Cardiopulmonary Resuscitation: From the Beginning to the Present Day

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- Cardiopulmonary resuscitation • Cardiac arrest
- Ventricular fibrillation • Defibrillation
- Ventilation • Chest compression

Cardiac arrest represents a dramatic event that can occur suddenly and often without premonitory signs, characterized by sudden loss of consciousness and breathing after cardiac output ceases and both coronary and cerebral blood flows stop. Restarting of the blood flow by cardiopulmonary resuscitation (CPR) potentially re-establishes some cardiac output and organ blood flows. CPR has the potential of re-establishing spontaneous circulation, often in conjunction with electrical defibrillation, but CPR is likely to be successful only if it is instituted within 5 minutes after the heart stops beating.[1–3] To this extent, the American Heart Association's concept of the "chain of survival," introduced in 1991 by Cummins and colleagues[4] addresses the priorities very well. This chain includes four links, namely: (1) calling for emergency medical assistance; (2) (bystander-initiated) basic life support; (3) early defibrillation; and (4) advanced life support. The first three links are focused on out-of-hospital cardiac resuscitation by nonprofessional providers. The critical time intervals, in part based on the Utstein templates for documenting the sequence of interventions,[5] begin with the call for emergency assistance, documents arrival time of rescuers (including bystanders), the interventions performed by the emergency medical responders at the site of the victim, and the sequences of interventions that follow. In the instance of ventricular fibrillation (VF), automated external defibrillators (AEDs) have enfranchised

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nonprofessional rescuers to reverse VF. Current evidence supports the value of a well-organized program of bystander-initiated CPR and, in some settings, public access defibrillation.[6] Within the past year, the chain of survival has been amended to include an additional link, namely postresuscitation management.[7]

This article summarizes the major events that encompass the history of CPR, beginning with ancient history and evolving into the current commitment to “save hearts that are too young to die.”[8]

THE HISTORY OF CPR

Early resuscitation attempts to reverse sudden death are as old as human history.[9] However, until the nineteenth century, routine resuscitation from death was not viewed as feasible.[10] Modern cardiopulmonary resuscitation emerged only during the latter half of the twentieth century, even though resuscitation by delivery of an electrical shock was demonstrated as early as the nineteenth century. In the 1900s, asphyxia was a major and even predominant cause of cardiac arrest because of drowning, aspiration, drug overdose, smoke inhalation, diphtheria, asthma, epiglottitis, and traumatic injuries to the head and chest. Accordingly, there was initial emphasis on airway devices and mechanical interventions for breathing. Electrical causes and, specifically electrocution, became significant causes of cardiac arrest in parallel with the emergence of electrical power in the late nineteenth and early twentieth century.[11] This prompted the development and use of defibrillation under the auspices of electrical power companies.[10,12] External mechanical methods for restoring blood circulation were a development of 1960s, when a sequence of interventions was established under the acronym ABCD:[13] Airway, Breathing, Chest compression, and Defibrillation. Although to some extent now modified to take into account priorities of chest compression over the airway, breathing, and defibrillation, the ABCD acronym continues to have practical utility, especially for other than primary cardiac causes of cardiac arrest, such as in newborns, children, and younger adults.

Airway

The earliest description of a method by which an airway could be secured may have been recorded in the Babylonian Talmud, edited between 200 BC and 400 AD.[14] The Talmud describes a lamb that sustained an injury to the neck, such that a large hole was created in the trachea. A hollow reed was inserted into the trachea and the lamb survived. More than a millennium later, Versalius,[15] the famous Belgian anatomist, inserted a tubular reed through a surgical tracheostomy. When the reed was connected to a fireplace bellows, the lungs were inflated. This anticipated the modern method of securing the airway followed by mechanical ventilation. In 1754, the first endotracheal tube was designed under the name of “air pipe.” It consisted of a coiled wire that was covered by soft leather. As described by White,[16] Doctor Pugh used this device for resuscitation after neonatal asphyxia. Endotracheal intubation and mechanical ventilation with bellows thereafter evolved as primary interventions, especially for drowning victims. The primary intervention for opening the airway and thereby assuring patency of the upper airways unobstructed by the flaccid tongue was described in 1783. One hundred years later in 1877, Howard[17] proposed that the tongue of drowning victim be positioned by the rescuer such as to obtain a patent airway. He advised that the tip of the tongue be withdrawn and displaced to the extreme right corner of the mouth. In 1788, Kite introduced a curved metal cannula for blind insertion through the mouth into the trachea. Although the intent was to minimize trauma to the soft tissues of the airway, such was not possible without visualizing the larynx. During the following century, new designs of endotracheal tubes evolved, including a tube with a sponge collar, perhaps the predecessor of currently marketed cuffed endotracheal tubes. Largely through the efforts of Trendelenburg in 1871,[18] these tubes gained popularity. In the 1890s, the introduction of the laryngoscope by Kirstein[19] revolutionized nontraumatic endotracheal intubation. The S-shaped oropharyngeal airway, which continues to be used to the present, was used by Peter Safar (**Fig. 1**), together with the now routine positions of the forehead and mandible with which a patent airway is secured in unconscious victims. Correct patency of the airway was described by Safar and colleagues,[20] who observed in anesthetized, breathing patients, the return of inflated gas into a bag that was connected to the endotracheal tube.

Ventilation

The earliest recorded reference to artificial breathing is in Egyptian mythology, in which Isis resuscitated her dead husband by breathing into his mouth.[21] The Old Testament is another source of impressive historical documentation of mouth-to-mouth breathing. In II Kings, chapter 4, the prophet Elisha is described as restoring the life of a boy by placing his mouth on the mouth of the child.[22] Between 200 BC and 500 AD, the Hebrews used mouth-to-nose ventilation for resuscitation of newborn infants.[23] Early efforts for restoring life of unconscious victims focused on breathing. Primitive fireplace bellows were used for this purpose. Bellows-to-nostril ventilation in human beings was first described by Galen, who in 175 AD inflated the lungs of dead animals. In the 1500s, Paracelsus reproposed the use of bellows to attempt resuscitation of dead persons.[24] Early mouth-to-mouth techniques were subsequently described in several eighteenth century publications cited by Safar.[25] William Tossach,[26] a British surgeon, used mouth-to-mouth resuscitation of a coal miner in 1732. After 4 hours the miner is described as conscious and able to walk without support. In 1745, there was a return to mouth-to-mouth ventilation as a safer and more effective method of ventilation, in contrast to the use of fire bellows.[18] In 1800, a report

Fig. 1. Moritz Shiff, considered the fathers of modern resuscitation.

that a single, rapid inflation with bellows produced a fatal pneumothorax[27] led rescuers to discard the routine use of bellows in favor of mouth-to-mouth breathing. Yet, the use of exhaled air for resuscitation was challenged in 1770 after Scheele[28] proposed the value of oxygen in lieu of the insufflation of expired air because expired air was then perceived to be "devitalized." The combination of devitalized expired gas and the risks of lung barotrauma produced by bellows therefore prompted the search for alternative methods of mechanical ventilation.

Early revival efforts centered on drowning victims. To clear water from the trachea and lungs, the presumed causes of drowning, the unconscious patient was suspended upside down or rolled on a barrel to produce compression and decompression of the chest. Such activity produced ventilation as well as chest compression.[13,17] In 1857, Marshall Hall advanced the "chest-pressure" method, which was modified in 1861 by Silvester[29] to become the "chest-pressure arm-lift" method of artificial breathing in supine patients. The method was later modified by Howard, who placed the victim in the supine position and compressed the chest intermittently to produce expiration and recoil inspiration. Tidal volumes generated by these methods were modest, however. In the early twentieth century, Schafer[30] placed the victim into a prone position and compressed the lower back to produce expiration and recoil (passive) inspiration, a method that was widely taught, including to one of the authors (M.H.W.) when he was a Boy Scout.

The first mechanical respirator was introduced in 1838 and represented a "tank respirator." Negative pressure was generated while the chest was enclosed in an air-tight tank, thereby producing active inspiration and allowing for passive expiration when ambient pressure was restored.[31] The Drinker respirator,[32] or "iron lung" that followed, paved the way for prolonged mechanical ventilation, especially for patients afflicted with neuromuscular failure of breathing, including cervical spinal cord injury and, most of all, paralytic poliomyelitis.

Intermittent positive pressure ventilation first evolved in Europe when cuffed tracheotomy tubes became available. In 1952, Bjørn Ibsen[33] used manual positive pressure ventilation during the Danish polio epidemics, with the participation of hundreds of medical students breathing for victims who had a tracheostomy tube attached to a vented rubber bag for delivery of air or oxygen. This is incorrectly cited by some historians as the beginning of the Critical Care Medicine, yet, such that represented only protracted mechanical ventilation outside of the operating room, rather than the era of continuous hemodynamic and respiratory patient monitoring and management that ushered in care of the critical ill in modern intensive care units in the late 1950s.

In 1954, the mouth-to-mask ventilation for resuscitation was proposed by Elam, which achieved arterial oxygen saturations of more than 90%.[34] Safar,[35] instead, reproposed mouth-to-mouth ventilation as an effective ventilation method during resuscitation because it required no instrumentation. Mouth-to-mouth ventilation generated arterial oxygen saturations as high as 97%. Endotracheal positive-pressure ventilation thereafter became a standard of care for sustaining ventilation, using positive-pressure valves, both the Bennett and Bird devices.[36] These compact ventilators had advantages of patient triggering, greater accessibility, and mobility, though not yet the predictability of delivery of specified volumes of air or oxygen. Subsequently, the self-refilling bag introduced by Ruben[37] in 1958, followed by the addition of the oxygen gas-powered pneumatic demand valve resuscitator in 1964, added important advances to support breathing in emergency settings.[38] The Engstrom became the first pratical volume-controlled, patient-triggered mechanical ventilator.[39] Concurrently, the valve-mask bag became the primary manual emergency-ventilation device for resuscitation, and it continues to be in active use to the present day.[38]

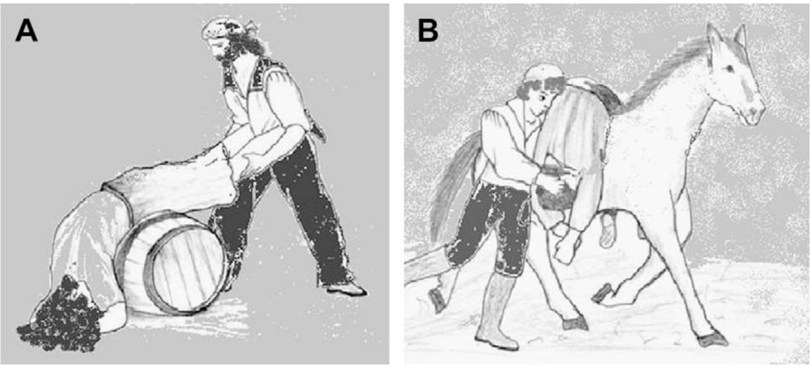

Fig. 2. The "barrel" (*A*) and the "trotting horse" (*B*) methods for chest compression (*Adapted from* Gordon AS. JAMA 1974;227(Suppl. 7)2:834–68; with permission).

Chest Compression

The importance of chest compression, also referred to in the I Kings, chapter 17, emerged again during the eighteenth century. The "barrel method" and the "horse method" (**Fig. 2**), in which victims were placed in prone position over a barrel or the back of a horse, forcefully produced chest compression during rolling or trotting.[13] Nevertheless, chest compression for restarting the circulation was still regarded as a lower priority than ventilation and, historically, even application of external pressure to the thorax was intended to produce breathing rather than circulation.[24] Indeed, it was direct cardiac compressions that Moritz Schiff[40] (**Fig. 3**) described in 1874, when he noted the carotid pulsations closely corresponding to the ejection of blood produced by directly squeezing the canine heart in a dog's open chest. This led to the term "open-chest cardiac massage." The method was effective experimentally

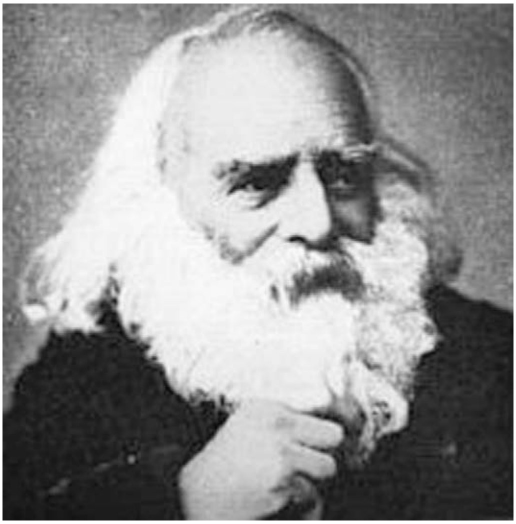

Fig. 3. Peter Safar, who first demonstrated carotid pulsations with open heart massage. (*Courtesy of* the Safar Center for Resuscitaion Research, University of Pittsburgh, Pittsburgh, PA; with permission.)

in that it returned spontaneous circulation in dogs after chloroform-induced cardiac arrest.

Soon thereafter, Rudolph Boehm[41] and Louis Mickwitz studied effects of cardiac compression in cats by pressing on the sternum and on the ribs. In 1883, Koening[42] described compressing the left precordium at the apex, which restored spontaneous circulation in a patient who had cardiac arrest accidentally induced by chloroform anesthesia. Friedrich Maass is credited with the first successful human closed-chest cardiac massage, in 1891.[10,13] However, all these initial trials remained anecdotal. A successful open-chest cardiac massage was performed in 1901 by Kristian Igelsrud, also after anesthesia-related cardiac arrest, and prompted renewed clinical interest in this resuscitation procedure.[43] Consequently, during the first half of the twentieth century, cardiac resuscitation was restricted to the operating room or in proximal in-hospital settings, which included experiences by one of the authors (M.H.W.) during his residency and fellowship training. In 1958, however, Kouwenhoven and colleagues[44] reawakened the potential value of chest cardiac massage when they observed that coincidental with the positioning of paddles on the anterior chest for delivery of an electrical shock, an arterial pulse was produced. This trio of two John Hopkins engineers and a surgeon then demonstrated that external chest compression restored spontaneous circulation in 14 of 20 victims of cardiac arrest, all of whom survived hospitalization. External compression could therefore be performed without surgical expertise or equipment, and now became widely taught and used, and open-chest cardiac massage became obsolete except for intraoperative or posttraumatic resuscitation. A combination of closed-chest compression and mechanical ventilation thereupon formed the platform after the 1960s, and remains as present-day CPR. A strong commitment to mouth-to-mouth or alternative methods of routine ventilation persisted as the co-equal of chest compression until the end of the twentieth century.

Defibrillation and External Pacing

The capability of electricity to stimulate contraction of muscle was clearly described by Galvani[45] in 1791. Ventricular fibrillation, naturally caused by lightering, was first induced experimentally by Ludwig and Hoffa in 1850, when they delivered an alternating electrical current directly to the ventricle of a dog's heart. Subsequently, John McWilliam[46] hypothesized that ventricular fibrillation rather than cardiac standstill was the predominant cause of cardiac arrest. However, the first demonstration that ventricular fibrillation could be terminated by an electrical current was in 1899, when Prevost and Battelli[47] observed that directly delivered low voltage AC currents induced ventricular fibrillation in dogs, and higher voltage currents terminated ventricular fibrillation. Hooker and colleagues[12] were specifically funded to study accidental electrocution by the Edison Electric Institute. They investigated the appropriate energy levels for effective electrical defibrillation by applying electrodes directly to dog hearts and subsequently to the intact thorax. In 1940, the famed Cleveland physiologist, Carl Wiggers,[48] confirmed both the efficacy of electrical defibrillation for reversing ventricular fibrillation and that of open-chest cardiac massage for restoring blood flow in dogs. Seven years later, the pioneer heart surgeon Claude Beck, also in Cleveland, successfully resuscitated a 14-year-old boy who developed ventricular fibrillation during a thoracoplasty for management of congenital chest deformity. Beck[49] performed cardiac massage for 45 minutes before attempted defibrillation. A supraventricular rhythm followed a second defibrillation attempt, with restoration of the pulse and therefore spontaneous circulation. Initially, alternating sinusoidal waveform currents were delivered to the myocardium with a physically large, heavy, and relatively immobile device. Dr. Paul Zoll[50] subsequently recorded the first successful closed-chest human defibrillation in 1955 in a man with recurrent syncope that terminated in ventricular fibrillation. In 1962, Dr. Bernard Lown[51] introduced direct current monophasic waveform defibrillation and demonstrated its superiority when compared with alternating currents. In 1979, the first portable external defibrillator was developed, the precursor to AEDs. A pharyngeal electrode for sensing, electrodes applied to the abdomen and tongue for delivery of a shock, and a simple algorithm to detect shockable electrocardiographic rhythms triggered automated delivery of either pacing or DC defibrillation shocks.[52] The present compact, battery-operated, portable percutaneous pacemakers and defibrillators provide for pacing in the instance of a heart block or cardioversion in the case of ventricular tachycardia or fibrillation. Such are in wide use by professional rescuers. Intelligent automated external defibrillators, which prompt the rescuer in the sequence of interventions before and during defibrillation, are now also commonplace and used by basic life support rescuers with minimal training.

MODERN CPR

The key events that provided the basis for modern CPR are summarized in **Box 1**. Clearly, the modern era of CPR emerged in 1960 with the publication by Kouwenhoven, Jude, and Knickerbocker.[44] Yet, there was little new that would soon be implemented but even more that had to be discarded. As cited above, the various prone and supine chest-pressure and arm-lift maneuvers failed to provide for either opening of the airway or effective ventilation. Mini-thoracotomy, as a routine for open-chest cardiac compressions, was discarded in favor of closed-chest compressions. Electrical defibrillation became a high priority. The now more simplified CPR interventions were extended to the larger domain of both professional and lay rescuers. In part fostered by Peter Safar, Asmund Laerdal in Stavenger, Norway created mannequins and other teaching devices and materials for CPR skill training, including devices for securing airway and for mouth-to-mouth ventilation,[53] chest compression, and defibrillation. Under the auspices of the National Academy of Science National Research Council, James Elam, Archer Gordon, James Jude, and Peter Safar formed a working committee, to which one of the authors (M.H.W.) was invited. This committee developed the first national guidelines for what to teach to whom and how, that was published in 1966.[54] Guidelines were also developed under the auspices of the World Federation of Societies of Anesthesiologists, which expanded guidelines for advanced life support, including cerebral resuscitation.[54,55] In the decade that followed the first National Conference on Standards for CPR and Emergency Cardiac Care was organized under the auspices of the American Heart Association (AHA), which thereafter assumed increasing responsibility for professional leadership of the field, both nationally and later internationally. In 1973, the second National Conference on CPR was held under the auspices of the AHA.[56] More than 3 million copies of the guidelines adopted at that conference were subsequently distributed worldwide, with the intent to promote the teaching of CPR to lay persons as well as medical professionals. Between 1973 and 1980, an estimated 12 million Americans had been trained in CPR and more than 60 million individuals worldwide.[57] Rapid-response systems evolved concurrently and emergency medical personnel, especially, were comprehensively trained in life-support interventions. In the United States, a professional group of rescuers were certified as Emergency Medical Technicians (EMTs), and subsequently, an advanced trained professional, EMT-paramedics, were in many instances organized as a part of traditional community fire rescue services.

Box 1
Key events in the emergence of modern CPR

1732— William Tossach used mouth-to-mouth ventilation for resuscitation of a coal miner.

1754—The first endotracheal tube was designed under the name of “air pipe.”

1773—Scheele isolated oxygen.

1838—The first mechanical respirator was introduced, the “Tank Respirator.”

1850—Ventricular fibrillation was first induced experimentally by Ludwig and Hoffa by delivering an alternating electrical current directly to the ventricle of a dog’s heart.

1874—Moritz Schiff introduced the “open-chest cardiac massage.”

1877—Howard proposed that the tongue of drowning victims had to be displaced cephalad such as to obtain a patent airway.

1891—Dr. Friedrich Maass performed the first documented chest compression in human beings.

1895—Kirstein introduced the laryngoscope.

1899—Prevost and Battelli observed that direct low voltage AC currents induced ventricular fibrillation in dogs and higher voltage currents terminated ventricular fibrillation.

1940—Carl Wiggers confirmed efficacy of electrical defibrillation and that of open-chest cardiac massage.

1947—Claude Beck successfully defibrillated a 14-year-old-boy who developed ventricular fibrillation during surgery.

1954—The mouth-to mask ventilation for resuscitation was proposed by Elam.

1954—James Elam proved that expired air maintained adequate oxygenation.

1955—Dr. Paul Zoll recorded the first successful closed-chest human defibrillation.

1956—Peter Safar and James Elam reproposed mouth-to-mouth ventilation for resuscitation.

1957—The United States military adopted the mouth-to-mouth resuscitation method to revive unresponsive victims.

1958—The self-refilling bag to assist ventilation was introduced by Ruben.

1958—Kouwenhoven and his colleagues, Jude and Knickerbocker, observed that compression of the anterior chest wall produced an arterial pulse.

1962—Dr. Bernard Lown introduced direct current monophasic waveform defibrillation.

1966—The first cardiopulmonary resuscitation guidelines were developed.

1979—The first portable external defibrillator was developed.

The call for resuscitation intervention is very large. Today, as many as 400,000 Americans and 700,000 Europeans sustain cardiac arrests each year.[58] Major efforts to improve outcomes from sudden cardiac death were intended to keep pace with an increasing incidence of cardiac arrest in communities with a predominance of elderly patients with ischemic heart disease.

Still, only 4% to 9% of victims of cardiac arrest survive,[59–62] and the scope of this worldwide epidemic prompted increasing international concern among industrialized nations. After the 2000 International Conference on the science of resuscitation, conferences have been scheduled on an international basis every 5 years, and the recommendations serve as the basis of national guidelines that fulfill local needs.

Yet, the emergence of well-trained rescue services have failed to continue to improve outcomes, except in unique public settings in which there is immediate access to CPR. It became apparent that CPR must be begun within less than 5 minutes of "sudden death."[63,64] It was also increasingly apparent that the promise of improved outcomes was contigent on bystander intervention. More specifically, bystander-initiated CPR by minimally trained nonprofessional rescuers became a high priority after 2000. If there was to be meaningful benefit after arrival of well-organized professional emergency medical responders in home settings, where 80% of cardiac arrest occur,[65] bystander-initiated CPR was needed. With bystander-initiated CPR, the likelihood of increased survival from out-of-hospital cardiac arrest was shown to increase as much as 10-fold.[66,67]

The latest International Conference, under the auspices of the AHA and the International Liaison Committee on Resuscitation (ILCOR)[58] in 2005, resulted in additional and major changes in CPR. The highest priority became uninterrupted precordial compression. To achieve such, interruptions for ventilations were to be minimized and lay rescuers were guided to less frequent or even abandonment of rescue breathing. The emphasis on repetitive defibrillations was moderated and only a single shock rather than three repetitive shocks was advised. The value of uninterrupted chest compression trumped the earlier procedures where chest compressions were stopped to deliver a series of up to three shocks and additional time was consumed to observe the electrocardiographic rhythm. This 2005 ILCOR/AHA conference also urged more focus on postresuscitation management, including routine use of hypothermia in the immediate postresuscitation interval.

Ventilation and Chest Compression

Although initial management of "sudden death" in the 2005 guidelines focused on chest compression rather than ventilation with which to sustain both coronary and cerebral blood flows, the airway and ventilation remain a predominant intervention for management of asphyxial cardiac arrest. These differences in priorities apply especially to the majority of neonatal, pediatric, and young adults in whom airway obstruction and loss of neural functions because of intoxications or neurotrauma are predominant.[58] Nevertheless, debate continues on airway management and the benefits of endotracheal intubation. Both optimal tidal volumes and frequencies of ventilation are still debated.[58] Out-of-hospital endotracheal intubation carries both a high failure rate[68] and as large as a 30% incidence of traumatic injury to the airway.[69] There is increasing use of the laryngeal mask airways because of the ease and predictability of placement and nontraumatic rapid insertion under the usually compromised circumstances of cardiac arrest. Assuring appropriate head and body position during nonasphyxial resuscitation is now an accepted routine. Even for asphyxial cardiac arrest, more modest rates of ventilation and, specifically 2 breaths for 30 compressions, were advised with tidal volumes of no greater than 8 mL/kg.[70] Professional rescuers have typically overventilated patients during out-of-hospital CPR, with less favorable outcomes, in part not only because of fewer interruptions of chest compression required but also because of the increases in intrathoracic pressure produced by lung inflations. The increases in intrathoracic pressure compromise venous return of blood to the heart and, therefore, the amount of cardiac output generated by chest compression.[71,72] By decreasing the frequency of ventilations, cardiac output and pulmonary blood flow are actually increased without compromise of arterial oxygen content or acid-base balance.[73] This prompted the 2005 guidelines consensus that compression/ventilation ratios of 30 to 2 be used in lieu of 15 to 2. Experts appreciated that ventilation is of little benefit unless cardiac output and, therefore, pulmonary blood flow are sufficient to allow for meaningful gas exchange. Because cardiac output during CPR is usually less than one-third of normal, correspondingly less ventilation is required to achieve optimal ventilation/perfusion ratios. Modest ventilation is generated by precordial compression alone and in amounts that are likely to be sufficient for oxygenation of the modest pulmonary blood flow.

Controversies remain regarding the value of routine oxygen breathing, either actively or passively delivered to the airway.[74–76] Spontaneous gasping itself creates pulmonary gas exchange during CPR.[77,78] However, gasping has additional and potentially favorable resuscitative benefits, not only because it produces ventilation but also because it generates compression and therefore cardiac output.[79]

In summary, ventilation has indeed become of lesser importance, except for asphyxial cardiac arrest.[58] No negative impact was observed after out-of-hospital cardiac arrest in human victims of sudden death when ventilation was omitted by the bystander CPR.[80–83] Accordingly, the American Heart Association has recently reiterated that bystanders who witness the sudden collapse of an adult should provide high-quality chest compression with minimal or no interruptions for ventilation. Exceptions include pediatric victims and victims of drowning, trauma, airway obstruction, acute respiratory diseases, and apnea of noncardiac cause.[84]

The evidence is secure that the quality of chest compressions is a major determinant of successful resuscitation.[85–89] Wik and colleagues,[85] grading bystander CPR, defined “good CPR” as generating a palpable carotid or femoral pulse. “Good CPR” improved outcomes in which 23% of victims were resuscitated, but only 1% in the absence of “good CPR.” The quality of chest compressions therefore has a major effect on outcomes.[90,91] Rescuer fatigue affects the outcomes of CPR. Even well trained professional providers cannot maintain effective chest compression for intervals that exceed 2 minutes.[92–95] The challenges are even greater during evacuation and transport of victims. Pike and colleagues[96] had recorded a method of mechanical chest compression and demonstrated its use in dogs as early as 1908. Therefore, the option of using mechanical devices to perform and maintain optimal chest compression has always been attractive.[97] Mechanical chest compression potentially overcomes operator fatigue, slow rates of compression, and inadequate depth of compression. A mechanical compressor also facilitates delivery of an electrical shock without interruption of compression by a human rescuer. Several new devices have recently been introduced to facilitate mechanical chest compression, and these demonstrated equivalency and potentially greater effectiveness than manual chest compression.[98–103]

Defibrillation

More effective electrical shocks have been evolved during the last decade with greater efficacy.[51,104] The monophasic damped sinusoidal waveform for defibrillation, which replaced alternating current shocks, had remained the standard for transthoracic defibrillation for almost 30 years, together with the monophasic truncated exponential waveforms. Biphasic waveform shocks, in which initial current flows are positive for a specified duration and then reverse to negative, were introduced only a decade ago. Such biphasic low-energy waveforms have not only supplanted higher energy monophasic waveforms, but have been modified by individual manufacturers to waveform configuration with a diversity of current magnitude and duration, slopes, and total energies delivered with improved first shock efficacy.[104–110]

The relatively large impact of AEDs since 1996 has allowed for extension of defibrillation capability from emergency medical personnel to minimally trained nonprofessional providers under the AHA banner of public access defibrillation.[64,111–115] The simplicity of operation, guided by voice prompts, have the rather impressive potential of “jump starting” the heart by rapid conversion of ventricular fibrillation or ventricular tachycardia before arrival of professional providers. Survival advantage has been demonstrated in public settings, but their use in homes, in which 80% of cardiac arrests occur, has not been proven beneficial.[111–115] When the duration of untreated VF is less than 5 minutes, the immediate delivery of the electrical shock is life saving,[116–119] and that applies to public sites, including airports[64] and casinos.[120]

Another, and not as yet fully explained aspect, is the reduced incidence of ventricular fibrillation, prompting lesser value to AEDs. Ventricular fibrillation accounted for approximately 40% to 60% of initial rhythms in out-of-hospital cardiac arrest settings in the United States in the early 1990s, but is now estimated to account for only 25% of all out-of-hospital cardiac arrests.[121–124]

Postresuscitation Management

After initially successful resuscitation, more than 60% of patients fail to survive to hospital discharge.[125] Moreover, as many as 30% of survivors manifest permanent brain damage.[126] Patients who are successfully resuscitated following cardiac arrest therefore present with what is now termed “post resuscitation disease.”[127] Most prominent are postresuscitation myocardial failure and ischemic brain damage. The greatest postresuscitation emphasis has been on long-term neurologically intact survival.[7] Evidence favoring correction of electrolyte and glucose abnormalities, control of postresuscitation cardiac rate, rhythm, systemic blood pressure, and intravascular volumes are cited, but objective proof of these interventions is still anedoctal. Of all interventions, the most persuasive benefits have followed the use of hypothermia.[7,128–131]

Within a short 5 years, this therapeutic intervention has proven to be neuroprotective.[132–136] The concept of hypothermia for reducing either or both ischemic and reperfusion injury of the brain represents another pioneering contribution of the late Professor Peter Safar and the persistence of his efforts through his students, and especially Professor Fritz Sterz.[132,135,137] In 1996, Professor Safar and colleagues[137] induced hypothermia by instilling Ringer’s solution maintained at a temperature of 4°C into the abdominal cavity of dogs after resuscitation from cardiac arrest. Cooling was maintained for 12 hours. Functional recovery was associated with minimal histologic brain damage. Two large randomized, controlled clinical trials published in 2002[132,133] documented improved neurologic outcomes in human patients following resuscitation from cardiac arrest. This led the ILCOR, together with the AHA, to recommend routine postresuscitation hypothermia in the range of 32°C to 34°C for between 12 and 24 hours in adult victims who were comatose following out-of-hospital cardiac arrest.[7] In animal studies, hypothermia to levels of 32°C to 34°C, preferably now begun during CPR, has promise of even greater survival and functional benefits.[138–140]

SUMMARY

The attempt to restore the heart beat began with the dawn of recorded history. Yet the modern era of CPR, which began in the 1960s, followed experimental and then human trials that demonstrated that the heart beat could be effectively restarted providing that interventions were prompt. These initially included restoration of breathing, recirculation of blood, and electrical conversion of otherwise fatal ventricular fibrillation.

The early emphasis on ventilation included assuring a patent airway and externally producing gas exchange. Blood flow was initially restored by open-chest cardiac massage and superceded by closed-chest precordial compression 15 years later. Electrical defibrillation was first used simultaneously with the advent of open-chest cardiac massage and has been progressively refined for closed-chest defibrillation, with more effective currents and waveforms and lower total energies delivered.

The emergence of automated defibrillators has allowed for defibrillation by nonprofessional rescuers. Both the reduced incidence of ventricular fibrillation and the increased efficacy of defibrillation when preceded by chest compression have reordered the priorities of CPR in favor of well-executed and uninterrupted chest compressions.

Within the last decade, there has been increasing focus on bystander CPR for maintaining minimal systemic blood flow. This provides the greatest likelihood of meaningful survival after the arrival of professional rescuers.

Finally, the persistent poor yield of meaningful survival after cardiac arrest, including a large falloff of recovery after restoration of spontaneous circulation, highlights the importance of better postresuscitation management. Of all recent advances in pursuit thereof, the early start of hypothermia appears to be the best option for minimizing postresuscitation complications and especially post ischemic brain injury.

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