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

The "Modern" Era, 1960 to Present

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ABSTRACT

This fourth and last installment of my history of basic airway management discusses the current (*i.e.*, "modern") era of anesthesia and resuscitation, from 1960 to the present. These years were notable for the implementation of intermittent positive pressure ventilation inside and outside the operating room. Basic airway management in cardiopulmonary resuscitation (*i.e.*, expired air ventilation) was de-emphasized, as the "A-B-C" (airway-breathing-circulation) protocol was replaced with the "C-A-B" (circulation-airway-breathing) intervention sequence. Basic airway management in the operating room (*i.e.*, face-mask ventilation) lost its predominant position to advanced airway management, as balanced anesthesia replaced inhalation anesthesia. The one-hand, generic face-mask ventilation technique was inherited from the progressive era. In the new context of providing intermittent positive pressure ventilation, the generic technique generated an underpowered grip with a less effective seal and an unspecified airway maneuver. The significant advancement that had been made in understanding the pathophysiology of upper airway obstruction was thus poorly translated into practice. In contrast to consistent progress in advanced airway management, progress in basic airway techniques and devices stagnated.

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> "Anesthetists who have not tried this two-handed hyperextension manipulation will be surprised to observe the combined effects of simultaneously pushing the vertex of the head backward and pulling upward on the symphysis of the mandible."
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> Editorial. J Am Med Assoc 1961; 176:608–9

During the "artisanal" anesthetic era (1846 to 1904) and the "progressive" era (1904 to 1960), airway patency in general inhalation anesthesia was provided using basic airway management techniques (*i.e.*, head extension and jaw thrust applied with or without a face mask).[1,2]

In the 1950s and 1960s, anesthesiologists revolutionized airway management in resuscitation by demonstrating the superiority of expired air artificial ventilation techniques (*e.g.*, mouth-to-mouth ventilation) to traditional manual methods (*e.g.*, Silvester, Schäfer, Holger Nielsen) and initiated the implementation of positive pressure ventilation[3] (fig. 1). In the process, they validated optimal techniques for the known airway maneuvers. Head extension in resuscitation—in contrast to the operating room—was applied with two hands, one hand on the chin and one on the vertex, mobilizing the occipitoatlantoaxial joint and upper cervical spine in the sagittal plane. Jaw thrust—in concordance with the operating room—was applied with two hands on the transverse plane by subluxating both temporomandibular joints. Both techniques elevated the chin, increased both the chin-cervical spine and chin-sternum distances, and positioned the mandible in front of the maxilla.[4]

The generic one-hand face-mask ventilation inherited from the progressive era (*i.e.*, the "E-C" technique) applied the thumb and index finger on the face mask dome (the "C") and the rest of the fingers dispersed along the mandibular body with the fifth finger at the angle of the jaw (the "E"). The E-C grip and the airway management devices that had served the anesthesia community for almost 100 yr were not reexamined or validated for use with the new positive pressure face-mask ventilation, and their limitations were carried over into the modern era.[3]

In the "modern" anesthetic era (1960 to the present), the paradigm shift from inhalation to balanced anesthesia and from spontaneous to positive pressure ventilation was implemented over several decades. Relying on spontaneous ventilation and an unprotected airway with a face mask, slow and strenuous inhalation induction was replaced by rapid intravenous induction with apnea, followed by endotracheal intubation. Adult inhalation anesthesia, supported by basic airway management, became the exception. The anesthesia provider in the modern medical center became the airway management expert at a time when positive-pressure face-mask ventilation morphed into a short, bridging technique, used between the time of pharmacologically induced apnea and tracheal intubation. "Cannot ventilate" was replaced by "cannot ventilate, cannot intubate."

Starting with the 1990s, the implementation of airway management guidelines, complex-monitoring systems, new

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Fig. 1. The early evaluation of mouth-to-mouth ventilation and validation of head extension as a two-hand technique by Peter Safar at the Baltimore City Hospital. Reprinted from Baskett PJF: Peter J. Safar, the early years 1924 to 1961, the birth of CPR. Resuscitation 2001; 50:17–22 with kind permission from Elsevier.

advanced airway management devices and techniques (*e.g.*, supraglottic airways, fiberoptic intubation, videolaryngoscopes), and consistent improvement in general anesthesia techniques and training led to the dramatic fall in anesthesia morbidity and mortality.[5,6]

The 1990s also marked the start of renewed interest in apneic oxygenation and extensive research into upper airway obstruction pathophysiology, especially in obese and obstructive sleep apnea patients. Unfortunately, it did not lead to significant progress in basic airway management guidelines and techniques. In the second half of the modern era, obesity reached epidemic proportions, with more than one-third (36.5%) of U.S. adults and 15% to 20% of European adults considered obese.[7] It is estimated that by 2020, 70% to 75% of the U.S. population will be affected by obesity.[8] The epidemic is also rapidly affecting developing countries.[9] In this context, optimizing advanced airway management devices and techniques has been prioritized and recognized as critical because of the reduced apnea tolerance of obese patients.

This article, the fourth in the series, follows the evolution of adult basic airway management from 1960 to the present in the Western world.

Development of Western Medicine in the Modern Era

Surgery and Medicine. In the modern era, surgery continued its rapid progress. Technology and newly developed surgical techniques allowed pediatric and adult cardiac surgery, transplantations of organs, implantation of organs engineered in the laboratory, and minimally invasive surgeries (*e.g.*, robotics).[10] One essential achievement of the profession was the "democratization" of surgery, meaning that in recent decades surgery established itself as "an essential tool for helping people live long and healthy lives," increasing the number of operations performed annually in the United States to 50 million.[11] Surgeons are involved in nonelective airway management outside the operating room—with a focus on "definitive" endotracheal intubation and surgical airway—as organizers and teachers of the Advanced Trauma Life Support courses.[12]

Medicine continued to develop in the early modern era along the progressive era scientific directions, whereas in the second half of the modern era, molecular biology, immunotherapy, genetics, and advances in technology and pharmacology provided new approaches for the control and cure of disease. Additionally, new invasive branches of medical practice (cardiovascular, digestive, hepatology, neurology) grew, requiring anesthesia support.[13] Along with these advancements came new challenges: iatrogenic complications and resistance to antimicrobial therapy.[14] As well, medical practitioners became involved in Basic and Advanced Life Support courses and emergency medicine physicians and providers became involved in nonelective airway management outside and inside the hospital.[15]

Anesthesia

Anesthetic Delivery Systems. Various anesthetic agents and delivery systems coexisted in the early modern era.[3,16] Open techniques involved dripping ether on a gauze-covered, wire-frame mask positioned on a spontaneously breathing patient. This was an unsophisticated method, not requiring a perfect face mask seal and resulting in a prolonged and unpredictable induction and maintenance of general anesthesia. Draw-over apparatuses, in which low resistance vaporizers delivered a known percentage of anesthetic agents, required special training (*e.g.*, Epstein-Macintosh-Oxford, Penlon Draw-over, Blease Universal vaporizer).[17] However, unlike open techniques, inhalation anesthesia with draw-over apparatuses and anesthesia machines required a perfect face-mask seal, making the technique laborious with elderly, edentulous, or bearded patients.[18]

Eventually in the modern era, workstations replaced historic anesthesia delivery systems. The initial monitors (*i.e.*, blood pressure, cardiac rate and rhythm, pulmonary inflation pressure, body temperature, inspired oxygen concentration, and gas tank pressure) evolved into modular systems.[19] Anesthesia workstation improvements were industry-driven; however, the ergonomic aspects of the anesthesia workspace, including airway management, were neglected.[20,21] As industry gradually unbalanced the "relationship between user and product," there came to be a growing reliance on branded anesthesia-related products. The anesthesia provider became a consumer with the risk of underutilizing workstation complex technology in basic (*e.g.*, face-mask ventilation) and advanced (*e.g.*, prolonged artificial respiration) ventilation activities.[22,23]

The 1960s saw the abandonment of negative pressure ventilation systems for unintubated patients who required short or emergent (*e.g.*, Pulmotor; Dräger, Lübeck, Germany) or prolonged or chronic (*e.g.*, Iron Lung; Collins, Warren E. Inc., Boston, Massachusetts) respiratory support.[3] The use of controlled, intermittent, positive pressure ventilation by means of artificial ventilators gained momentum. Ventilators using mechanical and electronic systems, then microprocessors, and finally digital technology were used for prolonged artificial ventilation of the intubated patient (*e.g.*, Siemens [Erlangen, Germany], Blease Anaesthetic Equipment Co Ltd. [Chesham, United Kingdom], Datex-Engstrom [Helsinki, Finland], Dräger [Lübeck, Germany], Ohio Medical Products-Ohmeda [Madison, Wisconsin]).[24]

Anesthetic Techniques

Open inhalation techniques with ether and chloroform did not allow rigorous control of agent concentration. Single-anesthetic intravenous techniques with analgesics (*e.g.*, morphine, pethidine) or induction agents (*e.g.*, thiopentone, hexobarbitone, methohexitone) were used in short cases. Intermittent intravenous injections were titrated clinically to avoid breath holding and limb movement (too light) or respiratory arrest (too deep). Hypnotic and analgesic depth was difficult to assess, and patients frequently had recollections of the operative event.[25] Both historical techniques relied on maintenance of spontaneous ventilation for safety and basic airway management for airway patency.[3] The anesthesia provider also had to master the emergent treatment of an accidental apneic episode.

As the modern era progressed, the new balanced-anesthesia technique became the standard for general anesthesia applied to spontaneously ventilating or apneic patients. It combined intravenous and inhalation agents with assisted or controlled ventilation. Basic and advanced airway management provided airway patency. Control of the anesthetic agent concentration was provided first with the Copper Kettle (Foregger Company, New York, New York) and later by agent-specific, temperature- (and flow-) compensated, direct-reading percentage vaporizers.[26,27]

In the 1960s, halothane displaced flammable agents (*e.g.*, ether, ethylene, and cyclopropane) as the inhalation agent of choice. Pancuronium, fentanyl, and ketamine were added as intravenous agents. Disposable endotracheal tubes with inflatable cuffs became standard, as did the concept of minimum alveolar concentration.[28] The new plastic intravenous catheters simplified the administration of balanced anesthesia.[29] The underventilated intraoperative and postoperative patient became a critical issue, and the impact of hypoxemia on surgical outcome was recognized.[30] In the 1970s, flammable anesthetics were discarded, whereas enflurane, etomidate, calibrated vaporizers, neuromuscular blockade monitoring, RAE (Ring, Adair, and Elwyn) tubes, and ear oximeters were introduced.[31] Advances in anesthesia and critical care also came about as a result of the experiences of the U.S. Medical Corps in the Vietnam conflict.[32,33] In the 1980s, isoflurane, propofol, and midazolam came into use, and oxygen monitoring and capnometry became widely available.[34,35] In 1986, the American Society of Anesthesiologists (ASA) adopted the "Standards for Basic Intraoperative Monitoring," which encouraged the use of pulse oximetry and capnography to increase patient safety. The 1990s then saw the clinical use of rocuronium, atracurium, cisatracurium, desflurane, sevoflurane, and dexmedetomidine. Versatile and potent inhalational agents replaced nitrous oxide,[36] although dentists continued to use nitrous oxide for conscious sedation and behavior management in pediatric patients mostly with supplemental oxygen.[37] Obesity was mentioned early in the modern years, but its impact on airway management, upper airway pathophysiology, and intra- and postoperative airway risk was largely ignored until the 1990s.[38] Anesthesia-related mortality in the United States decreased from two deaths per 10,000 anesthetics in the 1980s to about one death per 200,000 anesthetics a decade later. In the first decade of the 2000s, patient safety increased with (1) the ability to monitor oxygen concentration in the anesthetic mixture and oxygen saturation in the patient during the procedure and (2) the adoption of new standards addressing hypoxemia.[39,40] Sugammadex, the one new anesthesia drug, was also released, which provided the airway manager the ability to reverse profound rocuronium- or vecuronium-induced neuromuscular blockade.[41] Airway management guidelines and algorithms were developed to avoid hypoxemia during elective and emergent airway management.[42] Control of apnea and hypoxia became central to anesthesia practice.

Heralding a new, post-modern era for our specialty are (1) the expansion of anesthesia know-how outside the operating room, (2) the possible evolution of the anesthesiologist into a perioperative physician, and (3) the effort to provide anesthetic solutions to positively impact surgical outcome.[43]

Upper Airway Management

Traditionally basic airway management with a folded towel, wire, or inhaler face mask was provided with the right, dominant hand, while the left hand manipulated the drip bottle or the inhaler. This continued in the second half of the progressive era, with the left hand used to manipulate the unsophisticated anesthesia apparatus positioned to the left of the practitioner.[3,22] Later, the addition of a table to the anesthesia apparatus resulted in an anesthesia machine positioned to the right of the practitioner to allow the right hand to be used for new tasks (*i.e.*, charting, monitoring, machine manipulation, new airway management devices, medications, and suction). This forced the left hand to be dedicated to the face mask and the practitioner to adopt new habits to match conventions dictated by technologic progress.[44,45] The symmetrical design of the face mask proved versatile and supported the change. It is remarkable how this apparently major change in airway management technique that most likely challenged some practitioners was ignored in the literature. The technical details of manipulating the face mask were left up to each provider—in other words, basic airway management continued as a personal endeavor.

In the early years of the modern era, the dominance of basic airway management was still evident in both elective inhalation anesthesia and accidental apnea. Intubation was restricted to induced apnea in specific surgeries (thoracic, abdominal), or in accidental apnea—at "the time the difficulty [with face-mask ventilation], arises rather than in anticipation of difficulty." Some perceived advanced airway management "as a substitute for aptitude and technical skill in the maintenance of a good airway and satisfactory fit of the mask."[46,47] Intubation was considered complicated, traumatic, and unnecessary in most cases.

With advances in surgical practice, the limitations of basic airway management-based inhalational anesthesia became evident.[48] An endotracheal tube provided a hands-free, patent (avoiding asphyxia), and protected (avoiding aspiration) upper airway for positive pressure ventilation, and supported homeostasis in long and complex surgical procedures. Controlled ventilation with endotracheal intubation became a necessity, as balanced anesthesia with apneic muscle relaxation became the standard.[49] Difficulties with laryngoscopy and intubation were discussed early in the evolution of balanced anesthesia.[50] Starting in the 1980s, supraglottic airway devices were developed to address the limitations of the face mask and tracheal intubation.[51] Continuous improvement characterized the development of the new advanced airway management techniques and devices.[52]

Basic airway management in general anesthesia became secondary to advanced airway management. In patients at increased risk for pulmonary aspiration of gastric content, rapid sequence induction and intubation was described in 1966 with complete avoidance of face-mask ventilation. Today a significant number of U.S. practitioners use a "modified" rapid sequence technique testing the ability to ventilate—apparently without monitoring airway pressure—in cases where the clinical risk of hypoxemia outweighs the risk of aspiration.[53]

In head and neck surgery intubation and extubation challenges, the shared airway with the surgeon and the surgery-specific airway requirements are addressed with different anesthetic techniques and advanced airway devices used independently or in combination (supraglottic airways, conventional and video-assisted laryngoscopy, rigid and fiberoptic bronchoscopy, optical stylets). The oxygenation-centered airway management strategies developed for apneic and spontaneously ventilating head and neck patients (*e.g.*, high-flow oxygenation and ventilation, transtracheal jet ventilation) are pertinent to general anesthesia difficult airway management practice.[54]

Basic Airway Management in Resuscitation

Expired Air Ventilation. The groundbreaking work pioneered by anesthesiologists in the 1950s and 1960s recognized expired-air ventilation (*e.g.*, mouth-to-mouth) as the pillar of artificial respiration outside the operating room and demonstrated the failure of manual methods.[3] However, medical professionals had little interest in acute life-saving measures and rescuers resisted change, as they feared infection, had witnessed regurgitation with positive pressure ventilation, and ignored the importance of airway patency.[55,56]

Three two-hand airway maneuvers were proposed for expired air ventilation, including head extension ("head tilt"), pulling the jaw forward with a finger in the mouth behind the lower teeth ("chin lift"), and jaw thrust ("jaw lift").[4,57] The last two maneuvers proved difficult for lay rescuers to learn and apply. Maximal head extension limited by anatomy or pathology, as originally described by Clover in 1868 as "backward tilt of the head as far as possible," was adopted as the universal airway maneuver in expired-air resuscitation[58,59] (fig. 1). The label "head tilt/chin lift" diluted the concept of maximal head extension.[60] Hyperextension of the head was also instrumental in the mouth-to-nose artificial respiration indicated in victims with trismus or convulsions.[61,62]

The validated expired-air, artificial ventilation sequence (*i.e.*, "airway maneuver first [hyperextension], seal second [mouth-to-mouth ventilation]") existed in contradistinction to the operating room one-hand face-mask ventilation routine of first "pushing the mask on the face" then "pulling the mandible into the mask." Two anesthesiologists who pioneered expired air resuscitation, Elam and Ruben, recognized this and criticized the generic one-hand face-mask ventilation.[57,63] The effectiveness of positive pressure one-hand face-mask ventilation "was often annulled by the application of downward pressure on the mandible with a face mask," by the mask strap displacing the mandible posteriorly, or "because the extension usually performed with one hand is insufficient."[64] Inspiratory obstruction was "corrected" instinctively by using high inflation pressures and expiratory obstruction was addressed by opening the mouth to allow exhalation.[4,65]

In 1961, a static radiographic study of airway maneuvers applied on curarized, lean volunteers demonstrated that hyperextension of the head always provided a wider hypopharynx and a higher degree of stretch of the anterior neck structures than forward displacement of the mandible alone. The authors recommended that hyperextension of the head should be followed in case of failure with forward displacement of the mandible, separation of the lips (open mouth), and insertion of an oropharyngeal airway.[59] The same incremental approach to airway patency difficulty was suggested by Safar, and became the universal approach in face-mask ventilation inside and outside the operating room. The combination of the two maneuvers, head tilt/chin lift and jaw thrust, combined with a nasal or oral artificial airway device (*i.e.*, the triple airway maneuver), provided the highest incidence of airway patency.[66]

The dynamics of the upper airway during mouth-to-mouth ventilation and neck hyperextension were explored using cinefluorographic study of an anatomical sagittal section.[65] During forceful insufflation used to generate transient opening of a partial airway obstruction (pressure greater than 20 cm H_2O), the pharynx and hypopharynx underwent marked dilatation, increasing the dead space and the risk of gastric inflation. Generated by passive thoracic mechanics, the expiratory pressure in the apneic subject was always a small fraction of the inflating pressure, but still risked stomach inflation, as the tongue ("ball-valve") and the soft palate ("flap-valve") produced partial expiratory obstruction. Opening of the esophagus required less pressure than that needed for lifting the tongue base. Expiratory obstruction was addressed by opening the mouth (lay people) or use of an oropharyngeal airway (professionals) to bypass soft palate obstruction and support the tongue. The dynamics of airway obstruction during positive pressure ventilation pointed to the paramount role of a patent airway in both inspiration and expiration.

The newly validated two-hand hyperextension of the head described in resuscitation was unknown to the anesthesia practitioner.[1] A 1961 editorial advised the anesthetist to try the two-hand hyperextension manipulation in lieu of the one-hand routine attempt and predicted that practitioners will be "surprised" by the results.[67]

In the early 1960s, closed-chest cardiac massage was demonstrated to maintain functional blood pressure during ventricular fibrillation and asystole.[68] Rhythmic sternal pressure could not support ventilation of the lungs even in the presence of a patent airway; artificial respiration needed to accompany closed-chest cardiac massage, as "artificial circulation without oxygenation is futile." This concept generated the A-B-C (airway-breathing-circulation) sequence in cardiopulmonary resuscitation.[69]

In the 1980s, the Cardiopulmonary Resuscitation Committee of the Dutch Heart Association recommended the C-A-B (circulation-airway-breathing) sequence, as it considered that most cardiac arrests were episodes of ventricular fibrillation with well-oxygenated arterial blood available for several minutes. Implementation of mouth-to-mouth ventilation was hindered by the reluctance of bystanders and medical professionals to perform artificial ventilation (because of fear of tuberculosis and later AIDS), compromising the entire act of resuscitation.[70,71]

In 1985, Lesser *et al.*[72] argued against the de-emphasis of oxygenation in resuscitation, but, by 1997, Becker *et al.*[73] urged the resuscitation paradigm shift from the A-B-C to the C-A-B sequence on a global scale. The proposed model of passive inhalation "following elastic recoil of the chest" after chest compression and spontaneous gasping ignored the lessons learned from the failure of manual resuscitation techniques.[3] Safar[74] (and other authors[75]) considered that the new paradigm "created confusion and the erroneous impression for laypersons and the media that in sudden coma, bystanders will save lives merely pushing on the sternum."

In 2010, the Guidelines of the American Heart Association in accordance with the International Liaison Committee on Resuscitation Consensus on Science and Treatment Recommendations introduced the C-A-B paradigm for an untrained rescuer, with the primary emphasis on uninterrupted chest compression an minimal "no-flow times" with continuous and optimal cerebral blood flow.[76] Outside the hospital, oxygenation was *de facto* deferred to the trained rescuer; rapid response by the Emergency Medical Service became even more crucial than before. There are no prospective randomized studies to support the chest compression–only approach.[77]

The 2015 Guidelines reinforced this strategy. The only exception from the C-A-B protocol is considered the drowning victim that benefits from immediate correction of hypoxemia.[78] The options for airway management and ventilation of an unprotected airway during cardiopulmonary resuscitation included (1) no airway and no ventilation (compression-only), (2) compression-only with the airway held open (with or without supplementary oxygen), and (3) mouth-to-mouth, mouth-to-mask, and bag-mask ventilation. Agonal respirations and chest-compression-only resuscitation in an unprotected airway were found ineffective in generating adequate tidal volumes.[69,79,80] Shoulder elevation or rotation of the head to generate passive head extension in an unconscious patient was ineffective in the absence of a dedicated airway manager.[81,82] The downgrading of active basic airway management in resuscitation and its replacement with passive ventilation remains a debated topic.[83]

Passive oxygen delivery techniques are appealing for their simplicity and ability to be used during uninterrupted chest compression.[84,85] Bobrow *et al.*[86] evaluated passive oxygen insufflation (high-flow oxygen, non-rebreather face mask and the application of an unspecified airway maneuver "at the paramedics' discretion") and found it superior to bag-valve-mask ventilation during cardiopulmonary resuscitation. Today, application of passive oxygen insufflation in resuscitation is in its infancy and requires clear guidelines and a dedicated airway manager to ensure airway patency.

Bag-valve-mask Ventilation

In the 1960s, the limitations of expired air ventilation, the availability of the anesthesia face-mask ventilation model, and the introduction of the self-inflating resuscitator bag with a unidirectional valve (the AMBU bag: Artificial Manual Breathing Unit) resulted in the rise of the bag-valve-mask technique in resuscitation.[87] Use of the bag-valve-mask and advanced airway devices was limited to trained rescuers able to diagnose the victim's upper airway reflex response and avoid regurgitation, aspiration, and laryngospasm.

The resuscitation community, trusting the airway expert, assimilated the suboptimal operating room generic one-hand face-mask ventilation technique. Early resuscitation bag-valve-mask techniques followed the expired-air sequence of "airway maneuver first, seal second." A two-hand validated hyperextension of the head allowed the implementation and assessment of the magnitude of the airway maneuver before being converted into a one-hand grip for the seal[57] (fig. 2). This sequence was replaced by the generic one-hand operating room technique (*i.e.*, "seal first" [the "C"], "airway maneuver second" [the "E"]) that generated an underpowered seal ("snuggly apply the mask") followed by an unspecified airway maneuver ("pull the mandible into the mask").[57]

The narratives describing the one-hand face-mask ventilation in resuscitation, emergency medicine and anesthesia remained vague, impractical, and without specific endpoints.[88,89]

The new positive pressure ventilation technique required a perfect seal and an effective airway maneuver. This was addressed by tightening the ineffective E-C grip on the face mask and mandible. In the case of inexperienced users, poor face mask seal was/is considered the chief source of reduced ventilation and the suboptimal or ineffective airway maneuver was/is largely ignored.[90] The validity of the E-C technique with positive pressure ventilation was never questioned, and the techniques became accepted as dogma in resuscitation and the operating room. In artificial ventilation (expired-air and bag-valve-mask) two-hand techniques—with a validated and ergonomically sustainable two-hand airway maneuver and effective seal—were consistently proved to be more effective than the one-hand E-C technique.[91–93]

A non–E-C, one-hand technique was described in emergency medicine, but did not attain mainstream use.[94] After removing the hook ring from the connector, the "chin lift grip" was applied by placing the web space between the thumb and index finger on the connector with the rest of the fingers reaching for the chin. This generated a power grip that controlled the whole mask for the seal. The torque that maintained head extension was applied along the sagittal plane (fig. 3, left). The technique applies the "airway maneuver first, seal second" sequence.[94] This was in contrast to the suboptimal E-C technique (fig. 3, right). Novice airway managers were more able to provide an effective seal without decay of ventilation markers over time with the chin-lift grip technique and the author's (A.A.M.) asymmetrical ergonomic face mask.[95]

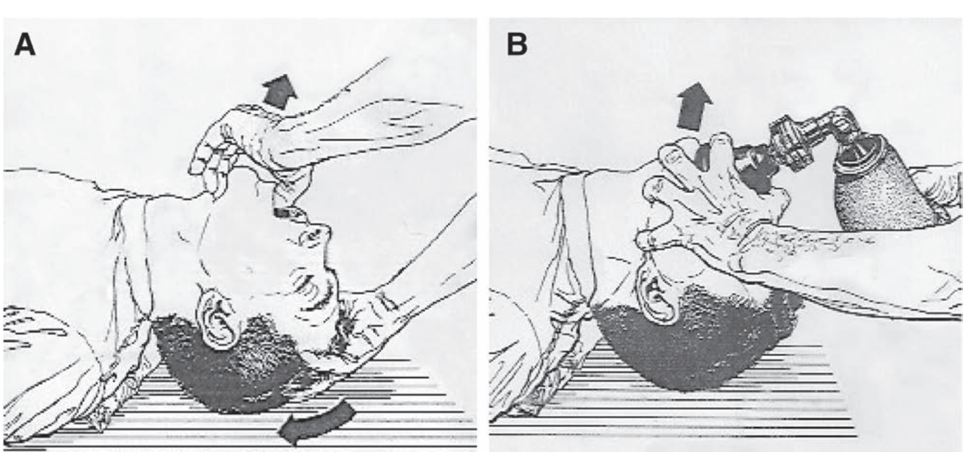

Fig. 2. "Airway maneuver first, seal second" sequence with a validated two-hand head extension (*A*) converted into a one-hand generic "E-C" grip (*B*). Reprinted with permission from Puritan-Bennett Operating instructions, Puritan Manual Resuscitator, 1967, Figure 4, p. 6 and Figure 6, p. 7.

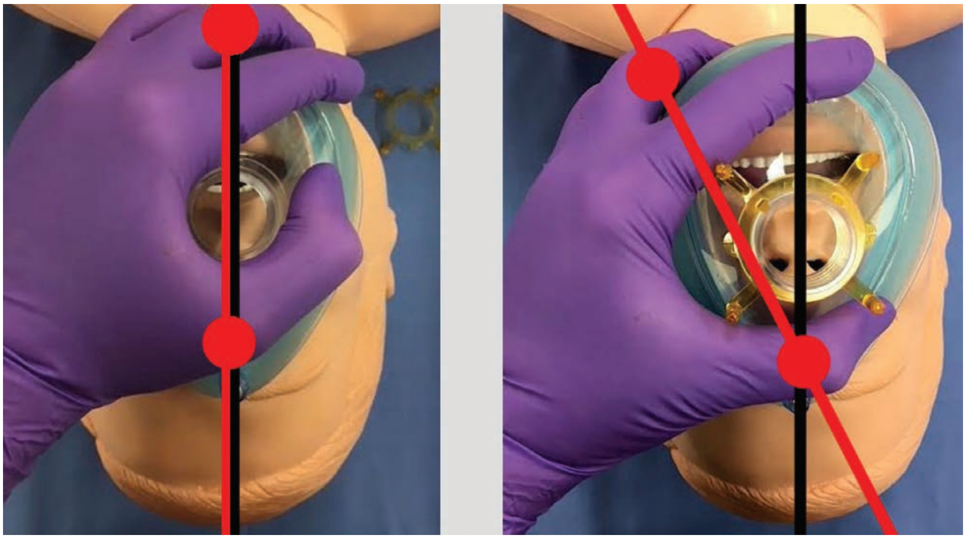

Fig. 3. Chin lift technique (*left*): hyperextension torque (*red line*) is maintained in the sagittal plane (*black line*). E-C technique (*right*): torque (*red line*) applied off the sagittal plane (*black line*). Pictures taken by Adrian A. Matioc, M.D.

At the end of the 1980s, the limitations of the "most basic and lifesaving ventilation technique" (*i.e.*, bag-valve-mask) went unnoticed, as the rise of intubation and supraglottic devices promised to resolve the problems of oxygenation and ventilation, indifferent of the location of the unconscious patient. The status quo in resuscitation basic airway management especially for nonprofessionals and professionals with little training was maintained to this day.

The 1986 Guidelines abandoned the head tilt–neck lift maneuver and recommended jaw thrust when cervical spine injury was suspected.[96] Two-hand jaw thrust generated less displacement in fresh cadavers with single injury patterns at the C1–C2 level when compared with two-hand head tilt–chin lift.[97]

In anesthetized and paralyzed lean patients undergoing face-mask ventilation in the operating room with maximum head extension, gastric insufflation diagnosed by auscultation occasionally occurred at inflation pressures of 20–25 cm H_2O and consistently at pressures exceeding 25 cm H_2O. Forcefully pushing back on the anterior neck structures (*e.g.*, cricoid pressure) to prevent gastric inflation increased the required inflation pressure and complicated airway management.[98]

Military airway management algorithms reflect injuries encountered on the battlefield, not typical conditions seen in civilian patients in cardiac arrest emergencies.[99] In contaminated environments, specific bag-valve-mask challenges imposed by personal protective equipment were encountered.[100]

Basic Airway Management in Anesthesiology

From 1960 to 1990. During the period 1960 to 1990, historical airway maneuvers (*e.g.*, pulling the tongue out with a forceps, repositioning an impacted large epiglottis with a forceps under direct vision, and suturing the tongue to keep it forward) were mentioned, but rarely used in elective or emergent positive pressure ventilation and disappeared from practice.[101] Passive head extension using the 19th century practice of hyperextension of the head with a roll under the shoulders or with the head at the edge of the bed was mostly abandoned as the sniffing position was adopted to optimize direct laryngoscopy.

The language used to describe airway maneuvers in the anesthesia literature (*e.g.*, "head tilt," "chin lift," "head slightly extended," "pulling up/forward the chin," "pulling the jaw backward and extending the neck") is vague, encouraging liberal interpretation and complacency. Elam noted correctly that in curarized patients an optimal airway maneuver attempt was critical and that an "additional ten degrees of [head] extension can make considerable difference" in airway patency.[64,102]

Isolated epiglottic impaction with severe glottic obstruction was described in the progressive era. Digital laryngeal examination of a suspected "overhanging epiglottis" and the lifting of an impacted epiglottis to normal position relieved the obstruction.[103,104] Using the flexible bronchoscope, Boidin pointed out in 1985 that "the tongue is not the only factor" in upper airway obstruction. The epiglottis was considered the main cause of obstruction, relieved by hyperextension of the head.[105] Insertion of an oropharyngeal airway did not guarantee a clear airway and most importantly did not preclude the need for an airway maneuver. The angle of retroflexion measured by the authors corresponding to a clear airway was functionally equivalent to the maximum head extension measured on cadavers in 1889 and conscious volunteers in 2007.[1] In 1989, magnetic resonance imaging in obese obstructive sleep apnea patients suggested that fat deposits in the soft tissue of the upper airway might predispose the supine, sleeping subject to upper airway collapse.[106]

Clinical experience confirmed that face-mask ventilation was difficult in edentulous and obese patients or those with receding jaws, nasogastric tubes, or short thick necks.[107] Basic airway management did not progress in the early modern years parallel with the intubation techniques.

From 1990 to the Present. Knowledge of basic airway management increased exponentially in the second half of the modern era. Nevertheless, it was not translated in new airway management algorithms or used to define a first optimal basic airway management attempt. The myth of the tongue obstructing the upper airway ingrained in the psyche of lay people and airway managers continues to limit the practice of basic airway management.

Mechanisms of Upper Airway Obstruction and Maneuvers

The stated purpose of airway maneuvers—head extension and jaw thrust—was to elevate the chin, stretch the anterior neck structures, and move the hyoid anteriorly, mobilizing the tongue, epiglottis, and soft palate.[108,109] The epiglottis-tongue unit was considered to respond consistently, while the soft palate, with weak, indirect connection to the mandible, responded inconsistently to airway maneuvers. The triple airway maneuver generated the best results. Isolated downfolding of the epiglottis after induction or extubation with glottic obstruction continued to be regarded as a singular event with uncertain prevalence.[110] The soft palate becomes central to the understanding of expiratory obstruction in obese/obstructive sleep apnea patients.[111]

One-hand Face-mask Ventilation Technique

The branding of the one-hand generic face-mask ventilation technique, as the E-C technique provided an effective educational tool, facilitating its universal spread. It is described in anesthesia and airway management textbooks worldwide and has become the default technique in practice and teaching with critical opinions generally ignored.[112]

New grips to improve mask seal were described—"the rotated mask hold," the "E-O technique," and the "Grip and Lift" technique and the "claw hand mask ventilation" grip.[113–116] All of these techniques followed the traditional "seal first, airway maneuver second" sequence. The "chin-lift" grip requires an "airway maneuver first, seal second" sequence.[117] Using a clinical stridor score, Iwanaga *et al.*[118] demonstrated in anesthetized, spontaneously breathing patients that a two-hand maximum head extension can be converted to a one-hand technique and was best maintained with the fingers on the chin.

Technical and Outcome Markers

Two recently proposed chin-elevation measurements described on healthy volunteers might be practical as *objective technical markers* to quantify airway maneuver extent. For head extension, the 42° angle generated by maximum extension of the head and for jaw thrust, the maximal mandibular advancement of approximately 20 mm in front of the maxilla.[119,120] The "airway maneuver first, seal second" sequence allows the objective assessment of the airway maneuver before the seal is applied. Inability to generate a two-hand maximal airway maneuver is an early warning that the face-mask ventilation attempt may fail, and an oropharyngeal or nasopharyngeal airway may be inserted before the seal is applied.

Traditional face-mask ventilation *subjective outcome markers* relate to sight (chest expansion, cyclical condensation on the dome), sound (chest auscultation), and touch (bag compliance).[121] Subjective ventilation outcome markers were the hallmark of the spontaneously breathing anesthetized patient monitoring during the artisanal and progressive era.[2,3] Relying solely on subjective markers, however, may encourage complacency as a suboptimal face-mask ventilation technique can generate a short-lived acceptable subjective outcome with unnoticeable slowly progressive deterioration leading to critical hypoxia.

Only *objective outcome markers* can correctly assess ventilation and gauge short- and long-term viability of the technique. The 2013 ASA Practice Guidelines for Management of Difficult Airway recommended objective markers of inadequate ventilation (*e.g.*, decreasing or absent oxygen saturation, absent or inadequate exhaled carbon dioxide, and absent or inadequate spirometric measurements of exhaled gas flow).[122] In the second half of the modern era, anesthesia providers embraced oxygen saturation with the continuous, audible signal. However, oxygen desaturation during an ineffective face-mask ventilation attempt can be delayed by preoxygenation or masked by rapid endotracheal intubation or insertion of a supraglottic device, giving the practitioner false reassurance. Oxygen desaturation is an inadequate outcome marker and herald failure of face-mask ventilation attempt.

In 2014, the Japanese Society of Anesthesiology recommended the use of three distinct capnogram waveforms as a reliable diagnostic tool for assessing the efficiency of ventilation during anesthesia: with plateau present (expected tidal volume range greater than 5ml/kg), only rapid upswing without plateau (2 to 5 ml/kg) and lack of waveform, meaning apnea or dead space ventilation.[123] In 2016, Lim and Nielsen proposed a scale for mask ventilation based on the best capnography tracing achieved with an optimal first attempt: Grade A – plateau present, Grade B – no plateau, with end-tidal carbon dioxide ($ETCO_2$) greater than10 mm Hg, Grade C – no plateau with $ETCO_2$ less than 10 mm Hg and Grade D – no $ETCO_2$. First two reflect effective and adequate and the last two inadequate and absent ventilation[124] (fig. 4). Sufficient oxygenation can occur with low tidal volumes when using a fraction of inspired oxygen (FIO_2) of 1.0. Joffe considers that tidal volumes of 4 ml/kg of predicted body weight (with 150 ml the average anatomical adult dead space) provides adequate oxygenation and may protect from gastric insufflation.[125] Implementing objective markers in the face-mask ventilation routine and switching the focus from deoxygenation (late sign) to ventilation (real time) would challenge the practitioner to critically reevaluate his/her technique and improve documentation of mask ventilation.

Situation awareness is an essential medical nontechnical skill for providing optimal performance. Applying newly optimized face-mask ventilation technique will impact all three components of situational awareness: perception (sensory input from subjective and objective markers), comprehension (understanding the information collected), and projection (projection of the expected future development of the patient's status).[126] The need for nearly simultaneous visual attention to the manual task of handling the face mask (left hand) and anesthetic bag and machine (right hand) and the observation of patient, monitors, and anesthesia machine leads to dispersion of attention during a face-mask ventilation attempt. An anesthesia practitioner will perform trade-offs between the frequency of information sampling and the effort needed to overcome the awkwardness and nonergonomic relationship with the device and workplace design.[3,127] Most likely the practitioner will choose to collect familiar subjective markers ignoring the objective markers visualized on a monitor that the provider is unable to see while performing specific physical tasks (*e.g.*, face-mask ventilation, laryngoscopy). Improvement of the display of information inside and outside the operating room is warranted.[128,129] Implementing ergonomic principles of hand-tool interaction and work environment, whether this is the field, ambulance, helicopter, or hospital, along with applying face-mask ventilation objective technical and outcome markers should be part of an optimal first face-mask ventilation attempt in the 21st century.

Difficult-mask Ventilation

In 1993, the ASA Task Force on Management of the Difficult Airway urged clinicians and investigators to express difficulty as numerical values.[130] In 2000, after 150 yr of uninterrupted use of the face mask, Langeron, in his seminal study on 1,502 patients, defined the clinical predictors of difficult mask ventilation.[131] Several authors studied the incidence of face mask difficulty and added new predictors to Langeron's original five.[132–135] Difficult face-mask ventilation clinical predictors can be classified as predictors that anticipate poor face mask seal (lack of teeth, presence of beard), increased soft tissue collapsibility (male sex, age greater than 55 yr, increased body mass index, history of snoring/obstructive sleep apnea, Mallampati Class III or IV, airway masses and tumors) or inability to perform an adequate airway maneuver (acute or chronic cervical spine pathology, history of neck radiation, limited mandibular protrusion).[136,137] Difficult mask ventilation predictors identified in the 21st century validated Hewitt's clinical work in the early 20th century.

Difficult mask ventilation incidence in the general population, reflecting current practice, was identified as between 5% and 8.9%, with difficult mask ventilation having a higher incidence of associated difficult intubation.[138] Using objective markers in electively ventilated patients

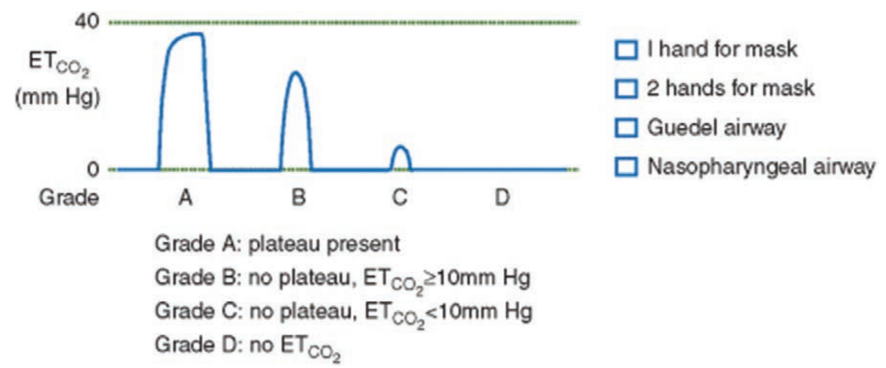

Fig. 4. Proposed scale for grading mask ventilation based on the best capnograph achieved. Reprinted from Lim KS, Nielsen JR: Objective description of mask ventilation. Br J Anaesth 2016; 117(6):828–9, with kind permission from Elsevier.

with whom one hand E-C technique was used Joffe *et al.*[125] described inadequate ventilation in 19% of the cases.

Han's grading scale used subjective markers to define face-mask ventilation difficulty.[139] The scale does not rely on a concept of first optimal face-mask ventilation attempt tailored to the patient's difficult mask ventilation predictors validating the status quo.

Difficult-mask Ventilation Predictors

Poor Seal. Edentulous and bearded patients have challenged anesthesia providers for more than 150 yr. Leaving the dentures in place was suggested and used since the 19th century and recently validated.[140] Nevertheless, easy postinduction face-mask ventilation with dentures in place provides no information about postextubation face-mask ventilation difficulty without dentures. There is no current single best solution to improve face mask seal in the edentulous and bearded patient.[141–144]

Increased Soft Tissue Collapsibility

Male-sex predisposition to pharyngeal collapse.[145,146] Elderly male patients tend to have increased pharyngeal resistance to airflow, with nasal obstruction, long soft palate, and preferential deposition of fat around the upper airway.[147]

Obese patients have been a basic airway management challenge since the artisanal anesthesia era and have become a critical issue in modern times.[66] In the 1990s, the dynamic study of pharyngeal closing pressures and pharyngeal endoscopy were introduced in the study of upper airway behavior in obese and obstructive sleep apnea patients. The increased volume of soft tissue structures and excess submandibular tissue correlates with increased risk and severity of obstructive sleep apnea.[148,149] Increased tongue dimensions may displace the hyoid inferiorly with increase of mandibulo-hyoid distance.[150–152] Isono proposed an upper airway model for obstructive sleep apnea of anatomical imbalance between the fixed craniofacial bony enclosure and excessive soft tissue volume that determined the airway space with dynamic interaction between the tongue and soft palate.[153,154] Responses to mandibular advancement was studied in obese and nonobese obstructive sleep apnea patients.[155–157] Velopharynx was narrowest during expiration.[157] The oral face-mask ventilation route is preferable, as obstruction at the soft palate should be bypassed.[158,159] A two-hand technique with triple airway maneuver and an oropharyngeal airway to support the oral ventilation route has been recommended for first optimal attempt.[160]

Inability to Perform an Adequate Airway Maneuver

Ineffective head extension can be associated with acute and chronic cervical spine pathology and a history of neck radiation therapy. A short thyromental distance may act as a surrogate for inadequate head extension.[161] Patients with restricted craniocervical movement due to pathology may have a reduced mouth-opening ability.[162] Ineffective jaw thrust can be identified by the limited mandibular protrusion test and the limited upper lip bite test.[163,164]

Strategies for Optimal Face-mask ventilation

Inspiratory *versus* Expiratory Airway Obstruction. Upper airway obstruction is a dynamic process: segments that are not the primary sites of obstruction during inspiration can generate obstruction during expiration.[165] Expiratory obstruction was appreciated in spontaneously breathing patient in the artisanal and progressive era but is unknown today. It occurs during deep sedation and positive pressure ventilation with the mouth closed in about one-third of patients and is not relieved by head extension.[166,167] Soft palate expiratory obstruction of the nasopharynx is often not suspected and is easily misdiagnosed as tongue induced inspiratory obstruction, since insertion of an oropharyngeal airway may address both. The first face-mask ventilation attempt in patients with velopharyngeal obstruction predictors (*e.g.*, obesity, snoring, obstructive sleep apnea) should include an oropharyngeal airway.[160]

Nasal *versus* Oral Route. At the beginning of the 20th century, Hewitt insisted on the clinical assessment of nasal patency, preferred the oral ventilation route, and encouraged the use of dental props and later of the oropharyngeal airway.[3] In 2017, Yamasaki demonstrated that nasal passage obstruction considerably reduces tidal volume achieved during face-mask ventilation, and regarded the practice as "essential for anesthesiologists to evaluate nasal airflow as part of airway examination."[168] Chronic nasal obstruction is often ignored in older males.[169] Nasal obstruction is a critical component in opioid-induced respiratory depression.[170]

A positive-pressure face-mask ventilation attempt with the mouth and lips closed commits to a nasal ventilation route with four possible upper airway obstruction sites that respond variably to airway maneuvers—nasal cavities (no response), soft palate (poor response), and tongue and epiglottis (best response).[137] The oral ventilation route is selected when using an oropharyngeal airway to bypass nasal and soft palate (nasopharyngeal) obstruction. It has two possible obstruction sites, tongue and epiglottis; both respond predictably to airway maneuvers.

Recent research considered nasal mask intermittent positive pressure ventilation in nonparalyzed, apneic selected adults to be superior to combined oral-nasal ventilation (*i.e.* face-mask ventilation).[171,172] However, the latter was generated with deliberate suboptimal conditions (head in neutral position, no airway maneuvers, head straps with no hand grip, no airway adjuncts) and without considering the dynamic of upper airway patency during inspiration and expiration.[173] The authors correctly stated, "this study situation may not be readily applicable to the clinical practice." Confusingly, the studies are cited as proof of the superiority of nasal ventilation over face-mask ventilation with traditional positive pressure ventilation.

With a patent airway, passive apneic oxygenation delivered pre- and peri-intubation by nasal cannula at 5 l/min prolongs functional apnea time, but is still not well defined for critically ill patients.[174–176] Two continuous positive pressure nasal techniques for high-flow oxygenation and ventilation are of interest. One uses a wide-bore nasal cannula to deliver up to 60 l/min of warmed and humidified oxygen (OptiFlow, Fisher and Paykel Healthcare Limited, New Zealand) and the other a tight-fitting nasal mask to deliver up to 15 l/min dry oxygen (SuperNOVA, Vyaire Medical, USA).[177–179] The transnasal humidified rapid-insufflation ventilatory exchange implemented with the first system promises to achieve oxygenation and ventilation without an invasive device and tidal respiratory movements.[180,181] In both sedated spontaneously breathing and apneic patients, airway patency is paramount. The role of high-flow techniques in reversing hypoxia without prior denitrogenation and in delaying hypercarbia in resuscitation was not explored.

One-hand *versus* Two-hand Technique. The airway maneuver applicable with one-hand face-mask ventilation technique is head extension, whereas the two-hand technique can generate jaw thrust or a triple airway maneuver. In 2010, Joffe *et al.*[125] confirmed Safar's 1958[66] finding that "an anesthesiologist is unable to advance and maintain the mandible forward an adequate distance when using only one hand [E-C technique] to hold the jaw." The two-hand face-mask ventilation technique has the hallmarks of an optimal attempt (*i.e.*, optimal bilateral symmetrical pressure on a symmetrical device and a validated two-hand jaw thrust). As in resuscitation, the two-hand technique is superior to the E-C one-hand technique in experienced and inexperienced hands.[93,122,182] The two-hand E-V technique (fingers two, three, four, and five along the chin – the "E" and finger one and the thenar eminence sealing the mask lateral to the connector – the "V") is superior to the two-hand E-C technique in obese patients, as the ergonomics of the grip allow a triple airway maneuver.[183] It can be applied as a one-person technique using pressure-controlled ventilation in the operating room with an anesthesia machine or, outside the operating room, with automatic resuscitation management systems (*e.g.*, Oxylator).[137]

Provider Hand Span, Grip Power, and Sex

The provider's limitations and needs have been largely ignored by research and industry. Tidal volume delivered with the one-hand E-C technique is influenced by the mask design, hand size, grip power, and sex of the provider.[184–186] Additionally, the daily, repetitive use of an unaccommodating face mask with a technique that does not maintain the wrist in neutral (semi-pronation) position to reduce the pressure in the carpal tunnel may lead to injury. In an obese patient, the practitioner with a small hand span may use a two-hand technique with the first attempt.

Administration of Muscle Relaxants

The historical clinical perception was that muscle relaxants improved face-mask ventilation. The Fourth National Audit Project by the Royal College of Anaesthetists and Difficult Airway Society found that, in some cases, light anesthesia and a reluctance to administer muscle relaxants might have caused patient harm.[187] The current debate about muscle relaxant administration during induction before or after effective face-mask ventilation is established is at the crossroads of two central airway management principles developed in the first and respectively the second half of the modern era: (1) "do not burn bridges" (*i.e.*, the "after" camp) and (2) "first optimal attempt" (the "before" camp).[188] Both claim to serve patient safety. In today's complex reality of providing effective ventilation, the "first optimal attempt" principle should guide airway management at all levels: basic, advanced and surgical.

The systematic study of the muscle relaxants effects on face-mask ventilation in anesthetized patients started in early 21st century.[189–191] The Warters grading scale has a point system that is based on the ability of the practitioner to achieve a target tidal volume of 5 ml/kg.[190] Soltész applied this objective grading system in potential difficult to ventilate patients to demonstrate that administration of rocuronium improved face-mask ventilation. The first attempt was optimized using an oropharyngeal airway and a triple airway maneuver. This study aligned the basic with the advanced airway management practice by optimizing the first attempt with pharmacology and technique.[191]

Head Position

During the late progressive years the sniffing position with the head elevated (Jackson's "amended" position) became the standard for an optimal direct laryngosopic intubation attempt and was adopted as routine preinduction head position.[192,193] Passive sniffing position (head elevated 6 to 7 cm without head flexion) increased the distance between the mentum and cervical spine and enlarged the bony box size, but it did not stretch the anterior neck structures.[194,195] The sniffing position with bite closure provided greater occipito-atlanto-axial extension.[196,197] Passive cervical extension with a cushion under the shoulders and with bite closure increased the size of the bony structure of the upper airway and stiffened the oropharyngeal and velopharyngeal airway.[198,199]

In obese patients, the ramping position (*i.e.*, shoulder elevated with head and neck extended to position the external auditory meatus in line with the sternal notch) is beneficial for face-mask ventilation (decreased pharyngeal closing pressure) and direct laryngosopic intubation.[153]

Lateral head rotation has been used to clear the airway since the 19th century, as it increased hand comfort of the practitioner in long cases. Two-hand face-mask ventilation technique with jaw thrust in anesthetized, apneic adult patients, and 45° head rotation significantly improved the efficiency of ventilation when compared with neutral head position.[200]

Stomach Inflation and Aspiration Risk

The distribution of gas volume between the lungs and stomach during positive pressure ventilation depends on patient variables (*e.g.*, lower and upper esophageal sphincter pressure, airway resistance, and respiratory system compliance) and on operator skill (*e.g.*, maintaining a patent airway, low peak inspiratory pressure [*e.g.*, 15 to 25 cm H_2O] using small tidal volumes [*e.g.,* 5 to 6 ml/kg], and decreasing peak inspiratory flow by slow inflation of the bag).[201,202] A two-hand face-mask ventilation technique with pressure-controlled ventilation may optimize the distribution of gas flow between lungs and stomach.[203,204]

Difficult-mask Ventilation Algorithm

The traditional difficult-face-mask ventilation algorithm is rooted in the progressive era and has a linear, trial-and-error approach with escalating tasks as attempts fail. It is time-consuming, prolongs apnea, and discounts the first optimal face-mask ventilation attempt concept. In 2013, the ASA Task Force on Management of the Difficult Airway recommended the evaluation of the airway for difficult mask ventilation predictors, but did not suggest any subsequent strategy.[122] The "Vortex" airway management approach considers a first optimal face-mask ventilation attempt as a two-hand technique supported by airway adjuncts and adequate level of anesthesia and muscle relaxation.[205] Routine use of E-C technique with subjective ventilation outcome markers, while ignoring difficult mask predictors and objective markers, makes a first optimal face-mask ventilation attempt elusive.[137] A new algorithm for face-mask ventilation attempt should include the concept of optimal first attempt tailored to the patient's basic and advanced airway management difficulty predictors. Administration of muscle relaxants should reflect the overall airway management plan in the specific patient.

Basic Airway Management Devices

Face Mask. The 1960s saw the implementation of balanced anesthesia and the need for airway control in the apneic patient.[2] The need for an airtight seal between the anesthesia delivery system and the patient was evident with advanced airway management holding the promise to solve the problem.

The change in face mask functionality did not trigger a revision of its design; it was expected that the practitioner was skilled in handling the device. As borrowed from Sibson, John Snow's original 1847 face mask features (*i.e.*, symmetrical dome, circuit connector, and soft rim with an anatomical contour) were preserved in the modern face mask. Traditional nondisposable opaque, reusable face masks were popular until the late 1980s: the Anatomical (Connell) was fitted with a wire gauze to make it malleable to fit the patient's face; the SCRAM (Selective Contour Retaining Anatomical Mask) had a cushion filled with plastic, and the entire mask body could be molded to any specific face shape (Ohio Medical Products); the Everseal allowed an airtight seal with minimal pressure on the dome (Medical and Industrial Equipment Ltd., United Kingdom) with a specific cushion designed used today in the disposable Intersurgical face mask; the Flotex featured a rubber flange instead of a cushion to be placed under the chin; and the Fleximask was a one-piece mold with a built-in malleable bridge (Harris Lake Inc.).[206] The early AMBU mask with a transparent dome and a "thumb rest" was very popular in resuscitation. The Rendell-Baker-Soucek mask was specifically designed for pediatric patients, to reduce dead space[207] (fig. 5).

The new disposable, transparent face masks launched in the late 1970s were made of silicone or vinyl and had soft, thick cushions to facilitate a good seal and to compensate for the lost malleability of the opaque face masks. The air-tight seal in the first mass-produced disposable face masks (Vital Signs, USA, followed by King Systems, USA) were provided by new rotational molding technology used for the cushions and injection molding for domes (fig. 5). Reinforcing the seal with a harness was and is a personal choice without any supporting data but with a "time-honored" role. Harness hooks although still offered with face masks are usually unused and end up discarded with an avoidable environmental cost.[208] The strap holder made the control of the whole dome nearly impossible, reinforcing an ineffective "C" on the dome (fig. 3, right).

The perception that the transparent mask supported patient safety, with color of the lips, condensation on the dome, and regurgitation/aspiration readily visualized, reinforced the generic underpowered grip, as the practitioner cleared the dome to observe the patient, thus removing the grip even farther from the sagittal plane. The color of the lips is an impractical marker for early hypoxia diagnosis. Condensation on the dome is not a reliable ventilation marker as ineffective dead-space ventilation generates reassuring condensation. Paradoxically, a transparent face mask allows the practitioner to detect complications (hypoxia and regurgitation) of a suboptimal face-mask ventilation technique that it seemingly reinforces.[209]

Fig. 5. Opaque modern face mask (used until late 1980s). *Upper row:* Unidentified generic mask, Ohio Medical Products conductive mask, Rush antistatic mask, Everseal mask (Medical and Industrial Equipment Ltd., United Kingdom). *Center:* Rendell-Baker-Soucek pediatric mask. Transparent face masks. *Lower row:* Ohio Medical mask (cca. 1970), Intersurgical silicone face mask (Intersurgical, Ltd, United Kingdom), symmetrical generic Artificial Manual Breathing Unit (AMBU)-King mask (King Systems/AMBU, USA), asymmetrical ergonomic face mask (Tuoren Medical Group, China). Picture taken by Adrian A. Matioc, M.D., at the Wood Library-Museum of Anesthesiology, Schaumburg, Illinois, with their kind support.

Face mask design and technique as developed through 150 yr of history was conferred legitimacy in modern era by industrial standardization. The design and sizing of face masks ignore the practitioner's variables (hand size, grip power, sex) with the practitioner continuing the historical exercise of adapting and improvising according to his/her knowledge, experience, and skill. The assessment of the overall satisfaction of anesthesia practitioners with current face mask brands led the authors to "encourage manufacturers to improve the disposable facemask design."[210,211] Recently redesigned face masks that support a one-hand power grip and head extension are the symmetrical Tao mask and the author's (A.A.M.) asymmetrical ergonomic face mask.[95,212,213]

Oropharyngeal and Nasopharyngeal Airways

In 1908, Hewitt's "oral air-way" was revolutionary.[214] The original "air-way" bite block copied the functionality of a very popular contemporary device, the mouth prop, which engaged in its specific profile the mandibular and maxillary teeth, stabilized the bite, maintained an open mouth and supported mandibular advancement (fig. 6). In less than a year, Hewitt's original bite block was replaced with a smooth, simplified profile, recognizable today, that was easier to insert between clenched teeth. The bite block lost its ability to support mandibular advancement and was limited to opening the mouth and creating a high-volume, low-pressure ventilation path that bypassed nasal, nasopharyngeal, and velopharyngeal obstruction.[215] The passive insertion of an oropharyngeal airway does not provide mandibular advancement and alignment of the mandibular and maxillary teeth, a reality consistently misrepresented in textbook illustrations and ignored by practitioners. Without active manual advancement of the mandible on the bite block, the airway obstruction generated by the depressed mandible is preserved (fig. 7). The misplaced belief in the simplistic mechanism of the oropharyngeal airway passively supporting the tongue (true to the dogma that the tongue is the central actor in airway obstruction) is still recognizable in today's practice.

As was the case with face masks, implementation of positive pressure ventilation and later the obesity epidemic did not trigger the reevaluation of oropharyngeal airway technique and design. A more caudal location of a large tongue (*e.g.*, obstructive sleep apnea) may complicate the sizing of the oropharyngeal airway.[216]

The most common oropharyngeal airways in use today were inherited from the progressive era—the Guedel (1933) and Berman (1949) airways[217] (fig. 6). The poor performance of the oropharyngeal airway as a passive device has also been demonstrated fiberoptically.[218] The functionality of the oropharyngeal airway and the cuffed

Fig. 6. Modern era oropharyngeal device. *First row, left to right:* Ovassapian Fiberoptic intubating airway (1987), Berman (1949), historic “Hewitt air-way” with unique bite block (1908), Guedel (1933). *Second row:* Berman expandable airway, Berman jaw retractor. *Lower row:* cuffed oropharyngeal airway (1992), Brook airway (1959), Safar’s Resusitube (1961). Picture taken by Adrian A. Matioc, M.D., at the Wood Library-Museum of Anesthesiology, Schaumburg, Illinois, with their kind support.

oropharyngeal airway was enhanced with airway maneuvers (head extension, jaw thrust, triple airway maneuver).[219–221] Oropharyngeal airways designed for fiberoptic intubation (*e.g.*, Williams, Ovassapian, Berman) have been reviewed as bronchoscope conduits.[222]

There is a wide variation in the shape of airways of the same size among the same or different manufacturers.[223] Current standards applicable in the United States and Europe do not assure uniformity of clinical practice, as they allow for a wide variation in design and may impact routine basic airway management that relies on experience with specific devices.[224,225]

In contrast to the oropharyngeal airway, the nasopharyngeal airway generates a high-pressure, low-volume ventilation path, stenting nasal, soft-palate, and base-of-the-tongue obstruction and ending in proximity to the glottis. They have been in use for more than 100 yr. The nasopharyngeal airway is a versatile device as it can be inserted in awake or anesthetized spontaneously breathing patients, and used to support spontaneous ventilation, positive pressure ventilation and fiberoptic intubation.[137,226,227] The traditional methods used to size nasopharyngeal airways are empirical and unreliable.[228] The binasal airway system popular in the early modern years was recently revived.[229,230]

In resuscitation the use of oropharyngeal or nasopharyngeal airways for a first bag-valve-mask ventilation attempt should be encouraged, as ventilation with airway adjuncts at the first attempt improved neurologic outcomes after in-hospital cardiac arrest.[231] Nasal obstruction is associated with serious opioid-induced respiratory depression with victims not responding to intranasal naloxone.[170] In the context of a worsening opioid epidemic, now declared a public health emergency, the active use of an oropharyngeal airway to open the mouth and bypass nasal obstruction may improve oxygenation and ventilation in this subgroup of victims.

Miscellaneous

Artisanal chin-support devices have been used in the 1960s to 1980s operating room to secure hands-free face-mask inhalation general anesthesia.[232,233] After the advent of the

Fig. 7. Passive insertion of an oropharyngeal airway does not advance the mandible. Pictures taken by Adrian A. Matioc, M.D.

laryngeal mask airway in the 1990s, these devices became obsolete. In the second half of the modern era, airway maneuver support devices were described: a "chin-up" system functioning in the sagittal plane used in the supine patient during sedation and "jaw manipulation" devices functioning in the transverse plane to support the angles of the mandible.[234–236] Recently, two studies have emphasized the importance of continuous jaw thrust and evaluated devices for mandibular advancement: the "Jaw-Thrust-Device" prototype and an adjustable intraoral appliance.[120,237]

In the modern era, self-inflating resuscitator bags replaced the manual bellows devices developed in the progressive era.[238,239] The first self-inflating resuscitator bag was designed by the Danish anesthesiologist Henning Ruben (1914 to 2004)—the AMBU bag. One of the most significant advances in anesthesiology and resuscitation in airway management revolution, the AMBU was pioneered by anesthesiologists in the 1950s and 1960s and has saved millions of lives. In today's context of an obesity epidemic, a self-inflating manual resuscitator with an audible indicator of exhalation may help in the diagnosis of exhalation obstruction.[240]

The suction system introduced by the American Sidney Yankauer (1872–1932) in 1907 in otorhinolaryngology is still very popular. Emergent airway management can be improved with large-bore suction catheters (*e.g.*, the new Suction Assisted Laryngoscopy Airway Decontamination [SALAD] technique) in patients at risk for massive airway contamination, such as those with gastrointestinal bleeding, small bowel obstruction, or traumatic injuries.[241,242]

Conclusions

In the modern anesthetic era, advanced airway management algorithms, devices, and techniques have been central to progress and safety in balanced general anesthesia. The face mask is the longest-serving airway management device, having been used uninterruptedly since 1847. It is iconic to our specialty (fig. 8).

During the first half of the modern era basic airway management in resuscitation was applied as expired air ventilation or bag-valve-mask technique. Both techniques are difficult to teach, master, and retain.[243–245] The de-emphasis in the second half of the modern era of expired-air artificial ventilation in basic life support (the C-A-B sequence) and the recommendation of two rescuers for bag-valve-mask instead of the (routine) one-hand technique in advanced cardiac life support reflects the need to find a simple and effective oxygenation system in the unconscious victim.[246] Advanced airway management techniques have not proved to be superior to the bag-valve-mask technique in prehospital or in-hospital cardiac arrest.[247,248] Böttiger[249] has questioned why there have been so few research projects, such a low level of funding, and scant public attention to cardiopulmonary resuscitation and speculated that it was "because more than 70% of sudden cardiac deaths occur at home" or "because this field of medicine and research is not as lucrative as the others."

The downgrading of face-mask ventilation in the operating room corresponded with the implementation of balanced anesthesia and the increased role of advanced airway management. The generic one-hand face-mask ventilation technique survived unchanged, with an underpowered grip generating an ineffective seal and an undefined airway maneuver. The historical inaccuracies and counterproductive concepts inherited from the artisanal and progressive era are still identifiable in current practice:

- the simplistic explanation of airway obstruction as caused by the tongue falling backward and lack of attention to the epiglottis and soft palate
- acceptance of the harness collar on the dome even when head straps are not used
- acceptance of the generic one-hand E-C grip as dogma with the use of the little finger at the mandibular angle for an elusive jaw thrust
- use of "seal first, airway maneuver second" sequence
- use of an oropharyngeal airway as a passive device
- reliance on subjective markers to assess ventilation outcome
- application of a linear, time-consuming and potentially traumatic algorithm for difficult face-mask ventilation attempts

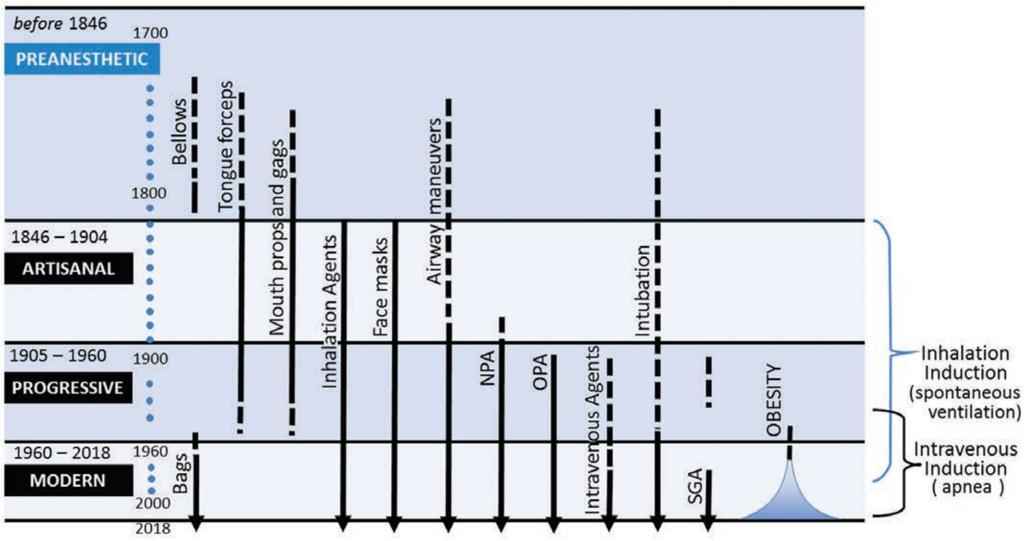

Fig. 8. Airway management devices, maneuvers, techniques, and anesthetic agents from 1700 to 2018, with dramatic increase of obesity line incidence in the modern era. *Interrupted line*, inconsistent use; *continuous line*, routine use. NPA, nasopharyngeal airway; OPA, oropharyngeal airway; SGA, supraglottic airways. Illustrator Kathryn Kleckner; used with permission from Education Service at William S. Middleton Veteran's Memorial Hospital, Madison, Wisconsin.

Face-mask ventilation settled on a paradigm that placed the burden on the provider, linking successful technique to his/her "experience and skill" and ignored the possibility that devices, techniques, and strategies could be improved and built into an optimal first attempt.

Simple steps to optimize a first face-mask ventilation attempt are:

- consider a two hand technique as first attempt in patients with multiple difficult mask ventilation predictors, the patient with cervical spine pathology, and providers with a small hand span[137]
- consider the "airway maneuver first, seal second" sequence to assess objectively the chin elevation before the seal is applied
- use of objective technical (measurement of the airway maneuver magnitude) and ventilation (end tidal carbon dioxide tracing, tidal volume, airway pressure) outcome markers[250]
- use of an oropharyngeal airway with the first face-mask ventilation attempt should be encouraged in patients with obesity, obstructive sleep apnea, cervical spine pathology, resuscitation and specifically opioid overdose

In the artisanal and progressive eras, the small number of obese patients, the slow recognition by medical practitioners of the importance of emergent intervention, and the misinterpretation of cyanosis all accommodated suboptimal airway management techniques and outcome.[1,3] The obesity epidemic, which started in the Western world and spread globally, has challenged anesthesia practice in general and airway managers in particular. Even now, not all practitioners recognize obesity as a risk factor for airway difficulty.[251]

The momentum generated by Langeron's difficult-mask ventilation definition in 2000 has not triggered a review of face-mask ventilation techniques, strategies, and algorithms or a break from traditional practice and intuitive teaching. Difficult mask ventilation predictors have been identified in elective, low-risk, operating room patients using subjective ventilation markers and not in high-risk, critical patients using objective markers.[252] Redefining difficult face-mask ventilation using objective markers and reevaluating difficulty and failure rate would trigger a review of face-mask ventilation techniques and strategies as a proactive system that supports a tailored response to patient, user and environmental predictors.

Basic airway management is still relevant today after 160 yr:

- in elective inhalation induction, deep extubation, conscious sedation, short general anesthesia cases, postinduction, and emergence and recovery from general anesthesia
- in high-flow nasal oxygenation systems[253]
- in elective, emergent and critical airway management—for preoxygenation[254] and perioxygenation during instrumentation to prolong apnea time, for direct and video laryngoscopy,[255] fiberoptic intubation,[256] and supraglottic airways[257,258]
- in new clinical settings—upper airway obstruction is still relevant in an unparalyzed patient with Suggamadex,

as it has no influence on the pharmacodynamics of the induction agent[259]
- all over the world, the farther the victim from a hospital, the sole oxygenation technique available in the hands of an unskilled rescuer is basic airway management

In 1911 at the height of inhalation anesthesia with an unprotected airway, Meltzer spoke of the upper airway passages as the "death space," and in 1912, Bellamy Gardner amplified it to "asphyxial death space."[260,261] Today, after 160 yr, there is no clear strategy for the optimal oxygenation and ventilation of an unprotected airway in elective and emergent situations. A 2009 editorial spelled out the need for improved basic airway management techniques and devices, and in 2017, Kheterpal considered that "identifying more effective mask ventilation techniques is a necessary focus for the field of anesthesiology."[262,263]

Basic airway management should include any set of noninvasive procedures performed to treat the unprotected upper airway obstruction used with or without minimally invasive medical devices to provide "oxygenation-management" in a sedated or unconscious patient.[264] Regarding physiology, pathophysiology, pharmacology, and clinical knowledge, the current wealth of information on upper airway obstruction needs to be converted into a simple model of managing the unprotected upper airway obstruction. Basic airway management, like advanced airway management, is the collective responsibility of providers, teachers, researchers, institutions, and industry.

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Competing Interests

Dr. Matioc holds U.S. Patent 6,651,661 B2 for the ergonomic face mask and U.S. Patent 8,640,692 for the advanced oropharyngeal airway.

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