SPECIAL ARTICLE

An Anesthesiologist's Perspective on the History of Basic Airway Management

The "Progressive" Era, 1904 to 1960

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ABSTRACT

This third installment of the history of basic airway management discusses the transitional—"progressive"—years of anesthesia from 1904 to 1960. During these 56 yr, airway management was provided primarily by basic techniques with or without the use of a face mask. Airway maneuvers were inherited from the artisanal era: head extension and mandibular advancement. The most common maneuver was head extension, also used in bronchoscopy and laryngoscopy. Basic airway management success was essential for traditional inhalation anesthesia (ether, chloroform) and for the use of the new anesthetic agents (cyclopropane, halothane) and intravenous drugs (thiopental, curare, succinylcholine). By the end of the era, the superiority of intermittent positive pressure ventilation to spontaneous ventilation in anesthesia and negative pressure ventilation in resuscitation had been demonstrated and accepted, and the implementation of endotracheal intubation as a routine technique was underway. **(Anesthesiology 2018; 128:254-71)**

> "As soon as anaesthetists learn to maintain a wide open airway and to keep the patient asleep without any cyanosis, anaesthetic deaths will become rarer."
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> Flagg PJ: *The Art of Resuscitation*, New York, Reinhold Publishing Corporation, 1944, p 177

THE "progressive" anesthetic era (author's term) from 1904 to 1960 was a transitional period between the artisanal era (1846 to 1904) and the current, modern era. By the end of the artisanal era, the two fundamental basic airway management techniques (head extension and mandibular advancement applied with or without a face mask in an unconscious patient) had been described. Multiple devices complemented these techniques, supporting patency during anesthesia or resuscitation.[1] Both spontaneous ventilation in anesthesia and manual ventilation and negative pressure ventilation in resuscitation shared a traditional respect for pulmonary physiology, with anesthesia maintaining and resuscitation mimicking natural ventilation. In contrast, the new intermittent positive pressure ventilation was considered unphysiologic and was associated with risks: airway trauma, pulmonary barotrauma, atelectasis, aspiration, and negative hemodynamic effects.

General anesthesia was perceived as inadequate and in need of a paradigm shift. Surgeons sought to avoid long and agitated inhalational induction and anesthetic-agent pollution in the operating room and poor muscular relaxation and pain control, nausea, vomiting, anesthetic shock, pneumonia, nephritis, and death.[2] Nonspecialized providers (nurses, orderlies, students, general practitioners, and house officers) continued to administer most of the general anesthetics.

During the progressive era, local and regional anesthesia replaced general anesthesia in many procedures. A surgeon using a local anesthetic could be independent of an anesthesia provider he had to pay. In war-ravaged countries during the First and Second World Wars, local and regional anesthesia were seen as valid options for a large array of procedures.[3] It is notable that the contributions of the medical professionals nominated for the Nobel Prize in medicine and physiology for anesthesia were in local anesthesia.[4]

Advances in medicine, physiology, pharmacology, intravenous techniques, and technology contributed to the "restatement of the [general] anesthetic principles."[5] Airway management evolved from the ventilation of an unprotected airway using a face mask to the ventilation of a protected airway using direct intubation with a cuffed endotracheal tube. This paradigm shift occurred slowly. By 1960, intermittent positive pressure ventilation was demonstrated and accepted to be the superior mode of ventilation both inside and outside the operating room. Throughout most of the progressive years, patients continued to live or die by the effectiveness of basic airway management techniques.

There were large geographical variations in anesthesiology in training, knowledge, resources, and patient outcomes. Some areas were devoid of anesthesia practice.[6] These discrepancies were measured in patient suffering and death. This article (the third in a series) follows the evolution of

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adult basic airway management from 1904 to 1960 in the Western world.

Development of Western Medicine in the First Half of the Twentieth Century

Medicine

Medical progress in the twentieth century followed the path established in the second half of the 19th century, with advances in basic sciences, clinical observation, scientific experimentation, and rational analysis enabling multitudes of discoveries. Advances in laboratory investigation, pharmacology (antiinflammatory agents, anticoagulants, analgesics, insulin, vitamins, sulfonamides, antibiotics, and psychotropic medications), vaccines, radiology, and radiotherapy transformed medicine into a modern and efficient practice. New specialties emerged: infectious disease, ophthalmology, oncology, neurology, endocrinology, epidemiology, and tropical medicine.[7] In the Western world, the hospital became the center of medical practice, clinical teaching (*i.e.*, bedside teaching, from *kline* or bed in ancient Greek) and research. The individual research scientist was replaced by research institutions such as the Rockefeller Institute of Medical Research (New York, 1901), the Rockefeller Foundation (New York, 1913), and the British National Institute of Medical Research (London, 1914). After the Second World War, advances in medical knowledge and medical industrial prowess were balanced by scrutiny of the new treatments and technologies with randomized controlled studies.[8]

Surgery

By the late 19th century, the framework for surgical progress was in place: major advances had been made in the knowledge of human anatomy, methods for intraoperative hemostasis, pathophysiologic basis of surgical disease, anesthesia, asepsis/antisepsis, and radiology. The challenge was to diversify from simple "external" procedures addressing pathology seen by both the patient and the surgeon (abscesses, superficial tumors, broken bones) to procedures addressing unseen but diagnosed pathology of the internal organs. This required development of clinical and radiologic diagnostic tools and new surgical procedures to allow exploration of anatomical cavities (abdominal, cranial, and thoracic).[7] Schools of surgery created around great personalities, national and international surgical societies and periodicals, and the standardization of postgraduate education all accelerated progress.[9] The complexity of surgical diagnosis and intervention required the availability of trained personnel for biochemical laboratories, radiology, anesthesia, medical services, blood banks, intensive care units, and heart–lung machines and made the hospital the center of surgical activity. Surgery progressed from excision and repair to reconstruction and transplantation, and new surgical specialties emerged: thoracic, cardiac, pediatric, neurologic, orthopedic, urological, plastics, and transplant (renal). The evolution of surgery and anesthesia were interconnected.

General Anesthesia

Anesthetic Delivery Systems

At the beginning of the twentieth century, anesthesia providers relied on anesthetic agents and delivery systems inherited from the artisanal era.[1] Ether had a large margin of safety but was flammable and stimulating and produced laryngospasm, nausea, vomiting, and "ether pneumonia." Chloroform was demonstrated to induce ventricular fibrillation and slowly fell out of favor.[10] Nitrous oxide was nonexplosive and pleasant but a weak anesthetic.

The most-used delivery technique was the open system, in which a volatile agent was dripped onto a gauze-covered wire-frame mask.[11,12] This unsophisticated technique did not need a perfect face mask seal, was easy to supervise, and was adequate for a large range of surgical procedures. Inhalers were devices that combined the face mask and the agent source in a compact handheld unit built to regulate the concentration of the anesthetic vapor.[1] Inhalers were imprecise and cumbersome, and most were abandoned after World War I. The handheld anesthetic delivery system was in close proximity to the patient, and the provider could easily observe both. The face mask was mainly controlled with the dominant right hand.[13]

In the second and third decades of the twentieth century, the anesthesia apparatus developed into a freestanding structure with mounted cylinders (nitrous oxide and oxygen), anesthetic agent (ether), and continuous controlled gas flow with flowmeters and vaporizers. The apparatus was usually placed to the left side of the user, explaining the left-handed flow pattern of the gas mixture from left to right to the outlet. Examples were the S.S. White (1900), C.K. Teter (1903), E.I. McKesson (1911), and J.T. Gwathmey (1912) units, the prototype of the very popular Boyle machine (1916 to 1937), the Magill apparatus (1928), and the Dräger, Foregger, and Heidbrink series.[14] Technical habits of anesthesia innovators dictated and manufacturers supported the left-hand manipulation of the apparatuses to allow right-hand manipulation of the face mask. The very popular Boyle anesthesia machine (Coxeters and Sons, England) further reinforced this behavior as it was designed to the specification of the left-handed Henry Edmund Boyle (London, 1875 to 1941).[15] Traditional habits and behavior were validated by industrial design and were (and are) accepted by practitioners as convention of use because mass manufacturing conferred on them the "standard" of practice status.[13]

The rebreathing bag and expiratory valves were removed from the face mask and placed on the anesthetic machine, making the handling of the mask less cumbersome. The face mask was mainly controlled with the dominant right hand. The closed and semiclosed anesthetic circuit with low flow of fresh gases, the carbon dioxide (to-and-fro) absorption system, and the circle system were all introduced at the end of the third decade of the twentieth century.[16] These anesthesia apparatuses allowed the provider to inflate the lungs by partially closing the spring-loaded expiratory valve and compressing the reservoir bag.

In the second half of the progressive years, a tabletop work surface and drawered cabinet were added to the pedestal-type anesthetic apparatus, producing a more modern anesthesia machine. The machine migrated to the dominant right hand of the user to access the regulating systems, cylinders, alarms, monitoring devices, and work surface for drugs, airway management devices, and record keeping, thus leaving the left hand to manipulate the face mask. The patient and the anesthetic delivery systems diverged, altering the historical work pattern of the anesthesia provider. Implementing the new technology was slow and hazardous.[17] By the end of the progressive years, the anesthesia machine had the ability to generate a continuous and controlled the flow of oxygen, nitrous oxide, and volatile agent and allowed assisted and controlled ventilation.[18] This system required an airtight delivery technique difficult to provide with a face mask but secured with a cuffed endotracheal tube. Although anesthesia progress was remarkable in major centers, most of the "anesthetist[s] paid much lip service to the innovation, and continued to pour ether and chloroform on the masks."[14]

Anesthetic Techniques

Until the 1950s, the central doctrine of inhalation anesthesia was the preservation of the patient's spontaneous ventilation: the anesthetic was titrated to the respiratory rate, avoiding respiratory depression. When spontaneous ventilation was deemed insufficient, it was assisted but rarely controlled. In 1956, there was still a debate between respecting spontaneous ventilation and "sacrificing principles for expediency" by using intravenous drugs.[19]

For nonoral, nonfacial surgery face mask ventilation, using basic airway management was the technique used to maintain airway patency during the implementation of the new anesthetic delivery systems and agents. Intubation was the domain of a few providers. Because endotracheal intubation faced firm opposition from experienced anesthetists, the technique was not expected to become a routine one.[20] They were opposed to controlled ventilation using an endotracheal tube and were unimpressed when arterial blood-gas measurements demonstrated the superiority of the mechanical ventilation *versus* the "expert hand on the bag" technique.[21]

There were several causes of inhalation anesthesia mismanagement during the transitional period.[22] First, nitrous oxide was administered without oxygen or with insufficient oxygen. Elmer Isaac McKesson (Toledo, 1881 to 1935) developed the "secondary saturation" technique to achieve deeper anesthesia and muscle relaxation by administering a high concentration of nitrous oxide and minimal or "no oxygen whatsoever."[23] Anoxia was evident, because it was dramatically associated with cyanosis, jactitation, and rigidity. In 100% concentration, nitrous oxide produced anoxia with brain damage or death.[24] The technique was used even after proof of anoxic and hypoxic cerebral damage was published.[25] The providers who primarily used the nitrous oxide anoxic technique—dentists—were the least likely to be trained in resuscitation and basic airway management. McKesson considered that dentists were able to use this technique successfully because they were not afraid of cyanosis, "which is the stumbling block in the minds of ether- and chloroform-trained anaesthetists and surgeon."[26]

Second, the switch from the routine single-anesthetic technique (ether or chloroform) to a combination of nitrous oxide and ether was marred by adverse outcome, because both were administered with crude and inexact techniques. Classically described stages of anesthesia became increasingly ill defined as new combinations of drugs were used.[27]

The third, and "most deadly factor," was the instruction manuals of the early gas-oxygen-ether apparatuses. These endorsed a hypoxic technique (5 to 10% oxygen) and recommended disregarding cyanosis, disseminating the erroneous idea of the "necessity and safety of cyanosis."[28]

Fourth, airway obstruction played a central role in asphyxia, because airway maneuvers in elective cases were passive ("a little chin lift"), without rigorous endpoints, and were applied aggressively only in emergent situations. The danger of asphyxiation was real, especially for the occasional anesthetist, as "death came suddenly with an intense cyanosis."[29] This model was prevalent even though many clear warnings had been issued to keep the airway patent and allow enough oxygen to avoid hypoxia. A cavalier approach to anoxia (cyanosis) and airway obstruction was routine at a time when most practitioners had limited or no facility or experience with intubation and assisted or controlled ventilation, thus setting the stage for respiratory complications.[30]

Ethylene was introduced in 1923 at the Presbyterian Hospital in Chicago as the first alternative to ether and chloroform and primarily used in the United States with nasal administration for dental and orofacial procedures. Ethylene–oxygen anesthesia was inflammable and explosive but with rapid and more pleasant induction, adequate muscular relaxation, and minimal postoperative vomiting, and it was used with a higher percentage of oxygen than the nitrous–oxide–oxygen anesthesia.[31]

Waters introduced cyclopropane, a new inhalation agent, in 1933.[32] It generated a rapid and smooth induction, was nonirritating, allowed the use of high oxygen concentrations, and provided good relaxation but was explosive and expensive. Cyclopropane hypoventilation associated with a high concentration of oxygen produced a pink patient, but one with dangerously high carbon dioxide levels. The ability to assist and control ventilation was a necessity, because the patient could "suddenly become deeply anesthetized and stop breathing."[33] Beverly Charles Leech (Regina, Saskatchewan, Canada, 1898 to 1960) developed the "pharyngeal bulb gasway" in 1935 (withdrawn from the Foregger catalog in 1962), an advanced supraglottic device that sealed the lower pharynx and supported the epiglottis for cyclopropane closed-circuit anesthesia. This allowed hand-free anesthesia, although "sometimes dorsi-flexion of the head and support of the chin improve breathing conditions."[34]

Thiopental, introduced into clinical practice in 1936, provided a dose-dependent, rapid, and pleasant induction, albeit with the risk of respiratory depression and arrest. The main challenge was to achieve adequate abdominal muscle relaxation without undue respiratory depression.[35] Whereas surgeons and patients requested the administration of the new, pleasant drug, incompetent users often administered large doses of thiopental without supplementary oxygen or the ability to support ventilation. Bad outcomes resulted.[36]

The introduction of curare in 1942 by Harold Griffith (Montreal, 1894 to 1985) revolutionized the practice of anesthesia by permitting muscular relaxation without the need for deep and dangerous levels of anesthesia.[37] In major centers, thiopental and curare were administered in small amounts maintaining spontaneous ventilation to guide dosage, while the provider assisted the patient's ineffective spontaneous breathing.[38] Unfortunately, curare had a small margin of safety between effective dose (diaphragm-sparing) and overdose.[39] Inadequate ventilation with significant carbon dioxide accumulation and hypoxia was unavoidable, explaining the high mortality in surgical patients receiving relaxants.[40] Through most of the progressive era, medical practitioners were not qualified to deal effectively with respiratory failure. The new practice of injecting an anesthetic drug intravenously (without control over its elimination) to achieve rapid unconsciousness was the domain of experienced practitioners.[41,42]

Until the Second World War, few anesthesia practitioners attempted to insert an endotracheal tube or routinely use an intravenous induction agent. This situation changed in the 1950s, after the synthesis and clinical use of succinylcholine, which provided a quick and profound muscular relaxation with optimal conditions for endotracheal intubation.[43] Halothane, a noncombustible, relatively nontoxic, and rapid-acting agent, was introduced into practice in 1956. Respiratory depression was a major risk, and because a large number of inexperienced providers were still involved in anesthesia, halothane manufacturers encouraged its use only in teaching hospitals.[44] By the end of the progressive years, "balanced anesthesia" became the accepted technique. The anesthesia provider "completed the transition from etherizer and passive observer of respiration to controllers of vital function."[45]

Basic Airway Management in Resuscitation

Manual Methods

The mainstays of artificial ventilation in the progressive years were the 19th-century manual methods that reproduced respiratory movements by manipulating the victim's upper extremities and thorax. Henry Robert Silvester (London, 1828 to 1908) popularized his now-namesake technique in 1858 for supine victims, Edward S. Schäfer (London, 1850 to 1935) introduced his now-namesake technique in 1904 for prone victims. Both methods were associated with ineffective airway management.[1] In 1932, the Dane Holger Nielsen (1866 to 1955) described another prone technique—the "back pressure-arm lift." Both Nielsen and Schäfer dismissed any supine method (the tongue and mucus fell backward) and recommended an ineffective positional airway technique (the head of the prone victim turned to the side with the tongue assumed to be falling forward clearing the airway).[46] The airway patency problem with manual methods was reflected in a survey of 35 "well-known anesthesiologists" conducted in 1952. The majority considered the prone position as the position of choice to prevent respiratory obstruction in an unconscious patient; a few favored the supine position; a few stated that there was no difference between the two positions; and several stated "frankly" that they did not know.[47] Manual methods were not suited for long-term ventilation.

Negative-pressure Ventilation Machines

Negative pressure ventilation machines confined the patient in an airtight tank and generated inspiration by expanding the thoracic cage with intermittent negative pressure applied to the outside of the body. Differential pressure generated between the subatmospheric alveolar and surrounding atmospheric pressure triggered inspiration. Expiration was passive.[48,49] The negative pressure ventilation was considered to mimic natural ventilation and to have a physiologic effect on the "flow of blood to or from the heart."[50]

Apparatuses were built primarily to assist ineffective (diaphragmatic) spontaneous ventilation for acute anterior poliomyelitis "merely to prevent cyanosis, or obvious respiratory distress." Other indications were carbon monoxide poisoning, alcoholic coma, drug poisoning, and postoperative respiratory failure. The most popular negative pressure machines were the 1929 Drinker–Collins tank respirator (the "iron lung"), followed by the 1938 Both portable cabinet respirator. These were metal boxes that encased the whole body, with the head protruding at one end through an airtight collar.[51] The Drinker respirator became standard equipment for artificial ventilation in hospitals from the 1930s until the 1950s in Europe and 1960s in the United States.

The airway was unprotected, and in cases with pharyngeal paralysis and massive secretions, pneumonia was unavoidable. The "iron lung" was inadequate for nursing and cumbersome for conscious patients, because they had to breathe synchronously with the machine.[52] The head was positioned passively on a pillow outside the tank. The airtight sponge-rubber diaphragm around the neck reduced the motility of the cervical spine and prohibited any airway patency–supporting body position. Cyanosis was a common occurrence. Bulbar poliomyelitis was an indication for tracheostomy performed on cyanotic, exhausted, and usually unconscious patients. Airway management consisted in clearing the upper airway of secretions and the use of temporary intermittent positive pressure ventilation with face mask in case of power failure or while opening the tank for nursing. In 1954, an evaluation of several negative pressure ventilation respirators was performed on intubated anesthetized and curarized patients ignoring the reality of the partial or total airway obstruction.[53] Prolonged intermittent positive pressure ventilation (more than 24 h) with an endotracheal tube was considered dangerous "because of the reaction of the trachea and vocal cords."[54]

Cuirasses (*e.g.*, Eisenmenger's "Biomotor," Sahlin–Stille, Monaghan respirators, Bragg-Paul "Pulsator") were airtight shells strapped around the abdomen and the lower thorax with a pump generating negative and positive pressure. They were much smaller and cheaper than the tanks but allowed more liberal basic airway management than tanks. Cuirasses were used to assist respiration in poliomyelitis and progressive muscular dystrophy and also heart failure, chronic respiratory disease, and intravenous general anesthesia with muscle relaxant for bronchoscopy.[49]

There is minimal literature describing basic airway management in acute settings with the use of cuirass. In 1904, in a case of asphyxia of undisclosed etiology, Rudolf Eisenmenger (1900 to 1946) applied bilateral mandibular advancement while working the foot bellows of his early cuirass.[52] He also recommended head extension followed, in case of failure, by immediate intubation and tracheotomy.[55] At the end of the progressive years, French authors described a thoracoabdominal cuirass for acute and chronic respiratory failure with negative pressure ventilation supported by intermittent positive pressure ventilation generated with a face mask attached to an oxygen source, possibly improving airway patency.[56]

Expired Air Ventilation

In the progressive years, the critique of the endorsed manual methods came from the operating room, where surgeons and anesthesia providers required quick and effective methods of ventilation in emergent situations. They realized the inefficiency of the manual methods and became comfortable with intermittent positive pressure ventilation in spite of the persistent historical concern that a pressure greater than 25 to 30 mmHg may rupture "the delicate air vesicles."[57] Few physicians practiced life-saving mouth-to-mouth ventilation in the operating room because it was not endorsed and had negative aesthetic connotations.[58] In 1906, Sir Robert Woods (Dublin, 1865 to 1938) recommended mouth-to-mouth ventilation with cricoid cartilage pressure; airway maneuvers were not mentioned.[59] Waters was concerned that sudden failure of respiration was "not a rare cause of death in the wards and operating rooms" and considered the lack of training of medical professionals to address this acute condition a "disgrace of the present day medical education." He commented that the time wasted "in procuring a piece of mechanical apparatus or a cylinder of oxygen" and the inefficient manual techniques applied with an "obstructed glottis" could be avoided by the instant use of "our own hands or our own respiratory muscles."[60] In 1943, Waters described mouth-to-mouth ventilation on the supine surgical patient, with one hand pinching the nose closed and the other on the chest to monitor respiratory movements; no active airway maneuvers were recorded.[61] In 1948, the U.S. National Research Conference on Resuscitation rejected mouth-to-mouth ventilation.[62] In 1951, the U.S. National Research Council and most American organizations accepted Nielsen's single-rescuer method.[63] Manual resuscitation methods became widely known in both lay and medical culture. During the Cold War, the U.S. Department of Defense and the Army Chemical Center sponsored research that concluded in 1950 that Nielsen was the method of choice in pulmonary resuscitation. Paralyzed volunteers were intubated, annulling the validity of the study for unintubated victims.[64]

James Elam (1918 to 1995), an anesthesiologist in St. Louis, used mouth-to-mouth ventilation as an "instinctive reflex" to keep patients alive during mechanical failures of the iron lung and later employed mouth-to-mask and mouth-to-endotracheal tube for the ventilation of patients paralyzed with succinylcholine. In 1954, Elam demonstrated on paralyzed patients that mouth-to-mask is equivalent to mouth-to-endotracheal tube ventilation in maintaining normal respiratory blood gas exchange. The face mask was secured with a "manual bilateral support." He commented that the "unpracticed operator is not apt to maintain a secure mask fit" with one hand while manipulating a bag with the other.[65]

Until 1956, Peter Safar (Vienna, Baltimore, and Pittsburgh, 1924 to 2003), the anesthesiologist who laid the foundation of modern resuscitation, paid little attention to how prehospital first-aid personnel provided artificial respiration." Mouth-to-mouth ventilation was revived by research funded by the U.S. armed forces. According to Safar, the "Army was flexible, quick and visionary" when everybody was stuck in the dogma of manual ventilation.[3]

In 1958, Gordon and Safar independently demonstrated and in 1959, Poulsen confirmed on paralyzed, unintubated volunteers that mouth-to-mouth ventilation was far superior to any manual technique.[66–68] They demonstrated effective ventilation and maintenance of very high oxygen saturation values in supine patients using mouth-to-mouth ventilation and pointed out the central role played by airway obstruction in the failure of manual methods and the need to define and standardize airway maneuvers for resuscitation. Mouth-to-mouth ventilation was unaccompanied by the routine expiratory compression on the abdomen, freeing both the rescuer's hands to maintain airway patency. Safar described the airway maneuvers as two-hand techniques used to stretch the front of the neck: head extension (hands in the sagittal plane on the chin and vertex extending the atlanto–axial–occipital joint) and forward displacement of the mandible. Mandibular advancement was accomplished by subluxating the temporomandibular joints, with the left thumb grasping the mandible at the symphysis and pulling it forcefully upward or with both hands in the transverse plane pushing the mandible forward.[69,70] The most effective maneuver was the triple airway maneuver, a combination of the head extension, forward displacement of the mandible, and an open mouth. All the airway maneuvers had the goal to position the "lower [mandibular] teeth in the front of the upper [maxillary]"one. Safar also described suboptimal aspects of mouth-to-mouth ventilation: the "support of the angle of the mandible by one hand" was insufficient for the maintenance of a patent airway; flexing the head generated airway obstruction; gastric distention was connected with airway obstruction; obese patients were difficult to ventilate; and laymen underestimated the force necessary to lift the jaw and the perils of ignoring a partial airway obstruction. He proposed a stepwise approach to provide airway patency in the supine patient: head extension (opened the pharynx in one-half to two-thirds of patients), followed by head extension associated with an oropharyngeal airway, and last, forward displacement of the mandible. Safar *et al.*[69] and Asmussen *et al.*[71] demonstrated the inaccuracy of the concept of the tongue falling forward and providing a patent airway in prone patients.

Safar attached a clinical marker for airway obstruction—"approximation of the chin and larynx" (chin toward chest)—and for airway patency—"increasing the distance between the larynx and the chin"—using the head extension, mandibular advancement, or both.[72] He demonstrated that the flexed neck generated airway obstruction both in the supine and in the prone position with or without an oropharyngeal airway: "The pharynx resembles a rubber tube which kinks with acute bending." In a radiologic study on anesthetized, spontaneously breathing, supine patients, head extension assured airway patency in 50% of the patients, whereas the other 50% needed forward displacement of the mandible, insertion of an oropharyngeal airway, or both.[73] The single most important cause of failure found was inadequate head extension.[74]

The premier anesthetist in London at the beginning of the twentieth century, Frederic Hewitt (1857 to 1916), preferred clinically the oral ventilation route over the nasal one. Hewitt's preference was confirmed in experiments on curarized volunteers upon whom mouth-to-nose-breathing met partial obstruction in 50% of adult subjects, even with maximal hyperextension of the head and with mandibular advancement. The valve-like action of the soft palate generated expiratory obstruction with the mouth closed.[75]

The radiologic study of Ruben *et al.*[76] of the air passage in curarized apneic patients (body mass index between 16.7 and 26 kg/m^2) had a clinical component, because the airway patency was tested with face mask ventilation. They confirmed radiographically the efficacy of maximal head extension (mouth closed) and forward advancement of the mandible (mouth open) as effective airway maneuvers and the importance of the upper cervical spine extension.

The single-rescuer manual technique with both hands used to generate ventilation was replaced by the single-rescuer intermittent positive pressure ventilation expired air technique with both hands used to provide airway patency. The U.S. Army and the American Red Cross adopted mouth-to-mouth ventilation for artificial respiration. At the end of the progressive years, mouth-to-mouth ventilation was accepted at a national and international level.[58]

Early Positive and Alternate Pressure Machines

In 1913, Samuel James Meltzer (New York, 1851 to 1920)[77] proposed continuous pharyngeal air insufflation applied with a pharyngeal tube or a well fitted face mask. Stretching the tongue and tying it to a pharyngeal tube or extending the tongue with a forceps generated the patent airway. Intrapharyngeal insufflation of oxygen concurrent with the Silvester method with the tongue pulled out and head hyperextended was described with "remarkable" results.[57]

Dräger (Lübeck, Germany), a firm well versed in mining rescue equipment technology, introduced the Pulmotor in 1907.[78] This was a mechanical resuscitation apparatus that used a face mask to apply positive pressure, producing inspiration (at 20 cm H_2O), followed by negative pressure, producing expiration (at minus 20 cm H_2O), in effect a positive-negative pressure resuscitator that created partial vacuum in the mask during exhalation phase.[79] The alternate-pressure ventilation technique depended on perfect airway seal and airway patency. Partial or total airway obstruction limited the positive pressure inspiration and triggered early negative pressure expiration, worsening the airway obstruction. The surgeon Otto Roth (Lübeck, 1863 to 1944), working with the manufacturer, realized the importance of airway patency and developed simple tasks for the nonmedical rescuer using the Pulmotor. A back wedge, offered with the device, or a blanket under the shoulders extended the victim's head. Dentures were kept in place and oropharyngeal airway use encouraged. The tongue was drawn out ("Zunge heraus!") with a forceps or clamp. The face mask was strapped to the victim's face for a perfect seal. Mandibular advancement (Esmarch–Heiberg maneuver) was recommended but represented in the instructions without face mask. Stomach inflation plagued the use of automatic respirators. An elastic band or heavy weight over the stomach was recommended. The Roth maneuver ("Handgriffe nach Roth") was applied with two fingers over the tracheal rings ("Luftrőhre"), compressing the esophagus to the spinal vertebrae and minimizing stomach inflation (fig. 1).[80]

The perceived advantages of mechanical resuscitation—less skill needed and less fatigue produced while 100% oxygen was provided, as well as the ability to ventilate a victim in a speeding vehicle—were annulled by the lack of upper airway patency. Many physicians condemned the Pulmotor as an inefficient and dangerous device, carrying risks of barotrauma and vomiting.[81] The lack of physician interest in resuscitation, the questionable effect of manual resuscitation

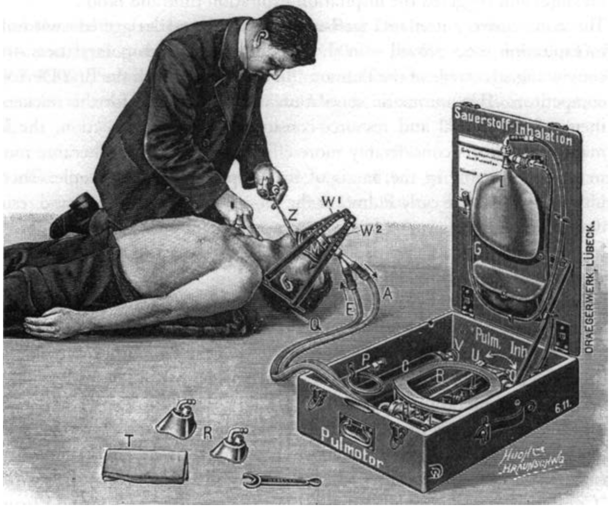

Fig. 1. Airway management with Pulmotor (1912): passively extended head, face mask strapped (Q) and tongue pulled forward with a forceps (*Z*). Pressure applied on the tracheal rings to compress the esophagus ("Roth maneuver"). Gwathmey JT: Anesthesia. New York, D. Appleton and Company, 1918, p 398.

techniques, and manufacturers' aggressive sales tactics allowed these expensive devices (*e.g.*, Pulmotor, E&J Resuscitator, MSA Pneolator) to fill a void in prehospital and hospital resuscitation.[82] The ubiquity of lay rescue squads using mechanical resuscitators convinced the public (and some hospitals) that resuscitation was a nonmedical effort. Waters considered this situation "a disgrace of a present-day medical education."[60] The operating room was the only site where physicians were directly involved in airway management and artificial respiration.

During the great Copenhagen spinobulbar poliomyelitis epidemic of 1952, the many instances of severe respiratory failure combined with impaired swallowing and pooling of secretions made evident the inefficiency of existing emergent and long-term respirators. The anesthesiologist Bjørn Ibsen (Copenhagen, 1915 to 2007) revolutionized medicine when he applied intermittent positive pressure ventilation outside the operating room. Manual intermittent positive pressure ventilation was used on a tracheotomized young patient who was rendered unconscious with thiopentone. Use of a Waters to-and-fro carbon dioxide absorber through a cuffed tracheal tube allowed effective ventilation (avoiding hypercarbia) and protection of the airway (avoiding pneumonia) and reduced mortality from 80 to 40%.[83] In 1954, a British editorial asserted that for prolonged ventilation, the only sensible policy was to protect the airway and "press on with the development of positive pressure machines."[84]

Basic Airway Management in Anesthesia

Early in the twentieth century, Frederic Hewitt placed airway management at the center of his practice.[85] His preoperative examination was focused on potential respiratory embarrassment during administration of anesthesia. For example, an edentulous patient or a patient with "hair about the face" would have a poor face mask seal. Obese patients and patients with enlarged tonsils had "natural narrow airways," being intolerant to techniques that limited the supply of air (*i.e.*, they became rapidly hypoxic), whereas plethoric patients had "engorged airway passages," lessening the capacity of the upper airway. A fixed or receding jaw made advancement of the mandible unpractical. Hewitt routinely checked nasal airway passages for patency. For patients with pathologically narrow upper airways (*e.g.*, tissue growth) or difficulty breathing while awake, he advised a preoperative tracheotomy. Hewitt considered that airway obstruction could happen anywhere between the nares, lips, and epiglottis during inspiration, expiration, or both.

Hewitt had a systematic airway management approach. If the nasal passages were open, head extension was produced by "pulling away the chin from the sternum" or "extending the head over the end of the operating table." These techniques were applied with the mouth closed and were successful in individuals with thin necks. In the case of nasal airway obstruction or masseter spasm, the immediate priority was to convert to an oral ventilation route. A clenched mouth was forcefully opened with a wooden wedge, Mason's gag, or a two-hand mandibular advancement. The open mouth gave access to the tongue (tongue forceps), epiglottis, secretions, vomit, blood, and foreign bodies. Hewitt's "case illustrations" are representative of airway management challenges encountered in the early twentieth century.[85]

Routinely, airway maneuvers were applied lightly during induction and maintenance and firmly in emergencies, when interference with free air passages was considered dangerous. The optimal depth of anesthesia was that "at which muscle tone is not entirely abolished, as evidenced by the ability of the patient to support his own chin with little assistance from the anesthetist." Patients who snored in normal sleep were allowed to "snore peacefully under anesthesia," this being an "audible evidence of the optimum depth of anesthesia."[86] The obese ("fat," "flabby," "short-necked," and "plethoric") patient was considered prone to snoring and "to become congested and obstructed during induction."[87] They were a "difficult mask," and Hewitt recommended the use of an oropharyngeal airway after induction.[88] Potential implications in anesthesia of upper airway pathophysiology in obese patients were not acknowledged.

Head extension was achieved by mobilizing the lower jaw with a finger hooked into the depression just below the symphysis mentis.[89] The one-hand control of the face mask produced an underpowered grip that required the opposite hand to hold forward the angle of the jaw for a unilateral jaw support when airway obstruction was evident (fig. 2). The use of two hands in "conjunction" was considered "distinctly valuable" but also "inconvenient," because the provider needed to attend to many tasks. The "Esmarch–Heiberg grip," mandibular advancement that propelled the mandibular teeth

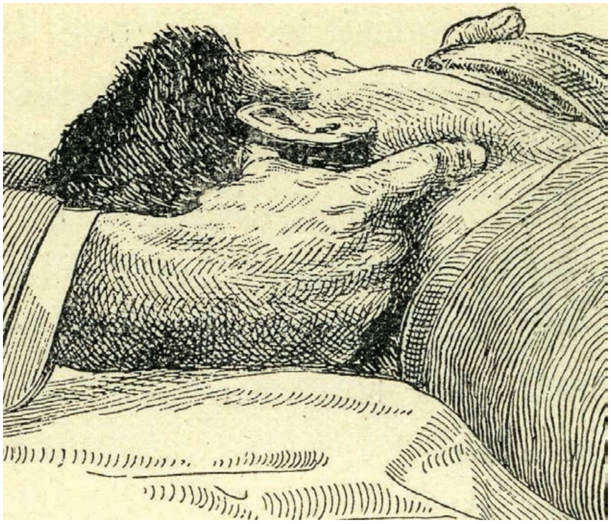

Fig. 2. Two-hand technique with a mask in elective case: the left hand gripped the mask, and the right index finger pushed the lower jaw forward. Hewitt FW: Anaesthetics and Their Administration, 5th edition. London, Henry Frowde and Hodder & Stoughton, 1922, p 492.

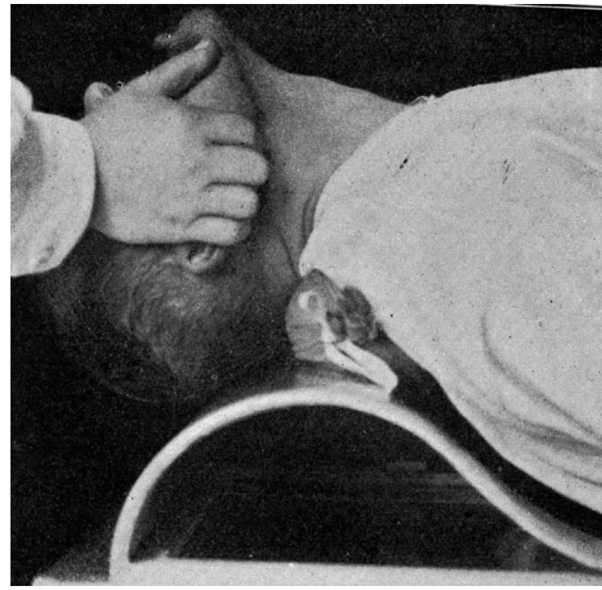

Fig. 3. Two-hand airway maneuver without a mask in emergent situation: bilateral mandibular advancement ("Esmarch–Heiberg" maneuver) supplemented with a passive head extension. v. Brunn M: Die Allgemeinnarkose. Stuttgart, Verlag von Ferdinande Enke, 1913, p 80.

in front of the maxillary teeth, was a two-hand technique usually applied in emergencies without a face mask. The mandible was maintained by one dedicated practitioner in the "central facial axis" as a "slight lateral displacement" that could lead to airway obstruction.[90] Head extension was associated with mandibular advancement (fig. 3).

The tongue was considered the primary cause of upper airway obstruction. Epiglottis and soft palate obstruction were rarely mentioned. Mandibular advancement was effective in lifting the tongue and, *via* the glossoepiglottic ligament, also addressed the epiglottic obstruction. The epiglottis was considered the sole cause of airway obstruction in emergent settings where mandibular advancement, traction of the tongue, and artificial respiration were ineffective. The impacted epiglottis acted as a valve completely blocking the larynx.[91] Digital examination of the larynx allowed lifting and repositioning of the epiglottis, opening the airway, and restarting ventilation.[92] Soft palate obstruction was bypassed in emergencies, because the mouth was opened and the oral ventilation route was favored.

Partial airway obstruction was common and mostly ignored in the operating room as the patient's respiratory rate and sound, chest expansion, and color were difficult to interpret by an inexperienced provider. In a deeply anesthetized patient, cyanosis was masked by supplemental oxygen, reinforcing the suboptimal face mask ventilation technique. Partial obstruction deteriorated to "abdominal rigidity" and straining with ineffective respiration that was exhausting ("devitalizing") the patient and interfering with administration of anesthesia.[93,94]

In "obstinate cases" (complete obstruction) when stridor became intense, cyanosis increased or respiration stopped, use of a forceps to pull the tongue forward was warranted. When all other maneuvers failed, laryngotomy was performed. In addition to active airway maneuvers, passive airway management were based on body position: the head-to-the-side position, the lateral body position, and the upright sitting position with the head tilted a little forward.[95]

The ubiquitous one-hand face mask grip accomplished many tasks. The fingers generated the mask seal and the airway maneuver and were also used to monitor the patient's facial, temporal, or carotid pulse, respiratory rate, jaw relaxation, swallowing, and skin temperature. Tachycardia, tachypnea, and deglutition were early signs of light anesthesia, heralding movement, spasm, retching, or vomiting.[96] The grip varied with the face mask type and size, the patient's facial anatomy, and the provider's hand size, skill, and experience, anesthetic technique, and personal interpretation of the patient's respiratory rate, cyanosis, and snoring. The practice of spreading fingers three, four, and five along the mandibular ramus was maintained even after clinical monitoring by touch became irrelevant. The fifth finger positioned at the mandibular angle related to the unfounded belief that it generated mandibular advancement. Although it was known that the anatomy of the temporomandibular joints mandated a symmetrical and significant force to produce and maintain subluxation and to push the mandible forward, the single-hand/little finger approach to mandibular advancement endured. The one-hand face mask ventilation technique was suboptimal, because the seal produced by the first and second fingers only partially controlling the dome was weak, and the torque for the head extension produced by the first and third fingers was underpowered. A strap was needed to stabilize the face mask and reinforce the seal. This one-hand grip was appropriate for the popular wire mask open technique that did not need a perfect seal.

The traditional acceptance of cyanosis as part of the anesthetic experience was supported by the false beliefs that limitation of oxygen intake increased the potency of the anesthetic, that the associated hypercapnia stimulated respiration, and that anesthetized patients had lowered metabolism and could therefore tolerate hypoxic conditions more readily than awake patients. The reliance on cyanosis as a sign of deep anesthesia and the misinterpretation of anoxia reinforced the "soft" implementation of airway maneuvers during routine cases. The airway maneuvers narrative was descriptive, without objective endpoints. In the third decade of the twentieth century, hypoxic anesthetic techniques were still accepted, but a distinction was made between "sub-oxygenation with a clear airway" and "cyanosis primarily caused by an obstructed airway."[97]

In 1908, Max Tiegel (Trier, 1875 to 1951) described the first high-pressure anesthetic ("überdrucknarcose") apparatus to be used "provisionally in the case of emergencies" and also thoracotomies. The face mask was difficult to manipulate, because it was connected to a rebreathing balloon, a hydraulic tank, and the source of the inhalation agent. Tiegel suggested tying the tongue with a silk noose before firmly positioning the mask (fig. 4).[98] The multiple pressure machines that followed Tiegel's supported assisted and controlled ventilation and required a perfect face mask seal. Many providers instinctively used the intermittent positive pressure ventilation technique with the "bag-mask" method now available, just as centuries ago midwives instinctively applied mouth-to-mouth ventilation to dying newborns, anonymously saving lives.[99] Early attempts to assist the spontaneously ventilating anesthetized patient were mentioned by Waters in 1920.[100] Continuous pressure on the breathing bag was used to relieve laryngospasm in the apneic patient.[101]

The use of cyclopropane from the mid-1930s through the mid-1950s and the need for a perfect face mask seal exposed the limitations of the face mask ventilation technique in prolonged cases. A tightly strapped face mask with an oropharyngeal airway was the routine interface with the patient. The results with assisted or controlled ventilation were "not altogether satisfactory," because "fairly often the stomach becomes inflated;" anesthesia was suboptimal with postoperative complications.[54] Helium was recommended in partially obstructed airways.[102] Griffith became an expert in cyclopropane anesthesia, and his single most important piece of advice to users was to practice endotracheal intubation. When a "little manual pressure on the bag did not relieve airway obstruction," emergent endotracheal intubation was to be considered. The reality of rescuing a failed basic airway management attempt with an advanced airway technique was born. Routine intubation was discouraged even in 1961 and considered to be just convenient for a practitioner "too lazy or too unskilled to hold the mask properly over the patient's face."[103]

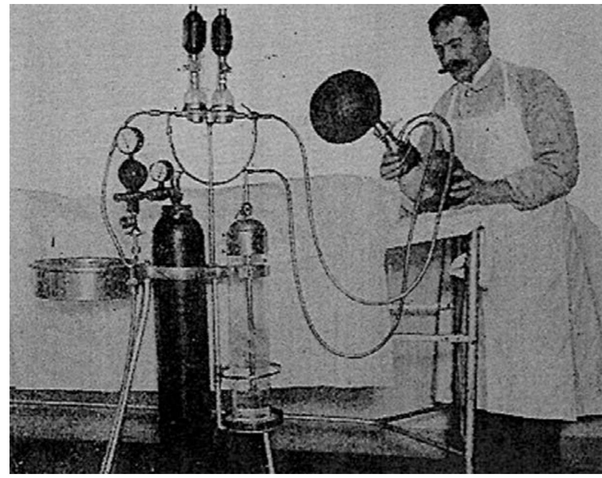

Fig. 4. Max Tiegel's positive pressure anesthesia apparatus (1909) with air-tight face mask seal without harness. Tiegel M: Überdrucknarkose. Beiträge zur Klinischen Chirurgie, 1909; 64:356.

In 1936, thiopental was used as an intravenous anesthetic for short cases and smooth induction. It was titrated slowly until the jaw dropped; then small amounts were added, guided by ventilatory depression.[104] The thiopental literature in the early 1940s was very limited in airway management details. After an intravenous dose was given for induction, the tongue was pulled forward and to one side with a forceps to keep the airway of the spontaneously breathing patient patent.[105] There was much uncertainty surrounding intravenous anesthesia, because practitioners "found it difficult to obtain both adequate anesthesia and satisfactory spontaneous respiration."[106]

At the end of the fourth decade of the twentieth century, anesthesia providers faced multiple risks of inducing apnea accidentally: premedication, ether, cyclopropane, curare, thiopental, morphine, hyperventilation, and spinal anesthesia. For the highly trained practitioner, apnea was no longer a clinical situation to avoid but part of anesthetic technique. Still, the main task for most practitioners was to provide airway patency with basic airway management in the spontaneously ventilating patient.

Intraoperative polypharmacy tended to generate postoperative airway obstruction and death in unconscious patients. Postoperative residual paralysis after curare and unrecognized airway obstruction was a new source of complications that required basic airway management.[107] During recovery, the unconscious patient was positioned on the side to protect against airway obstruction and vomitus.

Suxamethonium generated rapid and deep paralysis, and face mask ventilation was considered "easier than under any other circumstances, except possibly in the fresh cadaver."[108] Face mask ventilation was used to control ventilation with 100% oxygen after a hypnotic and muscle relaxant induction and before intubation.[109] The increased risk associated with face mask ventilation in an unprotected airway was recognized in obstetric anesthesia, and succinylcholine was adopted to quickly protect the airway with endotracheal intubation.[110] In the late 1950s, laryngospasm was treated promptly with positive pressure and low doses of succinylcholine.

In the middle of the progressive era, suction was introduced as a means to clear the upper airway. In patients with clenched jaws when nasal suctioning was not available, the tip of the oral suction tube was introduced into the oropharynx and passed "inside the cheek but outside the teeth until it enters the oropharynx through the space behind the last molar."[111] In 1946, aspiration pneumonitis was described in obstetric anesthesia.[112] In 1959, the technique of intravenous "crash induction" (thiopentone, suxamethonium) created optimal conditions for a rapid endotracheal intubation to protect the airway.[110] Cricoid pressure was added in 1961.[113]

A normal-sized adult, breathing spontaneously under inhalation anesthesia, with some muscular tone of the upper airway preserved, an extended neck, an oropharyngeal airway, and a strapped face mask probably had a marginal gas exchange with suboptimal airway patency. It was satisfactory for short cases but unphysiologic for long ones. Hypoventilation was a daily occurrence in the operating room because of the anesthesia provider's inability to evaluate the adequacy of ventilation with clinical markers (chest movement, expansion and compliance of rebreathing bag, color of the patient). Hypercarbia was an unknown entity for most physicians, whereas hypoxia (cyanosis) generated by respiratory depression was masked by gradually increasing the oxygen supply.[114]

At the end of the progressive era, the validated head extension was a two-hand technique used in resuscitation with expired air with torque generated in the sagittal plane between one hand pulling the chin maximally upward, away from the sternal notch, and the other pushing the occiput toward the interscapular region. Head extension was also the pertinent airway maneuver for the ubiquitous one-hand face mask ventilation. The middle finger that "held the chin up" and the first finger on the face mask dome provided an underpowered torque for the extension of the upper cervical spine. Fingers four and five were supporting the mandible. A suboptimal airway maneuver was built into the ubiquitous one-hand face mask ventilation technique. Paradoxically, these two techniques (the two-hand without and the one-hand with face mask) were perceived as providing an equivalent head extension, and the unvalidated one-hand face mask ventilation was pursued as the intermittent positive pressure ventilation technique of choice inside and outside the operating room (fig. 5).[115]

Airway management gained a central role in anesthesia practice and separate chapters in textbooks. In 1946, Cullen described basic airway management and direct intubation in the chapter "Airway" and considered that the chapter "took precedence" over all the others. He stated, "It is a conservative estimate that 90% of the deaths occurring in patients under anesthesia are due to improper management of the airway." He also acknowledged that nonanesthetic deaths that happened outside the operating room were not induced "directly from the drug, injury or disease but indirectly from

Fig. 5. Air-tight one-hand grip end of progressive years: submaximal head extension generated between fingers one and three, the little finger felt the facial artery pulse, and the middle, ring, and little finger felt for tracheal vibrations and swallowing. The suboptimal seal was supplemented with a harness. (Illustrator: Stefan Matioc)

asphyxia associated with obstructed airway."[116] The need to prioritize airway management teaching inside and outside the operating room was evident.

Resuscitation in Anesthesia

Resuscitation was the "orphan" of medical education.[117] The lack of training and standards in resuscitation was reflected by the extreme situation in which a physician or surgeon was "calling a fireman or a policeman or some other lay person to take charge of his desperately ill, asphyxiated patient."[118] "The absurdity reaches a climax when such lay groups are called into the operating room."[119]

The advancements pioneered in the first half of the twentieth century met a mostly untrained anesthesia workforce. Causes of death during general anesthesia were multiple: cumbersome and inaccurate anesthesia delivery systems, suboptimal airway management, inadequate knowledge for safely coordinating polypharmacy, acceptance of cyanosis as a normal part of anesthesia, and implementation of new respiratory depressant drugs without mastering controlled ventilation and endotracheal intubation.[120] Occasionally an attempt was made to compensate for operators' unfamiliarity with the new machines by attaching printed instruction cards to the machines.[121] The use of anesthesia in emergencies or outside the operating room increased the risk of complications.

Circumstances that correlated with anesthetic death in 1960 included induction complications, explosion, pulmonary aspiration, failure to secure the airway, hypoxia, overdose of agent, technical mismanagement, and maladministration of fluids.[122] The Baltimore Anesthesia Study Committee estimated that mortality risk associated with anesthesia was 4 per 10,000 operations. More than 50% of all deaths after surgery and anesthesia occurred in the patient's room.[123]

Upper airway obstruction was common. Many patients managed with basic airway management were hypoventilated, hypoxic, exhausted, and prone to vomiting. Effective airway maneuvers were applied when cyanosis was associated with labored or poor respiratory efforts, dark blue blood, or apnea. Manual resuscitation airway patency was provided by extending the head at the edge of the bed, forcing apart the clutched teeth, opening the mouth, pulling out the tongue, and swabbing mucus, blood, and vomitus (fig. 6). The liberal use of the tongue forceps, considered by many a sign of the "trade," which was "displayed by affixing them [tongue forceps] to the jackets," of medical providers, started to be criticized as a useless traumatic technique.[124]

In 1918, Gwathmey reviewed the artificial respiration techniques available in the operating room: negative pressure ventilation manual methods (Silvester or Howard) and pulmonary insufflation generated with apparatuses with a pressurized oxygen source attached to a face mask, a pharyngeal tube, or an endotracheal tube. Inflation of the lungs was generated by steadily and gradually increasing pressure by pressing the emergency oxygen valve. The face mask was tightly applied to the patient's face, the chin was elevated, and the chest was monitored for gradual expansion. When the face mask was lifted, passive expiration followed.[125]

The new anesthesia apparatuses and machines allowed intermittent positive pressure ventilation with the bag-mask system supported by oropharyngeal airway and nasopharyngeal airway. The results were not "altogether satisfactory," because the stomach frequently became inflated, and difficult ventilation and vomiting followed. Authors cautioned against airway obstruction generated by a strapped mask and insisted on forcing back the depressed lower jaw.[126] In 1943, Waters pointed out that the anesthesia provider was ready to administer intermittent positive pressure ventilation "at a second's notice" if patients ceased breathing by using a face mask and a pressurized bag with an anesthesia machine. In the absence of pressurized oxygen, it was the duty of the anesthetist to "hold the rubber tube in the mouth and keep the bag partly filled by blowing into it." Airway patency was provided by pushing the jaw forward or by mobilizing the tongue with a cloth or a large safety pin and a rubber or metal airway. To prevent inflation of the stomach, a hand or a moderate weight was placed over the upper part of the abdomen.[61]

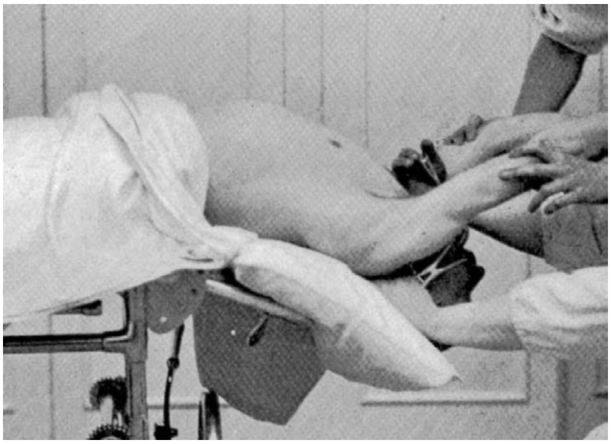

Fig. 6. Airway management and Silvester method in the operating room: passive head extension, mouth open with a gag, and tongue pulled forward with a forceps. Boyle HE: Practical Anaesthetics. London, Oxford University Press, 1907, Plate II.

A "cannot ventilate–cannot intubate" situation in 1959 was straightforward: "adequate ventilation could not be established owing to the fact that no available mask would fit the patient because her nose and mouth were so large" and "attempted endotracheal intubation failed." At the postmortem, the nose was completely obstructed by multiple polypous tumors.[127] Tracheotomy was the airway management technique of last resort, and it presented "great difficulties in actual practice because of the circumstances [under] which it has to be done," when the instruments of choice and skilled assistance were rarely available.[128] In 1960, accepted artificial respiration techniques in the operating room included manual methods, mechanical respirators, mouth-to-mouth ventilation, pulmonary insufflation, and intermittent positive pressure ventilation using an anesthesia machine.[129,130]

Basic Airway Management Devices

The face mask continued to be the primary airway management device, and the multitude of face mask designs reflected the diversity of anesthesia techniques and machines available.[131] The conversion of the face mask from a device supporting spontaneous ventilation to a device facilitating intermittent positive pressure ventilation did not trigger any design reevaluation. The functionality of the symmetrical face mask was never doubted. The face mask harness (*e.g.*, Boothby and Cotton, Gwathmey–Woolsey, Clausen) became a necessity, because anesthesia with cyclopropane and nitrous oxide with a closed circuit required a perfect seal with the patient's face. Although harnesses did not feature prominently in the anesthesia literature, there was a constant preoccupation of the industry and anesthesia leaders to optimize the face mask seal by coordinating the design of the cuff, hooks, symmetrical dome, and harness.[132] The harness hooks positioned on the face mask connector and partly covering the dome had a secondary effect on the one-hand face mask ventilation technique by restricting the area accessible for a power grip. Even today, the presence of hooks on certain face mask dictates the type of handgrip that can be used.[133] The face mask design was geared toward the seal and not airway patency. These specific elements of face mask design, along with the multiple tasks, which needed to be performed by the hand holding the face mask, defined the one-hand grip. The generic "push snugly the face mask on the face" and "pull the mandible forward" summarized the seal and the airway maneuver of the one-hand grip. Ombrédanne's inhaler was a rare example of a two-hand face mask ventilation technique built into the use of an anesthetic device. The face mask was fitted with two rings to accommodate the provider's thumbs, whereas the other fingers spread on the mandibular rami for mandibular advancement.[134] This airway management–optimizing feature may account for the longevity of the inhaler.

The need to support the airway maneuvers was reflected in a couple of short-lived airway management devices. One solid face mask was designed to "automatically" hold the jaw forward using a sagittal hook that worked on symphysis mentis (Jaros), and some wire-frame masks incorporated a jaw lever or a tongue lever to relieve airway obstruction.[135,136] Several devices were designed to implement the forward movement of the chin independent of a face mask. These devices applied a force along the sagittal axis—Erich Staudt's (Hamburg, 1894 to1972) jaw support ("unterkieferselbshalter")—or transverse axis—the Brunicardi and the Delorme bilateral jaw holders (fig. 7).[137,138]

Mouth gags, tongue forceps and clips, wedges, and mouth openers were largely inherited from the artisanal era.[1] These devices were used to forcefully overpower masseter spasm, unclench and open the mouth, and pull the tongue forward in a struggling anoxic patient. Their use declined after the invention of the oropharyngeal airway and the introduction of intravenous anesthetic techniques. The misuse of gags (damaged teeth) and tongue forceps (tongue lacerations) was criticized, but these devices were still available and used until the end of the progressive years, suggesting the difficulty of providing uneventful general anesthesia.

In 1908, after 56 yr of inhalation anesthesia history, Hewitt described his "oral air-way," which made anesthesia practice

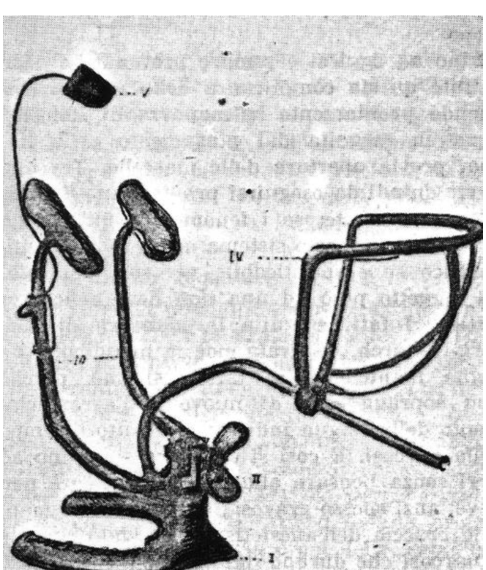

Fig. 7. Apparatus of Brunicardi (1922) for mandibular advancement (from left to right): mouth opener that worked as a dental prop and allowed the jaw to be rolled forward with bilateral symmetrical jaw thrusters and adjustable head support. Brunicardi O: Un apparecchio per mantenere la mandibula fissa in alto e la bocca aperta durante la narcosi chirurgica. Il Policlinico 1922; 29:1012.

safer and less traumatic.[139] He believed in the superiority of oral over nasal ventilation and repeatedly warned against ignoring obstruction of the nasal passage. The original Hewitt "air-way" had a metallic bite block with a circular groove to keep the teeth/gums apart and the mouth open—mimicking the role of dental props—along with an attached short, straight tube to keep the tongue away from the palate.[88] It was recommended only when respiration was obstructed, in the Trendelenburg position, and in short-necked muscular men.[140] The straight tube of the "air-way" was later changed to a curved one without any further justification.[141] The tip of the oropharyngeal airway was positioned near the glottis without affecting the epiglottis. A similar curved "breathing tube" was described by Coburn in New York in 1912 to complement the "busy" hand holding the mask tightly against the patient's face and performing "other tasks" and thus having "little opportunity . . . to hold the jaw forward."[142] The original tubular oropharyngeal airway design was replaced with a narrow, flat design that was easier to insert especially during "jaw spasm." The bite block no longer served as dental props had "as a rocker on which the jaw can be rolled forward," losing its initial functionality. The "air-way"—called oropharyngeal airway since the 1940s—was redesigned multiple times: Ferguson in 1913 (for use with open ether), Connell (flattened to make insertion easier), Lumbard in 1915 (made of wires), Waters (several variants with insufflation ports and vallecular extension), Karn in 1928 (an expanding artificial airway exerting pressure on the base of the tongue), Guedel in 1933 (nontraumatic, made of rubber), Shipway in 1935 (first cuffed oropharyngeal airway to prevent aspiration of blood during nasal surgery), English Divided airway in 1940 (guide for intubation when it was difficult to visualize the larynx), Berman in 1951 (open-sided, polyethylene, disposable), Safar in 1958 (an S-shaped airway formed by combining at flange level a size 3 with a size 4 airway used in resuscitation; fig. 8). Once interest shifted from basic airway management to direct intubation, the Guedel and Berman oropharyngeal airway became predominant, while multiple models of laryngoscopes inundated the market. The use of the oropharyngeal airway was not standardized, and authors had different recommendations. Some advocated its use in the first ventilation attempt of edentulous patients and patients with large flabby tongues. Others used the oropharyngeal airway routinely in all cases. In an edentulous patient, the oropharyngeal airway opened the mouth, stabilized the anatomical structures, and prevented the lips from falling inward, and the curved tube separated the tongue from the soft palate and posterior pharynx.[143]

There is a paucity of literature describing the insertion, troubleshooting, limitations, and complications of oropharyngeal airway use. Some authors considered that the use of the oropharyngeal airway "obviates the barbarous methods of tongue retraction and jaw holding."[144] On the other hand, Cullen[116] remarked that it "may be necessary to support the mandible" even with an oropharyngeal airway *in situ*. In a rare radiographic study of the Waters vallecular oropharyngeal airway, Fink[145] attempted to corroborate the highly variable upper airway obstruction anatomy, head extension, and

Fig. 8. Basic airway management devices used in the progressive era (from left to right): face masks (Dräger-type also known as Roth mask, wire frame Ochsner mask, Foregger-type mask with cushion), oropharyngeal airways (Hewitt with curved tube, Lumbard, Waters, Guedel, Berman, Safar resuscitation airway), and Carmalat tongue forceps (in the middle). Picture taken by the author at the Wood Library-Museum of Anesthesiology, Schaumburg, Illinois, with their kind support.

oropharyngeal airway design. Failure in obese patients was heralding today's clinical routine challenges.

In spite of warnings that the insertion of an oropharyngeal airway does not by itself guarantee an unobstructed airway, the postinduction depressed jaw was (and is) locked on the bite block without any mandibular advancement, potentially inducing an iatrogenic airway obstruction.[146] The symmetrical flanges positioned at the lips further reinforced the impracticality of advancing the mandibular teeth in front of the maxillary one. The conversion of the oropharyngeal airway from a "passive" (without associated airway maneuver) to an "active" (with associated airway maneuver) device did not occur with the new intermittent positive pressure ventilation techniques. The myth of the oropharyngeal airway as an effective passive device was (and is) reasserted in textbooks by illustrations that incorrectly depict the device *in situ* generating perfect airway patency by supporting the tongue with the head in neutral position without an associated airway maneuver.

The (straight) tongue blade used to "hold the tongue against the floor of the mouth" during oropharyngeal airway insertion was mentioned in the late 1940s. It was borrowed from medical practice, where it was used in conscious erect patients. In anesthesia, the tongue blade was used in obtunded, supine patients as a cheap and suboptimal device—in patients with small mouth openings, the device does not effectively control the tongue. Alternatively, it was recommended to use the thumb to hook and control the tongue after induction.[130,147,148]

Nasopharyngeal airways were routinely used in anesthesia and resuscitation to facilitate the nasal ventilation route, but nasal hemorrhage and inadequate tidal volume were recognized limitations. There were no standardized devices, and rubber tubes of firm texture were used. The larger the tube used, the better the airway. The length was adjusted after insertion (distance from nares to just above the glottis), and the exact depth was judged individually. After testing the ease of breathing, the device was cut and stabilized at the nares with a safety pin.[148]

In the late 1950s, the anesthesia community reinstated emergent intermittent positive pressure ventilation outside the operating room. This was performed with expired air and handheld devices modeled after the bag-mask system attached to the anesthesia machine. In 1943, Joseph Kreiselman[149] rediscovered the hand-operated bellows connected to a face mask, a nonrebreathing valve, and an inlet for oxygen. Multiple new bellows-type resuscitators were introduced: the Porton (Bernard Lucas, USA), the Oxford inflating bellows, the Blease manual resuscitator, and the Cardiff inflating bellows.[150] They were followed by Henning Ruben's (Copenhagen, 1914 to 2004) self-inflating bag with a unidirectional valve, marketed since 1957 as the Artificial Manual Breathing Unit bag,[151] which could be operated with the foot or even the crook of the elbow, leaving both hands "free to keep the mask airtight and the jaw forward," suggesting the benefits of a two-hand face mask ventilation technique.[152]

Conclusions

The progressive anesthetic years (1904 to 1960)—the era of the Great Depression and the First and Second World Wars and the Korean War—saw the transfer of anesthesia leadership from the noncommittal surgeon to the physician–anesthetist involved in clinical work and research. Academic departments of anesthesiology were created, anesthesia journals were published, and professional organizations were established, reflecting this progress. During this time, basic airway management was the technique of choice to provide airway patency in resuscitation and general anesthesia. Airway management success in this era was favored by the generally normal weight of the population. In 1960, in the United States, mean body mass index was $25\,kg/m^2$.[153]

Until the late 1950s, manual methods (Schäfer, Nielsen, Silvester) were the accepted artificial ventilation techniques; the negative pressure ventilation "iron lung" dominated long-term ventilation, and mechanical "alternative pressure" ventilators (*e.g.*, Pulmotor) were used in prehospital resuscitation. Airway patency proved to be the major problem with both mechanical respirators and manual resuscitation techniques. Between 1956 and 1960, several anesthesiologists demonstrated the effectiveness of intermittent positive pressure ventilation in resuscitation with expired air ventilation, the futility of manual techniques, and the validity of the airway maneuvers.

The new general anesthesia paradigm—balanced anesthesia—was based on a combination of inhalational and intravenous drugs, rapid induction, endotracheal intubation, and intermittent positive pressure ventilation. It promised to resolve the deadly triad—hypoxia, hypercarbia, and aspiration—and increase patient safety and surgeon satisfaction. Anesthesia practitioners evolved from being "content with haphazard methods of administering the powerful drugs" to incorporating pharmacology, physics, biochemistry, and engineering into their routine practice, achieving scientific maturity.[154] What had been considered the primal sin of intermittent positive pressure ventilation —the destruction of alveoli—outlined early in the 19th century was never scientifically disproved but was reconsidered in light of experience.[111] At the end of the progressive years, the paradigm shift—from a single inhalation agent to balanced anesthesia, from an unprotected to a protected airway, from spontaneous ventilation to intermittent positive pressure ventilation in anesthesia—was accepted but not fully implemented. This transition allowed anesthesia to match the requirements of all surgical disciplines.

The transition from the "artisanal" to the "progressive" era in the operating room was marked by the industrial development of anesthesia apparatus. Anesthesia machines allowed intermittent positive pressure ventilation to be used to manage accidental and later electively induced respiratory failure. In medical centers, the anesthesia provider was gradually exposed to deep anesthesia (cyclopropane, halothane), rapid induction (pentothal), paralysis (curare, succinylcholine), assisted ventilation (bag-mask ventilation), and controlled ventilation (mechanical respirators). Anesthesia providers had to learn new skills and take responsibility for the patient's ventilation, thus becoming experts in airway management.

In the late 1950s, anesthesiologists exported their knowledge of airway management and ventilation techniques outside the operating room. The benefits of intermittent positive pressure ventilation were demonstrated and accepted in resuscitation and critical care, as well as in surgery. Anesthesiology unified the concept of emergent and elective ventilation inside and outside the operating room. The regime of spontaneous ventilation in anesthesia and negative pressure ventilation in resuscitation ended. One-hand face mask ventilation established itself as the ubiquitous basic airway management technique. Two-handed face mask ventilation was not advocated as a routine technique. There were no cervical spine precautions. Face mask ventilation use was consolidated once the early supraglottic airways—*e.g.*, the Doyen pharyngeal tube, the Leech pharyngeal gasway, the Primrose cuffed oropharyngeal throat tube—failed to take hold in practice.[155]

Airway management techniques and devices traditionally used in the operating room with spontaneous ventilation were transferred to the new intermittent positive pressure ventilation technique without reevaluation. Certain inaccurate and counterproductive basic airway management concepts stemming from this transfer became embedded in practice:

- The concept of the tongue obstructing the upper airway of the unconscious patient with minimal concern for epiglottic, nasal, and soft palate obstruction
- The concept of airway obstruction occurring during inspiration with expiration obstruction largely ignored (usually generated by the soft palate)
- Acceptance of the face mask harness without consideration of the airway obstruction induced by pushing the mandible downward
- Acceptance of the harness collar on the face mask ventilation port without consideration of the fact that it limited the grip on the dome
- The myth that the face mask grip with the little finger at the mandibular angle implemented mandibular advancement
- The concept of the oropharyngeal airway as a passive device scooping the tongue off the posterior pharynx in the absence of an associated active airway maneuver
- The concept of using a stepwise escalation of face mask ventilation technique adjusted to ventilation difficulties instead of a first optimal attempt tailored to the patient's and provider's specifics

The airway obstruction and basic airway management model developed during the artisanal era was not pursued scientifically. In the progressive years, self-experimentation, experimentation on fresh cadavers, and radiologic studies to elucidate airway patency were few and clinically inconsequential. Basic airway management skills were derived from experience. Safar's work validated two-hand airway maneuvers—head extension and mandibular advancement—in expired air resuscitation. Central to airway management effectiveness was the extension of the head. This was a known maneuver from artisanal era resuscitation (Howard's "utmost extension of the head and neck at the edge of the bed") and from laryngoscopy and bronchoscopy.[1] Head extension (renamed chin lift, head tilt, head backwards) together with mandibular advancement (jaw thrust, forward or upward mandibular displacement) became part of the triple airway maneuver. All the maneuvers described in resuscitation had the goal of positioning the mandible in front of the maxilla. The distance between the chin and the larynx was opened to the maximum. Paradoxically, the anesthesiologists who were successful in validating basic airway management in resuscitation did not follow through with the same idea in the operating room for one-hand face mask ventilation.

In the progressive era, basic airway management persisted in an artisanal mode without adopting physiologic principles and objective markers. Advanced airway management was adopted before basic airway management pathophysiology was elucidated. Direct intubation developed scientifically into a practical model that was applicable for teaching and research. The one-hand face mask ventilation technique developed into a simplistic model that encouraged a personal approach. Although intubation pursued a "culture of innovation," face mask ventilation—in spite of its ubiquity—was shrouded in a "culture of compliance."[156] In this context, face mask ventilation was acknowledged as art, and intubation was acknowledged as science.

The basic airway management weaknesses were compounded in its history.

Will basic airway management get the scientific attention it needed and deserved in modern times?

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Competing Interests

Dr. Matioc holds U.S. Patent 6,651,661 B2 for the ergonomic face mask, receives royalties from the Tuoren Group (Menggang, Henan, China) for the ergonomic face mask product, and also holds U.S. Patent 8,640,692 for the advanced oropharyngeal airway.

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ANESTHESIOLOGY REFLECTIONS FROM THE WOOD LIBRARY-MUSEUM

Crimean Thornapple Depicted by Liebig's Extract of Meat Company

These images are from the French language version of the trade card distributed by the Liebig Company, which was famous for both producing beef extract and being named after Professor Justus von Liebig, one of chloroform's discoverers. Relying on the coasts of the Black and Caspian Seas as sources for *Datura stramonium*, the Liebig Company depicted a Crimean Russian peasant spilling out a basket (*upper right*) of harvested thornapple fruits. Collected fruits were sorted and decorticated at the Liebig factory (*lower left*), where a powerful anticholinergic slurry of scopolamine, hyoscyamine, and atropine could be extracted for pharmaceutical purposes. (Copyright © the American Society of Anesthesiologists' Wood Library-Museum of Anesthesiology.)

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