

# Chapter 31

## A BRIEF HISTORY OF MILITARY ANESTHESIA

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## INTRODUCTION

For 150 years, the medical departments of the U.S. military have provided state-of-the-art anesthesia within the limitations imposed by the battlefield. From the Mexican War (1846–1848), when the first anesthetic was administered during military surgery, to the Persian Gulf War (1990–1991), military medicine has adapted civilian advances in anesthesiology for use in wartime. Those advances included new drugs, new techniques, new machines, and an expanded role for the anesthesia provider. In turn, the civilian practice of anesthesiology has benefited from lessons learned on the battlefield.

For most of this period, civilian anesthetists counseled the military about what to bring and what to

leave at home during deployment. Complex and cumbersome machines, logistical priorities, and the need for simplicity at the front complicated the provision of modern anesthesia in war. By the Vietnam War, however, the military had its own anesthesia specialists and was no longer dependent on civilian medicine for advice. In the 1960s, the field of military anesthesia produced intensive care specialists and a decade later, practitioners of critical care. Critical care medicine led to a natural alliance of military and civilian anesthesiology in the treatment of trauma.

This chapter is intended to be a brief survey, not a comprehensive study, of the events surrounding the history of military anesthesia.

## EARLY ANALGESICS

Man has tried to conquer pain since the beginning of recorded history. Primitive peoples sought pain relievers in herbs, roots, seeds, flowers, opium, mandrake, hemlock, the mulberry tree, and even the garden lettuce, among other remedies. A sea sponge saturated with the juices of soporific plants became the major analgesic of the Middle Ages, although drugged wine, “not enough drug to be poisonous,” but sufficient to put one to sleep, was considered the safest anesthetic. By the middle of the 17th century, whiskey, gin, and rum had replaced most drugs, considered unsafe since there was no way to standardize dosage, although occasionally physi-

cians used opium. The search for a successful anesthetic continued, but, “in practice, the reduction of pain depended upon the speed of the surgeon.”<sup>1(p44)</sup>

The fear of pain kept patients from committing themselves to the surgeon’s knife. Many preferred to risk death than to undergo the terrible agony of an operation while fully conscious. Once strapped to the table, some screamed and struggled, begging the surgeon to be quick; some “fell into a trance-like state,” which made the operation easier but did not bode well for their recovery; some cursed or prayed; some endured bravely and quietly; others wept and fainted (Figure 31-1). All suffered “severe nervous

**Fig. 31-1.** Surgery and anesthesia before ether (ca 1800). Photograph: Courtesy of William Clayton Petty, MD, Captain, Medical Corps, US Navy, Bethesda, Md.



shock” and afterward a “long period of depression,”<sup>2(pp505–506)</sup> which interfered with healing and delayed convalescence. Only recently have scientists discovered that severe pain actually produces chemical imbalances in the brain that can cause depression and death. The 19th-century British surgeon Sir Benjamin Richardson wrote:

I have heard many express that if they had known beforehand what the suffering was, and the effects subsequently endured, they would rather have faced death than such a fearful struggle for continued existence.<sup>2(pp505–506)</sup>

The presence of pain also interfered with the

development of surgery as a science. Because of the patient’s fear of pain, and the surgeon’s unwillingness to operate except in traumatic amputations or as a last resort, when all else had failed, operations were few in number. They also were few in kind, because of the necessity of devising operations that could be done quickly. In the 18th century, these were chiefly confined to the surface of the body, including excision of tumors, amputation of limbs, various plastic operations, cataract removal, lithotomy, and herniotomy. With pain such a barrier to good surgery and the saving of life, it is not surprising that men through the centuries have sought ways to alleviate it.<sup>2</sup>

## THE EVOLUTION OF ANESTHESIA

The search for a successful anesthetic received great impetus with the discovery of gases and their effects on respiration. In 1772, the Englishman Joseph Priestley discovered nitrous oxide gas (Figure 31-2). Twenty-eight years later, Humphry Davy determined that nitrous oxide destroyed physical pain and suggested the anesthetic possibilities of the agent (Figure 31-3). In 1818, Michael Faraday noted the soporific effects of sulfuric ether after breathing the gas himself and anesthetizing a cat. His achievement received little attention. In 1824, Henry Hill Hickman, another Englishman, successfully anesthetized animals with carbon dioxide, introducing the principle of anesthesia by inhalation. His published results became the first separate publication on anesthesia. In their day, Davy’s, Faraday’s, and Hickman’s discoveries received slight notice.<sup>1,3</sup>

Hypnosis as a method of pain relief received impetus from the work of Franz Anton Mesmer (1734–1815) of Vienna, which advocated “animal magnetism” as a cure for body ailments. Although contemporary physicians and scientists thought of him as a quack, Mesmer had followers in Britain, the United States, and India who claimed to have performed operations under mesmerism. Apostles of somnambulism, a development of mesmerism, became convinced of its ability to relieve pain during surgical procedures. Also, James Braid of Manchester believed that hypnotism could either moderate the pain or produce a state whereby the patient was unaware of the pain. Although other practitioners of surgery failed to produce painless operations with this method, their attempts helped to establish a mind-set for the possibility and acceptance of surgery without pain.<sup>1,3</sup>

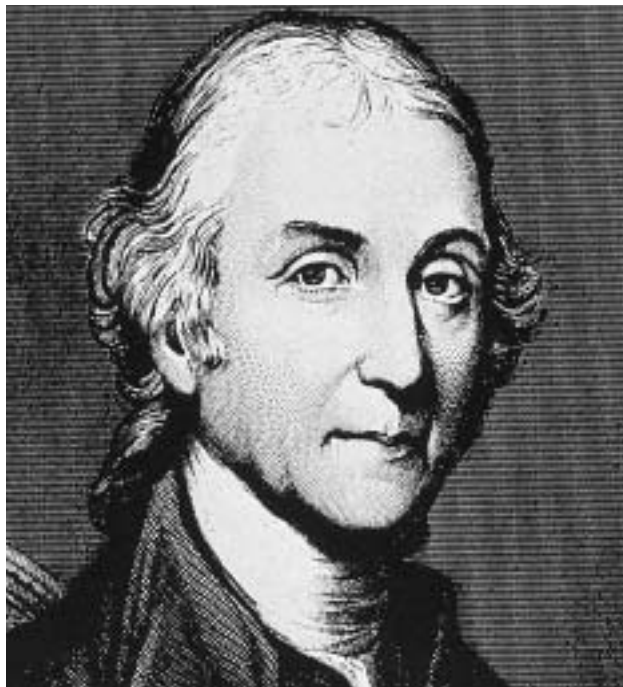
Pain continued to dominate surgery and interfere with its advancement as a science. Then the discovery of ether anesthetic changed everything.

### The Discovery

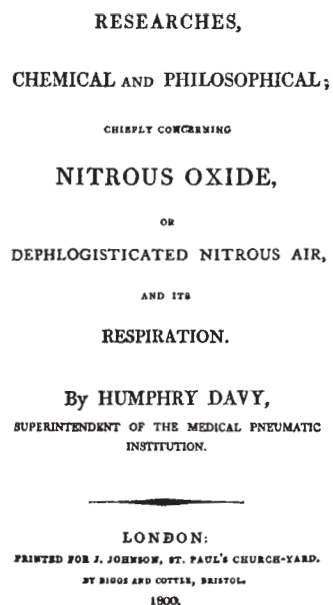
The search for painless surgery has many precursors, but four names will always be linked with its discovery, each vying for the honor of being the discoverer of anesthesia and each with his own partisans. Crawford W. Long (Figure 31-4), a Georgia physician, in 1842 excised two tumors from a patient under ether but delayed publication of the event and lost the worldwide recognition he might have received.

Horace Wells, a dentist from Hartford, Connecticut, used nitrous oxide (laughing gas) in his practice in 1844 but was unable to stage a successful public demonstration of the gas in surgery in Boston, Massachusetts. Although ridiculed after his failure, he continued to use nitrous oxide on his own patients. William T. G. Morton, a Boston dentist, used ether to extract a patient’s abscessed tooth (Figure 31-5). Morton had witnessed Wells’s experiments with nitrous oxide and had followed the suggestion of Charles Thomas Jackson, a chemist, to use pure ether instead of laughing gas.

On 16 October 1846, a little more than a fortnight after the painless tooth extraction, Morton successfully demonstrated ether anesthesia in a surgical operation at Massachusetts General Hospital. This staging of the first successful demonstration of ether anesthesia resulted in a gradual acceptance and graded application of this method for painless surgery. Jackson claimed the triumph for himself because of his suggestion to use ether instead of nitrous oxide.



**Fig. 31-2.** Joseph Priestley (1733–1804) is the man most responsible for introducing modern chemical and physical studies of gases. A politically controversial, nonconformist minister, he produced and described nitrous oxide in 1772. Photograph: Reprinted with permission from Thomas KB. *The Development of Anaesthetic Apparatus*. Oxford, England: Association of Anaesthetists of Great Britain and Ireland, Blackwell Scientific Publications; 1975: 106.



**Fig. 31-3.** (a) Sir Humphry Davy (1778–1829) was the first to describe the analgesic properties of nitrous oxide. This steel engraving was made from a portrait by Thomas Phillips, which was painted in 1826 when Davy was President of the Royal Society. (b) In 1800, at the age of 22, Davy published his first major contribution in what became a magnificently productive career. Photograph (a): Reprinted with permission from Nuland SB. *The Origins of Anesthesia*. Birmingham, Alabama: The Classics of Medicine Library, Gryphon Editions, Ltd; 1983: 190. Photograph (b): Reprinted with permission from the American Society of Anesthesiologists, Park Ridge, Ill.

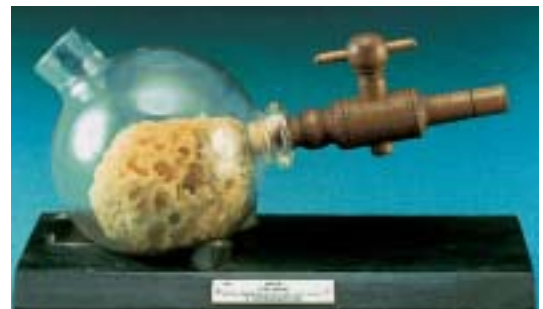


**Fig. 31-4.** Crawford Williamson Long administered ether for a surgical procedure 4 years before the public demonstration of ether anesthesia by William T. G. Morton. This photograph, one of the few known of Long (1815–1878), from Jefferson, Georgia, was probably taken between 1854 and 1861. It depicts a staged demonstration of an amputation under ether anesthesia. Long is believed to represent the “surgeon”; his brother, the “anesthetist,” holds an ether-impregnated cloth over the mouth and nose of the “patient.” Photograph: Reprinted with permission from Special Collections, Briscoe Library of The University of Texas Health Science Center, San Antonio, Tex.

a



b



**Fig. 31-5.** (a) This famous painting by artist Robert Hinckley (1853–1941), “The First Operation With Ether,” shows William Thomas Green Morton (1819–1868) first publicly administering sulfuric ether to a surgical patient on 16 October 1846 in the Massachusetts General Hospital surgical amphitheater. (b) Morton’s ether inhaler (1846). This is a replica of the apparatus used in the first successful public demonstration of ether anesthesia. Photograph (a): Reprinted with permission from John Knowles, MD, and Henry R. Viets, MD, Boston, Mass. In: *JAMA*. 1965;194(2):cover. Photograph (b): Reprinted with permission from the Charles King Collection of Historic Anaesthetic Apparatus (Colour Slide Collection), Association of Anaesthetists of Great Britain and Ireland, London, England.

Like so many other discoveries, ether anesthesia was the culmination of many hours of research and discovery, and to many belong the credit. Regardless of who gets the honor, ether anesthesia remains one of the most important discoveries in the history of medicine and an essential element in the development of the art of surgery.<sup>1,4</sup>

Improvements in ether administration began appearing from the time of its discovery. The original method of dropping ether on cloths and inhaling it from them gave way to ether administration by means of an inhaler apparatus, which produced more uniformly successful results. The first ether inhaler, designed by William Morton and used by him from the first, consisted of a glass globe containing an air hole, a glass tube, and a mouthpiece with valves that permitted the patient to inhale a mixture of ether and air into his lungs and exhale the breathed vapor into the room.

By the spring of 1847, nasal inhalation—breathing ether through the nose—was in use. A simple sea sponge shaped to fit the face and then saturated with ether replaced Morton's cumbersome glass vessel. Meanwhile, Morton patented his invention and tried unsuccessfully to sell it to the U.S. government for use on the Mexican front.<sup>1,5</sup>

### The Mexican War

Military anesthesia received its baptism of fire during the Mexican War (1846–1848), when a U.S. Army contract physician directed the use of diethyl ether to an accidentally injured teamster in General Winfield Scott's command. In the spring of 1847, using an ether-dispensing apparatus that he had brought with him to Veracruz, Edward H. Barton, surgeon of the Third Dragoons, Cavalry Brigade, Twiggs' Division, successfully anesthetized the patient before the amputation of both legs. An eyewitness to the surgery proclaimed:

The unfortunate man was soon rendered completely insensible to all pain, and indeed, to everything else, and the limb was removed without the quiver of a muscle.<sup>6(p30)</sup>

The first military use of anesthesia was a resounding success.

Despite this triumph, a number of surgeons remained skeptical of the new discovery, complaining of its dangerous side effects. U.S. Army surgeon John B. Porter attributed severe hemorrhage during an amputation in summer, 1847,

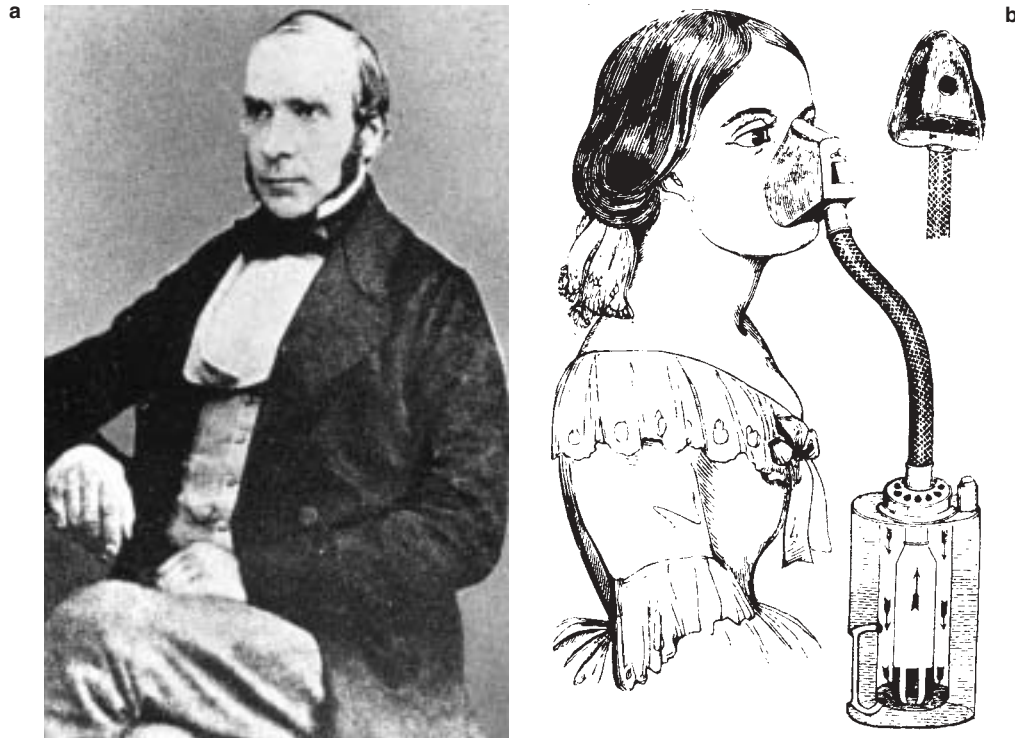
to the pernicious influence of the ether. [He remarked that] anesthetics poison the blood and depress the nervous system, and, in consequence, hemorrhage is more apt to occur, and union by adhesion is prevented.<sup>7(p18)</sup>

He considered anesthetic agents to be unnecessary and even injurious in the treatment of gunshot wounds and, at the end of the war, decided never to use them again. Future anesthesiologists would know that ether evaporates more quickly at warmer temperatures; that soldiers in pain, shock (ie, hypovolemia), and hemorrhage respond differently to the anesthetic; and that a low cardiac output increases sensitivity to the depressant action of anesthetics.<sup>7-9</sup>

Porter also believed painless surgery to be an unnecessary interference in the soldier's development of healthy, masculine endurance, a view held by military surgeons on both sides of the Atlantic. "Heroic manly fortitude, heightened by the 'excitement' of battle, rendered soldiers insensitive to the pain of 'almost any operation,'"<sup>10(p150)</sup> declared British military surgeon Rutherford Alcock. At this time, most military surgeons scoffed at surgical anesthesia as a product "of misguided effeminate sentimentalism."<sup>10(p146)</sup> In 1847, this viewpoint, plus fear of the unfamiliar, prejudice, and staunch opposition to change, blinded army surgeons to the value of ether. As a result, they used anesthesia sparingly during the Mexican War and forfeited an opportunity to contribute significantly to the growth of the new science.<sup>1,10</sup>

In 1849, however, the almost universal acceptance of ether anesthesia prompted the U.S. Army to order an allowance of 2 lb of sulfuric ether for every 100 men, officially sanctioning the drug's use. The army added chloroform, discovered in 1847, to its list of regular drugs for the purpose of testing its advantages in surgical operations. Although occasional sudden convulsions and deaths were attributed to chloroform, the drug had certain advantages over ether: small doses of chloroform would put the patient to sleep quickly and peacefully; and the drug was neither flammable, a matter of considerable concern during the days of operations by candlelight, nor odorous like ether. Therefore, chloroform was more pleasant to take.

The administration was made easier by Englishman John Snow's development of a chloroform inhaler (Figure 31-6). This device, composed entirely of metal, a conductor of heat, and placed in contact with water to regulate temperature, enabled the anesthetist to control the strength of the



**Fig. 31-6.** (a) The Englishman John Snow (1813–1858) was the first physician to specialize in anesthesia. (b) He produced this chloroform inhaler in February 1848. Snow devoted his life to making the art of anesthesiology a science; he also made lasting contributions to epidemiology. Photographs: Reprinted with permission from Shephard DAE. History of anaesthesia: John Snow and research. *Can J Anaesth.* 1989;36(2):224, 230.

vaporized air. Chloroform became the drug of choice for British surgeons. U.S. surgeons used chloroform for eye surgery but preferred ether for other operations, considering its odor the only significant drawback. Military surgeons used both anesthetics.<sup>7,11,12</sup>

During the War in the Crimea (1853–1856), the British army used chloroform almost exclusively, and the French employed the agent often. George H. B. Macleod, a British surgeon, became convinced of chloroform's attributes as a result of his experiences during the war. The Crimean War

has shown that chloroform, both directly and indirectly saves life; that it abates a vast amount of suffering; that its use is as plainly indicated in gunshot as in other wounds; that if administered with equal care, it matters not whether the operation about to be performed be necessitated by a gunshot wound, or by any of the accidents which occur in civil life.<sup>13(p126)</sup>

Although sulfuric ether and chloroform became the two most popular anesthetics before the Ameri-

can Civil War, civilian physicians tried other agents. Surgeons at the Massachusetts General Hospital preferred chloric ether, which is chloroform dissolved in alcohol in assorted ratios, to regular chloroform or ether. Other products cited in the literature of the time included morphine, cocaine, ethylene, amylene, and a method called "the vapor of Benzid." Some very conservative surgeons used none of the anesthetic agents then on the market, relying instead on the old standbys of alcohol and opium. One surgeon declared: "[I]f my patients will have an anesthetic agent [I] will give them as much good whiskey as they will drink."<sup>7(p19)</sup> Some surgeons believed that opium prevented inflammation by lowering irritability.<sup>7</sup>

Between the Mexican War and the American Civil War, most surgeons practiced anesthesia conservatively and selectively, using it only some of the time and only on people meeting certain criteria. The Massachusetts General Hospital performed one of three "potentially painful" operations without anesthesia in 1847 and 1848.<sup>10(p190)</sup> The patient's age, gender, condition, and the type of

operation to be performed influenced the surgeon's decision about whether to anesthetize. Children received anesthesia more than anyone else. Women received anesthesia in 69% of minor operations, and men in 50%.<sup>10(p191)</sup> Surgeons made the judgment that men did not need anesthesia as much as women and children.

Both military and civilian surgeons performed surgical anesthesia for amputations more than for any other type of operation, considering it more humane. Many mid-19th-century surgeons believed that surgical anesthesia killed about 5% more patients than operations without anesthetics.<sup>10(p220)</sup> Contemporary statistics retrieved later proved this conclusion incorrect: infection from industrial injuries probably caused deaths that were originally attributed to the anesthetic in operations on seriously injured persons. Still, in the 19th century, surgeons practiced selective anesthetization. They wished "to balance life saving and painkilling, the need to reconcile a universal science with human variability."<sup>10(p238)</sup>

### The American Civil War

Mid-19th-century attitudes about anesthetics influenced who received anesthesia early in the American Civil War (1861–1865). Soldiers were at the mercy of military surgeons, who, as in the Mexican War, had almost total control over anesthetic policy.<sup>10</sup> By late 1862, however, the Union army attempted to standardize and centralize anesthetization policy as part of an overall reorganization of the medical service aimed at regulating treatment regimens in general. On 30 October 1862, Jonathan Letterman, Medical Director of the Army of the Potomac, issued a circular letter that embodied a hospital reorganization plan that recommended that each of the 18 division hospitals appoint an assistant surgeon in charge of anesthesia. The circular letter specified who would make the decisions but not what those decisions would be. The individual doctor could still use his own discretion about anesthetization, "[b]ut the degree of centralization instituted by Letterman almost certainly did serve to minimize the extreme variations in military anesthetic use."<sup>10(p183)</sup>

Letterman's concern was propitious, considering the widespread use of anesthetics during the Civil War. The army medical service reported employing surgical anesthesia in no fewer than 80,000 cases. Surgeons preferred chloroform 76%<sup>14(p887)</sup> of the time, although a mixture of ether and chloroform, or ether alone, were popular in general hospi-

tals. The average insensibility time for chloroform was 9 minutes, compared with 17 minutes for ether and chloroform and 16 minutes for ether alone.<sup>14(p896)</sup> Because of its ease of induction and the small amounts required, chloroform was the anesthetic of choice for field surgeons, who were surrounded by wounded soldiers in need of rapid relief.

Medical officers also liked the drug's nonflammability, its sweet smell, and its tendency to produce less vomiting and excitability among patients. Aware of its dangers—on occasion, patients inhaling the drug became convulsive and suffered cardiac arrest and sometimes liver damage—surgeons were careful to place time limits on the administration of chloroform and to ensure that the patient inhaled adequate amounts of air along with the anesthetic. In cases of exhaustion resulting from long-established injuries, when chloroform was considered too dangerous to use, ether became the preferred anesthetic agent.<sup>7,14,15</sup>

Despite the overwhelming use of anesthetics, the North reported, for cases studied, only 37 deaths due to the administration of chloroform; the South reported 2. One Confederate doctor exclaimed: "The safety of the substance was remarkable when you consider how loosely it was used!"<sup>15(p95)</sup> The Army Medical Department cited only 2 deaths from ether and 2 from chloroform and ether. The practice of cautious administration of anesthetics by surgeons of both armies may account for the good safety record. However, that chloroform anesthesia caused so few deaths in an era of little patient monitoring is difficult to believe. Many anesthesia deaths may have gone unrecorded or were incorrectly attributed to wounds. In March 1865, Surgeon General Joseph K. Barnes was sufficiently troubled by anesthesia deaths that he ordered U.S. Army surgeons to report on their experiences with these agents.<sup>7,14,15</sup>

The mode of administration of ether, chloroform, or a mixture of both remained quite simple during the Civil War. In a technique known as the *open* method, a liquid-soaked sponge, cloth, or handkerchief was placed over the patient's nose and mouth. For many operations in the open air, a funnel served as an inhaler to prevent excessive evaporation. Although less complicated than the elaborate systems used in modern gas anesthesia, the open method was an effective and relatively safe mode of achieving anesthesia on the battlefield.<sup>14,15</sup>

To prevent the waste of chloroform, a scarce commodity in the South, Confederate surgeon J. J. Chisolm employed a short, flattened cylinder with a plate on its broadest side and two nosepieces



connected to the cover. Chloroform dripped through the plate of the Chisolm inhaler onto a sponge or folded cloth, which offered a broad area for evaporation, inside the cylinder. The patient's limpness, a rough but nevertheless quite reliable signal, let the surgeon know that the anesthetic was working and surgery could commence. Often the soldier received a premedication of whiskey to calm his nerves and desensitize him, which also reduced the amount of anesthetic needed.<sup>14,15</sup> A few fearless souls, who probably considered it cowardly to use an anesthetic, "would simply lean back and let the bloody operator saw away, telling the anesthetist to save his sweet-smelling potion for those who came in screaming."<sup>15(p96)</sup>

For the alleviation of pain, army surgeons also used analgesics such as alcohol and opiates. The widespread use of alcohol to relax a patient before the administration of an anesthetic caused some medical officers to worry about the masking of symptoms, but that problem never became significant during the Civil War. However, the possible overuse of opiates, especially opium in the treatment of diarrhea, was blamed for the many cases of drug addiction reported after the war. To reduce pain, army physicians also administered morphine and, on occasion, cannabis for tetanus and head injuries.<sup>7</sup>

The supply of anesthetic agents during the war remained more than adequate for the North but just marginal for the South. The drug manufacturer E. R. Squibb, the North's chief supplier, had perfected the method of mass production of drugs at Brooklyn's U.S. Naval Hospital laboratory a few years before the war started. Capturing medical supplies also augmented stocks. Supply trains of both sides got bogged down in mud or fell victim to enemy raiding parties. For example, Stonewall Jackson's men ran off with thousands of cases of chloroform at the Battle of Winchester. The South often used this form of supply replenishment.<sup>15</sup>

Anesthesia came into its own during the Civil War. Military surgeons demonstrated its usefulness beyond doubt and improved its safety through the knowledge acquired from thousands and thousands of administrations of ether and chloroform.<sup>15</sup>

### **Late-19th-Century Advancements**

During the latter part of the 19th century, surgical anesthesia advanced to include new administrative techniques, other drugs with special properties, and innovative machines for the delivery of

anesthetics. Closed inhalers, which had been improved since the Morton and Snow devices of the 1840s and 1850s, appeared in greater numbers. Noteworthy was the J.T. Clover inhaler, which regulated the flow of the anesthetic with air or with another anesthetic (Figure 31-7). Gardner Q. Colton popularized the use of pure nitrous oxide in dental operations in 1863. A mixture of nitrous oxide and oxygen appeared in anesthetic practice and led to the development of gas machines for surgical anesthesia. The latter were hardly used before World War I.<sup>1-3</sup>

The development of the hypodermic syringe (Figure 31-8) permitted the use of morphine during inhalational anesthesia and as a preanesthetic medication. The discovery of the anesthetic properties of cocaine led to the use of the drug topically in eye surgery, in nerve block anesthesia, by injection in or around the spinal canal to reduce pain, and in the first spinal anesthesia in man. (Spinal anesthesia became generally used in the Vietnam War.) Ethyl chloride became a local anesthetic agent late in the 19th century.<sup>1-3</sup>

William Stewart Halsted discovered conduction anesthesia by injecting the new drug cocaine into a nerve in 1885. The discovery's drawbacks made it controversial. Surgeons feared the lowering of blood pressure, especially in seriously injured patients; the psychic factor of the patient's being aware of his surroundings while undergoing surgery; and the poisonous effect of the drug, which could be habit-forming. With nerve block anesthesia as an option, however, surgeons began to choose the anesthetic to fit the patient rather than to select patients who were fit for anesthesia. The mid-19th-century practice of selective anesthetization was nearly over.<sup>10,16</sup>

The greatest influence on the development of anesthesia as a science was Joseph Lister's discovery of antiseptics during the latter part of the 19th century, which drastically reduced infection in surgery. Antiseptics and anesthesia together led to the advancement of surgery by making surgery less unhygienic and less dangerous. Also contributing to clean surgery at this time was the acceptance of the germ theory of disease in 1890, after developing gradually from the 1860s. Rubber gloves and operating coats began to appear in the operating room about 1900.<sup>17</sup> According to historian Martin S. Pernick:

The gradual adoption of antiseptic surgery also helped end selective anesthetization.... The complex rituals of Lister's technique virtually demanded that all patients be immobilized with anesthesia.<sup>10(p238)</sup>

**Fig. 31-7. (a)** Joseph Thomas Clover, shown filling the reservoir bag of his chloroform apparatus with an accurate mixture of 4½% chloroform in air. **(b)** Clover's chloroform apparatus (ca 1860); the original is in the Wellcome Medical Exhibit, Science Museum London, England. A known quantity of chloroform was injected with a syringe onto a warmed metal surface inside the brass container (right). The concertina bag (left) was then filled with air, which was blown into a 7.2-L bag (not shown) with the chloroform. A large-diameter breathing hose and mask were connected to the bag to complete the nonbreathing circuit. Dr. Clover is said to have given 7,000 anesthetics using 4½% chloroform without a death. **(c)** Clover's chloroform apparatus (ca 1870); the original is likewise in the Wellcome Historical Medical Museum.

The photograph shows the carrying case, folded reservoir bag made of impermeable material, hand bellows, chloroform vaporizing chamber with graduated glass syringe for injecting liquid chloroform, and connecting tube reinforced with a wire coil to prevent kinking. In the foreground, Clover's facepiece with an inflatable rubber rim, a feature that came into use with nitrous oxide anesthesia (ca 1870), and the metal junction, which has become detached from the filling tube and reservoir bag. Photograph (a): Reprinted with permission from Sykes WS. *Essays on the First Hundred Years of Anaesthesia*. Vol 3. Edinburgh, Scotland: Churchill Livingstone; 1982: 133. Sources for (b): (1) Sanson AE. *Chloroform, Its Action and Administration*. London, England: Churchill; 1865: 187. (2) Macintosh R, Mushin WW, Epstein HG. *Physics for the Anaesthetist*. 3rd ed. Oxford, England: Blackwell Scientific Publishers; 1963. Photograph (b): Reprinted with permission from *Wellcome Trends in Anesthesiology*. 1944;12(1):5. Photograph (c): Reprinted with permission from Duncum BM. *The Development of Inhalation Anaesthesia With Special Reference to the Years 1846-1900*. London, England: Oxford University Press, The Wellcome Historical Medical Museum; 1947: 246.

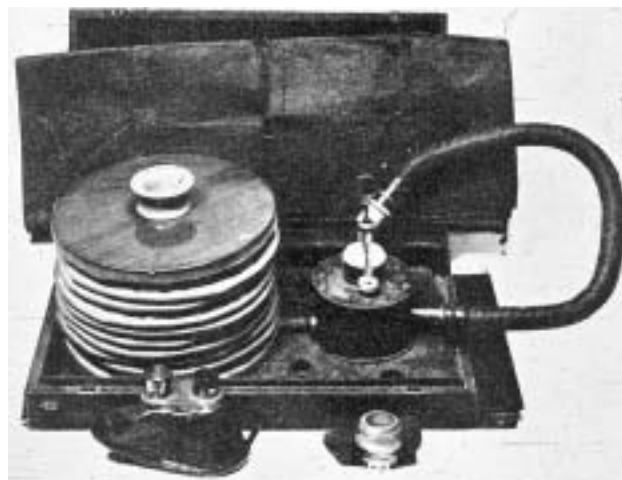
a



b



c





**Fig. 31-8.** Alexander Wood's syringe, which is displayed in the Royal College of Physicians in Edinburgh, Scotland. Intravenous anesthesia could not have been developed without the syringe, although Wood himself used his syringe to deliver anesthetic *locally*, not intravenously. His 1855 paper was titled *A New Method of Treating Painful Neuralgias by the Direct Application of Opiates to Painful Points*. Photograph: Reprinted with permission from Dundee JW, Wyant GM. *Intravenous Anaesthesia*. Edinburgh, Scotland: Churchill Livingstone; 1988: 1.

The almost universal practice of painless surgery eliminated objections to women becoming surgeons and operating room nurses. In the 1880s, increasing numbers of female personnel began administering anesthetics, under the guidance of surgeons. In the following decade, the U.S. Army had no objection to female nurses working alongside military surgeons in the care of the wounded.<sup>10</sup>

By 1902, both the army and the navy opened graduate schools of military medicine, where military surgeons studied the new science of bacteriology and sanitation mainly for public health work. Graduate medical education outside of the military at this time focused on learning specialized fields, such as antiseptic and aseptic surgery. Modern internship programs were just beginning in the major hospitals in Britain.<sup>18</sup>

### The Spanish–American War

Antisepsis, of course, played an important role in the Spanish–American War, which was fought in the Caribbean and the Philippines at the end of the 19th century. During this conflict, antisepsis reduced the four greatest enemies of the wounded soldier: hospital gangrene, secondary hemorrhage, pyemia, and erysipelas. If the wounded survived the immediate effects of the injury—the explosive force of the small-caliber bullet had been greatly overestimated—the prospects of recovery were good.<sup>19</sup>

Actually, military surgeons performed fewer operations and administered less anesthesia per capita during the war with Spain than during the American Civil War. There were no stacks of amputated limbs as there had been during the Civil War. Tropical diseases, such as malaria and yellow fever, were the great killers during the Spanish–American War. To assist an inadequate number of skilled and trained medical officers, the medical department hired female contract nurses. Their help proved so

beneficial that after the war, in 1901, they were organized into a female nurse corps under former contract nurse Dita H. Kinney.<sup>19–21</sup>

For surgical patients not seriously enfeebled by disease, chloroform administered by the drop method was the anesthetic of choice. (Drop chloroform was also used extensively during the Boer War [1899–1901] and the Russo-Japanese War [1904].) Soldiers considerably weakened by tropical ailments received ether, which was less potent and slower in onset of action than chloroform and therefore presumably less dangerous in the sick patient. During operations to incise and drain abscesses, surgeons preferred to work without an anesthetic, using only whiskey to relax the patient.<sup>19</sup>

Surgical procedures that posed great danger to the patient were avoided whenever possible. Bullets were allowed to remain in the body undisturbed unless they could readily be removed without additional risk. Some patients with penetrating wounds of the chest and abdomen did well without surgery. Conversely, to save the lives of patients suffering from empyema, surgeons opened chest cavities and extracted pus. A day or two before the operation, they aspirated the patient's pleural space to achieve partial pulmonary expansion before admitting air into the pleural cavity. They preferred to perform the surgery under partial anesthesia, using strychnia and alcohol to minimize the dangers of the anesthetic. In most cases of surgery for empyema, the patients completely recovered.<sup>19</sup>

Surgeons supervised other medical officers and corpsmen in the administration of anesthesia, as the discipline was relatively young and had few specialists. Antisepsis and conservatism helped to make surgery successful during the Spanish–American War.<sup>19</sup>

Although by the turn of the century individual practitioners with special skills were specializing, particularly in the new aseptic surgery—even naval hospitals at this time had the post of supervising

surgeon—no formal courses existed in anesthesia. Anesthesia providers were usually medical students, interns, or nurses in metropolitan hospitals, and family practitioners in rural hospitals. They learned to administer anesthesia through observation or from gas machine manufacturers, who would teach the art to anyone who would buy a machine.<sup>18,22</sup>

On the eve of World War I, however, several hospitals in the United States offered to physicians 6 months of postgraduate courses in anesthesia, including instruction in anatomy, physiology of the respiratory tract, pharmacology of anesthetic agents, and training in the administration of the commonly used drugs. For nurses, several hospitals offered courses in the administration of anesthetics, lectures by physicians, and work on cadavers, including the passing of laryngeal tubes.<sup>18,22</sup> Hospital curricula reflected the growing interest in anesthesiology as it was about to enter an important era of its development.

## World War I

While still an uncertain science, anesthesiology was forced prematurely into service in World War I (1914–1918). Military anesthesiologists Frederick Courington and Roderick Calverley described the state of the art of anesthesiology in 1914:

Anesthesia machines were new and hardly widely accepted. There was no standardization of equipment; nothing fit together. Bottled gases were available but miserably cumbersome. Continuous-flow anesthesia with quantification of gas flow was scarce. Wire screen vaporizers, with names like Schimmelbusch, were simple, available, cheap, and “good enough.” There were other vaporizers, but most were little improved since the time of Joseph T. Clover, 50 years before the war. Airways were sometimes available, but endotracheal intubation meant that a small, cuffless tube was inserted into the trachea through the glottis for insufflation of ether. Oxygen enrichment of air was uncommon. Nitrous oxide, known in England as “gas” and almost unknown in Europe, was frequently given in various pseudoscientific asphyxial mixtures. There were no muscle relaxants, nor was there an understanding of controlled ventilation or of the need for it. Venipuncture was a surgical cutdown. Rational fluid therapy would not become routine for decades, while blood transfusion was a near perfunctory act, rarely used. Trauma and shock, the unavoidable ingredients of war, were not understood, and therefore not effectively treated. Sir Frederick Hewitt had published a major text of anesthesia in England by 1893, and Dr. James Tayloe

Gwathmey, a prominent New York anesthetist, published the first comprehensive American anesthesia text in 1914.<sup>23(pp642–643)</sup>

The *American Journal of Surgery* produced the first *Quarterly Supplement of Anesthesia and Analgesia* in October 1914, 2 months after the war in Europe started.<sup>23</sup>

## Personnel

At the start of hostilities in 1914, few anesthesia providers were available to serve on the western front, and anesthesia was often left in the hands of inexperienced people. Early in the war, non-specialty-trained medical officers in the British casualty clearing stations, located at least 7 miles behind the front line and where initial surgery took place, administered anesthesia, often unsuccessfully. One British anesthesiologist remarked: “The bulk of preventable deaths at a casualty clearing station was due to improper anesthesia, giving the wrong anesthetic or giving the right anesthetic wrongly.”<sup>24(p103)</sup>

To keep anesthesia out of inexpert hands, the British army appointed anesthesiologists to clearing station staffs in 1916. Even those proved too few to handle the casualties of an enemy push or offensive. After the Battle of the Somme in September 1916, one clearing station received 17,000 stretcher cases and experienced 700 deaths. A Canadian anesthetist lamented the lack of trained anesthetists at this battle:

In a severe action, a [casualty clearing station] is very busy and I cannot imagine any place where the services of a skilled anesthetist would be more useful. A [casualty clearing station] cannot, however, afford to have too much cumbersome apparatus as when the army moves, it moves too. We had four operating tables going simultaneously. One day we had over 70 operations. A few days before we had admitted 760 wounded within 24 hours. There were a great many severe chest wounds.<sup>23(p644)</sup>

Responsibility for anesthesiology during the Great War rested mainly with reserve officers (both Allied and American) who came from civilian medicine into the armed forces for the duration of the war. Men like George Crile, a surgeon from the Cleveland (Ohio) Lakeside Unit, who volunteered to help the British Expeditionary Forces in France before the United States entered the war. He established an American Ambulance Hospital in Neuilly, bringing his own supplies and trained civilian nurse

anesthetists with him. He and most of his staff served in the U.S. Army once the United States entered the war in April 1917. Dr. Crile helped shape the practice of surgery and anesthesiology during World War I.

In anticipation of the United States' entry into the war, the U.S. Army and the U.S. Navy appointed their first anesthesiologists (physician anesthetists) to the Medical Corps in 1916, with the rank of lieutenant. In April 1917, the army drafted dentists for anesthetic service, contracted for women physician anesthetists, and brought in nurse anesthetists to serve at base hospitals in England and France. They joined nurse anesthetists at American Ambulance Hospitals, such as the one run by Dr. Crile at Neuilly. Those women inspired the British army to train over 200 nursing sisters in anesthesia for service in France in 1918. The U.S. Army sent its own nurses to schools of anesthesia that had developed in the United States in response to the demands of war. After training, they returned to their bases to instruct others in anesthesia. (No records are available on the number of nurse anesthetists in the army during the war. On 11 November 1918, the U.S. Army Nurse Corps reached 21,480 nurses: 3,524 were regular nurses and 17,956 were reserve nurses.<sup>22(pp22-23)</sup>) To provide more anesthetists, Dr. Arthur Guedel, a physician anesthetist in charge of anesthesia for the U.S. Army, made daily rounds to base hospitals in the war zone, giving instruction in anesthesia. He administered open-drop ether at field hospitals, commuting between them by motorcycle. Guedel wrote a fundamental guide to inhalational anesthesia in 1937.<sup>22,23,25,26</sup>

To produce skilled combat surgeons, in 1918 the U.S. Army Medical Department's Division of Surgery arranged with some of the nation's finest medical schools to have medical officers receive intensive instruction in war surgery, including the treatment of wounds and the administration of anesthetics. Schools in New York; Boston, Massachusetts; Philadelphia and Pittsburgh, Pennsylvania; Chicago, Illinois; Cleveland, Ohio; New Orleans, Louisiana; and Rochester, Minnesota, participated in the program. On their return to army camps, the medical officers who took the courses instructed others in war surgery and anesthesia.<sup>27</sup>

Despite those efforts, there were never enough experienced anesthesia providers at the front. A nurse anesthetist, who administered anesthesia from June to November 1918, at a U.S. Army mobile hospital in the Chateau-Thierry area of France, recalled:

How many anesthetics I gave during the World War, I cannot determine, except that when the big drives were on, lasting from a week to ten days, I averaged twenty-five to thirty a day.... During the drives patients came in so fast that all the surgeons could do was to remove bullets and shrapnel, stop hemorrhages and put iodoform packs in the wound and bandage it. As soon as they were through operating on one patient, I would have to have the next patient anesthetized.<sup>22(p24)</sup>

Another anesthetist, who treated 34 cases in 1 day, recalled: "While one patient was being operated on, another was being prepared for surgery, as the dressing was being applied to the third."<sup>23(p645)</sup> The operations during those drives were of necessity quick, deft, and light.

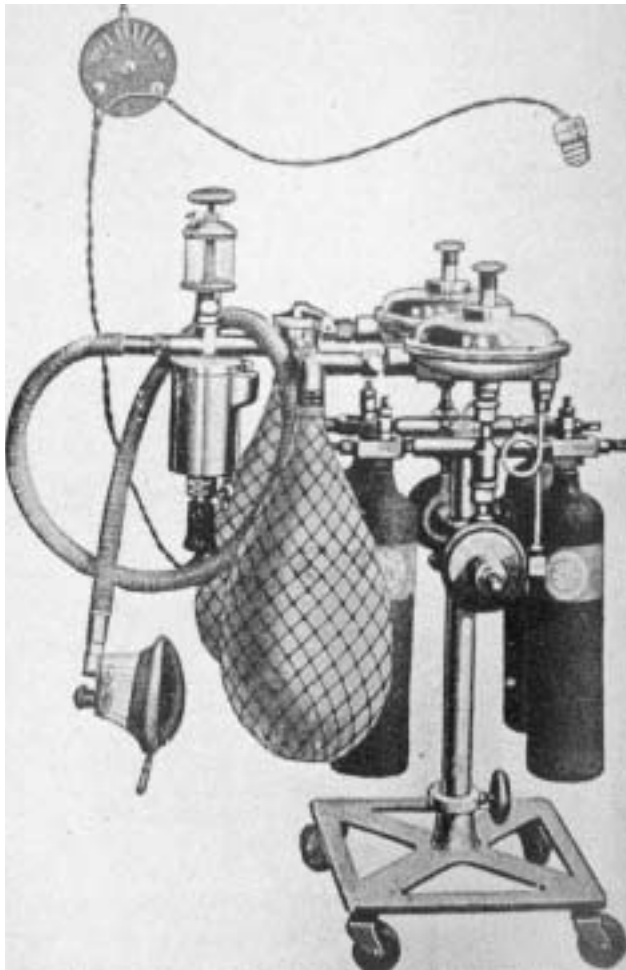
### *Equipment*

Anesthesia providers needed to bring to the front supplies that were mobile and adequate for mass casualties. They also wanted to give the best anesthesia possible. Those wishes were usually contradictory, because the best anesthesia machines were often cumbersome and not easily transportable, and required experts to operate. Additionally, early in the war, certain machines, anesthetic equipment, and agents, as well as skilled anesthetists, were in short supply. For example, in 1917, the army's list of anesthesia supplies included ether, chloroform, and ethyl chloride only—but no anesthetic equipment.<sup>23</sup> World War I anesthetists, like medical men in every war, had to "make do," given the logistical constraints and the newness of the specialty.

The first anesthetists to feel the pinch were those of the British armed forces, who had been fighting since 1914. At the outbreak of war, these men had only chloroform and simple wire vaporizers known as the Schimmelbusch mask (Figure 31-9). Within a few months, ether became available, which they administered by the open method. In 1915, a Canadian medical team brought to England the new Ohio Monovalve anesthesia apparatus, which, unlike British machines, provided a steady flow of gas at a uniform pressure (Figure 31-10).<sup>23,28</sup>

In 1916, the new Shipway ether/chloroform apparatus, although not as advanced as the device from North America, became available. The machine of Dr. Francis Shipway, a British anesthetist, consisted of two bottles, one for chloroform and one for ether, and a three-way tap, which allowed air to be blown through one bottle at a time or through both in varying proportions as one wished. A tube

**Fig. 31-9.** The Schimmelbusch wire frame mask (ca 1890), the most widely known of all wire frame masks, was developed by Carl Schimmelbusch (1860–1895), a surgeon in Berlin, Germany. The lower rim of the mask, which collected surplus anesthetic liquid, is curved to allow air to be drawn under it during chloroform administration. With padding, this wire mask could be used for ether administration. Source: Thomas KB. *The Development of Anaesthetic Apparatus*. Oxford, England: Blackwell Scientific Publications; 1975: 252. Photograph: Reprinted with permission from the Charles King Collection of Historic Anaesthetic Apparatus (Colour Slide Collection), Association of Anaesthetists of Great Britain and Ireland, London, England.



**Fig. 31-10.** The Ohio Monovalve anesthesia machine, an advanced apparatus from North America, with its continuous flow, multiple gases, and heated vaporizers, also became popular in Europe early in World War I. Photograph: Reprinted from Gwathmey JT. *Anesthesia*. New York, NY: Appleton; 1914.

from the device passed through a lint mask or directly into the patient's mouth or nose. The Shipway apparatus provided even and light administration of the anesthetic and was superior to the drop method. With the advent of the Shipway machine, warm ether vapor became the British anesthetic of choice when nitrous oxide and expert gas administrators were unavailable.<sup>23,28</sup> Shipway's nitrous oxide/oxygen/ether apparatus became available in 1920 (Figure 31-11).

For American anesthetists, the U.S. Army adopted the American Red Cross' nitrous oxide–oxygen machine, perfected by Captain James T. Gwathmey, an anesthetist from New York and a reserve officer who served on the western front (Figure 31-12). Gwathmey's machine provided an airtight mask that fitted closely to the face, an escape valve, a mixing bag close to the inhaler, and a rough gauge for measuring the proportion of the gases. Like the British army, the U.S. Army on the western front had gas machines but little nitrous oxide until a nitrous oxide plant from Cleveland, Ohio, opened in France in mid-1918, just a few months before the war ended. Dr. Crile, a great advocate of the use of gas, had, of course, brought his own supply with him to France. When nitrous oxide was unavailable, the Americans used ether, chloroform, or ethyl chloride, in that order.<sup>29</sup> Logistics became a determinant in the delivery of combat anesthesia.

#### *Anesthetic and Delivery Method of Choice*

Since Halsted's discovery of conduction anesthesia in the 1880s, surgeons had begun selecting the anesthetic agent and method of delivery that suited the patient's condition and the type of surgery he needed. This reasoning prevailed at the second session of the Inter-Allied Surgical Conference, held in Paris in 1917.

**Fig. 31-11.** Shipway's nitrous oxide/oxygen/ether apparatus (1920), a modification of earlier equipment, could be used in the draw-over mode if gases were unavailable by means of extra inlets into the ether jar and a complex control tap. Source: Thomas KB. *The Development of Anaesthetic Apparatus*. Oxford, England: Blackwell Scientific Publications; 1975: 152–153. Photograph: Reprinted with permission from the Charles King Collection of Historic Anaesthetic Apparatus (Colour Slide Collection), Association of Anaesthetists of Great Britain and Ireland, London, England.



The conference's conclusions about choice of anesthetic and treatment for war injuries confirmed the value of nitrous oxide in military surgery:

- *Treatment of gaseous gangrene.* Anesthesia by means of nitrous oxide with oxygen is considered the best; when this is not to be had, ether may be substituted.
- *Traumatic shock.* Local anesthesia combined with general anesthesia by means of nitrous oxide is the best. Next to this ether appears to be the least harmful. Spinal injections have produced varying results according to the surgeons employing them, especially in amputations of the lower limbs. The use of chloroform is dangerous.
- *Amputations.* In the case of serious shock, the use of nitrous oxide and oxygen is desirable; ether is the next best anesthetic. Only in the case of cerebral wounds is any other anesthetic method advised.
- *Cerebral wounds.* Local anesthesia is preferred for the operation. The sitting posture tends to diminish hemorrhage and is easily maintained in secondary or delayed operations.<sup>29(p166)</sup>

Allied armies, in general, followed the conclusions of the Paris conference of 1917.

Although healthy men with light wounds could receive any of a number of anesthetics, military surgeons in World War I preferred the advantages of nitrous oxide mixed with oxygen, when they could get it. The British considered the mixture,

in experienced hands, ... the ideal anesthetic for such patients, since it fulfilled the three essential conditions—safety, speed, and a rapid recovery. [The last permitted] immediate evacuation by ambulance and train.<sup>28(p182)</sup>



**Fig. 31-12.** Gwathmey's nitrous oxide/oxygen/ether apparatus (1913). This early apparatus utilized, for the first time in anesthesia, the water-sight flowmeter manufactured by Cotton and Boothby in 1912. The ether bottle is missing in this example of the apparatus, which shows only the flowmeter and cylinder yokes. Source: Thomas KB. *The Development of Anaesthetic Apparatus*. Oxford, England: Blackwell Scientific Publications; 1975: 139–142. Photograph: Reprinted with permission from the Charles King Collection of Historic Anaesthetic Apparatus (Colour Slide Collection), Association of Anaesthetists of Great Britain and Ireland, London, England.

But the ideal method was often unrealistic. Although the gas was beginning to become popular, it was not manufactured in great quantities. Hence, the short supply of nitrous oxide and of skilled administrators until late in the war led the British to use warm ether vapor more than any other anesthetic. For lightly wounded men, the French preferred ethyl chloride because of their "need to induce quickly, perform minimal surgery and transport [patients] sitting up in ambulances."<sup>23(p650)</sup> A vehicle could transport more casualties who were sitting rather than lying down. When the agent of choice was unavailable, the anesthetist made a judicious substitution of another drug and method.<sup>23,28</sup>

For chest surgery, U.S. Army anesthetists chose a light nitrous oxide–oxygen analgesia combined with local anesthesia. Using the results of animal experimentation and accounts from surgical teams at the front, Captain Gwathmey, working out of the U.S. Army's medical research laboratory in France, devised an effective anesthesia for chest surgery. Using a full preoperative dose of morphine to produce analgesia, he gradually

administered 3:1 nitrous oxide and oxygen under 5–7 mm continuous positive pressure with a mask, adding light ether as required.<sup>23(pp649–650)</sup>

...

During the operation, the proportions of the gas–oxygen mixture and the pressure transmitted to the trachea were varied to meet conditions.<sup>29(p179)</sup>

The Gwathmey method permitted intrathoracic surgery "without necessitating deep anesthesia for the introduction of intratracheal or endopharyngeal tubes."<sup>29(p179)</sup> Although greatly improved anesthesia permitted lifesaving thoracic surgery during World War I, chest surgery remained hazardous for all patients and, in general, "...anesthesia contributed significantly to surgical mortality."<sup>23(pp649–650)</sup>

For thoracic surgery, British anesthetists, in most cases, used chloroform or ether and oxygen with the Shipway apparatus. If the patient was of a placid temperament and sufficiently under the influence of morphia or omnopon, a few surgeons used "local infiltration combined with the administration of gas and oxygen."<sup>28(p183)</sup>

For abdominal operations, both American and British military surgeons established that regional anesthesia with novocaine to relax the abdominal muscles followed by general anesthesia with nitrous oxide–oxygen produced the best results. Warm

ether vapor was the accepted substitute for nitrous oxide in those operations.<sup>28,29</sup>

Military surgeons also found nitrous oxide–oxygen, if properly administered, to be the best anesthetic for major amputations. When the gas was not available, surgeons substituted low spinal anesthesia, sometimes with a blood transfusion to overcome the anesthetic's tendency to lower the blood pressure.<sup>28,29</sup>

For operations on the severely wounded in shock, expert anesthetists, including many from the U.S. Army Nurse Corps, administered nitrous oxide–oxygen in the ratio of not more than 3 parts gas to one part oxygen to avoid deep anesthesia and cyanosis. (Future anesthetists would consider even this ratio too dangerous.) A higher ratio might have caused as great a fall in pressure as was produced by ether. When nitrous oxide was unavailable and ether was substituted, sometimes a blood transfusion or a gradual infusion of a gum–salt solution ("6 to 7 percent of gum acacia in 0.9 percent sodium chloride"<sup>30(p194)</sup>) accompanied ether administration for patients in shock to maintain or even raise the head of arterial pressure. Intravenous fluids or blood plasma did not receive widespread use, however, and physicians considered some hypovolemic patients simply inoperable.<sup>28,30</sup>

For gassed patients, anesthesia providers preferred nitrous oxide–oxygen. But if the anesthetic was not available, medical personnel used local, regional, or spinal anesthesia. Ether irritated the respiratory tracts of patients exposed to chlorine and other gases and was seldom used. Both British and American armies found that patients who had been gassed gave no special problem on the operating table.<sup>28,29</sup>

The Allies had differing opinions about the value of spinal anesthesia during World War I. Dr. Crile thought that spinal anesthesia was of value in all but rush periods, provided that the psychic factor of the wide-awake patient was eliminated by partial anesthesia, either morphine or light nitrous oxide, and that the fall in blood pressure was prevented by a blood transfusion. Most British surgeons did not favor spinal anesthesia because of its danger to hypovolemic or hemorrhaging patients. One French surgeon strongly advocated spinal anesthesia for all surgery below the 10th thoracic nerve. Most surgeons agreed that spinal and local anesthesia were preferred methods when respiratory disease made inhalational anesthesia difficult.<sup>23,28,29</sup>

Regarding local anesthesia, a survey of base hospitals in France by the American Red Cross, which



was in charge of medical research for the American Army, revealed that anesthesia providers recommended local anesthesia in combination with morphine whenever possible. The technique suited the demands of war surgery, especially during "rush periods at the front"<sup>29(p175)</sup> when nitrous oxide–oxygen was unavailable and little time existed for the prolonged induction and recovery periods that normally followed the administration of ether or chloroform. Infiltration with novocaine was in common use alone or in combination with nitrous oxide–oxygen.<sup>28,29</sup>

### ***Blood Transfusions and Other Treatments for Shock***

Although the condition of shock had been known to military surgeons for 300 years, its causes, onset, and development remained a mystery. During World War I, British medical officers in the field, in conjunction with members of the Wound Shock Committee of the Medical Research Committee, studied the problem. American scientists, under the auspices of the National Research Council and the U.S. Army Surgical Research Laboratories, investigated shock during the war. Walter B. Cannon, U.S. Army Reserve officer and physiologist from Harvard University, studied shock and resuscitation with American and British forces in France and England and became a member of the British Shock Committee in 1917. He and allied scientists shared research findings and results in investigating the mysteries of shock.<sup>31</sup>

Cannon focused on treatments for shock when he became the director of a center for surgical research at the Central Medical Department Laboratory of the Army Expeditionary Force at Dijon, France, in 1918. He maintained a close relationship between the laboratory and the proving ground by establishing a network of resuscitation teams to treat soldiers in shock on or near the battlefield.

From May to November 1918, medical officers received instruction at weekly classes in Dijon on the nature of shock, onset theories, clinical symptoms, development circumstances, and treatment beliefs. They mastered methods of matching blood and giving blood transfusions. These officers went from the classroom to the shock wards at U.S. Army hospitals, where the seriously wounded received blood transfusions and other treatments in preparation for surgery later.<sup>22,30–32</sup>

The importance of blood volume in the treatment of shock was revealed during World War I. Medical officers had reported that "in cases of profound

shock accompanied by loss of blood, excellent results are obtained from direct blood transfusion."<sup>33(p42)</sup> Because of the difficulties of giving transfusions at clearing stations during an attack, Captain (later Major) Oswald H. Robertson, U.S. Army, favored the collection, storage, and preservation of whole blood.<sup>34</sup> At his suggestion, small quantities of liquid blood had actually been preserved and transported considerable distances up to regimental aid posts. The addition of new red blood cells were, in Robertson's opinion, "the only means available of increasing the oxygen-carrying power of the blood....[T]his constitutes the unique value of blood transfusion."<sup>33(p42)</sup>

Robertson was a pioneer in establishing the concept of the world's first blood bank. He joined Cannon at the surgical research laboratory in Dijon, France, in August 1918, where he helped untangle the problem of "the efficacy of using gum acacia in the treatment of shock."<sup>31(p243)</sup> He concluded that there was an absence of convincing data as to gum acacia's usefulness in the treatment of shock.

At the end of World War I, William M. Bayliss, a distinguished British physiologist who had served on the Wound Shock Committee of the Medical Research Committee during the war, regretted "that so little positive evidence is forthcoming as to the superiority of blood transfusions. Statements are made on the basis of general impressions, rather than on convincing proof...."<sup>33(p347)</sup> Without convincing data, medical authorities might underestimate the importance of blood transfusions in the treatment of shock after the war.<sup>33</sup>

Also, the World War I Shock Committee's attempts to study shock were generally unsuccessful and led to fallacies. For example, the Committee had concluded at the end of the war "that the absorption of toxins from injured tissues was the primary cause of traumatic shock."<sup>35(p29)</sup> That belief led to misconceptions about the relationship of muscle injury to shock in the postwar years. Little progress was made on the relation of anesthesia to the development of shock. The Committee's great achievement, however, was in giving recognition to the complex problem of wound shock.

Other treatments for shock during World War I included restoration of lost body heat by surrounding the patient with blankets; injection of morphia to reduce pain and restlessness; and the return of blood from the large veins of the abdomen to the heart by raising the foot of the bed, a practice used for years in civilian hospitals, to permit gravity to aid the blood's return. Shock ward officers re-

ported that the technique had no marked effect on either systolic or diastolic pressure. They also observed that the use of vasoconstrictor drugs to improve circulation in shock was futile, as clinical and experimental observations showed that the heart was not primarily affected in shock.<sup>30</sup>

Aftercare in World War I shock wards included monitoring of the patient's blood volume until it was restored to the normal level, a difficult procedure under field conditions, and the provision of fluids by either mouth or rectum until the urinary output equaled the water intake. Although military physicians stressed the need to watch for unfavorable developments and to treat them accordingly, postoperative care was not well developed in World War I.<sup>30</sup>

Despite its limitations, treatment of the seriously wounded during the war produced valuable lessons about shock and resuscitation. Cannon observed<sup>30</sup> that

- shock wards required two resuscitation teams, each consisting of a medical officer, a nurse, and an orderly;
- withdrawing 500 to 750 mL of blood did the slightly wounded man no harm, and saved the life of a soldier suffering from shock or severe hemorrhage;
- in preparation for shock cases, resuscitation officers needed to provide heating arrangements, transfusion equipment, and blood donors (and to determine their blood grouping); and
- resuscitation officers needed to perform or direct transfusions, give the surgeon their judgment of the optimum time for surgery, and do clinical work for the surgeon—so long as this work did not interfere with the resuscitation officer's important duties in the shock ward.

After a rocky start, military anesthesia greatly developed during the war to the benefit of the patient, the surgeon, and the war effort. For the first 2 years of the conflict, military anesthesia sorely lacked trained providers, advanced equipment, and supplies of nitrous oxide. Many soldiers' lives might have been saved had this not been the case. During the last 2 years of the war, the availability of improved apparatus, the employment of expert anesthetists, and the administration of warm ether vapor or nitrous oxide–oxygen instead of chloroform, whose potency could become dangerous, undoubtedly saved many lives.

Reserve officers from civilian medicine, who served as consultants to the armed forces, preferred nitrous oxide–oxygen anesthetic for most operations. The realization that this anesthetic required expert administration emphasized the need for trained anesthetists in the armed forces. As a result, the armed forces sent officers to study war surgery and anesthesia at medical schools throughout the country and nurses to schools of anesthesia that had developed in the United States in response to the demands of war. However, most of those students never made it overseas, as the war ended shortly after the buildup of American hospitals had begun.

Valuable information on the treatment of shock and resuscitation was produced during World War I, but the complex problem of shock remained shrouded in mystery. Nevertheless, the recognition of anesthesiology as a special field increased, as did the recognition of the anesthesia provider as a specialist rather than a technician. In 4 years, the state of the art of anesthesiology had vastly improved.<sup>29</sup> However, although anesthetists, like other specialists, found a home in the armed forces, decades would pass before the institution of residency programs in the U.S. Army.

After World War I, Dr. Crile wrote the chapter on anesthesiology for the official medical history of the war. His knowledge about anesthesia during the war led him to conclude<sup>29</sup> that

- nitrous oxide–oxygen, a light anesthetic, was the preferred anesthetic for the patient in shock; its administration required expert handling;
- in cases of profound exhaustion, spinal anesthesia would cause no serious fall in blood pressure if the patient first received an ordinary transfusion of blood;
- the psychic factor of being aware of the operating room and staff might be overcome by morphine or very light nitrous oxide anesthesia, or by light partial ether anesthesia; and
- ether, on the other hand, caused pneumonia in abdominal cases during the winter, was unsuitable in infections, and had a tendency to cause a fall in blood pressure after the operation; hence, ether should not be used in cases of shock.

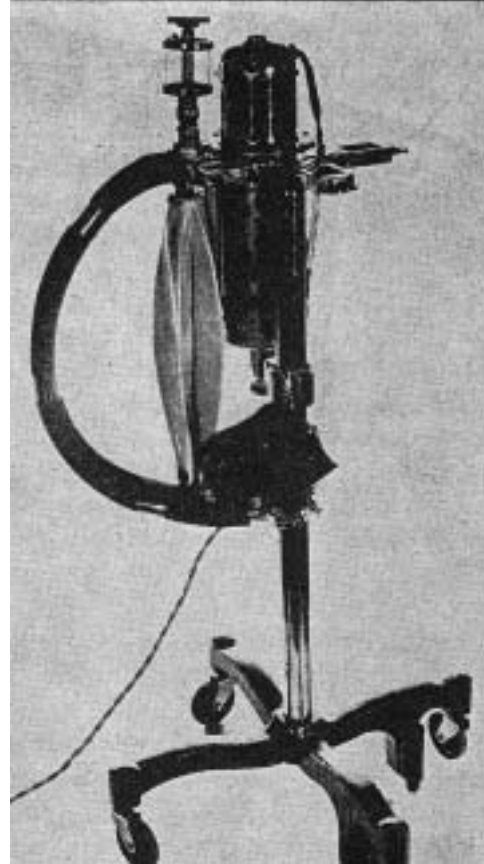
Whether 20th-century medicine would substantiate these revelations remained to be seen.

## Between the World Wars

The experiences of anesthesia providers in the Great War helped shape the revolution in anesthesiology that occurred during the 1920s and 1930s. As a result of the contribution of nurse anesthetists during the war, nurse anesthetist programs grew in number in both civilian and military medicine. Veteran physician anesthetists used their organizational skills and medical expertise to convince hospital personnel, mainly surgeons, across the country to establish divisions of anesthesia. As a result, departments of anesthesiology with residency programs began to appear. In 1939, the medical department of the U.S. Army began formal training of physicians in anesthesiology, one officer at a time, while increasing internships and post-graduate education in specialties in general. On the clinical side, transfusions, fluid therapy, intravenous anesthesia (revolutionized by the appearance of the barbiturates, especially pentothal, which is now known as sodium thiopental), and rebreathing anesthesia machines became more common (Figure 31-13).<sup>1-3,22,36,37</sup>

Anesthesiology grew as a profession during this period. Physician anesthetists founded the American Board of Anesthesiology in 1937 as an affiliate of the Board of Surgery and as an independent board to pass on the qualifications of trained anesthetists in 1941. The American Society of Anesthetists, a physician organization, grew out of the New York Society of Anesthetists and later became the American Society of Anesthesiologists. The American Association of Nurse Anesthetists, founded in 1931 to help guide the education of nurses in anesthesia, enhanced its power and helped cement the rivalry between nurse anesthetists and physician anesthetists, which had begun in the 1920s. Shortages of physician anesthetists meant that nurse anesthetists dominated most medical departments. New journals and books on anesthesia appeared in Europe and the United States, and an exhibit on anesthesia opened at the 1939 New York World's Fair. The roots of modern anesthesia were firmly planted between World War I and World War II.<sup>36,37</sup>

Other developments during this period included new techniques and agents. The improvement of the soft metal needle made continuous spinal anesthesia possible by permitting the use of very small doses and eliminating concern over the wearing off of the anesthetic. The endotracheal catheter, developed by British plastic surgeons Ivan Whiteside



**Fig. 31-13.** This rebreathing anesthesia machine, made in 1918, was offered to the US Army in June 1918. Photograph: Reprinted with permission from Jackson DE. Anesthesia equipment from 1914 to 1954 and experiments leading to its development. *Anesthesiology*. 1955;16:962.

Magill and Edgar Stanley Rowbotham for use on wounded World War I veterans, gave anesthetists “direct control of the respiratory tract and its contents”<sup>1(p286)</sup> and provided the surgeon a quiet field in which to work. The combination of the new technique with the new anesthetic cyclopropane enabled the anesthetist to “synchronize the movements of the lung with the work of the surgeon.”<sup>1(p286)</sup>

In the search for the ideal anesthetic, divinyl oxide, a cross of ether and ethylene (an anesthetic that was fast in action but weak), appeared. By producing a rapid and brief anesthesia, divinyl oxide, later replaced by sodium thiopental, put the patient to sleep before the ether was administered, rendering ether more pleasant. New anesthetics like Nembutal and the barbiturates—evipan and sodium thiopental—administered by the intravenous route came rapidly into favor. Man improved

or produced machines for the administration of a variety of anesthetics. Those developments boded well for the future of anesthesia.

The development of the carbon dioxide-absorption technique made possible modern and efficient gas anesthesia machines (Figure 31-14). This technique permitted the patient to receive measured amounts of anesthetic gases and oxygen by adding ether to the mixture in small doses until the desired level of anesthesia was achieved. Expired gases passed through a soda lime canister that absorbed carbon dioxide before the gases entered a rebreathing bag, and the patient, on impulse, breathed in a warm blend of vapor and oxygen or of gases and oxygen. The containment of all gases in a closed circuit greatly reduced the chance of fire as well as the cost of anesthesia, since enclosed agents were not likely to escape. This technique also enabled the anesthetist to manage the patient's breathing and to maintain periodic positive-pressure anesthesia. This procedure was a boon to the anesthetist on the eve of World War II.<sup>38</sup>

Shock therapy, however, which is best studied in war, with its numerous casualties and major injuries, was an area that showed little improvement in the interwar years. After World War I, shock study took place in "experimental laboratories, in which attempts were made to [analyze shock] by physiologic and chemical techniques under a wide variety of experimentally induced conditions."<sup>35(p29)</sup>

Developments in shock therapy were understandably slow. The theory of toxemic shock persisted until the late 1920s, when A. Blalock, E. Parsons, and D. E. Phemister "demonstrated that shock pro-

duced by trauma to the limbs is not the result of toxemia but of a local loss of blood and fluid and of circulating blood volume."<sup>35(p29)</sup>

N. E. Freeman and his associates concluded from their observations "that the blood volume is a more reliable index of shock than the blood pressure," but the misconception persisted that "true shock [is] a generalized increase in capillary permeability."<sup>35(p30)</sup> Other fallacies also persisted, notably, that blood plasma is as effective as whole blood in the treatment of shock. Also, no practical way of determining blood volume under field conditions was developed during the years between World War I and World War II.

By 1940, the military, which had few medical specialists of any kind, depended largely on civilian medicine for specialized training of medical personnel and fulfillment of mobilization goals. Reserve medical officers and nurses entered the military in increasing numbers during the emergency buildup of 1940 and 1941. Specialists like Henry Swartley Ruth of the Philadelphia General Hospital taught young military physicians the values, concerns, and ideas of civilian medicine. The military started to respect specialization, accepting a civilian tenet that the "best care" for their patients "meant specialized care."<sup>18(pp7-8)</sup> The army took specialization into account when making assignments during the war. The navy established residency training in naval hospitals in 1944. Specialization was fast becoming an important factor in military medicine.<sup>18</sup>

## World War II

### Personnel

Even in World War II (1939–1945), however, there were never enough trained anesthetists to meet the needs of the military. At army hospitals in the United States, nurses gave inhalational anesthesia, while surgeons administered spinal, local, and regional anesthetics. At overseas theaters of operations, the military overcame shortages of skilled personnel and provided assistants for periods of peak loads by the continual training of nurse anesthetists, dentists, medical officers pressed into service, and corpsmen within the theater. Some dental officers learned drop ether and spinal anesthesia. Because surgery in forward-area hospitals taxed intelligence, judgment, resourcefulness, and technical ability, the army made every effort to assign its best-trained anesthesia providers to the combat zone. Anesthetists rendered great service in the



**Fig. 31-14.** The To-and-Fro Absorber was introduced by Ralph Waters, MD, in 1923 at the University of Wisconsin. Carbon dioxide-absorbent granules were placed in the canister; the patient was allowed to breathe "to and fro" through the canister. The device was accepted rapidly because it was simple and practical. Photograph: Courtesy of Ohmeda, Inc., Madison, Wis.

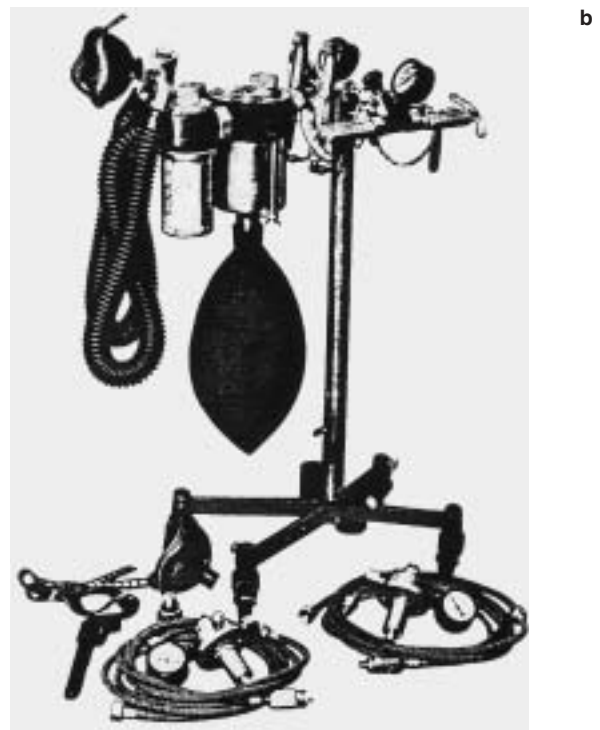
forward areas of the North African Theater of Operations, where shortages of trained and experienced anesthesiologists persisted through 1943. By 1944, two skilled anesthesiologists served in each field and evacuation hospital sent to Europe, and one on each auxiliary surgical team on the front line (Figure 31-15).<sup>38-41</sup>

### *Anesthetics and Equipment*

Shipping priorities and the need for simplicity at the front limited the choice of anesthetics and machines that accompanied frontline medics overseas, despite a wide range of agents and devices available at the start of the war. Combat anesthetists needed to have agents that could be hand carried and administered by improvised techniques and equipment. A scarcity of trained personnel narrowed the choice of drugs to those that people with limited experience could administer. Scarce shipping space and the need for forward-area hospitals to move quickly prohibited the employment of cumbersome equipment. The complex anesthesia apparatus, such as delicately adjusted gas machines, ran the risks of leakage and loss of serviceability due to rough handling during movement on short notice.<sup>38</sup> There was a need for portable gas machines in each platoon of the highly mobile (300-bed) field hospital.



**Fig. 31-15.** Anesthesia as it was administered during World War II. Photograph: Courtesy of National Library of Medicine, Medical History Section, Bethesda, Md.

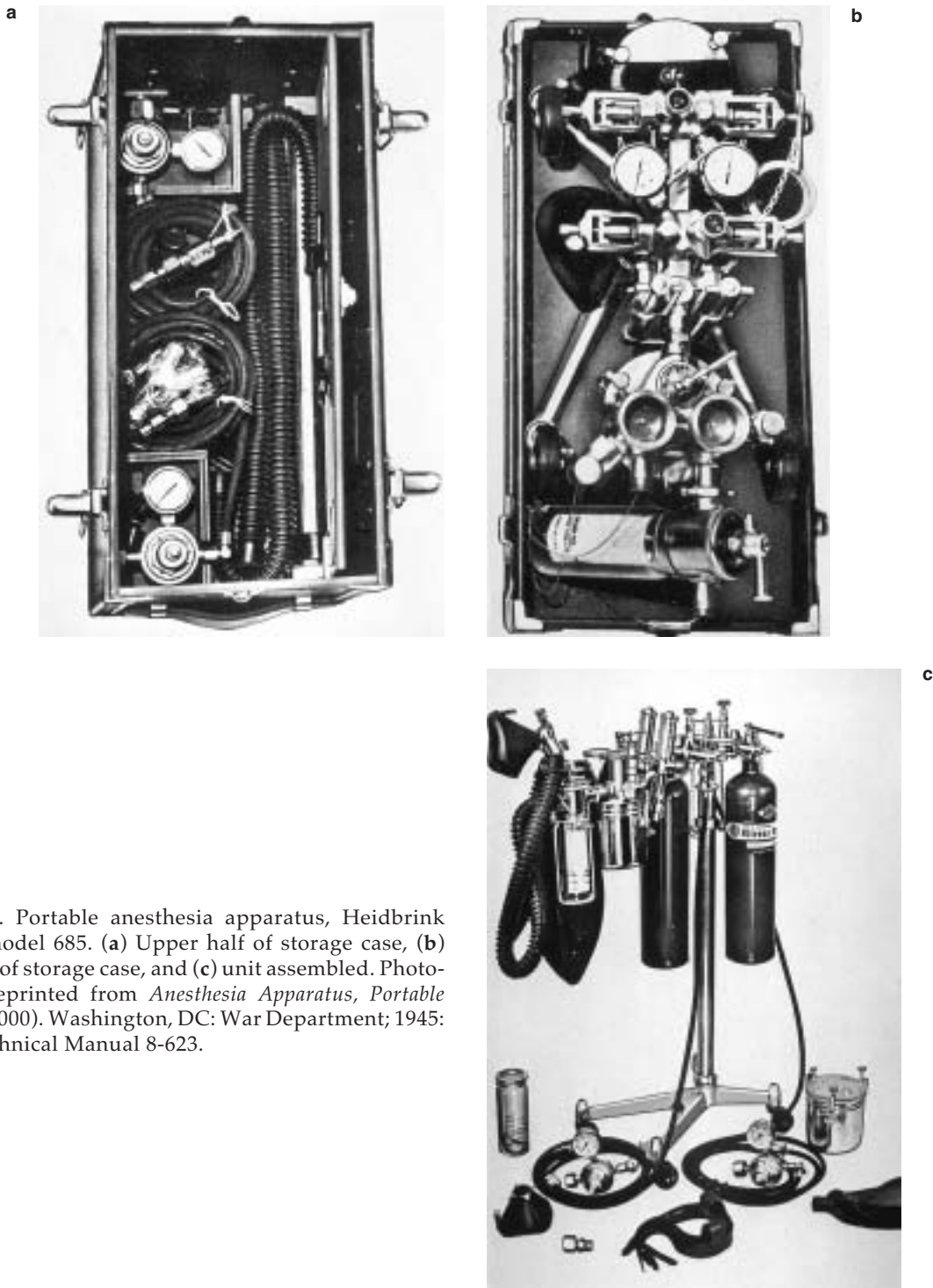


**Fig. 31-16.** Portable anesthesia apparatus, McKesson model 675, (a) packed in its carrying case and (b) assembled. Photographs: Reprinted from *Anesthesia Apparatus, Portable* (Item 9350000). Washington, DC: War Department; 1945: 4-5. Technical Manual 8-623.

tal or small (750- or 400-bed) evacuation hospital, “where intermittent positive pressure was essential for adequate care of nontransportables.”<sup>40(p600)</sup>

The army issued four types of portable machines in World War II—the Ohio, McKesson, and

Heidbrink (affectionately known as the “pig”), which were standard in civilian hospitals (Figures 31-16 and 31-17), and the Beecher machine, designed especially for active combat by Henry K. Beecher, reserve medical officer and Anesthesia



**Fig. 31-17.** Portable anesthesia apparatus, Heidbrink military model 685. (a) Upper half of storage case, (b) lower half of storage case, and (c) unit assembled. Photographs: Reprinted from *Anesthesia Apparatus, Portable* (Item 9350000). Washington, DC: War Department; 1945: 12, 13. Technical Manual 8-623.

Consultant to the North African–Mediterranean Theaters of Operation (October 1943–August 1945).

Light, compact, and easily hand carried, the Beecher machine could develop positive pressure in the airway without depending on tanks of oxygen, which were often unavailable at the front. Foot bellows were dispensed with when oxygen was on hand. The maintenance of a constant flow of room air through the apparatus allowed the system to continually flush, making the use of soda lime–carbon dioxide absorbent unnecessary. The device was encased in a compact container with enough capacity to hold a laryngoscope; intratracheal tubes; an aspiration bulb and catheter for emptying the bronchi; a packet of an induction agent, normally sodium thiopental; and two cans of ether, each weighing 1 lb. A fully loaded container weighed 25 lb.

Although designed specifically to make thoracic surgery possible without compressed air, the Beecher machine proved useful in combat for inhalational anesthesia, the administration of oxygen, and artificial respiration. This simplified machine became the apparatus that anesthetists used most often in World War II after mid-1944 and the buildup for Normandy. Before then, portable machines were in short supply, particularly in the North African theater. In the absence of portable machines, anesthetists relied on agents and methods that did not require movable devices, risking the lives of some patients.<sup>25,38,39</sup>

U.S. Army anesthetists had a wide variety of agents to choose from, including ether, chloroform, ethyl chloride, nitrous oxide, sodium thiopental, procaine, tetracaine hydrochloride, and cocaine. Cyclopropane and ethylene also were on hand, but military anesthesia machines were not equipped to handle those flammable bottled gases under pressure in cylinders. Hence, they were not used in combat.<sup>38</sup>

When machines were available, the choice of anesthetic usually depended on the experience of the anesthetist, the preference of the surgeon, and the problems of surgery. Ether anesthesia combined with oxygen, following induction with nitrous oxide, became popular because of its simplicity of administration, ready availability, easy tolerance by patients, and general safety. Ether's disadvantages, "irritat[ion] to the mucous membranes of the respiratory tract...[and] disturbance of metabolism, the blood sugar frequently being elevated from 100 to 200 percent,"<sup>42(p69)</sup> were outweighed by its advantages, particularly its margin of safety, since anesthetists were not equally trained, experienced, and capable.

Ether became the preferred anesthetic for casualties who were seriously wounded or in shock, which completely reversed the practice of World War I. By 1941, physicians knew that an impaired circulatory system took prolonged ether anesthesia well and that, according to Beecher, a man in shock tolerated ether far better than an animal in shock. Since trauma patients could take ether, then men less badly off could also take ether. In the Mediterranean Theater of Operations, where U.S. troops had been engaged in combat since November 1942, ether was the preferred anesthetic in more than 90% of cases.<sup>25(p182)</sup> In the European theater, inhalational anesthesia was used 86.2% of the time in Seventh U.S. Army field hospitals, compared to only 23.2% of the time in their evacuation hospitals, where fewer trauma cases were seen, and intravenous anesthesia with sodium thiopental became the preferred method.<sup>39(p549)</sup>

Nevertheless, the scarcity of portable machines, but more importantly, of fully experienced anesthesiologists, led to inexperienced choices of agent and method for patients in critical condition. In the North African theater in 1943, for example, in the interest of time, inexperienced anesthesiologists used spinal anesthesia or intravenous anesthesia with sodium thiopental when the poor condition of the patient dictated inhalational anesthesia. This trend was increased by the shortage of anesthesiologists trained in inhalational anesthesia using "carbon dioxide absorption and intermittent positive pressure administered through an endotracheal tube."<sup>40(p603)</sup> Shortfalls of machines and skilled personnel led to substandard combat anesthesia.

Sodium thiopental, a popular anesthetic, proved valuable as an induction agent preceding ether anesthesia of men in good condition, sometimes as an adjunct to spinal anesthesia, and as a sole agent for procedures of short duration. If the operation lasted longer than 30 to 45 minutes, the anesthesia provider switched to ether. Sodium thiopental had the advantages of being readily available; simply and compactly designed; easily and smoothly induced, even by inexperienced physicians; and with few undesirable aftereffects, all of which made it a good drug under combat conditions.

Medical personnel would not use sodium thiopental on patients suffering from shock, an impaired intake of oxygen, severe hemorrhage, inflammation "in the region of the carotid body or carotid sinus,"<sup>38(p72)</sup> gas gangrene, severe burns, when the operative position interfered with the airway or complicated artificial respiration, or when intracranial surgery was required. Bad-risk

patients tolerated full barbiturate anesthesia poorly. Hence, sodium thiopental was used more often at evacuation hospitals, further back along the evacuation chain than in field hospitals, where more shock cases were observed. In Seventh U.S. Army hospitals, for example, intravenous anesthesia with sodium thiopental was used 53.1% of the time in evacuation hospitals and only 2.8% of the time in field hospitals.<sup>39(p549)</sup> Surgical problems influenced the anesthesia method chosen by combat medics.<sup>25,38,39</sup>

The medical department learned the hard way about the danger of using sodium thiopental on patients in shock. During the aftermath of the attack on Pearl Harbor on 7 December 1941, a number of patients suffering from traumatic shock and acute loss of blood experienced respiratory failure and died as a result of sodium thiopental anesthesia used intravenously. Those patients also did not receive a transfusion of blood or gum-salt solution, as the lessons of World War I regarding volume resuscitation were lost to medical practice between the wars. As a consequence of those deaths, anesthesiologists switched to open-drop ether, which proved safer for patients in shock. Casualties attended to later in Europe and the Pacific benefited from this new appreciation of the risks of sodium thiopental anesthesia on hypovolemic patients.<sup>43</sup>

A number of the other drugs supplied to the army received limited use. Since civilian practice discredited chloroform because of its intensely depressing effect on the circulatory system, it made little sense to use chloroform on wounded men suffering circulatory damage. Nitrous oxide became a routine induction agent but never the sole anesthetic. Oxygen concentrations of 21% or 30% or more always accompanied the gas. Ethyl chloride became a satisfactory induction agent if administered cautiously. In World War II, unlike in World War I, physicians understood the acceptability or unsuitability of most anesthetic agents.<sup>25,38</sup>

### ***Methods of Choice***

Medical officers considered the best method of anesthetic administration for military surgery to be closed-circuit anesthesia, either the closed-circle flow absorption method of the Heidbrink and McKesson machines, or the closed to-and-fro absorption technique of the Beecher machine. This system conserved body heat and moisture, maintained a high oxygen level while controlling the carbon dioxide volume in the blood, preserved desired degrees of anesthesia, regulated respiration,

and maintained positive pressure. There was an increasing use of the closed-system technique as the war progressed.<sup>25</sup>

Although spinal anesthesia became an acceptable practice in World War I for wounds of the extremities and pulmonary trauma, the method was considered undesirable in World War II military surgery for a number of reasons: the technique caused a lowering of blood pressure in badly wounded men suffering from trauma and loss of blood, it made surgery lengthy and variable when other casualties were waiting for attention, and it allowed the undesirability of full consciousness in an apprehensive casualty fresh from the battlefield. Of 3,154 cases of abdominal injuries in the Mediterranean theater, anesthesia providers used spinal anesthesia on 3 patients only, each one in good condition and with minimal wounds.<sup>25(p185)</sup> Its limited use in combat reflected the belief that spinal anesthesia was a poor choice for badly wounded men at the front.<sup>25,38</sup>

Other regional or local anesthesia had limited use in combat. Early in the war, the English found that seriously wounded men tolerated poorly the moderate discomfort and psychological trauma of being conscious of their surroundings. The Allies therefore used local anesthesia for minor surgery on "easy-going" patients, who had exhibited a tolerance for occasional discomfort and other inconvenience. Local and regional block, normally with procaine, proved useful in certain neurosurgical and maxillofacial operations, but, in general, the method was not practical because of the multiplicity of wounds in each patient.<sup>38,44</sup> One anesthesiologist regretted not fully testing the combination of local anesthesia with a light inhalational anesthetic, which, he thought, might have had excellent potentialities in military surgery.<sup>25(p185)</sup>

Medical personnel performed topical anesthesia with tetracaine hydrochloride or cocaine. They used cocaine also for bronchoscopy or to ease a difficult intubation. Endotracheal intubation occurred routinely in intracranial, maxillofacial, and abdominal operations performed under general anesthesia; in all thoracic operations in which the pleura was involved; and in operations of more than 1 hour.<sup>25,38</sup>

### ***Shock Therapy and Resuscitation***

The anesthesia provider played an integral part in preoperative management, necessitating a knowledge of shock therapy and preanesthetic medication. Lessons of World War I regarding shock



therapy and resuscitation were relearned, modified, and practiced in the North African theater by April 1943. When the flow of casualties was heavy and a shock team was unavailable, both anesthetists and surgeons worked in the resuscitation ward. Here patients received whole blood, pooled plasma, and 5% dextrose and water. If time allowed, the anesthetist conducted an examination of the patient before determining his presurgical medication. The anesthetist routinely used atropine (gr 1/100, equivalent to 0.6 mg), often in combination with morphine, given intravenously. The application of anesthetic care to trauma developed greatly during World War II, when evacuation from the front line to definitive care took 4 to 6 hours.<sup>25</sup>

Evacuation began shortly after an aid man gave the conscious casualty morphine and called for a litter squad. Depending on the wound, the medic administered plasma; dressed the wound; and filled out an emergency medical tag indicating the man's name, serial number from his dog tag, and the nature of the wound. The battalion aid station litter squad carried the wounded man back to the aid station, where he was examined for the first time by a medical officer, the battalion surgeon. The surgeon could administer more plasma and morphine and send the casualty to the collecting station for transfer by ambulance or litter bearer to the division clearing station, located 5 to 10 miles behind the front. Here, surgeons assigned to auxiliary teams performed acute surgical care, and, in the European and Mediterranean theaters, shock teams, including an anesthetist, saw the patient for the first time. When the patient was strong enough to be moved again, medical personnel transported him another 8 to 12 miles to an evacuation hospital, still under canvas and still in the combat zone. After the provision of definitive care, hospital authorities either evacuated the casualty to the rear or, if he was fully recovered, sent him forward for return to duty.<sup>45</sup>

Shock wards of field or evacuation hospitals were crucial to a patient's recovery during evacuation. Shock wards were headed by medical officers chosen from the internists or junior surgeons on the staff, or led by anesthetists and surgeons when the flow of casualties was heavy. Ideally, specific surgical or shock teams were assigned to the patient and stayed with him throughout his surgery to provide continuous care.<sup>42</sup>

The shock teams appraised the wounded man's therapy needs to enable him to tolerate surgery or evacuation to a rear hospital. A patient in shock did not remain in the same condition for any length of

time. The team assessed the man's trends in both pulse rate and blood pressure (their quality and upward or downward trends were most important) to check the adverse forces at work. His degree of thirst and mental status, both of which medical officers paid little attention to in World War I, were found to be useful in evaluating the degree of shock. It was important to prevent a regression in the patient's condition in preparation for surgery.<sup>42</sup>

The anesthetist continued management of the hypovolemic patient in the operating room, administering high concentrations of oxygen to reestablish normal metabolism; anesthesia to abolish pain; blood transfusions to restore and maintain blood volume; dextrose and saline to rehydrate patients; and artificial respiration, if conditions indicated. The anesthesia providers did all they could to maintain a viable patient, while the surgeons worked as quickly as possible in light of the patient's needs.<sup>42</sup>

Casualties in shock or who had been in shock were usually easy to anesthetize, probably as a result of the resuscitation process practiced by military anesthetists. Military patients seldom experienced severe excitement—in contrast to patients in shock in civilian practice. Military anesthetists gave casualties in shock a light anesthesia compatible with their surgery because such patients tolerated deep anesthesia for brief periods only. Sometimes anesthetists authorized to administer curare used the agent as a muscle relaxant to facilitate intraperitoneal manipulations during periods of light anesthesia. Patients in shock, suffering thoracoabdominal wounds, or both, received nitrous oxide–ether anesthesia by the closed endotracheal technique and curare in various dosages and at various times during the operation. None of those cases suffered postoperative complications or deaths that could be attributed to the use of curare. Anesthesia providers stressed the importance of employing the endotracheal technique when using curare. Military anesthetists greatly expanded the role of the anesthesia provider in the care of the trauma patient during World War II.<sup>42</sup>

Volume resuscitation was pivotal in the treatment of patients in shock during the war. Early in the conflict, physicians relied on blood plasma because of the limited supply of whole blood, which resulted from general unpreparedness for war, and a myriad of theories about shock. Some experts considered blood plasma as effective as whole blood in the treatment of shock, easier to preserve and transport than whole blood and without the requirement of matching and typing. Shortages of blood for volume replacement, despite the use of

blood donors in the field, meant a delay in surgery until the patient was stabilized. In February 1943, patients received treatment for shock in clearing stations for up to 24 hours before surgical therapy was even attempted. Medical officers did not give blood postoperatively to overcome anemia and promote wound healing or, for that matter, oxygen to improve circulation during this early period.<sup>33,42</sup>

The readier availability of whole blood in 1944, which followed the establishment of blood procurement centers in U.S. cities and refrigerated blood banks in rear combat hospitals, led to a change in the concept of stabilizing the casualty *first*, in favor of rapid preparation for surgery and a reduction in the time lag as compared with 1943. The concept of prompt operation required an understanding of what could be achieved by resuscitative measures and what was impossible. Medical officers came to realize that all that was needed was to make the patient safe for surgery. Since a seriously wounded man could slip back into shock once he had been brought out of it, surgery should not be delayed once he was resuscitated from shock. World War II anesthesiologist Lieutenant Colonel Henry K. Beecher stated that

all military surgeons, no matter what their original point of view, eventually realized the importance of operating as soon as the patient had been brought to optimum status within a minimum period of time.<sup>42(p21)</sup>

The recognition of the essential unity of resuscitation and operation was an important surgical advance late in the war. The lessons learned about volume resuscitation in World War I had to be relearned in World War II.

Military surgeons also changed their minds about blood plasma's usefulness in the treatment of shock. The consideration of plasma as the ideal substitute for whole blood in the emergency treatment of shock and hemorrhage in war wounds was so entrenched early in the war that it handicapped the development of more effective measures for the management of shock. As the war progressed, however, experience proved the effects of plasma to be transient. Plasma brought men out of shock and maintained blood volume during transportation to the hospital, where a blood transfusion could be started. Plasma became a lifesaving stopgap measure only until the patient could receive whole blood.<sup>42</sup>

British anesthesiologists had concluded similarly about the transient nature of blood plasma. Of the

10% of all patients requiring resuscitation before surgery in British forward hospitals in March 1943, one out of five required whole blood.

If treated with plasma alone, [remarked a medical officer of No. 1 Casualty Clearing Station in southern Tunisia,] the blood pressure [could] be brought back but [fell] again with operation and [did] not come back a second time. Patients treated with plasma remain[ed] pale, the pulse [was] rapid and the labile blood pressure [was] very sensitive to further operative procedures.<sup>33(p36)</sup>

In general, wounded American soldiers received one additional unit of plasma to three units of whole blood at the hospital. About two thirds of patients received another 500 mL of blood each, and about one third received 1,000 mL of blood each. Patients were considered ready for surgery when the systolic blood pressure was 80 mm Hg and tending upward, when the pulse volume was good and the rate tending downward, and when the skin was warm and the color good. Sometimes albumin, which was expensive in terms of the quantities of blood needed to prepare it but had small bulk (corpsmen could line their pockets with it), was used to elevate a low blood pressure in situations in which space and weight were at a premium.<sup>42</sup>

To establish effective resuscitation procedures based on scientific evidence, the medical department set up stationary research laboratories in the Mediterranean theater in late 1943 and early 1944 "to study by formal biochemic [*sic*] methods certain aspects of shock, hemorrhage, and dehydration,"<sup>33(p348)</sup> and a mobile laboratory in September 1944, called the Board for the Study of the Severely Wounded in the Mediterranean Theater of Operations, "to observe shock on a big scale"<sup>33(p353)</sup> and get insights into its nature. In the opinion of the Medical Research Committee of the theater,

[i]t was essential...that the so-called impressions derived from experience be documented by hard, cold facts about the condition of a freshly wounded man.... The collection of data needed to be extended to a sufficient number of casualties to make the findings conclusive.<sup>33(p349)</sup>

The loss of lessons learned from World War I due to the absence of convincing data and the confusion over shock therapy early in World War II were the catalysts for this effort at documentation by scientific evidence of effective resuscitation procedures experienced during World War II.

Data collected from studies of thousands of badly wounded soldiers during the Italian campaign proved that the liberal use of whole blood transfusion was necessary for the success of reparative wound surgery. Extensive laboratory tests on at least 37 of those patients confirmed the absence of hemoconcentration in shock. The mobile research team, headed by Colonel Beecher, studied the physiological effects of blood loss in 186 severely wounded patients, concluding, in the broadest sense, that "wound surgery [was] inseparable from the management of wound shock."<sup>46(p13)</sup> Surgery became part of the continuous process of resuscitation. The team also determined that plasma, whole blood, penicillin, and sulfa drugs were not harmful to the kidneys, a question of concern in treating the severely wounded. Studies of wounded patients immediately after admission to forward hospitals helped to formulate procedure for the clinical management of the seriously impaired.<sup>33,46</sup>

Other resuscitative measures used in World War II included

- relief of physical and mental pain by sedation (barbiturate, usually sodium amytal) and administration of morphine,
- management of the local wound through control of hemorrhage and the application of splints,
- conservation of body heat,
- emptying of the stomach before anesthesia to avoid the risk of aspiration, and
- administration of oxygen to produce a lowered pulse rate and a better coloration of the blood.

Medical officers administered oxygen by nasal tube after it had been humidified by being bubbled through a water column. Patients usually tolerated well a gas flow of 4 to 5 L/min of 100% oxygen. A closed system with carbon dioxide absorption, usually by the Beecher machine, provided higher concentrations of oxygen, if needed. Vasoconstrictor and stimulating drugs were of no value in the management of battle casualties and were almost never used.<sup>33</sup>

### *Auxiliary Surgical Groups*

To assure quality anesthesia and surgery, specialty consultants from Auxiliary Surgical Groups, each consisting of four surgical teams that performed frontline surgery in the absence of hospi-

tals, visited forward units to check on patient supervision. Those consultants addressed relevant problems and recommended solutions.<sup>47</sup>

### *Statistics*

Statistics from the Mediterranean theater reveal a record of safety in the prevention of anesthesia deaths. Surveys conducted in the Mediterranean theater in September 1943 and September 1944 show only 12 deaths attributed to anesthesia in 27,564 administrations of anesthetic agents.<sup>38(p78)</sup> Seventh U.S. Army hospitals attributed 11 deaths in 44,630 cases wholly or in part to anesthetic administration between 1 November 1944 and 30 April 1945.<sup>39(p550)</sup> One World War II anesthesiologist credited this safe record to more standardized methods and increased experience,<sup>38(p78)</sup> which made anesthesia safer for the seriously wounded man.<sup>38</sup> Statistics for World War II are sadly lacking, however, regarding numbers of physician and nurse anesthetists, anesthesia deaths in other theaters, and the frequency and place of employment of specific agents and techniques.

### *World War II Experience in Summary*

World War II (1939–1945), like most wars, began with shortages of almost everything, including anesthesia providers. Continual training in anesthesia at home and overseas helped to provide the armed forces with skilled people, but never in the numbers needed. Although a variety of anesthetics were on hand during the war, ether's availability, ease of administration, and margin of safety made the agent most popular. Sodium thiopental given intravenously proved invaluable for preliminary anesthesia or as a sole agent. Sodium thiopental's compactness and ease of induction made it an ideal anesthetic for the good-risk patient under combat conditions.

Closed-circuit anesthesia with the simple Beecher machine gradually gained wide acceptance as a satisfactory method at forward area hospitals, where portable machines were needed. The apparatus proved useful in combat for inhalational anesthesia, the administration of oxygen, and artificial respiration.

The availability of whole blood in theaters of operation and the development of shock wards improved treatment and resuscitation of the patient in shock. Finally, medical departments in World War II officially recognized the administration of

anesthetics as a highly skilled occupation and the anesthetist as a specialist.

### ***Postwar Recruitment***

After demobilization, the U.S. Army had to find ways to attract qualified physicians into military service. The army's acceptance of specialization, which resulted in the establishment of residency programs in 1947, helped. The army, like the navy, however, still depended on civilian reserve officers to serve as consultants to those programs. In 1948, to obtain specialists, the army began commissioning residents in civilian hospitals for service in the army. Most volunteers for this program had received some financial support from one of the military services during their medical school training. With specialization so popular and widespread in the country, the army began to develop graduate education programs that would maintain military medical standards while attracting and retaining skilled physicians in the service. By 1950, those programs were well on their way.<sup>18</sup>

### **The Korean War**

Graduate medical education programs helped meet the needs of mobilization for the Korean War (1951–1953), which began with North Korea's invasion of South Korea in summer, 1950. The armed forces took young physicians who had recently finished residency programs in military hospitals and sent them to Korea. According to Howard D. Fading, Consultant in Neurology to The U.S. Army Surgeon General, the army's residency program "saved the bacon in the Korean War, and if it can never demonstrate another value, this alone proved its worth."<sup>18(p12)</sup>

When the numbers of medical officers were insufficient to meet the armed forces' needs, they began to draft young physicians from civilian hospitals and graduate education programs. The doctor draft in January 1951 helped relieve the critical shortage of medical officers, and courses given at general hospitals helped relieve the shortfall of nurse anesthetists, but specialists, including anesthesiologists, were in short supply throughout the war.<sup>18</sup>

At first notice, the treatment of the battle casualty in Korea seemed almost ideal. Personnel, equipment, and supplies, in most respects, were adequate. There were ample amounts of whole blood and prompt evacuation of the wounded from Korea. Casualty buildup did not pose a problem. Nor were

new data gathered on the anesthetic management of the wounded during the Korean War.<sup>48</sup>

But this picture was deceiving. Casualty care in Korea was far from ideal. Frontline evacuations were less effective in Korea than in World War II. Korea's mountainous terrain meant a long evacuation from the front to the aid station and from the aid station to the mobile army surgical hospital (MASH). The helicopter helped, but there were never enough. At a meeting of the Armed Forces Medical Policy Council on 18 June 1951, Brigadier General Crawford F. Sams, head of SCAP's (Supreme Commander for the Allied Powers) Public Health and Welfare Section, said he did not doubt

the quality of the front-line hospitals and the professional care available in them. [But, he lamented,] our death rate...is far higher than the last war because many do not reach the hospitals.... My impression is about 4,000 men [who have died] should be alive.<sup>49(p189)</sup>

Senior U.S. Army medical officers linked defective evacuation directly to medical specialization and professional development within the army to the detriment of military training. As army medicine became more professional, more expert, and more in line with civilian medicine, the army neglected to prepare physicians for field service. The army plucked young physicians straight from army hospitals and sent them to Korea without having had field medical experience. To meet immediate needs early in the war, medical officers in the civilian internship program also found themselves on the Korean front with no military training, and they suffered. Afteraction reports revealed that "some were captured, some were killed, [and] many performed ineffectively as officers."<sup>18(p11)</sup>

Additionally, the budget cuts of 1949 and 1950 had left the armed forces deficient in men, supplies, and training. Financial constraints had produced a paucity of medical personnel and hospital beds, with which a peacetime army could deal, but which became a problem once war began. The U.S. Army never had as many medical units in Korea as it needed; ambulance companies numbered about half of what was required, and the 750-bed evacuation hospital, which served as the backup unit to the 400-bed evacuation hospital and field and surgical facilities, was absent from Korea. Evacuation hospitals could not absorb sudden heavy casualty loads. Only U.S. air superiority and the presence of U.S. Army hospitals in Japan helped prevent a backlog of casualties awaiting evacuation from Korea. The

MASH worked well, and the blood program and combat psychiatry repeated the successes of World War II. But combat medics had to learn basic military surgical procedures "like wound debridement and delayed closure."<sup>49(p363),50</sup>

The lessons of World War II regarding anesthesia were also mostly forgotten. The limitation on the amount of anesthetic equipment and supplies that could be brought to the front made a variety of agents and techniques unavailable. Qualified anesthesiologists were scarce in forward units, such as surgical hospitals, where judgment and experience were highly necessary. Little standardization of anesthesia equipment made interchanges difficult among U.S. models, and among U.S. machines and those of other countries. There were national differences in terminology, electric current, and the coloring of gas cylinders. For example, a green U.S. cylinder contained oxygen and a green British cylinder contained carbon dioxide. Such practices led to letters of complaint to members of the U.S. Congress about the dismal anesthesia conditions in the war zone.<sup>26</sup>

Anesthesiology, like other medical specialties, was in a time of transition. The machines available to the armed forces were the World War II variety: the pig, the Foregger and McKesson machines, and the Beecher device. Some reserve officers brought their own anesthetic machines from civilian practice to Korea. An anesthesiologist from Massachusetts General Hospital, sent to the Far East Command to investigate anesthesia problems, brought with him a new compact anesthesia machine as well as methadone, a morphine substitute then undergoing clinical trials in the United States.<sup>26,49</sup>

The preferred agent and machine depended on the anesthetist's orientation and training. Some received training in sodium thiopental for the seriously wounded; others in nitrous oxide with adequate amounts of oxygen. One anesthesiologist reported using 50% to 60% nitrous oxide in oxygen (most likely with a relaxant and a narcotic) on the severely wounded patient, with satisfactory results. He wanted to spare the hypovolemic patient the consequences of a more potent depressant. Without definitive data to prove one agent or technique better than another, Robert D. Dripps, Civilian Consultant in Anesthesia to The U.S. Army Surgeon General, remarked, "[I]t seemed wise to permit anesthetists to apply those methods with which they [were] most familiar."<sup>48(p119)</sup> Regardless of which agent or machine was used, Dr. Dripps continued, the patient's susceptibility had to be kept in mind and his dosage carefully watched.<sup>48</sup>

Anesthesia providers reported using cyclopropane for the hypovolemic patient, and with good results. They also prepared a 0.5% solution of procaine for infiltration anesthesia and a 1% solution for nerve block. The muscle relaxant drugs, especially tubocurarine chloride and succinylcholine, proved useful in allowing rapid intubation of the trachea and providing muscular relaxation for varying periods of time. Patients in shock sometimes reacted to succinylcholine with exaggerated motor activity, resembling clonic convulsions. One anesthesiologist suggested that this represented a diminished amount of plasma cholinesterase. During the Korean War, anesthesiologists thought that shock exaggerated the motor activity associated with succinylcholine. Future anesthesia providers would know that motor activity resembling convulsions was a normal response to succinylcholine and not exaggerated by hypovolemia. For preoperative medication, anesthetists in Korea used morphine or sodium thiopental intravenously, as had been done in World War II.<sup>48</sup>

The lessons of World War II regarding resuscitation were retained for the Korean War, except that in Korea more information was available about the problem of homologous serum jaundice in untreated plasma. After World War II, plasma was subjected to ultraviolet sterilization as part of its processing to prevent serum hepatitis. But complete sterilization was never achieved, and hepatitis continued to follow the use of plasma no matter how it was treated. During the Korean War, the armed forces had to take the calculated risk of using plasma, even though it might cause hepatitis, because they needed an agent for resuscitation until the casualty could reach an installation and receive a transfusion of whole blood. The risk was considerable. Late in 1951, the incidence of hepatitis after plasma transfusion reached 21%, in sharp contrast to the reported World War II incidence of 7.5%. Part of the explanation was that much of the plasma used in Korea in the first months of the war had not been treated at all. Moreover, different diagnostic criteria were used in the two wars. In World War II, the diagnosis was chiefly clinical. In the Korean War, any elevation of the serum bilirubin was considered an indication of hepatitis. On 20 August 1953, Circular No. 73, Department of the Army, directed that because of the risk of serum hepatitis, the higher cost, and the need to use it for the production of specific globulins, plasma would not be used "to support blood volume" unless dextran was not available.<sup>35</sup>

The Korean War experience provided lessons for the future regarding equipment, organization, edu-

cation, and training. Among the recommendations made were the following<sup>48</sup>:

- the standardization of equipment, fittings, and electrical current;
- the inclusion of equipment for infants and children in anesthesia kits (one seventh of the South Korean population were refugees at some time during the war);
- the provision of a field anesthesia record that would fit into the emergency medical tag jacket and accompany the casualty; and
- increases in numbers and varieties of drugs.

Also promoted were the following<sup>48</sup>:

- the employment of anesthesia consultants in forward surgical hospitals, in order for them to obtain first-hand knowledge of the problems involved so as to advise and train others more authoritatively;
- the collection of data on techniques used for various operations, deaths related to anesthesia, the anesthetics administered, and the physical condition of the patients;
- the preparation of manuals and training films for military anesthetists that would include the basic aspects of resuscitation, pharmacology, and physiology; and
- the study of problems associated with the management of battle casualties and nuclear and chemical warfare.

Many questions arose from the anesthesia experiences of World War II and the Korean War that required investigating.

Although the importance of anesthesia and combat care were appreciated in World War I, World War II, and the Korean War, only in 1954 did the U.S. Army institute a 3-year residency program in anesthesiology, following an internship. Also, after the Korean War, the appointment of a senior consultant in anesthesia to the Office of The Surgeon General helped initiate the correction of some of the anesthesia problems that had been revealed during the Korean War. In civilian medicine, university departments of anesthesiology had begun to break away from the surgical departmental structure and to emerge as separate departments.<sup>47,48,51</sup>

While anesthesia came into its own in civilian hospitals, the Selective Service Act of 1950 and the Cold War of the 1950s and 1960s produced a large peacetime military establishment. To support this establishment and keep pace with the standards of

medical care provided in civilian life, the medical department needed to expand and improve its method of recruitment. The appointment of Dr. Frank Berry, a colonel in World War II and a New York surgeon, as Assistant Secretary of Defense for Health and Medicine was an important step in that direction. In 1954, the Berry Plan permitted physicians to postpone their military obligation under the draft until they completed their internship and residency programs: "This allowed for the continuous training of doctors (a pedagogical good) while at the same time providing the military services with completely qualified medical specialists."<sup>18(p13)</sup> Retention of physicians with only a 2-year military obligation under selective service, however, remained difficult, and the balance between specialists and general medical officers suffered.<sup>18</sup>

Another way the military acquired specialists was to make specialist training available to its medical officers. Twenty-four residency training programs in 8 army hospitals in 1959 grew to 28 programs in 17 hospitals a decade later, as the army built up for the Vietnam War. Expanding residency programs helped retain physicians through either military obligation or personal decision. Specialized training also permitted the military to meet the standards of civilian care.<sup>18</sup>

The new emphasis on specialized training benefited military anesthesia, which was fast becoming an important part of the structure of the U.S. Army Medical Department. The army acquired skilled anesthetists by offering members of the U.S. Army Nurse Corps 52 weeks of training in anesthesiology at six U.S. Army Medical Centers and Hospitals, namely, Brooke Army Medical Center, Walter Reed Army Medical Center, and Letterman, Fitzsimons, Beaumont, and Madigan Army Hospitals. Nurse anesthetists also attended anesthesia workshops at army hospitals. The training of U.S. Army nurse anesthetists met the requirements for certification by the American Association of Nurse Anesthetists.<sup>52</sup>

Besides offering internships and residencies in anesthesia, the U.S. Army Medical Department arranged for Medical Corps officers to take long courses in anesthesiology at civilian institutions, such as the University of Pennsylvania, and to attend review sessions in anesthesiology at Lackland Air Force Base, Texas. With the army's encouragement, military anesthesiologists in increasing numbers became board certified. No longer was the medical department dependent on civilian medicine for anesthesia consultants; it had its own professors of anesthesiology, although it still relied on skilled nurse anesthetists to augment hospital staffs.<sup>52</sup>

## The Vietnam War

By the mid-1960s and the Vietnam War (1965–1972), military anesthesiologists were making the tough decisions, like what (people, agents, and machines) to bring to battle and what to leave home, and what level of care to provide. Civilian anesthesiologists had faced those issues during World War I and World War II. Incorporating lessons learned from previous wars regarding anesthesia care and evolving new concepts about critical care in Vietnam, the military

- deployed anesthesiologists to forward medical support hospitals;
- expanded the role of the anesthesiologist in the sustainment of life before, during, and after surgery;
- advanced the resuscitative process;
- introduced new anesthesia machines; and
- standardized anesthesia equipment.

These anesthesiologists also developed in Vietnam many of the ideas, particularly regarding critical care, subsequently used in civilian anesthesia in the United States. Developments in anesthesiology during the Vietnam War years have been well described elsewhere by Manfred (“Dutch”) Lichtmann, an army anesthesiology professor who served in Vietnam and later as Consultant in Anesthesiology to The Surgeon General.<sup>47</sup>

The allocation of anesthesia providers to Vietnam followed the pattern of the deployment of regular troops. Early in the war, anesthesia personnel were sent as advisors and then as members of “K” teams assigned to fixed facilities and rotated to other hospitals according to casualty needs. After the military buildup of 1965, anesthesia personnel strength multiplied, with nurse anesthetists forming the bulk of the increase. Their numbers from 1968 until the phase-down began were about 65 but reached as high as 95 at one time. To obtain nurse anesthetists, the army fostered a move toward nurse anesthesia education at the master’s degree level and upgraded the requirements for attaining such a degree.<sup>47,53</sup>

Anesthesiologists, trained to board-certification levels in military residency programs, were first deployed to forward surgical hospitals during the Vietnam War. Fully trained or board-certified anesthesiologists, however, were a luxury in Vietnam, as the residency training program, although growing, was still small. Of the 35 anesthesiologists covering 16 hospitals in 1967 through 1968, only 4 were board certified, 16 were fully trained, and 15

had learned on the job. The latter were sent directly to Vietnam following an internship and 14 weeks’ instruction in anesthesiology. Although the army hoped that the physician trained on the job would work with another anesthesiologist, sometimes the former physician was the only anesthesiologist at the hospital. In those cases, the physician relied on an experienced nurse anesthetist to help and guide him. Together they formed a solid anesthesia care team. Lichtmann recalled:

The severity of casualties, the austerity of the environment, and the continuous pressure and intensity of the care required molded physician and nurse anesthetist into a cohesive anesthesia care team.<sup>47(p1300)</sup>

The anesthesia care team that Lichtmann referred to was an ideal, brought about by the exigencies of war. The rivalry between nurse anesthetists and physician anesthesiologists was put aside to deal with the problems at hand. While nurse anesthetists played an important role in military medicine—the armed forces needed them—they played a less significant role in civilian medicine, where physician anesthesiologists reigned supreme.

This team helped care for many casualties during the Vietnam War. The U.S. armed forces suffered 46,000 killed in Vietnam and 300,000 wounded.<sup>54(p410)</sup> The wounds were usually multiple and devastating, the result of mine, high-velocity missile, and booby trap injuries. Yet casualties who would not have survived in other wars were salvaged here. Crucial to their survival were the immediate availability of whole blood, rapid resuscitation from shock, and helicopter transfer to hospitals. The latter brought the patient to definitive treatment faster than in any previous war. The time between wounding and effective treatment averaged 10 hours in World War I, 5 hours in World War II and Korea, and 1 hour in Vietnam. Rapid and effective air evacuation meant recovery for most of the wounded who reached definitive care.<sup>54,55</sup>

Speedy helicopter evacuation from the front in Vietnam also allowed continuous resuscitation. Initially the corpsmen, who were trained at the Medical Field Service School by noncommissioned officers and sometimes physicians, restored breathing (usually through mouth-to-mouth resuscitation) and occasionally started infusions of intravenous fluids. Helicopter evacuation medics continued the process. At the hospital, medical personnel started a 14-gauge intravenous line in the basilic or the external jugular vein and, under the supervision of

or managed by an anesthetist, performed airway care, which sometimes required the use of an oropharyngeal tube, an endotracheal airway, or a tracheostomy. The triage officer selected those casualties who responded to resuscitation for anesthesia and surgery on the basis of severity of wounds. He informed anesthesia personnel which patient was next and the patient's condition. Well-functioning operating rooms had good coordination between the triage area and anesthesia providers.<sup>47,56</sup>

Anesthesia personnel continued resuscitation in the operating room and provided anesthesia. Those casualties who could not be resuscitated without surgical intervention received slight anesthesia with airway and ventilation control and continued "infusions of blood, colloids, and electrolytes."<sup>56(p800)</sup> While surgical teams operated on the patient to repair wounds, anesthesia personnel used all their skills to help keep the patient alive. John Jenicek, Consultant in Anesthesiology to The U.S. Army Surgeon General during the Vietnam War, described the expanding role of anesthetists in support of surgical procedures during that conflict.<sup>47,56</sup>

It [became] the mission of the anesthesia team to support the circulating volume, the oxygen demand, and the anesthetic needs of the patient as well as to treat and correct all abnormal physiological and pharmacological responses of the casualty; all the while providing as near optimal surgical conditions as possible for the other equally busy surgical teams. It is this new concept of resuscitation-anesthesia-surgery, organized and functioning as a unit [and combined with speedy evacuation], which [produced] the highest survival rate seen in any conflict thus far.<sup>56(p800)</sup>

This new approach to field medicine—continuous resuscitation combined with speedy evacuation—resulted in lowered hospital mortality: 2.2% in Vietnam compared with 4.5% in World War II. Significantly more critically wounded survived to reach base hospitals in Vietnam than in World War II. Eighty-seven percent of those hospitalized in Vietnam returned to duty, another wartime record.<sup>55</sup>

Preoperative medication and induction techniques during the Vietnam War followed civilian practice. With no standardized policy on premedication established, anesthesia providers based their drug selection on their background and training. The most commonly used premedication drugs were the barbiturates (pentobarbital, secobarbital) and morphine with atropine or scopolamine. The induction agent of choice was sodium thiopental used with a relaxant.<sup>47</sup>

Problems associated with induction anesthesia included the reduction or elimination of the patient's protective responses to hypovolemia caused by too large a dose, the increased chance of tracheal aspiration of gastric contents because of soldiers eating immediately before being wounded, and cardiac arrest on induction of anesthesia by patients who received succinylcholine after suffering muscle injuries or severe burns. Finally, mismanagement of the airway or a short period of apnea during induction sometimes proved lethal. Gale Thompson, the first consultant in anesthesiology to be sent to Vietnam, reported that 76% of patients receiving general anesthesia received tracheal intubation. There are no statistics available for anesthesia deaths.<sup>47</sup>

Military anesthesiologists used a variety of agents and machinery in Vietnam because the war escalated slowly, allowing the U.S. Army Medical Department to establish in the combat zone large fixed hospitals (unlike in World War II, where mobile hospitals were the norm) with sophisticated equipment and skilled staffs. The chief anesthetic agents used included diethyl ether, halothane, methoxyflurane, nitrous oxide-oxygen, and spinal anesthetics. Of the 282 anesthetic administrations, mainly on civilians, given at the 8th Field Hospital from April 1962 to January 1963, 9% were diethyl ether, 15% halothane, and 39% spinal anesthetics, according to John Chase Daniels, the first U.S. Army anesthesiologist in Vietnam.<sup>47</sup>

Early in the war, halothane, which had widespread use in the United States, received limited use "because it caused hypotension and could prove lethal in the 'in-circuit' vaporizers that were on field machines," recalled Lichtmann.<sup>47(p1302)</sup> According to Brian F. Condon, a U.S. Army anesthesiologist in Vietnam and later Consultant in Anesthesiology to The U.S. Army Surgeon General:

The "in-circuit" vaporizer or "number 8 jar" allowed the concentration of anesthetic to be varied by the pulmonary minute volume as well as the dial setting. This made prediction of anesthetic agent inspired concentration difficult. Therefore a hypovolemic, low-cardiac-output patient could easily be overdosed and hypotension could occur with little or no warning.<sup>57</sup>

After the U.S. Army equipped field machines with the Fluotec Mark 1 and 2 vaporizers in 1967, halothane replaced ether as the standard field anesthetic. As a trauma anesthetic, halothane's advantages included nonflammability, rapid recovery after brief operations, less nausea and vomiting than with ether, and good urinary production after fluid



resuscitation. The drug, which could be given with oxygen alone, became the most frequently administered anesthetic from 1968 to 1971.<sup>47</sup>

Other anesthetic agents proved highly beneficial in Vietnam. Methoxyflurane served as an analgesic for short procedures or to augment muscle relaxation in prolonged abdominal operations. The drug could function in "large in-circuit vaporizers" and in "low-flow, high-oxygen systems."<sup>47(p1302)</sup> From 1970 on, nitrous oxide–oxygen with a relaxant, a narcotic, and, at times, a major tranquilizer added, became a popular general anesthetic as the use of halothane decreased. The literature of the time reported on hepatic injury due to halothane. Meperidine or morphine and later fentanyl became the most frequently used narcotics.

Innovar, a combination of droperidol, a major tranquilizer, and fentanyl, a synthetic high-potency narcotic, sold in a fixed ratio of one to the other, was found to be difficult to use (too much droperidol) and to cause patients to be sleepy and even catatonic in the recovery room. Anesthetists began using the

drugs separately, with the droperidol, the longer-lasting drug, given near induction and fentanyl added as the patient required. This combination became the main anesthetic in the last years of the war.<sup>47,57</sup>

Ketamine proved valuable as a primary anesthetic agent for superficial wounds, "with the incorrect assumption that patients could protect their airways under its influence."<sup>47(p1302)</sup> Popular relaxants were succinylcholine used for induction, and curare used for maintenance. To avoid prominent hypotension, anesthesiologists administered curare in two or three incremental doses. Doses of neostigmine and atropine reversed the effect of competitive relaxants. Because field hospitals had no Wright respirometers or blockade monitors, anesthesia providers estimated reversal by observing the patient's cough, hand-grip strength, and head or arm lift.<sup>47,57</sup>

Various forms of regional anesthesia proved useful, as well. From February 1970 to May 1971, anesthesia providers at the 91st Evacuation Hospital performed spinal anesthesia in 15% of cases.

TABLE 31-1

**ANESTHETIC ADMINISTRATION, U.S. ARMY 67TH EVACUATION HOSPITAL, DECEMBER 1970 TO JULY 1971**

Anesthetic Administration	December 1970	February 1971	April 1971	June 1971	July 1971	Total	Percentage of Total
N <sub>2</sub> O–O <sub>2</sub>	28		5	4	6	43	4
N <sub>2</sub> O–O <sub>2</sub> –Halothane	86	71	40	34	32	263	26
N <sub>2</sub> O–O <sub>2</sub> –Methoxyflurane	51	74	102	19	11	257	26
N <sub>2</sub> O–O <sub>2</sub> –Meperidine	18	21	25	3	3	70	7
N <sub>2</sub> O–O <sub>2</sub> –Morphine	7	1	23	20	8	59	6
Axillary	10	2		6		18	2
Spinal	24	11	6	5	10	56	6
Caudal	3	1				4	—
Intravenous	6	49	37	64	40	196	19
Ketamine		27	35	52	32	146	
Innovar		21	2	12	8	43	
Diazepam		1				1	
Infiltration	17	11	10			38	4
						1,004	
Operative deaths	3	2					
Total number of cases	235	236	247	156	110	984	

N<sub>2</sub>O: nitrous oxide; O<sub>2</sub>: oxygen

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TABLE 31-2

## ANESTHETIC ADMINISTRATION IN EIGHT U.S. ARMY HOSPITALS IN JANUARY 1968

Anesthetic Administration	2nd Surg.	7th Surg.	8th Field	12th Evac.	24th Evac.	45th Surg.	67th Evac.	85th Evac.	93rd Evac.	Total	Percentage of Total
N <sub>2</sub> O–O <sub>2</sub> -Halothane	367	27	157	414	301	165	253	259	562	2,505	82
N <sub>2</sub> O–O <sub>2</sub> -Methoxyflurane		4	23	3	3	10	10	18	19	90	3
N <sub>2</sub> O–O <sub>2</sub> -Thiopental	16	1		7	18	4	7	5	7	62	2
N <sub>2</sub> O–O <sub>2</sub> -Ether			1								
O <sub>2</sub>					5					5	
Regional	1	1	30	20	15	1	10	41	15	134	4
Spinal	11	10	30	74	67	14	27	19	26	<u>278</u>	9
										3,069	
Infiltration	138	8	85	88	77	11	66	91	66		
Total number of cases	539	90	431	629	501	164	371	431	636		
Personnel											
3115 B				1	1				1		
3115 C	1	2					1				
OJT			1	1	1	1		1	1		
3445	2	3	3	6	6	3	4	2	5		

N<sub>2</sub>O: nitrous oxide; O<sub>2</sub>: oxygen; 3115 B: board-certified anesthesiologist; 3115 C: fully trained anesthesiologist; OJT: on the job (ie, physician partially trained in anesthesia); 3445: certified nurse anesthetist

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Epidural anesthesia evinced benefits in vascular repairs and grafts. When the casualty load was heavy, anesthesia personnel reinjected epidural catheters between cases in the operating room. Upper-extremity nerve blocks and Bier blocks (regional intravenous anesthesia) also proved valuable. The absence of double tourniquets sometimes caused local anesthetics to leak. Regional, especially spinal, anesthesia was more popular with anesthesia providers in the Vietnam War than in World War II. Spinal anesthesia's simplicity made it perfect for combat. The method had become more popular in the civilian sector by this time as well.<sup>47</sup>

In his essay on Vietnam titled "Military and Battlefield Anesthesia," Lichtmann constructed five tables (Tables 31-1 through 31-5) that

give some temporal and geographic impressions of the anesthetics used. These reports are incomplete but do show trends over several years, as well as the impact of logistics, as in the case of the 67th Evacuation Hospital ([Table 31-1]), where methoxyflurane

was used in 25 percent of cases primarily because that was the only anesthetic they had available.<sup>47(p1302)</sup>

In late 1971 and early 1972, in the 95th Evacuation Hospital in Da Nang, regional anesthesia was used in 23% of total cases done. Axillary and interscalene arm blocks as well as spinal and epidural blocks were popular. A regional anesthetic for an arm debridement in a stable patient would allow the procedure to be done in the holding area with minimal surgical equipment. This practice kept the patient from going to the operating room and therefore saved sterile equipment, drapes, and the time of skilled personnel for more serious cases. Two to four regional procedures per day were common at the 95th Evacuation Hospital.<sup>57</sup>

Recovery rooms in Vietnam resembled intensive care units in major civilian medical centers. Patients who could not be safely extubated immediately after surgery required "ventilatory, nutritional, and hemodynamic care in addition to wound care,"<sup>47(p1302)</sup> recalled Lichtmann. Recovery room

**TABLE 31-3**  
**ANESTHETIC ADMINISTRATION IN EIGHT U.S. ARMY HOSPITALS IN APRIL 1968**

Anesthetic Administration	2nd Surg.	12th Evac.	17th Field	18th Surg.	27th Surg.	36th Evac.	45th Surg.	67th Evac.	71st Evac.	85th Evac.	93rd Evac.	Total	Percentage of Total
N <sub>2</sub> O-O <sub>2</sub> -Halothane	257	409	68		154	180	111	224	294	214	603	2,771	79
N <sub>2</sub> O-O <sub>2</sub> -Methoxyflurane	7	3	3	204	1	31	3	1	13	9	4	286	8
N <sub>2</sub> O-O <sub>2</sub> -Thiopental	16	11	16		7	2	1	3			6	78	2
O <sub>2</sub> -Thiopental						1						1	
Thiopental						1						1	
Neurolept analgesia						1						1	
Meperidine-N <sub>2</sub> O-O <sub>2</sub>					1							1	
Relaxants													
Curare					22							22	
Succinylcholine drip					10							10	
Regional													
Block	4	4		3	5	6	2	1	14	29	33	107	3
Spinal	9	27	11	29	6	44	2	23	50	39	2	251	7
Epidural										2		2	
												3,499	
Infiltration	191	46	30	198		135	63	64	237	121	35		
Total number of cases	483	621	151	434	278	358	185	766	608	485	684		
Personnel													
3115 B		1									1		
3115 C	1			1	1		1	1					
OJT		1	1			1			1	1	1		
3445	2	6	2	3	3	4	4	4	4	2	5		

N<sub>2</sub>O: nitrous oxide; O<sub>2</sub>: oxygen; 3115 B: board-certified anesthesiologist; 3115 C: fully trained anesthesiologist; OJT: on the job (ie, physician partially trained in anesthesia); 3445: certified nurse anesthetist

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staff, he stated, provided continuous nursing care, using electrocardioscopes, defibrillators, ventilators, and other respiratory techniques, often with the anesthesiologist in attendance.

Because there was no military occupation specialty for respiratory therapists, a system developed whereby personnel at Walter Reed Army Medical Center identified those skilled people as they came into service and coordinated their assignments, so that respiratory therapists were distributed throughout the hospitals in Vietnam. The military had plenty of opportunities to practice critical care medicine in Vietnam.<sup>47</sup> Declared Lichtmann: "The recovery rooms of those large

field hospitals did not differ greatly from the busy intensive care unit of a large urban hospital...."<sup>47(p1302)</sup>

Early in the war, anesthesia equipment was adequate but antiquated. Anesthesia providers initially deployed brought with them the World War II-era 0400 and 0430 Heidbrink machines (the pig). These machines had 400-mL metal carbon dioxide absorbers but only a closed-circle vaporizer, which, as was stated above, was not readily adaptable for use with the newer potent inhalational agents such as halothane. In 1967, the army adopted the Ohio Model 785 Field Anesthesia Machine, which had undergone several design changes since production began in 1958, and orThe

**TABLE 31-4**

**ANESTHETIC ADMINISTRATION AT THE U.S. ARMY 91<sup>ST</sup> EVACUATION HOSPITAL, FEBRUARY 1970 TO MAY 1971**

Anesthetic	1970											1971				Total	Percentage of Total
	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May			
Halothane	240	248	311	239	247	235	177	162	163	189	156	165	117	65	2,714	52	
Methoxyflurane	44	40	4	23	9	2			3	4		3	30	12	174	3	
N <sub>2</sub> O-O <sub>2</sub>	18	13	26	10	28	62	110	91	68	72	107	147	118	104	974	19	
Blocks	22	36	19	16	8	7	6	10	20	21	16	19	20	31	251	5	
Spinals	93	105	65	44	37	60	68	48	62	58	49	39	47	30	805	15	
Infiltration	22	15	17	7	7	6	12	10	12	15	2	8	6	11	150	3	
Other			2	2	11	1	1	4	2	1			37	28	41	130	2
Ketamine											29	14			<u>43</u>		
															5,198		
Endotracheal	260	221	305	*	251	284	277	230	228	256	244	303	232	167	3,258	63	
Total cases	439	459	444	343	337	373	483	313	329	403	404	428	*	291	5,046		

\*Information missing

N<sub>2</sub>O: nitrous oxide; O<sub>2</sub>: oxygen

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dered a number of these machines for issue to all medical units (Figures 31-18 through 31-21). The new anesthesia device weighed less than 95 lb; could be carried by one individual from surgery to vehicle; and could be air-dropped in one package, except for its four gas cylinders or pressure tanks.<sup>26,47,57</sup> The machine had a two-canister carbon dioxide absorber; was capable of accommodating

cylinders of nitrous oxide-oxygen; had pressure regulators for those gases, a large in-circuit vaporizer, a heater rod

to stabilize vaporization temperatures in all weather, [and was] capable of delivering anesthetic mixtures over a temperature range of 4°C to 38°C.... The era of administering ether with wet-drapes over the "ether screen" had ended.<sup>26(pp66-67)</sup>

**TABLE 31-5**

**ACTIVITIES REPORT FOR THE U.S. ARMY 3<sup>RD</sup> FIELD HOSPITAL, 1967 THROUGH 1968**

	Census Year 1967	Census Year 1968	Increase (%)
Total hospital admissions	6,747	11,382	69
Surgical procedures	2,857	6,406	124
Major	1,882	3,296	75
Minor	975	3,110	219
Deaths in hospital	148	150	1

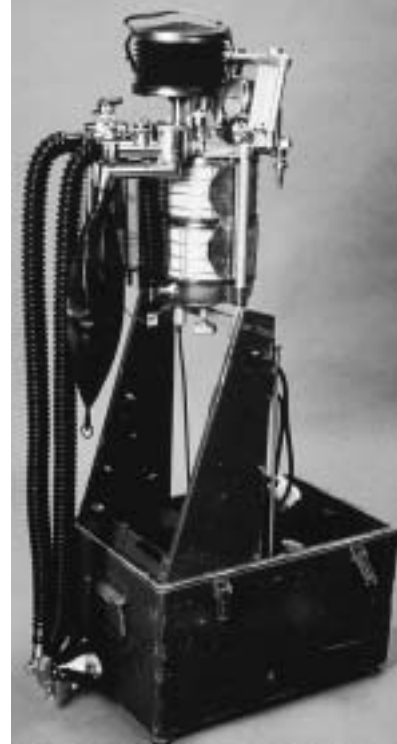
1968 mortality rate for admissions: 1.3%

1968 mortality rate for surgical procedures: 2.3%

Adapted with permission from Lichtmann MW. Vietnam. In: Grande CM, ed. *Textbook of Trauma Anesthesia and Critical Care*. St. Louis, Mo: Mosby-Year Book; 1993: 1305. Numbers amended by the original author for this publication, 1995.



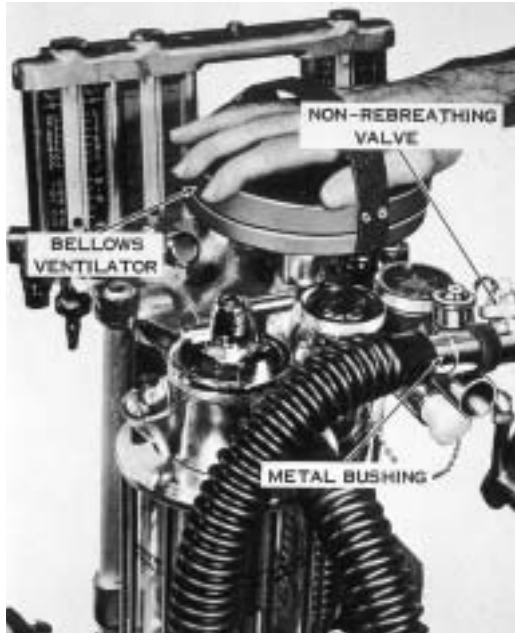
**Fig. 31-18.** Military Field Anesthesia Machine Model 785. The ether/chloroform in-circuit vaporizer is seen at bottom left. Flowmeters, seen left to right, are for nitrous oxide (blue), cyclopropane (orange), and oxygen (white, the international color for oxygen). A pressure gauge, calibrated in centimeters of water, monitors the pressure in the breathing circuit. Immediately below the pressure gauge is a round button, the oxygen flush valve. Two one-way valves for the breathing circuit can be seen at the bottom right. The white plug with a small chain attached, seen in the center of the photograph, can be removed and replaced by the hand-operated concertina bellows (also see Figs. 31-19 and 31-21). Photograph: Courtesy of William Clayton Petty, MD, Captain, Medical Corps, US Navy, Bethesda, Md.



**Fig. 31-19.** Military Field Anesthesia Machine Model 785, with breathing hoses and rebreathing bag attached. Carbon dioxide-absorbent granules have been placed in the canisters. The hand-operated concertina bellows is in place. Photograph: Courtesy of William Clayton Petty, MD, Captain, Medical Corps, US Navy, Bethesda, Md.

**Fig. 31-20.** A small, 110-volt cylindrical heater can be installed in the vaporizer to heat ether in cold climates and to stabilize its temperature during induction of anesthesia. A rapid ether induction can cause the outside walls of the vaporizer to coat with ice. The heater will maintain ether at a stable temperature, eliminating the marked reduction in vaporization of ether during induction. Photograph: Courtesy of William Clayton Petty, MD, Captain, Medical Corps, US Navy, Bethesda, Md.





**Fig. 31-21.** The 1968 Ohio Model 785 Field Anesthesia Machine. Photograph: Reprinted with permission from Model 785 anesthesia apparatus, nitrous oxide, oxygen, ether, and cyclopropane, portable, 4-cylinder capacity. *Instruction and Service Manual*. Madison, Wis: Ohio Chemical and Surgical Equipment Company; Oct 1968: 11.

Vietnam War was the first conflict in which anesthesia providers used equipment standardized to written specifications. The implements included endotracheal tubes, laryngoscopes, adapters, venotubes, carbon dioxide absorbents, vasopressors, and new relaxants. The capstone to the modernization effort was the regulation of a new field anesthesia chest. The chest weighed 110 lb when fully loaded with over 100 items and a 3-day supply of drugs, and could be air-dropped. Standardization provided the army with high-quality supplies and drugs in a medical specialty “where,” according to John A. Jenicek, former Consultant in Anesthesiology to The U.S. Army Surgeon General, “the margin for error [did] not tolerate a substandard approach.”<sup>56(p801)</sup>

Unlike that in any previous war, casualty care in the Vietnam War during the late 1960s and early 1970s was equal to, and in some respects better than, the treatment provided in the most sophisticated medical centers in the United States. There were two main reasons: (1) the gradual escalation of the war enabled the U.S. Army Medical Department (AMEDD; the acronym became established during the early 1970s) to establish fixed,

well-equipped hospitals with highly trained staff; and (2) the air superiority enjoyed by the United States facilitated a rapid and effective evacuation system to those hospitals for definitive treatment. As a result, medical personnel were able to salvage most of the wounded who had not been killed outright on the battlefield.

The Vietnam War, more than any previous conflict, gave a new face and a new character to anesthesia providers. They played a pivotal role in preserving life before, during, and after surgery, redefining the meaning of intensive care. AMEDD’s establishment of fixed, well-equipped hospitals, specially staffed with highly trained people, provided trauma treatment to rival that of any civilian trauma center in the world.

### The Post-Vietnam War Era

The role of the anesthesiologist continued to expand in the post-Vietnam War era in the realm of resuscitation and critical care medicine. Advancements in anesthesiology as practiced in conflicts since the Vietnam War are well described elsewhere.<sup>58-60</sup> The anesthesiologist diagnosed and alleviated pain by simple and complex techniques, such as nerve block and intravenous anesthesia. In the operating room, the anesthesiologist used modern, sophisticated equipment to administer anesthesia and monitor blood pressure, central venous pressure, left atrial pressure, and so forth to make surgery safer for the patient at risk. In the recovery room, recalled Jenicek,

a skilled staff, often trained and instructed by the anesthesiologist, provid[ed] immediate and continuous nursing care to protect the patient as far as possible from drug-induced respiratory depression, hyper or hypotension and a myriad of anesthetically or surgically induced occurrences that [might] beset the organ systems at [that] time.<sup>61(p387)</sup>

They used ventilators, antiarrhythmic drugs, cardiac monitors, or cardiopulmonary resuscitation, often with the anesthesiologist in attendance.<sup>61</sup>

The recognition by anesthesiologists, later joined by cardiologists and other specialists, of the possibility of saving patients by aggressive treatment in the early stages of a debilitating illness or acute trauma led to the discipline of critical care medicine, the successor to intensive care medicine. Enthusiasts of critical care designed curricula to enhance the skills of those wishing to work in this special field.<sup>61</sup>

The expanded knowledge and role of the anesthesiologist has led to more research in the field of anesthesiology and critical care, and increased and enlarged journals of anesthesiology and publications on the subject in major scientific periodicals. To John Jenicek, "Anesthesiology is art and science coexisting in the world of modern medicine, in a discipline that is demanding, exciting, and rewarding."<sup>61</sup>(pp388-389)

Because armed combat equates with trauma, Brian Condon, former Consultant in Anesthesiology to The U.S. Army Surgeon General, believes it is time for a natural alliance between military anesthesia and trauma anesthesia in the civilian sphere.<sup>57</sup> The military might help forge that alliance, especially since trauma anesthesia is receiving little national attention at present.<sup>62</sup>

## SUMMARY

The military has shared man's eternal quest to alleviate pain and make possible the humane treatment of survivors. Military and civilian anesthesia providers have learned from each other strategies to promote the merciful treatment of the seriously impaired patient. The military has developed its own

cadre of specialists, capable of independently solving complex medical problems. The military's vast and valuable experience in caring for combat casualties has advanced the field of critical care medicine and has led to a natural alliance of military and civilian anesthesiology in the treatment of trauma.

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