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

The "Preanesthetic" Era—1700 to 1846

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ABSTRACT

Basic airway management modern history starts in the early 18th century in the context of resuscitation of the apparently dead. History saw the rise and fall of the mouth-to-mouth and then of the instrumental positive-pressure ventilation generated by bellows. Pulmonary ventilation had a secondary role to external and internal organ stimulation in resuscitation of the apparently dead. Airway access for the extraglottic technique was to the victim's nose. The bellows-to-nose technique was the "basic airway management technique" applicable by both medical and nonmedical personnel. Although the techniques had been described at the time, very few physicians practiced glottic (intubation) and subglottic (tracheotomy) techniques. Before the anesthetic era, positive-pressure ventilation was discredited and replaced by manual negative-pressure techniques. In the middle of the 19th century, physicians who would soon administer anesthetic gases were unfamiliar with the positive-pressure ventilation concept. **(Anesthesiology 2016; 124:301-11)**

THE modern history of airway management starts in the 18th century with the pursuit of a technique to "distend" the lungs of the "apparently dead" victim. Critical scientific and social developments allowed the budding idea of resuscitation to progress in a time when "strong and general prejudice existed against the practicability of resuscitation."[1] This historical context generated extraglottic, glottic, and infraglottic techniques to access the trachea.

Basic airway management (BAM) techniques (mouth-to-mouth and bag-valve-mask ventilation) are ubiquitous lifesaving procedures used today by laypeople and medical professionals alike. BAM techniques are extraglottic ventilation techniques applied usually to the unconscious patients and require two concomitant events: a seal to allow the use of a positive-pressure gas source (*e.g.*, lungs, bellows, or bags) and the relief of upper airway obstruction (UAO). Although today the concept seems intuitive, its development and implementation was a complex and lengthy process. It is remarkable how slowly the airway maneuvers for UAO relief (chin lift/head extension and jaw thrust) were defined and incorporated in positive-pressure ventilation (PPV) techniques. Validation of these airway maneuvers occurred in 1958 and only for resuscitation (expired air ventilation).[2] The airway maneuver incorporated in the one hand face mask technique was never validated. Currently, there is no optimal one hand bag-valve-mask technique described. This is in sharp contrast with the supraglottic devices and video-laryngoscopes developed in scientifically rigorous research and development programs.

Concepts attached to BAM—emergent therapeutic intervention, oxygenation, PPV, physiologic limitations of resuscitation, and diagnosis of death—were described during the Enlightenment but only fully developed in 1950s.[3] This article discusses the development of BAM in the "preanesthetic" era from the 1700s to the birth of modern anesthesia in 1846.

The Rise of Modern Medical Sciences

The airway management narrative is linked to the history of medical sciences. The physicians who laid the foundation of modern resuscitation and airway management in the 18th century were practicing medicine in the framework of medical systems that explained life, health, disease, and treatment in a single speculative scheme. The medical system, the humoral doctrine, first proposed by Hippocrates (460 to 370 B.C., Kos, Greece) and refined by the Roman Galen (129 to 199), was the beacon of medical practice until the middle of the 1800s, the period during which inhalation anesthesia became a practical reality. An imperfect balance of the four body humors (black bile, yellow bile, phlegm, and blood) caused the illness. The treatment to rebalance the humors was debilitating as it focused on fluid "*elimination*": bleeding (declined in practice only in late 19th century!),

Corresponding article on page 264.

Submitted for publication June 18, 2015. Accepted for publication August 18, 2015. From the Department of Anesthesiology, University of Wisconsin School of Medicine and Public Health, and William S. Middleton Memorial Veterans Hospital, Madison, Wisconsin.

 Anesthesiology 2016; 124:301–11

<zdoi;10.1097/ALN.0000000000000955>

blistering, purging, sweating, and vomiting. In the second half of the 18th century, the humoral doctrine was challenged by the new medical systems championed by William Cullen (1710 to 1790, Edinburgh)—doctrine of irritability—and by his student John Brown (1735 to 1788, Edinburgh, then London)—the doctrine of excitability. Health was viewed as a state of excitability resulting from a proper balance of stimuli. The practical benefit was that treatment focused on "*stimulants*" (*e.g.*, full diet, wine, exercise, opium, camphor, or musk).[4] The final theory, the organ sympathy one considered health the result of a "balance of excitement" maintained between internal organs (*e.g.*, stomach, intestines, lungs, and heart).[5] Applying stimulants to one organ would positively influence the other. These theories endorsed the use of stimulants in resuscitation to "reanimate the irritability" of specific vital organs and by sympathy the associated organs.[6]

The apparently dead were characterized by the "loss of heat and excitation" both applicable in the act of resuscitation by means applied externally (friction, agitation, and contact with hot objects) and internally (irritative and emetic substances and intrarectal/intestinal fumigation). Fumigation was a resuscitative procedure that consisted of insufflation of tobacco smoke into the victim's rectum to stimulate the intestines and by sympathy other vital organs (*e.g.*, lungs). Lung distension was also an organ "stimulation" technique. The heart was still considered the vital organ and asphyxia was a symptom not a pathophysiological entity. Death in asphyxia ("a" [without] and "sphyxis" [heartbeat] in Greek) was by cardiac arrest attested by the lack of pulse. Asphyxia-related research intensified and different authors (Andreas Vesalius, Robert Hook, John Hunter, Edmund Goodwyn, Xavier Bichat, James Phillips Kay) agreed that insufflation of the lungs should be included in resuscitation.

Joseph Black's (1728 to 1799, Glasgow and Edinburgh) discovery in 1754 of the "toxic" carbon dioxide in expired air and Joseph Priestly (1733 to 1804, Birmingham, England, then Northumberland, Pennsylvania) and Swedish chemist Carl Wilhelm Scheele's (1742 to 1786) discoveries of oxygen partially clarified the content of inspired and expired air. However, even after Antoine-Laurent de Lavoisier's (1743 to 1794, Paris) and Pierre Simon Laplace's (1749 to 1827, Paris) demonstrations of respiration as a combustive chemical reaction supporting life, the dogmatic approach dictated by the medical theories that kept artificial respiration at the periphery of resuscitation would not change.

In the 18th and 19th centuries, most of the scientific work in asphyxia, resuscitation, and artificial respiration involved a limited number of physicians, scientists, and physiologists from England, Scotland, and Continental Europe.

The Prehumane Societies Period

Infant Resuscitation

The oldest proponents of mouth-to-mouth ventilation (MMV) and the unsung heroes of resuscitation were the midwives joined in the late 18th century by male doctors with training in anatomy and the use of forceps (man-midwives or *accoucheurs*). Their skill, rooted in tradition, clinical observation, and experience, was used for the treatment of asphyxia neonatorum for centuries and was called the Midwives' Secret.[6,7] Breathing as an indication of life was embedded in the *psyche* of laypeople and professionals as the baby "came to life" crying. Also, the legal definition of the extrauterine life was related to respiration as the distention of the lungs with air was used to investigate infanticide as early as the 18th century. The hydrostatic lung test (docimasia pulmonum, from the Greek *dokimadsein* = testing) demonstrated that aerated fetal lungs float in the water.[8] The gravity of an extinct life at birth and the proximity of the rescuer forced the midwives to apply a simple and intuitive PPV extraglottic artificial respiration technique: the MMV. They resuscitated the apparently dead baby in the context of a significant infant and maternal mortalities and the need for emergency baptism. The midwives were allowed to proceed with an emergency baptism on a terminally ill baby. The introduction of the obstetric forceps created more opportunities to revive "languid" newborns.[9] The midwives were the only professional group in the early 18th century who preserved childbirth knowledge. Physicians had no appropriate training to assist in childbirth or perform resuscitation. Even with a suboptimal technique, there were many lives saved in spite of the fact that physicians considered MMV vulgar and undignified. The Church, through its Jesuit inquisitor Francesco Emanuele Cangiamila (1702 to 1763, Palermo), recommended resuscitation of the dying baby. In the theology of the Catholic Church, a dead unbaptized infant would spend afterlife in Limbo being deprived of the happiness in Heaven. Remarkably, he recommended artificial respiration before stimulation: "Most importantly and before all other procedures (author's note: stimulation), warm human breath should be insufflated through a tube into the infant's mouth. Its nostrils should be closed so that the air cannot escape; the air should be warm and should come from a healthy and virtuous person."[10]

Surgeon and obstetrician Benjamin Pugh (1715 to 1798, Chelmsford, Essex) recommended in 1754 the mouth-to-tube ventilation after blind insertion of his "air pipe" as far as the larynx during the breech extraction with delayed extraction of the head. In search for a simple technique for similar clinical situations, Pugh abandoned the "air pipe" for a transvaginal hand technique that allowed the air to have access to the larynx by pressing down the tongue, opening the trapped child's mouth, and allowing spontaneous ventilation before the head's delivery. For the nonbreathing delivered baby, Pugh strongly supported MMV.[11]

Adult Resuscitation

The rationale for resuscitation of the adult drowned victim has several roots: the concern in the Age of Enlightenment with the well being of the fellow man, the fear of being

buried alive (a fear that persisted to the end of the 19th century), and the increasing number of workable and taxpayer people drowning along the busy water routes of the major cities. Nevertheless, in the prehumane society period, popularization of artificial respiration was an individual effort with minimal impact on learned and laypeople.

In 1732, the Scottish physician William Tossach (1700 to 1771, Edinburgh) successfully used MMV to resuscitate a coal miner. Tossach's account published in 1744 detailed his technique, limitations, and improvements: "I applied my Mouth close to his, and blowed my breathe as strong as I could; but having neglected to stop his Nostrils all the Air came out at them; Wherefore taking hold of them with one hand and holding my other on his Breast at the left Pap [nipple] I blew again my breath as strong as I could. Raising his Chest fully with it: and immediately I felt six or seven very Quick Beats of the heart."[12] Expiration was passive. Oxygenation was not the objective, but "setting the lungs in motion" was. Resuscitation was followed accordingly with bloodletting. The patient survived. There was no mention of airway obstruction. Considering the widespread knowledge of this episode in Britain and Europe, Trubuhovich considered it as a "founding moment" in the airway management of modern reanimation.[13] Nevertheless, the Royal Society did not further explore this avenue.

John Fothergill (1712 to 1780, Edinburgh), a Quaker physician who settled in London, was a great supporter of the MMV technique described by Tossach and criticized the use of bleeding and stimulants in resuscitation. He did not improve on the MMV technique but describes its advantages: immediate availability, economy, provision of warm and moist air, and protection from barotrauma. Fothergill foresaw the need to train the public, as the technique could be "practicable by everyone who happens to be present at the Accident, without Loss of Time, without Expence, with little Trouble, and less Skill." However, the Royal Society of London did not support his endeavor, and the technique had few followers. He suggested the use of a bellows (bellows-to-mouth) as an alternative but without the advantages of MMV.[14]

In 1740 in France, the "Avis" [Notice] for recovery of the apparently dead written by the scientist René de Réaumur (1683 to 1757, Paris) reissued in 1758 and 1760 introduced insufflation of hot air into the mouth as the best resuscitation method. This remarkable document was posted with the intent to educate the "masses."[15] Traditionally, a passerby would not intervene or would use customarily brutal resuscitative maneuvers and only if the victim was still breathing. In this document, the concept of emergency did not exist because it stated that the resuscitation could start even hours after of the accident.[16]

The Scottish physician William Buchan (1729 to 1805) had a great role in spreading the MMV technique by describing it in *Domestic Medicine* a popular book with several editions and translations between 1769 and 1913. The technique was similar to Tossach's with added active expiration by pressing on the chest and abdomen.[17]

The "Humane Societies" Period (1767 to 1846)

In 1767, the first Society for the Recovery of Drowned Persons was founded in Amsterdam. The Dutch Humane Society recommended the following for resuscitation: warmth, fumigation, friction, bleeding, and MMV with active expiration (the "Dutch method"). The British Institute established in 1774 (to become the Royal Humane Society [RHS] in 1787) adopted MMV as the "ready" technique for the public.

The Humane Societies, created in the spirit of Enlightenment in nearly all European countries, developed and endorsed scientific resuscitation techniques, published literature, and provided financial support to build receiving houses (positioned strategically along rivers and lakes) equipped with resuscitation instruments. This marked the beginning of the institutional endorsement of resuscitation. The RHS partnered with physicians and laypeople to implement its policies in what was as much a social as a medical experiment. Participants were asked to change their common belief that a person who does not breathe is not dead but "apparently dead" and could be saved by new techniques. In this context, the RHS had to tailor its policies to the level of acceptability of both the physicians (respecting medical theories) and the laypeople (developing simple techniques and offering monetary rewards). The race was on to find a simple, effective, and socially accepted artificial respiration technique that anybody could apply immediately, successfully, and without complications on an apneic victim. The race is still on!

1767 to 1800: Decline of MMV and the Rise of Artificial Ventilation with Bellows

Mouth-to-mouth ventilation did not make a breakthrough in adult resuscitation. Scientists declared that expired air was poisonous as it contained larger quantities of carbon dioxide and smaller quantities of oxygen than air. Disgust for direct oral contact was the main deterrent. Hygiene in general and oral hygiene in particular were lacking. Only the upper classes had access to crude oral hygiene techniques. Bad breath was considered to carry or cause disease, and the breath of mortally ill patients was considered dangerous, as the lungs were part of the humoral balancing system.[18] The mouth of a drowned victim presented with froth, detritus, vomit, and water. In 1800, the river Thames was the main sewage system for 1 million people. Fothergill attempted to address this inconvenience by recommending the rescuer to "make a funnel of his right hand, placed that by the outer (ulnar) part over the nostril," and breathe forward and backward through it. However, this technique had no chance of success with its poor seal and the absence of airway maneuvers.[19]

The lack of public compliance regarding resuscitation was driven also by the indignity of maneuvers, the potential nakedness of the victim, and the socially unacceptable participation of both sexes and all social strata (ranging from physicians as aristocracy and down to urban poor). Lastly, the population was afraid of public, legal (moving a body represented interference in the course of justice), and religious reprisal. Physicians were not used to touching the patient except for taking the pulse and they were expected to display a gentlemanly comportment, which was generally inconsistent with resuscitation maneuvers. Physicians likely coordinated the resuscitation effort without actually directly participating hands-on.

The MMV description was generic: "blow with force into the lungs, by applying the mouth to that of the patient, closing the nostril with one hand and gently expelling the air again by pressing the chest with the other."[20] Technical limitations were related to the impossibility of applying MMV to a victim with clenched mouth, the inability to gauge the amount insufflated, and the risk that inflation of the stomach could compromise ventilation. Resuscitation efforts would go on for hours, exhausting the rescuers. Airway maneuvers for UAO relief were not described condemning MMV to a suboptimal attempt. The physicians' clinical experience with MMV was irrelevant. The absence of an animal model added to the inability of the physician-physiologist to improve the technique in the laboratory.

The efficacy of MMV (or any other resuscitation technique) was unknown and impossible to establish as these techniques were applied randomly or simultaneously on victims with diverse medical condition (UAO, hypothermia, shock, syncope, respiratory or cardiac arrest, death, and many more). There was very little evidence of MMV being performed or successful in adults. Resuscitation was a complex list of interventions with the simplest (*e.g.*, warming) techniques first applied.

Bellows were anecdotally described in human resuscitation and routinely used in animal physiology experiments. They were readily available next to each fireplace. With the dawn of Humane Societies in the second half of the 18th century, MMV would be replaced with instruments: airway devices attached to manually driven PPV devices using atmospheric air pumps by Nooth (1788) and Courtois (1790), bags by Chaussier (1780) and Kite (1788), and double-action bellows for inspiration and expiration by John Hunter (1776), Gorcy (1789), and Kite (1788). The airway devices defined the ventilation route: extraglottic (bellows-to-nose or to mouth), glottic (bellows-to-larynx), and subglottic (bellows-to-trachea). The development of artificial respiration devices followed the trend instated during the Enlightenment of solving problems by inventing instruments.

Evolving into the leading international institution for resuscitation, the RHS developed with the help of leading medical personalities, strategies, techniques, and devices. Physicians in England, Scotland, and Continental Europe contributed significantly to this work.

England and Scotland

John Hunter (1728 to 1793, London), distinguished scientist and surgeon, reported to the RHS in 1776 on tracheotomized and bellows ventilated animal experiments and extrapolated his findings to the resuscitation of the drowned.[21] He considered that in drowning, the "blood is damaged by want of the action of the air in respiration." Loss of respiration was followed by the "heart's motion ceasing": restoration of breathing will restore the heart's motion. This was in contrast with the traditional theories explaining death by drowning as apoplexy or collapse of the lungs. Hunter recommends as a first step in his "algorithm" blowing air into the lungs using his two-chamber bellows (active inspiration and expiration), followed by stimulants and heat. The bellows were adopted by the RHS in 1782 as substitute to MMV of which Hunter was not a supporter.[22] Instead, Hunter recommended an extraglottic airway technique ("bellows to nostril/mouth") without describing the seal or airway maneuvers but incorporating the "larynx gently pressed against the esophagus and spine." Although this maneuver is linked today with the cricoid pressure to prevent regurgitation during the PPV, it had two other purposes. First "to prevent the stomach and intestines being too much distended by the air and leave room for the application of more effectual stimuli [warm wine]." Second the closing of the esophagus, along with the mouth and nostrils, sealed the system, and outlined the ventilation conduit between the nostril and trachea. Thus (forced) the positive-pressure inspiration could be successful even in the absence of airway maneuvers. The bellow's ability to assist with negative-pressure expiration was doubtful and active expiration described as pressure on the chest continued to be part of the RHS's recommended technique.[23]

Hunter recognized the need for an optimal attempt in critical situations and recommended the use of oxygen, urgent intervention, immediately available devices, and a team approach. The assistant should be "well acquainted with the methods …and both together may often be attended with success, though each separately might have failed."[21]

In the same year in Scotland, William Cullen published his letter to Lord Cathcart (President of the Board of Police) with recommendations regarding recovery of the drowned persons.[24] He stated that, in the apparently dead, applying external and internal heat and stimulants could restore the sensibility of the nerves and the irritability of the muscular fibers. In contrast with Hunter, artificial respiration was not a priority. Cullen recommended a progression from extraglottic (expired air, bellow to nose/mouth) to glottic (Dr. Monro's blind intubation technique) and then subglottic ("open the windpipe"/"Bronchotomy") technique. The last two were considered expert techniques for the highly trained physician. The extraglottic ventilation was applied with the mouth, nostril, and esophagus closed. To prevent cerebral congestion, patient transport was recommended as "stretched out with the head and upper parts a little raised, and care is to be taken to avoid the neck's being bent much

forward." This position would be recommended in the future and might have helped victims with marginal breathing to survive.

In 1782, the RHS recommended using the bellows with "cricoid pressure" in preference to MMV.[25] Resuscitation kits were provided with tubes and nose nozzles to be used with bellows (approximate 500 ml capacity). Implementation of an extraglottic ventilation technique with the nasal route for inspiration, an oral route for forceful expiration, and cricoid pressure required at least three instructed participants. Physicians were summoned only for a glottic or subglottic airway access.

Charles Kite (1760 to 1811, Gravesend, Kent, England), a member of the Company of Surgeons in London, noted in 1788 that restoring the suspended action of the lungs was of "utmost importance."[26] The extraglottic technique is similar to Hunter's that required coordination of three people. Kite supported the use of simple bellows and passive expiration ("the thorax will naturally contract"). In case of difficulty, this was remedied "by bringing the tongue forward, which being connected to the epiglottis by inelastic ligaments, must of course be elevated." The next step in his algorithm was blind intubation and then, if a surgeon was present, tracheotomy. Kite and John Savigny (London), a surgical instrument maker, created a portable resuscitation kit containing airway management and stimulation equipment. This system, although labeled highly efficient, would have been cumbersome and ineffective for the uninitiated.

Edward Coleman (1765 to 1839, London) trained with Dr. Kite in Gravesend (Kent, England) and became a physiologist (Professor at Veterinary College, London) with special interest in asphyxia.[27] His resuscitation approach was to "first expand the lungs… and stimulate the heart by a shock of electricity." He upheld the three ventilation techniques: extraglottic (three rescuers), glottic (guided intubation), and subglottic (tracheostomy). He discussed some difficulties of the extraglottic technique: the three rescuers should be in "perfect concord," the cricoid pressure may be inefficient, the "mechanical inflation of the stomach" would prevent the lungs from expanding, and the epiglottis may obstruct the upper airway. Coleman recommended dispersing the stomach air by abdominal pressure. His airway kit, developed with the instrument maker Field, contained an inspiratory/expiratory valve that needed a fourth person to operate the artificial respiration devices[28] (fig. 1).

Edmund Goodwyn (1756 to 1829, London), a physician and avid experimental physiologist, defined in 1783 that UAO develops in unconscious persons by the flaccid tongue falling posteriorly and occluding the opening of larynx.[29] In 1805, he recommended a simple resuscitation plan: "heat to the body and air to the lungs." A valveless "pump" that could be used in an emergency even by the "awkward and ignorant" supported his ventilation techniques.

James Curry (1756 to 1829, Edinburgh, Northampton, London) mostly practiced medicine in London. In 1792, he restated the importance of immediate "artificial breathing" with the algorithmic approach from simple to complex: extraglottic (three rescuers), glottic, and subglottic.[30] He encouraged improvisation in the absence of the airway management devices. The nasal airway could be replaced with a rolled-up card "in the shape of a funnel" and the lack of a bellow supplemented by the rescuer "blowing in the nostril." Curry discussed airway obstruction generated by the tongue "drawn back into the throat." Although he recommended drawing it forward by inserting a finger, there is no explanation of how this airway maneuver would work once the finger is removed. However, in the chapter dedicated to the stillborn child, Curry did not mention the MMV, a technique still practiced by midwives. Instead, he recommended a supraglottic technique: pharyngeal intubation with a "female catheter" (or "wooden tube") with the assistant inflating the lungs by blowing into it.

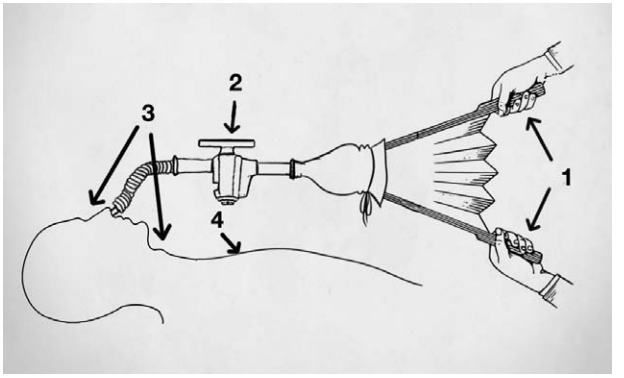

Fig. 1. Coleman's "bellows-to-nose" positive-pressure rtificial respiration system was managed by four rescuers working in concord the bellows (1), the inspiratory/expiratory valve (2), the nose and larynx (3), and the chest (4) (illustrator: Stefan Matioc).

In 1795, the British physician Anthony Fothergill (1732 to 1813) summarized the understanding and intervention in UAO: "In many instances of this nature, the tongue is drawn back into the throat, so as to shut down the Epiglottis and to close the aperture of the windpipe like a valve, by which the admission of air is prevented. This may be easily remedied by drawing the root of the tongue forward and by raising the valve with a finger."[31]

France

Although the Humane Societies in Amsterdam and London were established by private efforts, in France the public institutions organized the recovery and resuscitation of the drowned. Philippe-Nicolas Pia (1721 to 1799, Paris), a pharmacist and elected deputy mayor of Paris, set up in 1772 a rescue system for the drowned along the Seine built on the military structure of *la Garde de Paris* and included the use of his *boîte-entrepôt* ["resuscitation kit"]. Although ventilation with the extraglottic bellows to nostril was recommended, stimulation of multiple organs (*e.g.*, rectal insufflation) took precedence.[32]

In 1780, obstetrician François Chaussier (1746 to 1828, Dijon then Paris) relying on hospital experience gave a unique insight of reanimation in a controlled environment. He rejected MMV as he thought the expired air was noxious and recommended oxygen in the reanimation of the newborn. Chaussier built an apparatus to compensate for the loss of seal when ventilating with bellows through the mouth. The face mask, an impermeable leather-chamoix, covered the nose, mouth, and chin and was connected by a tap to a reservoir bag (well-cleaned bladder) that could contain air or oxygen (fig. 2). The face mask seal could be achieved by hand grip, with a ribbon or adhesive plaster. The system could be adapted to a nostril nozzle. The apparatus was portable, ready to use, and had all the elements of a modern bag-valve-mask system. In 1806, while considering extraglottic ventilation "better than nothing," he recommended intubation of the newborn and ventilation with exhaled air, atmospheric air, or oxygen. He considered stomach inflation as the limiting factor of the extraglottic technique. Unfortunately, his face mask technique had no followers.[33,34]

Jean Joseph De Gardanne (1782) recommended the use of the bellows for ventilation with the extraglottic technique (bellows to nostril) although in a low hierarchical position and described dental and tongue injury if the mouth was forced open.[35] He noted that the tongue was a possible obstruction during ventilation. He mentions MMV as a last resort in the absence of any other apparatus if the rescuer was able to overcome one's loathing for the technique.

Pierre Christophe Gorcy (1758 to 1828), Chief Physician at the military Hospital in Metz (France), developed his *soufflet apodopnique* ["double bellows"] almost at the same time with Hunter. It was designed for active inspiration and expiration, equipped with valves and a stopcock to administer oxygen. Just like the bellows used in Great Britain, Gorcy's device was cumbersome and exposed wood, metal (valves), and leather to rapid deterioration.[36]

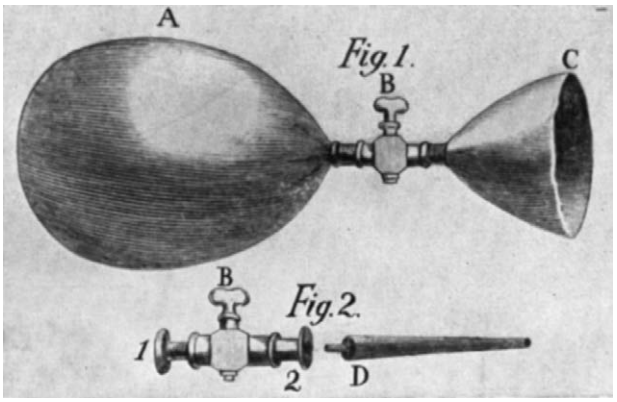

Fig. 2. Chaussier's positive-pressure "bag-valve-mask" was designed to function with air or oxygen (from bag A controlled by valve B); the mask (C) was interchangeable with the nose nozzle (D). Reproduced, with permission, from Mushin WW, Rendell-Baker L: The Origins of Thoracic Anaesthesia. Wood Library-Museum of Anesthesiology, Park Ridge, Illinois, 1991; Chapter VI: The beginnings of intubation. Page 39 (fig. 18): Chaussiere's bag and mask for inflation (1780); image courtesy of the Wood Library-Museum of Anesthesiology, Schaumburg, Illinois.

The French Revolution dismantled the resuscitation infrastructure. In postrevolutionary France, it was again the state's responsibility to reorganize along the directions established by Pia. The airway management followed transport, friction, and stimulants with the extraglottic technique using the nostril airway. The resuscitation kits—supplied by *La Prefecture de Paris*—contained also instruments such as iron spoons and boxwood crowbars to forcefully open the mouth.[37]

Antoine Portal (1742 to 1832) in 1805 supported extraglottic ventilation in adults and MMV in stillborn children in spite of all the negative connotations associated with the latter.[38]

Denmark

In 1796, Johan Daniel Herholdt (1764 to 1836)—physician and Rector of the University of Copenhagen—and Carl Gotlob Rafn (1769 to 1808)—scientist who worked in the Danish Administration—reviewed the literature and recommended best practice for lifesaving measures for drowning victims.[39] They developed a logical algorithm for artificial respiration describing several techniques starting with a simple compression of the chest using both hands to set the lungs in motion "until more suitable means are available." This technique replicated natural respiration but without UAO relief. They considered MMV safe as air collected in a bag and drawn into the lungs would "not become choking until it has been in the lungs either repeatedly or for a long period of time." Herholdt and Rafn referred to the positive clinical experience using MMV in newborn resuscitation. Manual ventilation and MMV techniques were followed by extraglottic, glottic, and subglottic techniques. Airway obstruction could be generated by impurities in the mouth, the glottis "convulsively contracted," epiglottis "pressed back," or tongue falling back. By using a sponge, the nose, mouth, and pharynx should be cleaned. Pulling the tongue forward will lift the epiglottis. Herholdt and Rafn considered death in drowning due to hypoxia (by respiratory obstruction and failure) with artificial respiration for oxygenation being the primary treatment. Unfortunately, this excellent book reflecting hands-on experience was written in Danish and had limited circulation.

The Perceived Limits of PPV (1800 to 1826)

At the beginning of the 19th century, resuscitation was a well-defined intervention with artificial respiration considered after transport, drying, warming, and friction. The RHS did not endorse MMV, as carbon dioxide in expiratory air was "similar to what arises from burning charcoal."[40] Oral access was considered impractical as most of the victims had their mouths clenched and needed violent techniques to open it. This probably diverted the interest from developing an oral interface for ventilation (the face mask). The endorsed technique for nonmedical rescuers was the extraglottic nostril airway with

bellows or own blow.[41] This technique now 50 yr old started losing ground because of its inefficiency. The need for several knowledgeable assistants and an airway kit limited immediate intervention. Operating the bellows was cumbersome and could not be used by "the awkward and ignorant."[42] The use of the bellows are described in the RHS Report of 1814: "When you wish to inflate, press the brass lever; open the bellows; then let go the lever, and, by shutting the bellows, force the air into the lungs. To extract the air, open the bellows without touching the lever; and to expel the foul air, press the lever (to open it), and shut the bellows, by which means the extracted foul air will be thrown away; then still keeping the lever open, dilate the bellows, by which means it will be again filled with fresh air." There was another orifice for stimulating vapors that was supposed to be coordinated with the artificial ventilation.

In 1815, Curry described an oiled silk bag, with a stopcock fitted to it, and recommended to be used instead of the bellows that are "nearly useless" as they are "weak" and cannot push the air through "any resistance (that) was opposed to its passage into the lungs" [UAO]. Curry pointed to the froth and mucus occupying the throat as the obstruction site and recommended a sponge to remove it after drawing forward the tongue. Described at the time when PPV was compromised, this approach was not implemented.[43]

Instruments as intermediaries between the patient and rescuer were considered the realm of barbers, surgeons, and dentists. As such surgeons and apothecaries were most noticeable in the list of medical assistants of the RHS. Instruments also carried a connotation of expertise that discouraged laypeople from using them.

The search for a simple technique to replace the instrument-driven PPV pointed toward manual negative-pressure ventilation techniques. In 1812, the RHS mentioned as an alternative where "bellows or other apparatus cannot be had … to excite the natural inspiration and expiration, by pressure on the thorax, ribs, and abdominal muscles merely by the hands, so as to press out as large a portion of the internal air as possible and then removing the hands." There was no concern for upper airway patency.[44]

Positive-pressure ventilation was discredited on both sides of the Atlantic. In 1814 in New York, Ansel W. Ives in his dissertation for the degree of Doctor of Medicine recommended the immediate ventilation technique pioneered by the famous British surgeon Astley Cooper: using the hands by pressing on the chest and abdomen for active expiration followed by passive inspiration by lifting the hands and relying on the chest elasticity.[45] Surgeon Alexander A. Stevens, who studied under Sir Astley Cooper, in an address to the Humane Society of New York in 1818 criticized the different types of resuscitation machines as being "unnecessarily complicated" and dissimilar: "if a Physician take the pains to familiarize himself with the management of one machine, he is not secure against embarrassment in the use of another." His recommendations remain valid today: the fitting pieces of a device should be "permanently together, that they may always be kept ready for immediate use." Alternatively, Stevens described a manual pressure technique relying on the "elevation and depression of the ribs" that can be applied immediately at the scene of the accident.[46]

The Decline of PPV and the Rise of Negative-pressure Ventilation (1827 to 1846)

In 1827, Jean-Jacques Leroy d'Étiolles (1798 to 1860, Paris) presented a paper to the French Academy of Science in which he demonstrated experimentally that it was possible to kill tracheotomized animals by forcefully inflating the lungs with bellows (pneumothorax).[47] Use of force with bellows was recommended to compensate for an (unintubated) obstructed upper airway. In 1829, two well-known scientists François Magendie (1783 to 1855, Paris) and André Duméril (1774 to 1860, Paris) confirmed, at the request of the Academy, Leroy's finding on intubated human cadavers (and described emphysema after PPV), condemning the technique for the next 50 yr.[48] It was demonstrated in 1888 that drowning generates pulmonary emphysema.[49] The endotracheal tubes used in the animal and human cadaver experiments bypassed any potential UAO invalidating these results for any extraglottic ventilation techniques.

Leroy's intent was not to compromise the PPV but to refine it (today the Advanced Cardiac Life Support guidelines recommend "avoiding excessive ventilation"). Nevertheless, the Academy rejected his newly designed "calibrated bellows," which limited the tidal volume according to the patient's age. Subsequently, Leroy developed a "front-to-back pressure" manual method of ventilation that applied simultaneous pressure on the supine victim's abdomen and thorax and a "split-sheet method" of generating inspiration and expiration by manipulating a bandage-sling placed over the chest and abdomen.[50] He warned that during ventilation the upper airway should be patent. As an inventor and urologist, he addressed the UAO by designing an intubation aid that could be used also to keep the glottis open by pressing the base of the tongue and elevating the epiglottis: and early oropharyngeal airway[47] (fig. 3). Unfortunately, the illustration of his manual ventilation technique represented a supine patient with the mouth closed (fig. 4). The UAO relief maneuver was missing. This depiction would persist in the future, and UAO relief would not be portrayed consistently as intrinsic to negative-pressure ventilation.[51] Although manual ventilation was not an extraglottic technique and did not need a seal for a gas source, airway maneuvers were mandatory for an optimal attempt.

The French Academy (1829) and the RHS (1832) banned the use of bellows and tubes used in PPV and reverted to basic stimulation methods for resuscitation: warming, tickling, rubbing, and applying stimulant vapors to the drowned patients.

In 1831, British surgeon John Dalrymple recommended a version of Leroy's technique to the RHS and suggested a "side-to-side " compression employing long bandages with active expiration and passive inspiration. The rescuers were supposed to compress and relax the bandages at a rate of 25 per minute. From 1833, the RHS recommended John Dalrymple's technique as the only acceptable artificial ventilation method

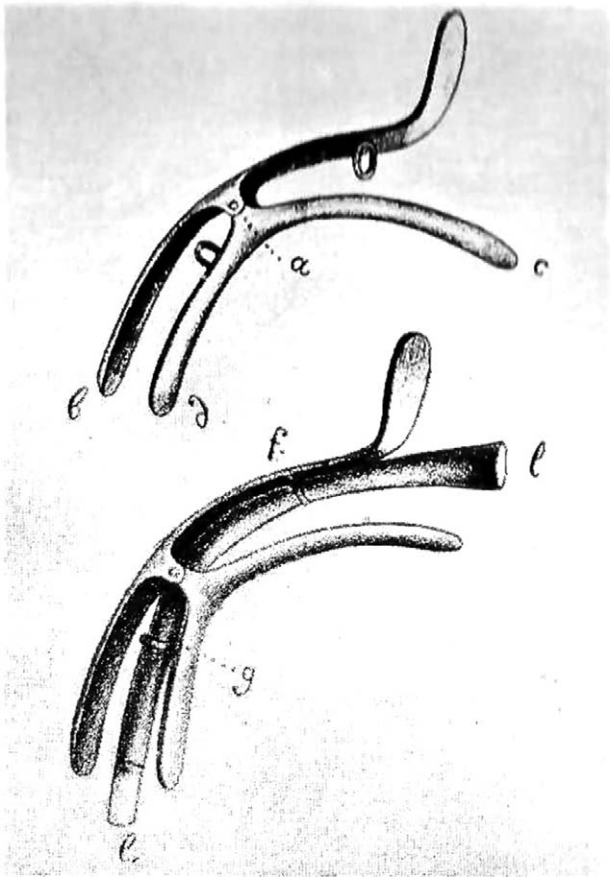

Fig. 3. Leroy's intubation device could be used to relieve upper airway obstruction: an early oropharyngeal airway. Reproduced, with permission, from Mushin WW, Rendell-Baker L: The Origins of Thoracic Anaesthesia. Wood Library-Museum of Anesthesiology, Park Ridge, Illinois, 1991; Chapter V: Resuscitation. Page 36 (fig. 15): Leroy's "safety" bellows and instruments for intubation (1827); image courtesy of the Wood Library-Museum of Anesthesiology, Schaumburg, Illinois.

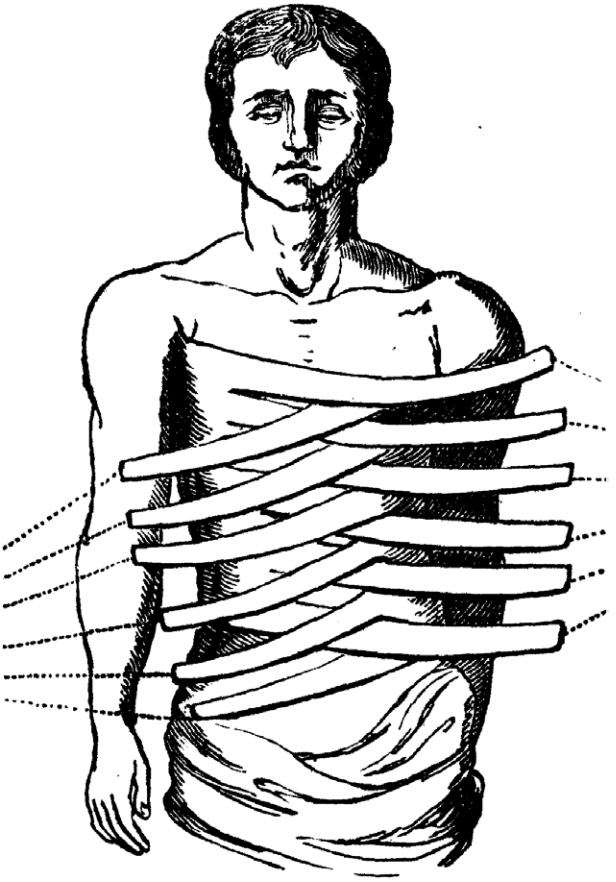

Fig. 4. Leroy's negative-pressure "split-sheet" artificial respiration technique. The method is represented without an airway maneuver for upper airway obstruction relief (Reprinted by permission of the Royal Humane Society, London, United Kingdom. From the 74th Annual Report of the Royal Humane Society, Compton and Ritchie, London 1848. Methods of treatment. Artificial respiration by bandage. Page 65).

for the nonmedical rescuer until in 1858 Silvester's method was introduced. The use of Dalrymple's method use was rarely recorded.[23] There were no instructions for UAO relief, but respiration was monitored at the nostril with a flame of a candle or a fine down of feather. The associated illustration had no representation of UAO relief maneuvers.[52] In drowned victims, artificial respiration was still second to rewarming.

In France in 1835, Charles Chrétiene Henri Marc (1771 to 1840, Paris), responding to an official request by the *Prefet de Police* of Paris, reviewed the literature in search for "best practices" in resuscitation. He presented a plethora of positive-pressure airway devices in the context of devaluated PPV concept. He included many practical observations: bellows were sophisticated but impractical (complicated, expensive, and easily degraded), and the extraglottic techniques prone to failure as the tongue contacted the palate and the epiglottis will be pushed toward the glottis with each forced inspiration. The simplest ventilation technique promoted was the "pressure" technique—by hands or bandages recommended by Leroy.[53]

On both sides of the Channel, the instrumental extraglottic PPV ventilation changed its standing from "simple" to "difficult" and was recommended only to trained professionals along with the glottic and infraglottic techniques. It was resolved to "dispense with (active) lung inflation at least by nonprofessional people" as it was exceedingly difficult to perform. Even an experienced practitioner as Mr. Woolley, well-known medical assistant to the RHS functioning at the receiving house in Hyde Park at Serpentine in London admits in 1835 that in all successful resuscitations he "never performed the operation of inflating the lungs."[54]

There were a few dissenting voices. In 1841, John Snow (1813 to 1858, London) was critical of the consistent underuse of pulmonary resuscitation by the RHS. He states:" It is their [RHS's] opinion that the period in cases of asphyxia when artificial respiration might be successful in restoring life is very short, and scarcely more than momentary; and as it but rarely happens that such means can be applied at the precise moment, artificial respiration should be considered as a secondary means." Snow considered this opinion "perfectly astounding" and recommended

the rescuers to "have an instrument for artificial respiration in the boat" to be used immediately, for otherwise "the process of asphyxia will be going on." If the apparatus was not available, he supported the Dalrymple technique. Snow recommended PPV in opium poisoning. In 6 yr, John Snow would introduce the face mask to anesthesia practice.[55] In 1845, John Eric Erichsen (1818 to 1896, Copenhagen, then London) attempted to revive PPV, also disagreeing with the RHS that artificial respiration was of secondary importance in resuscitation. While he considered Leroy's and Dalrymple's method appropriate for the nonprofessional, he recommended, for the physician, PPV with oxygen using a syringe designed to avoid the overdistention attributed to the bellows. In spite of being awarded the Fothergillian Medal by the RHS for his essay, his recommendation did not stimulate any further interest.[56] Ultimately, Snow and Erichsen (both clinician-physiologists) failed in their effort to convince the RHS to reconsider the resuscitation sequence "warming-artificial respiration." Snow's recommendation: "…warmth ought not to be applied until respiration were first restored" was not adopted.

Other Instances of Airway Management

All through this period, the glottic (intubation) and subglottic (tracheotomy) techniques were recommended in resuscitation but were very rarely used and only by physicians or surgeons. Alexander Monro Secundus (1713 to 1817, Edinburgh), Claude-Nicholas Le Cat (1700 to 1768, Rouen, France), and Pierre Joseph Desault (1738 to 1795, Paris) described different intubation techniques. Advantages of these invasive methods were the bypassing of UAO and the decrease of stomach inflation with improvement of ventilation. Tracheostomy was used in Tours, France, as a rescue procedure for croup on spontaneously breathing children by Pierre Bretonneau (1778 to 1862) and his pupil Armand Trousseau (1801 to 1867). It was "not performed until death seemed inevitable" after leaches and blisters applied to the neck had failed.[57]

Because anatomists had used PPV for centuries to keep animals alive during demonstrations, PPV survived in the laboratories where physiologists were routinely ventilating animals using bellows or syringes through a tracheostomy.[58] One of the most remarkable episodes occurred in 1814 when Sir Benjamin Brodie (1783 to 1862, London) experimenting with curare (wourali) used PPV with bellows on an intubated female donkey until full recovery. Brodie is an example of the challenges facing implementation of scientific ideas in practice as he held a dogmatic view of the use of artificial respiration in human resuscitation until his death.[50]

Conclusions

In the 18th century, Western science had a clear understanding that resuscitation should be attempted in the apparently dead. As a "public" endeavor, the application of heat, stimulation, and artificial respiration was in the "hands of the people," and the RHS had to oblige with simple, approachable, and uncontroversial techniques. However, complex and partially resolved scientific concepts (*e.g.*, respiratory arrest—asphyxia, cardiac arrest, and hypothermia) failed to translate into technological solutions to assure timely treatment of the apparently dead.

Empirical MMV saved lives when practiced by nonphysicians (midwives) in times of "scientific ignorance" but was rejected by the medical community on the basis of a misinterpreted scientific finding. Because of social, esthetic, and scientific reasons, the bellows as an adult artificial respiration technique replaced the MMV initially adopted by the Humane Societies. Ironically, the RHS rewarded a midwife in 1802 for performing MMV for 500 times on infants.[59] MMV continued to be used in asphyxia neonatorum and sporadically in adult drowning.[50,60] The ambivalence of the medical establishment regarding the newborn and adult MMV persisted until the 1950s.

The end of 18th-century approach to pulmonary inflation paralleled largely 20th-century practice.[61] At its peak of sophistication, airway management included all contemporary categories: extraglottic (MMV, cannula to nostril, and cannula to mouth), glottic (intubation), and subglottic (opening the windpipe). The development of these techniques was remarkable in a time dominated by dogmatic medical theories. Curry had a rational physiological view on resuscitation with a totally unscientific medical approach, self-prescribing bloodletting, blistering, and mercury.[62] Unfortunately, practicing physicians had minimal or no interest or experience in resuscitation and airway management. After the introduction of bellows, artificial respiration maintained its secondary status in resuscitation for the coming decades as the few authors interested in the topic reused conventional ideas maintaining the status quo. The recommended technique for laypeople was the extraglottic "nostril airway" ventilation by a rescuer's lungs or bellows. Although the concept was sound, the implementation was cumbersome, ineffective, and underused, and the technique did not have time to mature. The first 150 yr of artificial respiration history did not generate a viable PPV extraglottic technique. Just like MMV, instrumental PPV was (unjustly) rejected.

In the first quarter of the 19th century, the negative-pressure manual methods were introduced as the artificial respiration technique of choice. By then, the RHS was affluent with great international prestige, and the manual negative-pressure techniques were well received and unchallenged until the 1950s.

Inspiratory and expiratory airway obstruction relief was not well understood and described. Deficient techniques focused on directly lifting the tongue obstructing the pharynx and subsequently the epiglottis obstructing the glottis and cleaning the pharyngeal secretions and detritus. UAO was counteracted by forceful inspiration generated by bellows and active expiration by chest and abdomen pressure. The need for continuous UAO relief (during inspiration and expiration) with both positive- and negative-pressure techniques was not recognized. There were no reliable airway maneuvers described. We can speculate that the scarcity of an obese population could have mitigated the impact of suboptimal airway management techniques.

Resuscitation also points to a new aspect of modern medicine: progress as matching theoretical and practical advances

(science matched by technology). The significant advances in asphyxia research in animals were not matched by corresponding simple and efficient PPV artificial respiration techniques in humans. Valid science translated into impractical technological choices. Realizing this mismatch, Erichsen pointed to airway management as a critical undertaking: "*The whole value of artificial respiration, however, depends upon the manner in which it is employed*."[57] His remark is valid today.

As resuscitation techniques moved away from complex, useless, and time-consuming stimulation techniques, artificial respiration maintained its secondary status and moved away from PPV and its corollary UAO relief. Ultimately, PPV lost the endorsement of scientific bodies and was thus excluded from scientific scrutiny. A historical moment that could have elucidated and build expertise in airway management was lost. Subsequently, in the negative-pressure artificial respiration era, the short-lived PPV was seen as a "*backward step in the progress of the Art*."[22] It would take 130 yr for the PPV concepts developed in the 18th century to be reintroduced and validated in modern resuscitation.

Resuscitation and later anesthesia placed the physician in a new and sometimes uncomfortable position outside acceptable medical and social boundaries. Both disciplines required direct contact with the patient, use of instruments, and were manipulating physiology rather than curing a disease. Resuscitation was a coordinated action to reestablish vital physiology and anesthesia a controlled alteration of consciousness. Because both lacked prior traditions, both were perceived as new sciences by physicians, clerics, and the public alike. Advancement in both fields was slow due to the limited scientific interest from practicing physicians.

After the first 150 yr of resuscitation history, both elements of BAM, UAO relief and PPV seal, were missing from the physician's (and soon the physician-anesthetist's) armamentarium. Ironically for the coming 100 yr, the face mask, an extraglottic airway management device, would provide the predominant route for administrating anesthetic gases. Just like the midwives were challenged by the severity and proximity of the dying newborn, so the anesthesia provider will face new (iatrogenic) life-threatening entities—acute asphyxia and cardiac arrest—requiring immediate diagnosis and intervention.

Both inhalation anesthesia and its offshoot, airway management, will start their epic journeys disadvantaged.

1846 was around the corner.

Acknowledgments

The author thanks Karen Bieterman, M.L.I.S., Judith Robins, M.A., and Teresa Jimenez, M.S., L.I.S. (Wood Library-Museum of Anesthesiology, Schaumburg, Illinois); Mark Schroeder, M.D., and Elizabeth Yun, M.D. (Department of Anesthesiology, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin); and Douglas Bacon, M.D., M.A. (Department of Anesthesiology, University of Mississippi Medical Center, Jackson, Mississippi).

Support was provided by departmental sources and by a 2013 Paul M. Wood Fellowship at the Wood Library-Museum of Anesthesiology, Schaumburg, Illinois, awarded in the author name for this topic.

Competing Interests

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

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