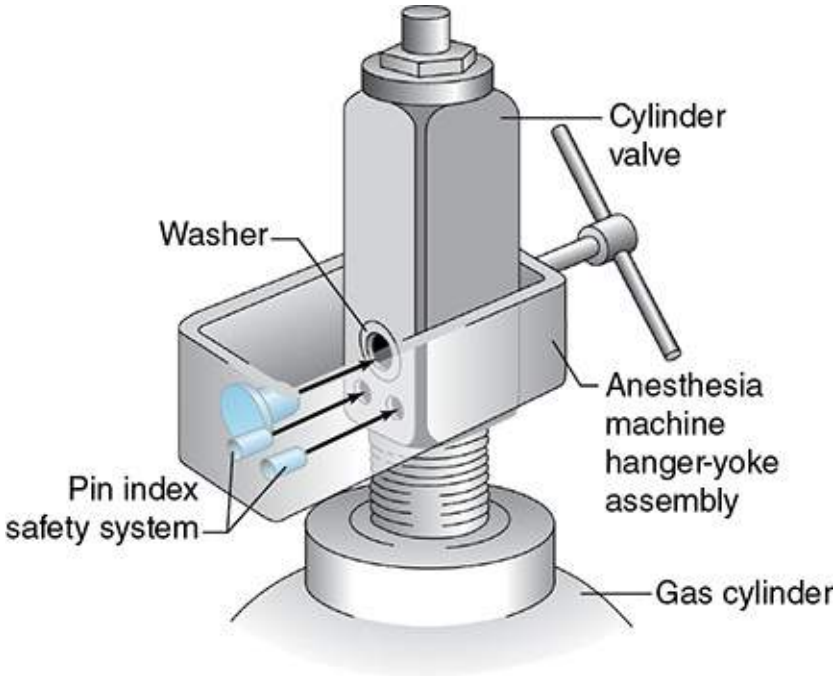

FIGURE 2–4 Pin index safety system interlink between the anesthesia machine and gas cylinder.

The functioning of medical gas supply sources and pipeline systems is constantly monitored by central and area alarm systems. Indicator lights and audible signals warn of changeover to secondary gas sources and abnormally high (eg, pressure regulator malfunction) or low (eg, supply depletion) pipeline

pressures (Figure 2–5).

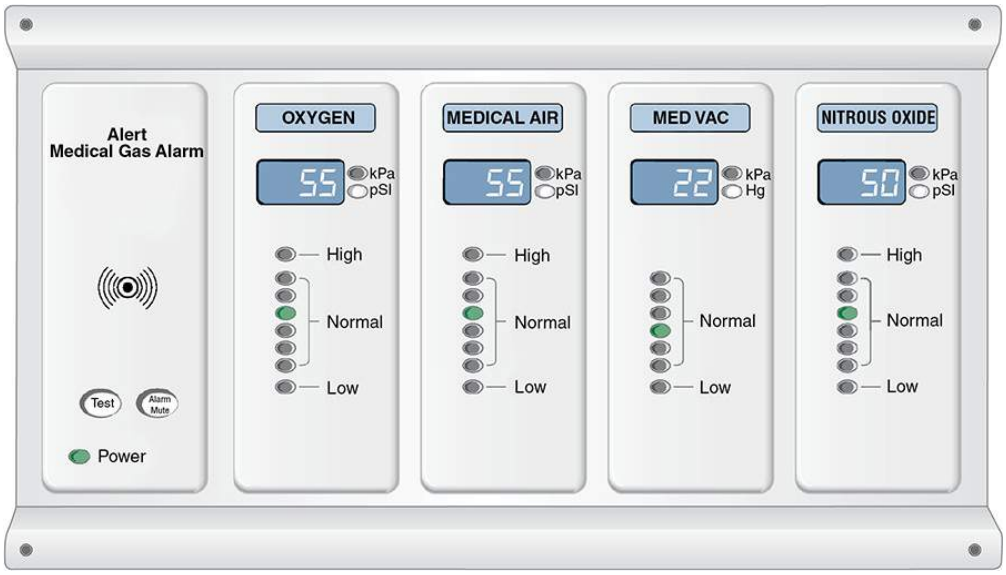

FIGURE 2–5 An example of a master alarm panel that monitors gasline pressure.

Modern anesthesia machines and anesthetic gas analyzers continuously measure the fraction of inspired oxygen (Fi_{O_2}). Analyzers have a variable threshold setting for the minimal Fi_{O_2} but must be configured to prevent disabling this alarm. The monitoring of Fi_{O_2} does not reflect the oxygen concentration distal to the monitoring port and thus should not be used to reference the oxygen concentration within distal devices such as endotracheal tubes. Due to gas exchange, flow rates, and shunting, a marked difference may exist between the indicated Fi_{O_2} and the actual oxygen concentration at the tissue level.

Environmental Factors in the Operating Room

TEMPERATURE

The temperature in most operating rooms seems uncomfortably cold to many conscious patients and, at times, to anesthesia providers. However, scrub nurses and surgeons stand in surgical garb for hours under hot operating room lights. As a general principle, the comfort of operating room personnel must be reconciled with patient care, and in adult patients temperatures should be maintained

between 68°F (20°C) and 75°F (24°C). Hypothermia has been associated with wound infection, impaired coagulation, greater intraoperative blood loss, and prolonged hospitalization (see Chapter 52).

HUMIDITY

In past decades, static discharges were a feared source of ignition in an operating room filled with flammable anesthetic gas vapors. Now humidity control is more relevant to infection control practices. Humidity levels in the operating room should be maintained between 20% and 60%. Below this range the dry air facilitates airborne mobility of particulate matter, which can be a vector for infection. At high humidity, dampness can affect the integrity of barrier devices such as sterile cloth drapes and pan liners.

VENTILATION

A high rate of operating room airflow decreases contamination of the surgical site. These flow rates, usually achieved by blending up to 80% recirculated air with fresh air, are engineered in a manner to decrease turbulent flow and to be unidirectional. Although recirculation conserves energy costs associated with heating and air conditioning, it is unsuitable for WAGD. Therefore, a separate waste anesthetic gas scavenging system must always supplement operating room ventilation. The operating room should maintain a slightly positive pressure to drive away gases that escape scavenging and should be designed so fresh air is introduced through, or near, the ceiling and air return is handled at, or near, floor level. Ventilation considerations must address both air quality and volume changes. The National Fire Protection Agency (NFPA) recommends 20 air volume exchanges per hour to decrease risk of stagnation and bacterial growth. Air quality should be maintained by adequate air filtration using a 90% filter, defined simply as one that filters out 90% of particles presented. Although high-efficiency particulate filters (HEPA) are frequently used, these are not required by engineering or infection control standards.

NOISE

Multiple studies have demonstrated that exposure to noise can have a detrimental effect on human cognitive function, and prolonged exposure may result in hearing impairment. Operating room noise has been measured at 70 to 80 decibels (dB) with frequent sound peaks exceeding 80 dB. As a reference, if

the speaking voice has to be raised above conversational level, then ambient noise is approximated at 80 dB. Noise levels in the operating room approach the time-weighted average (TWA) for which the Occupational Safety and Health Administration (OSHA) requires hearing protection. Orthopedic air chisels and neurosurgical drills can approach the noise levels of 125 dB, the level at which most human subjects begin to experience pain.

IONIZING RADIATION

Anesthesia providers are exposed to radiation as a component of either diagnostic imaging or radiation therapy; examples include fluoroscopy, linear accelerators, computed tomography, directed beam therapy, proton therapy, and diagnostic radiographs. Human effects of radiation are measured by units of absorbed doses such as the gray (Gy) and rads, or by equivalent dose units such as the Sievert (Sv) and Roentgen equivalent in man (REM). Radiation-sensitive organs such as eyes, thyroid, and gonads must be protected, as well as blood, bone marrow, and the fetus. Radiation levels must be monitored if individuals are exposed to greater than 40 REM, and the most common method of measurement is by film badge. Lifetime exposure can be tabulated by a required database of film badge wearers.

A basic principle of radiation safety is to keep exposure “as low as reasonably practical” (ALARP). The principles of ALARP optimize protection from radiation exposure by the use of *time*, *distance*, *and shielding*. The length of time of exposure is usually not an issue for simple radiographs such as chest films but can be significant in fluoroscopic procedures such as those commonly performed during interventional radiology or pulmonology, c-arm use, and in a diagnostic gastroenterology center. Exposure can be reduced to the provider by increasing the distance between the beam and the provider. Radiation exposure over distance follows the inverse square law. To illustrate, intensity is represented as $1/d^2$ (where d = distance) so that 100 millirads (mrads) at 1 inch will be 0.01 mrads at 100 inches. Shielding is the most reliable form of radiation protection; typical personal shielding is in the form of leaded aprons, thyroid collars, and glasses. Physical shields are usually incorporated into radiological suites and can be as simple as a wall to stand behind or a rolling leaded shield to place between the beam and the provider. Although most modern facilities are designed in a very safe manner, providers can still be exposed to scattered radiation as atomic particles are bounced off shielding. For this reason radiation protection should be donned whenever ionizing radiation is used.

As use of reliable shielding has increased, the incidence of radiation-associated diseases of sensitive organs has decreased, with the exception of radiation-induced cataracts. Because protective eyewear has not been consistently used to the same degree as other types of personal protection, radiation-induced cataracts are increasing among employees working in interventional radiology suites. Anesthesia providers who work in these environments should consider the use of leaded goggles or glasses to decrease the risk of such problems.

Electrical Safety

THE RISK OF ELECTROCUTION

The use of electronic medical equipment subjects patients and health care personnel to the risk of shock and electrocution. Anesthesia providers must have an understanding of electrical hazards and their prevention.

Body contact with two conductive materials at different voltage potentials may complete a circuit and result in an electrical shock. Usually, one point of exposure is a live 110-V or 240-V conductor, with the circuit completed through a ground contact. For example, a grounded person need contact only one live conductor to complete a circuit and receive a shock. The live conductor could be the frame of a patient monitor that has developed a fault to the hot side of the power line. A circuit is now complete between the power line (which is earth grounded at the utility company's pole-top transformer) through the victim and back to the ground (**Figure 2–6**). The physiological effect of electrical current depends on the location, duration, frequency, and magnitude (more accurately, current density) of the shock.

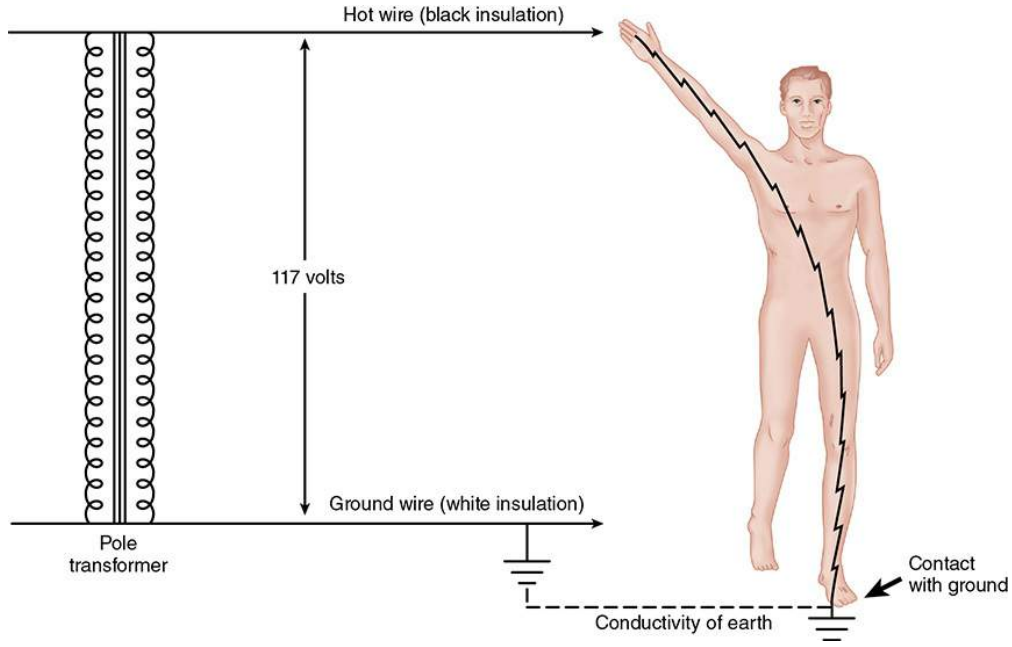

FIGURE 2–6 The setting for the great majority of electric shocks. An accidentally grounded person simultaneously contacts the hot wire of the electric service, usually via defective equipment that provides a pathway linking the hot wire to an exposed conductive surface. The complete electrical loop originates with the secondary of the pole transformer (the voltage source) and extends through the hot wire, the victim and the victim's contact with a ground, the earth itself, the neutral ground rod at the service entrance, and back to the transformer via the neutral (or ground) wire. (Modified with permission from Bruner J, Leonard PF. *Electricity, Safety, and the Patient*. St Louis, MO: Mosby Year Book; 1989.)

Leakage current is present in all electrical equipment as a result of capacitive coupling, induction between internal electrical components, or defective insulation. Current can flow as a result of capacitive coupling between two conductive bodies (eg, a circuit board and its casing) even though they are not physically connected. Some monitors are doubly insulated to decrease the effect of capacitive coupling. Other monitors are designed to be connected to a low-impedance ground (the safety ground wire) that should divert the current away from a person touching the instrument's case. The magnitude of such leaks is normally imperceptible to touch (<1 mA, and well below the fibrillation threshold of 100 mA). If the current bypasses the high resistance offered by skin, however, and is applied directly to the heart, current as low as 100 μA (*microshock*) may be fatal. The maximum leakage allowed in operating room equipment is 10 μA.

Cardiac pacing wires and invasive monitoring catheters provide a direct

conductive pathway to the myocardium. In fact, blood and normal saline can serve as electrical conductors. The exact amount of current required to produce fibrillation depends on the timing of the shock relative to the vulnerable period of heart repolarization (the T wave on the electrocardiogram). Even small differences in potential between the ground connections of two electrical outlets in the same operating room can place a patient at risk for microelectrocution.

PROTECTION FROM ELECTRICAL SHOCK

Most patient electrocutions are caused by current flow from the live conductor of a grounded circuit through the body and back to a ground (Figure 2–6). This would be prevented if everything in the operating room were grounded except the patient. Although direct patient grounds should be avoided, complete patient isolation is not feasible during surgery. Instead, the operating room power supply can be isolated from grounds by an **isolation transformer** (**Figure 2–7**).

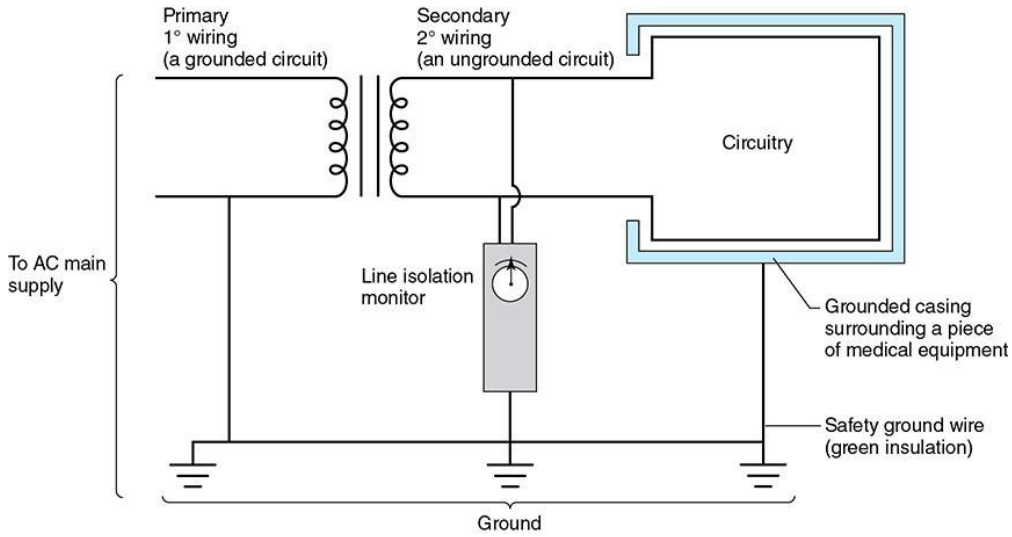

FIGURE 2–7 A circuit diagram of an isolation transformer and monitor.

Unlike the utility company's pole-top transformer, the secondary wiring of an isolation transformer is not grounded and provides two live ungrounded voltage lines for operating room equipment. Equipment casing—but not the electrical circuits—is grounded through the longest blade of a three-pronged plug (the *safety ground*). If a live wire is then unintentionally contacted by a grounded patient, current will not flow through the patient since no circuit back to the secondary coil has been completed (**Figure 2–8**).

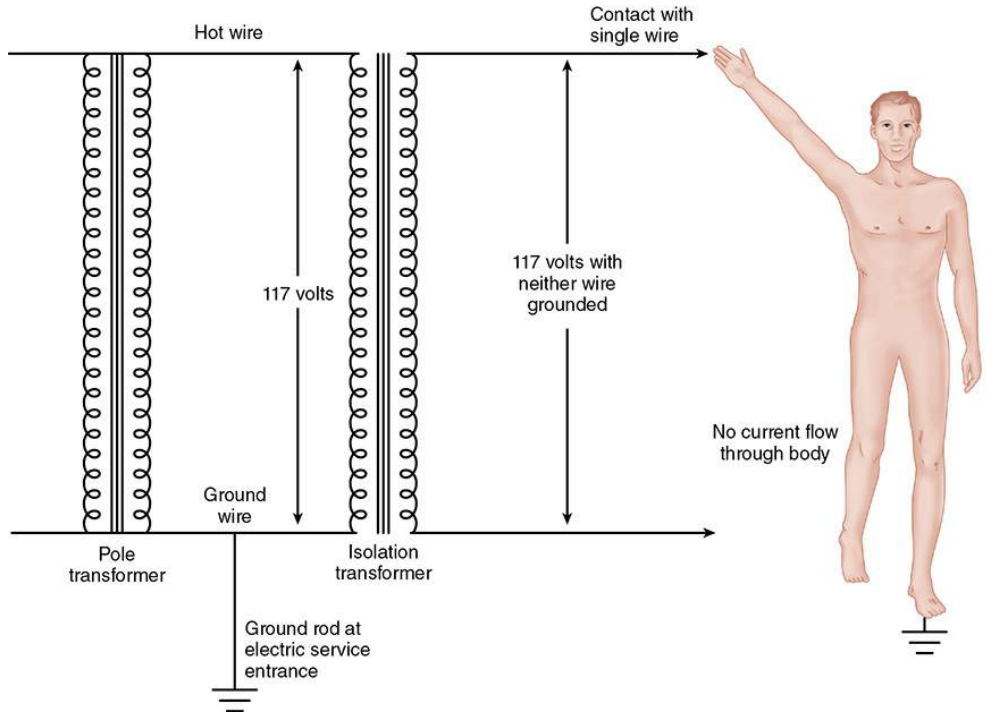

FIGURE 2–8 Even though a person is grounded, no shock results from contact with one wire of an isolated circuit. The individual is in simultaneous contact with two separate voltage sources but does not close a loop including either source. (Modified with permission from Bruner J, Leonard PF. *Electricity, Safety, and the Patient*. St Louis, MO: Mosby Year Book; 1989.)

Of course, if both power lines are contacted, a circuit is completed and a shock is possible. In addition, if either power line comes into contact with a ground through a fault, contact with the other power line will complete a circuit through a grounded patient. To reduce the chance of two coexisting faults, a **line isolation monitor** measures the potential for current flow from the isolated power supply to the ground (**Figure 2–9**). Basically, the line isolation monitor determines the degree of isolation between the two power wires and the ground and predicts the amount of current that *could* flow if a second short circuit were to develop. An alarm is activated if an unacceptably high current flow to the ground becomes possible (usually 2 mA or 5 mA), but power is not interrupted unless a ground-fault circuit interrupter is also activated. The latter, a common feature in household bathrooms and kitchens, is usually not installed in locations such as operating rooms, where discontinuation of life support systems (eg, cardiopulmonary bypass machine) is more hazardous than the risk of electrical shock. The alarm of the line isolation monitor merely indicates that the power supply has partially reverted to a grounded system. In other words, while the line

isolation monitor warns of the existence of a single fault (between a power line and a ground), two faults are required for a shock to occur. Since the line isolation monitor alarms when the sum of leakage current exceeds the set threshold, the last piece of equipment added is usually the defective one; however, if this item is life-sustaining, other equipment can be removed from the circuit to evaluate whether the life safety item is truly at fault.

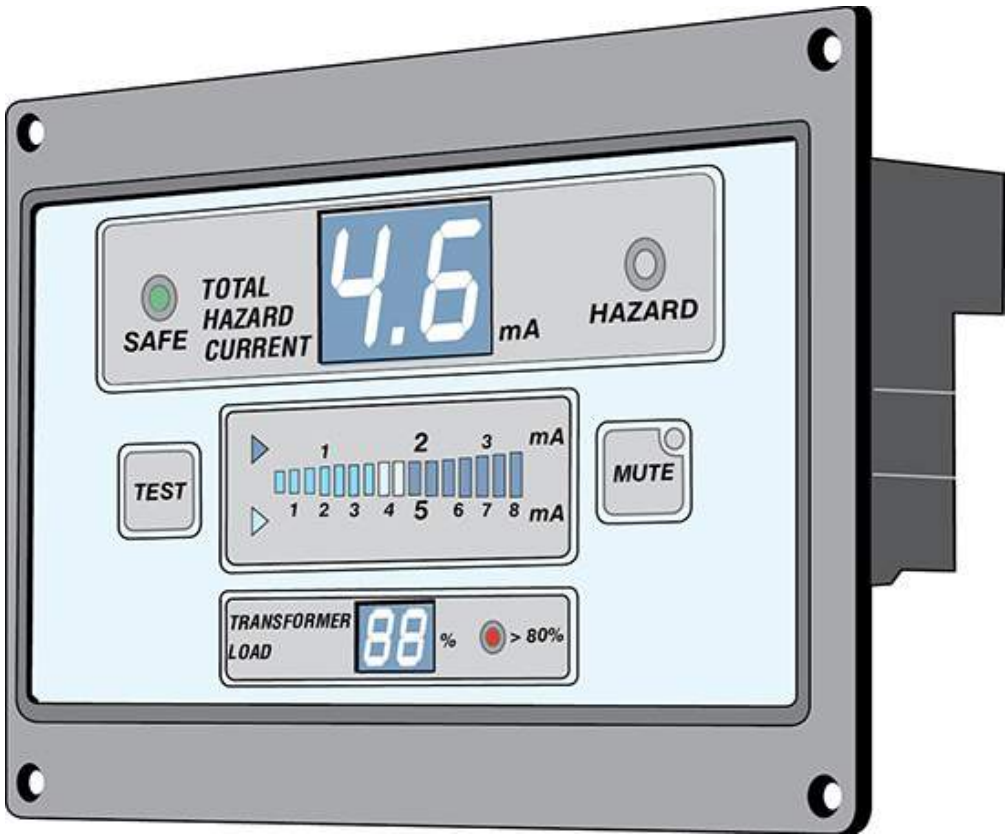

FIGURE 2–9 A line isolation monitor.

Even isolated power circuits do not provide complete protection from the small currents capable of causing microshock fibrillation. Furthermore, the line isolation monitor cannot detect all faults, such as a broken safety ground wire within a piece of equipment. There are, however, modern equipment designs that decrease the possibility of microelectrocution. These include double insulation of the chassis and casing, ungrounded battery power supplies, and patient isolation from equipment-connected grounds by using optical coupling or transformers.

In the latest edition of the U.S. NPFA 99 Health Care Facilities Code, building system requirements for facilities—including electrical systems—are

based upon a risk assessment carried out by facilities personnel with the input of health care providers. The risk levels are categorized in levels as follows:

Category 1—Facility systems in which failure of such equipment or system is likely to cause major injury or death of patients or caregivers

Category 2—Facility systems in which failure of such equipment is likely to cause minor injury to patients or caregivers

Category 3—Facility systems in which failure of such equipment is not likely to cause injury to patients or caregivers, but can cause patient discomfort

Category 4—Facility systems in which failure of such equipment would have no impact on patient care

Category 1 locations and systems will have the greatest amount of reliability and redundancy; lesser categories will have less stringent requirements. All codes under the 2012 edition of the NPFA 99 will be determined by the risk assessment category. Under the electrical code, operating rooms are defined as a wet location requiring electrical systems that reduce the risk of electrical shock hazards. If an operating room is used for procedures without liquid exposure, such as rooms used for central line placement or eye procedures, facilities can perform a risk assessment and reclassify the operating room as a nonwet area.

SURGICAL DIATHERMY (ELECTROCAUTERY, ELECTROSURGERY)

Electrosurgical units (ESUs) generate an ultrahigh-frequency electrical current that passes from a small active electrode (the cautery tip) through the patient and exits by way of a large plate electrode (the dispersal pad, or return electrode). The high current density at the cautery tip is capable of tissue coagulation or cutting, depending on the electrical waveform. Ventricular fibrillation is prevented by the use of ultrahigh electrical frequencies (0.1–3 MHz) compared with line power (50–60 Hz). The large surface area of the low-impedance return electrode avoids burns at the current's point of exit by providing a low current density (the concept of *exit* is technically incorrect, as the current is alternating rather than direct). The high power levels of ESUs (up to 400 W) can cause inductive coupling with monitor cables, leading to electrical interference.

Malfunction of the dispersal pad may result from disconnection from the ESU, inadequate patient contact, or insufficient conductive gel. In these situations, the current will find another place to exit (eg, electrocardiogram pads