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Part I

Introduction

## A history of cardiopulmonary resuscitation

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For much of recorded history, humans have viewed death as irreversible. For religious and scientific reasons it was considered impossible, or even blasphemous, to attempt to reverse death. It was not until the latter part of the eighteenth century that humans began to believe that resuscitation was possible. Another 200 years passed before the skills for resuscitation were developed to a degree that made the reversibility of cardiac arrest a practical reality in the 1960s. Many important observations and much real progress had nevertheless been made during the intervening years. But the clinical problems were poorly understood, the implications of new discoveries were not always appreciated, single components of life-saving were attempted in isolation, procedures that were potentially effective were often displaced by those of no value, and suitable technology was lacking. Resuscitation had to await its time. Nevertheless, its history is of interest and has important lessons for us today.

### The earliest years

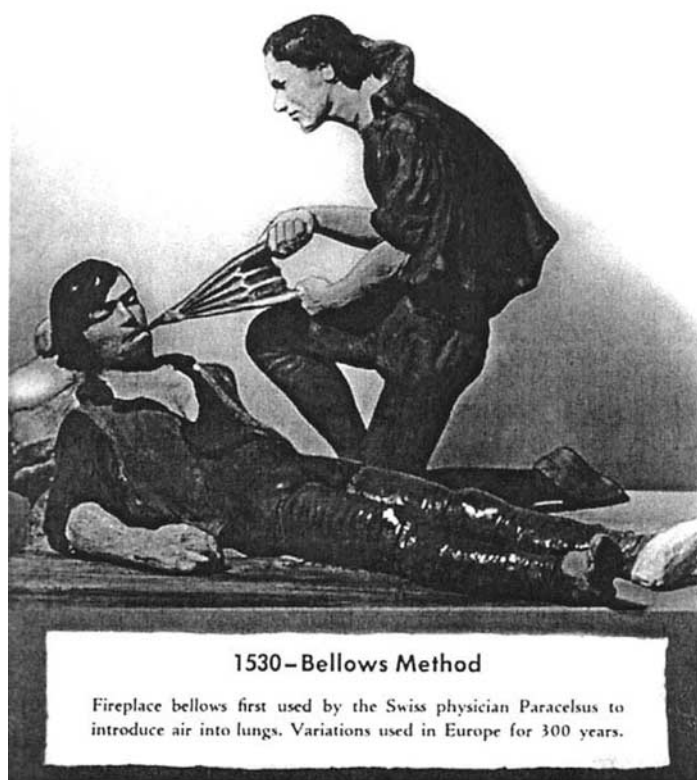
The first written account of a resuscitation attempt is that of Elijah the prophet. The story in the Bible tells of a grief-stricken mother who brought her lifeless child to Elijah and begged for help. Elijah stretched himself upon the child three times and, with the assistance of God, brought the child back to life. An even more detailed account of a resuscitation attempt is that of the prophet Elisha, a disciple of Elijah. The child of a Shunemite couple whom Elisha had befriended suffered from a severe headache. He cried out, “*Oh, my head, my head!*” and collapsed. Was this a subarachnoid bleed? The Bible gives no further clues. The boy

died several hours later. The frantic mother found Elisha who entered the house and:

... placed himself over the child. He put his mouth on his mouth, his eyes on his eyes, and his hands on his hands, as he bent over him. And the body of the child became warm. He stepped down, walked once up and down the room, then mounted and bent over him. Thereupon, the boy sneezed seven times, and the boy opened his eyes.

Some authorities speculate that the weight of Elisha compressed the child's chest and that Elisha's beard tickled the child's nose and caused subsequent sneezing! Perhaps this is the origin of the phrase “*God bless you*” following a sneeze.<sup>1</sup>

From biblical times until the Middle Ages, several people stand out in the quest to reverse sudden death. Among these is Galen (AD 130 to 200), who lived in Greece. His writings – more than 22 volumes – influenced medicine for the next 1300 years: until the sixteenth century he was considered the final authority on all matters related to health and disease. His experiments, conducted mostly on pigs and monkeys (human vivisection was taboo!), constituted a fund of anatomical and physiological knowledge. Throughout the Middle Ages, there could be no divergence from the “truth of Galen” – however wrong he may have been in some of his writings.<sup>2</sup> Galen taught that the innate heat of life was produced in the furnace of the heart. It was turned on at birth and extinguished at death, never to be lit again. This strongly held belief, passed on through the centuries, is one reason why no one believed that death could be reversed. A non-breathing person was not receiving pneuma; the heart's furnace became permanently cooled.



**Fig. 1.1.** The bellows method of ventilation (courtesy of the Chicago Museum of Science and Industry).

With the end of the Western Roman Empire in AD 476, Western culture entered a millennium of intellectual stagnation that influenced every aspect of society, including medicine. The first stirring of modern scientific inquiry occurred during the Renaissance and reached fruition in the Enlightenment of the eighteenth century. The work of the two great anatomists of the Renaissance, Andreas Versalius and William Harvey, finally began to erode the inviolable “truth of Galen.”

In 1543 Andreas Versalius (1514 to 1564), at 28 years of age, published *De Humani Corporis Fabrica*,<sup>3</sup> a remarkable treatise on human anatomy which began to discard the ancient Galenic superstitions. Versalius’ ability to refute the statements of Galen was due largely to the availability of cadavers. The judge of the Padua criminal court became interested in Versalius’ early work and in 1539 made the bodies of executed criminals available, apparently delaying executions for his convenience.<sup>4</sup> Although, strictly, he was not the first in the sixteenth century to describe artificial ventilation, he described how the lungs of animals collapsed after the chest was opened and that the heart was then affected.<sup>3</sup> But then:

... that life may... be restored to the animal, an opening must be attempted in the... trachea, into which a tube of reed or cane should be put; you will then blow into this, so that the lungs may rise again and the animal take in air... I have seen none... that has afforded me greater joy!

Versalius must be considered the true father both of modern anatomy and of resuscitation. Sadly, his heterodox views were widely condemned. To avoid execution, allegedly for conducting an autopsy on a nobleman whose heart was seen to be beating, he set out on a pilgrimage to the Holy Land but died before he was able to return.<sup>4–6</sup>

As is so often the case, a new idea emerges almost simultaneously from more than one source. The illustration on the use of bellows for artificial ventilation (Fig. 1.1) is from the frontispiece of the 1974 American Heart Association publication on standards for cardiopulmonary resuscitation;<sup>7</sup> it has a notation that the method dates from 1530. It was in that year, 13 years before the publication of Versalius’ great work, that Paracelsus<sup>8</sup> was said to have used the technique in an apnoeic patient. But he, too, was a controversial figure, driven out of Basel to wander through Europe, eventually to meet a violent death.<sup>9,10</sup> He had much less influence on subsequent events than did Versalius. Indeed, no firm evidence exists to confirm the belief that Paracelsus was responsible for the use of bellows for ventilation or indeed wrote on the topic at all!<sup>12</sup>

In the following century, the pace of progress quickened. The English physician William Harvey, who had studied in Padua 60 years after Versalius, was the first to provide a definitive description of the circulatory system in *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus*.<sup>11</sup> *De Motu Cordis*, as it is commonly known, wrought a revolution in medicine and biology after it was published in 1628 with only 17 brief chapters and 72 pages. Robert Hooke was among a group of gifted all round British scientists in the latter part of the seventeenth century, which included Robert Boyle, Isaac Newton, Thomas Willis, and Christopher Wren.<sup>12</sup> He was a prominent member and Curator of the Royal Society which had been founded in 1660. In October 1667, Hooke demonstrated to the members of the Society – using a dog – that the movements of the heart and lungs were independent of each other but that the action of the heart was entirely dependent on lung inflation with air.<sup>13</sup> Hooke also experimented with combustion and showed that fresh air was essential for burning charcoal and that “satiated air” would not support combustion. One hundred years before the discovery of oxygen, Hooke drew the analogy between fresh and “satiated” in combustion and in respiration in animals “*who live no longer than they have fresh air to breath.*”<sup>14</sup>

By the eighteenth century, the stage was set for an explosion of experimentation and growth in knowledge about the human body. This burgeoning of scientific discovery and the development of the scientific method occurred during the period known as the Enlightenment. Its leaders claimed that the means to discover truth was through the scientific method. The rise of secularism and the concomitant rise of science allowed the first attempts at resuscitation to be made. In the mid 1700s the four main components of resuscitation (artificial ventilation, artificial circulation, electricity, and emergency medical services) began to emerge. They would eventually develop and coalesce, giving us the ability to reverse death.

### The search for artificial ventilation

Deaths during the eighteenth century must be placed in their medical context. People did not generally die from cardiovascular disease; they died principally from accidents, infectious disease, drowning, and smoke inhalation from fires. One of the first accounts of mouth-to-mouth resuscitation appeared in 1744,<sup>15,16</sup> although the event actually took place in 1732. A Scottish surgeon named William Tossach was called to a man overcome by

nauseous steam arising from coals set on fire in the pit. His skin was cold, there was not the least pulse in either heart or arteries and not the least breathing could be observed. I applied my mouth close to his and blowed my breath as strong as I could, but having neglected to stop all his nostrils, all the air came out of them, wherefore taking hold of them with one hand . . . I blew again my breath as strong as I could, raising his chest fully with it and immediately I felt six or seven beats of the heart.

Tossach added that the man had walked home 4 hours later. Tossach modestly commented that his technique “*is at least very simple, and absolutely safe, and therefore can at least be no harm, if there is not an advantage in acquainting the publick of it.*” John Fothergill, a London practitioner, did feel when he learned of the incident in 1745<sup>17</sup> that for facts of such great importance it is the duty of everyone “*to render them as extensively public as it is possible.*” And so indeed he did, with a list of indications for its use that included suffocation in water.

Drowning was by then a matter of great and growing concern. Fothergill, together with wealthy and benevolent gentlemen in Holland, was influential in the formation in 1767 of a Society for the Recovery of Drowned Persons in Amsterdam (*Maatschappij tot Redding van Drenkelingen*), later called the Humane Society (Fig. 1.2a). One year after its establishment, magistrates in Milan and Venice began

similar societies. In 1769, the city of Hamburg passed an ordinance providing notices to be read in churches describing assistance to be given to drowned, strangled, and frozen persons and those overcome by noxious gases. Paris began a rescue society in 1771, followed by London (Fig. 1.2b) and St. Petersburg in 1774.<sup>18</sup> Within 4 years of its founding, the society in Amsterdam claimed that 150 persons were saved by their recommendations.<sup>19</sup> The members of the society recommended: (a) warming the victim; (b) removing swallowed or aspirated water by positioning the victim's head lower than feet, applying manual pressure to the abdomen, and tickling the victim's throat; (c) stimulating the victim by such means as rectal and oral fumigation with tobacco smoke; (d) using a bellows or mouth-to-mouth method (mouth-to-mouth or mouth-to-nostril respiration is described including the advice that “*a cloth or handkerchief may be used to render the operation less indelicate*”); and (e) bloodletting. In general, 6 or more hours were considered a reasonable duration for a resuscitative effort.<sup>19,20</sup>

Unfortunately, mouth-to-mouth ventilation was soon discouraged by the Royal Humane Society of London. This was partly on aesthetic grounds, a consideration even today, but also because Priestley had discovered by 1774 that the composition of expired air was different from that which was inhaled – and therefore “*unfit to enter any lungs again.*”

Although some recommendations for mouth-to-mouth ventilation continued through the nineteenth and early twentieth centuries,<sup>21</sup> it was well out of fashion and virtually forgotten. William Hunter considered it to be “*a method practised by the vulgar.*”<sup>22</sup> So it was that the Royal Humane Society in 1782, less than 10 years after it had been formed, recommended bellows once again in preference to mouth-to-mouth ventilation.<sup>18</sup> By this time, the technique had been developed and refined. In 1776, John Hunter (the brother of William Hunter who guided his early career) had presented to the Society the results of experiments in which bellows were designed to be introduced into one nostril, while at the same time the other nostril and the mouth were occluded. Its mechanism generated both positive and negative pressure.<sup>23</sup> It is noteworthy that John Hunter had also gained considerable experience in humans and made attempts to revive persons who had been hanged as a judicial process.<sup>24</sup>

But using bellows to blow into the nose was clearly not satisfactory, nor universally accepted. The Versalius technique of tracheal intubation was becoming fashionable again, even while bellows and the mouth-to-mouth methods were still in vogue. There were very full details of the technique in a letter from Dr William Cullen<sup>25</sup> dated 1776: “*Dr. Monro informs me, it is very practicable to introduce directly into the glottis and trachea a crooked tube such*





Fig. 1.2. (a) An account of the founding of the Amsterdam Rescue Society in 1767. (b) Cover of *Royal Humane Society of London Transactions*, showing medals awarded to rescuers (by courtesy of the Society).

as a catheter used for a male adult.” Dr. Munro, a professor of anatomy, had other prescient views, for in the same letter we read:

Whether blowing in is done by a person’s mouth or by bellows, Dr. Munro opines that the air is ready to pass by the gullet into the stomach, but that this may be prevented by pressing the lower part of the larynx backwards upon the gullet. To persons of little knowledge of anatomy it is to be observed that the pressure should be only on the cricoid cartilage, by which the gullet may be flattened, while the passage through the lungs is not obstructed.

Cricoid pressure became accepted in anesthesia and in resuscitation 185 years later after its description by Sellick,<sup>26</sup> but he and others subsequently became aware of Dr. Munro’s earlier recommendation.<sup>27</sup>

Despite all the shortcomings and ill-advised notions on treatment, efforts to prevent death from drowning were

nevertheless effective. Herholdt and Rafn<sup>28</sup> reported in a landmark publication of 1796 that 990 lives had been saved by 1793, with a survival rate over the previous 9 years of 50%. The efforts showed commitment and ingenuity. The amphibious craft illustrated in Herholdt and Rafn’s book (Fig. 1.3) was used to move quickly over rough ice to reach drowning victims; if the ice gave way, the rescuer himself would not be at risk because he had a safe haven all around him. The value of postural drainage to empty the lungs was, however, more controversial, especially as it was recognized that the lungs even in fatal cases might remain relatively dry.

By this time, interest had been aroused not only in resuscitation but also in the numbers being treated. Charles Kite was an active member of the London Humane Society who wrote an *Essay on the Recovery of the Apparently Dead* in 1778 describing the epidemiology of drowning for which he



Fig. 1.3. An amphibious rescue craft designed for work on ice.

was awarded the Silver Medal of the Society.<sup>29</sup> He has been described as the father of resuscitation epidemiology.<sup>30</sup> He emphasized the need to keep accurate records and the need for speedy intervention. He advocated artificial ventilation with warm air or “*dephlogisticated air*” (see below) and suggested cricoid pressure and treatment of cardiac arrest with electric shocks. He was a methodical person and designed a pocket resuscitation kit in a case with “*a collection that comprehends every article except an electrical machine*” and also a description of the correct way to use these instruments<sup>31</sup> “. . . it will prove a very considerable acquisition to the resuscitation air.” He practiced his theories and describes vividly his experience of a remarkable recovery from drowning in a soldier with a head injury.<sup>32</sup>

At this time, the concepts of fresh and satiated air, set down by Versalius and Hooke two and one centuries earlier, were refined by three scientists working in different countries and more or less independently, although they had some contact. Although the credit for discovering oxygen is usually given to Priestley (1775)<sup>33</sup> from England and Lavoisier from France (1775),<sup>34</sup> it is now agreed that Carl Scheele, a Swedish chemist working in Germany was the first to isolate “*fire air*” in 1772 and 1773. He demonstrated that this was essential for plants to live but could not make an accurate analogy with human respiration. He was slow to publish his findings and his paper of 1777<sup>35</sup> followed that of Priestley who had published his work 2 years earlier in 1775.<sup>33</sup>

Priestley was a Yorkshireman who had trained as a priest and a teacher but had a passion for the composition and chemistry of gases.<sup>36</sup> In 1774, while acting as librarian to the Earl of Sherborne, Priestley had collected a colorless odorless gas from heating red mercuric oxide with sunlight focused through a 12-inch burning lens. He had isolated oxygen but did not call it that – he called it “*dephlogisticated air*” and recorded that it supported combustion vigorously and that a mouse survived in a sealed container filled with this gas for much longer than in atmospheric air. He inhaled the gas himself and “*I fancied that my breast felt peculiarly light and easy for some time afterwards.*”<sup>37</sup>

Lavoisier was born in Paris and studied both law and a wide spectrum of scientific subjects, including geology, mineralogy, electricity, anatomy, biology, chemistry, botany, and weather forecasting.<sup>36</sup> In 1766, he was awarded a Gold Medal by the King for the design of a new form of street lighting for Paris. Lavoisier was aware of the work of Scheele and Priestley but branched out further. He was able to demonstrate that “*air eminently respirable*” or “*fire air*” or “*dephlogisticated air*” was an element, and that when combined with hydrogen it formed water. This newly discovered element was renamed oxygen. He undertook a number of experiments that showed that oxygen was consumed during respiration and carbon dioxide and heat were produced, especially during exercise and after a robust meal.

Both Priestley and Lavoisier were liberals and supported the French Revolution. This was not to stand them in good

stead. Priestley was vilified in England and had to emigrate to the United States where he died in Pennsylvania in 1804. Lavoisier was beheaded in public (immediately after his father-in-law). Joseph-Louis Lagrange is quoted by Wilkinson<sup>36</sup> as having said “*It took only an instant to cut off that head but it is unlikely that a hundred years will suffice to produce a better one.*”

In the middle of the nineteenth century, a major change occurred in artificial respiration. Marshall Hall (1790–857), a physician in London, advocated the use of mechanical expansion and compression of the chest wall. In his paper *Asphyxia, its rationale and its remedy* of 1856,<sup>38</sup> he criticized the Royal Humane Society’s techniques, and recognized that in a supine position the victim’s tongue and larynx fell back and blocked the airway. His method involved repeatedly shifting the victim’s position from prone (expiratory) to side (inspiratory) 15 times a minute.<sup>39</sup> Over the next 100 years, dozens of other mechanical methods were promoted. Henry Silvester, a London physician, advocated raising the victim’s arms above the head to expand the upper rib cage and then placing them on the chest and applying pressure to cause exhalation.<sup>40</sup> A New York physician, Benjamin Howard, described what he called the direct method in which the victim was placed on his or her back while a bystander held the tip of the tongue.<sup>41</sup> The rescuer knelt astride the patient’s hips and pushed into the upper abdomen and squeezed the ribs at a rate of 15 times per minute. In 1890, the Royal Medical and Chirurgical Society in England formed a committee under the chairmanship of Sir Edward Sharpey-Shafer to evaluate current methods but concluded that they were all inadequate.<sup>42</sup> (Shafer has caused confusion by adding Sharpey to his name in honor of his teacher in anatomy and physiology, William Sharpey.) Although essentially an histologist and the author of the standard textbook of the time, *Essentials of Histology*, which had appeared in 1899 and continued through 17 editions until 1953,<sup>43</sup> Shafer also had a profound interest in artificial respiration. He developed a new method<sup>44</sup> with intermittent pressure on the back of the prone victim which he believed not only achieved adequate gas exchange, but also maintained an open airway, allowed water and mucus to drain away, posed no other risk to other organs, was easy to learn, and could be performed without fatigue. Shafer did comparative experiments on his laboratory assistant using each of the methods devised by Hall, Silvester, Howard, and himself and claimed that his own method produced by far the best expired minute volumes (6.76 L). Although this method faced considerable opposition (and some said that perhaps Shafer’s laboratory assistant was too keen to please his professor<sup>45</sup>), it gradually became a standard, both throughout much of Europe and in the United States, and

was not dropped from the First Aid Textbook of the American Red Cross until 1959 when the whispers of its detractors rose to a clamor.<sup>46</sup>

The methods used for mechanical artificial respiration did vary, however, on a geographical basis. Silvester’s method was followed in Germany,<sup>47</sup> Holland, and Russia, whereas Schafer’s method was followed in the United States, England, France, and Belgium.<sup>48</sup> Colonel Holger Nielsen, in Denmark, believed that the best solution to the controversy was to develop yet another method that combined the best features of both the popular techniques. His original plan was to have two rescuers: one was to perform prone pressure on the lower back to cause exhalation, whilst the other rescuer was to lift the arms above the victim to facilitate inhalation. The Danish Red Cross rejected this proposal in 1930 because it could not be performed by a single person. Nielsen went back to the drawing board. Apparently, his breakthrough came when he visited a masseur for relief from rheumatic pains in his shoulders. Nielsen noticed that when the masseur pressed down on his shoulder blades he experienced a forceful expiration. This personal experience led him to suggest in 1932 that a single rescuer be positioned at the head of the victim, alternating pressure on the upper back for expiration with arm lifting for inhalation. He presented physiological data to support the superiority of his prone back pressure–arm lift method over Schafer’s or Silvester’s techniques. Acceptance of Nielsen’s method by Red Cross societies was rapid. Instruction in the new artificial respiration spread throughout Europe and to the United States.<sup>48</sup>

Frank Eve, a physician who practiced in Hull in Yorkshire, adopted a different approach.<sup>49</sup> He regarded the thorax as a cylinder with a piston, the diaphragm. He noted that the cylinder wall is often rigid, especially in elderly men and in victims of drowning. He believed it was better to exploit the piston element

Essentially the method consists of laying the patient on a stretcher which is pivoted about its middle on a trestle and rocking up and down rhythmically so that the weight of the viscera pushes the flaccid diaphragm up and down.

Eve produced case reports in 1932<sup>50</sup> to support his rocking method and experimental evidence in 1933<sup>51</sup> claiming tidal volumes of 650 ml – much greater than the various chest compression and arm lift methods. His technique was officially adopted and endorsed in the United Kingdom by the Royal Navy during the Second World War, before being superseded by the expired air method.

In 1949, Archer S. Gordon began evaluating different methods of artificial respiration to determine which was most effective. Gordon’s research included measurements



on fresh corpses from the adult wards of Cook County Hospital in Chicago. With no research funds available at first, Gordon worked with no salary and, since he was on-call 24 hours, slept in his supervisor's office. He later recalled: *"When I received a call that a patient had expired, I rushed across the street, got my cart of equipment, rushed to the ward, moved the corpse to a secluded examining room, and proceeded with my studies."* Gordon would insert a tube into the trachea and connect it to a respirometer; it was long before the days of sophisticated electronic measurement devices. He measured the results of his experiments on the smoked drums of a kymograph. Not only did he smoke the paper for the drums himself, but also after each case he would shellac the tracing in order to preserve the record. Gordon's early results were published in 1950.<sup>52</sup>

Meanwhile, the US Defense Department became interested in his work; some form of manual resuscitation might help soldiers stricken by nerve gas. At the instigation of the military, Gordon began working with live subjects. He anesthetized medical student volunteers and paralyzed them with curare in order to carry out procedures similar to those used on corpses. By 1951, his considerable bank of data had shown that a modified Holger Nielsen method of manual respiration surpassed all others that he had tested, in terms of efficacy and ease of performance learning. In a subsequent paper,<sup>53</sup> Gordon alluded to mouth-to-mouth and mouth-to-nose artificial respiration, but stated that because of the *"difficulties involved in studying and teaching the method, it has not been included in these tests."* It was a missed opportunity. Had Gordon included mouth-to-mouth ventilation in his tests, he would have found it to be far superior to any of the manual methods.

Gordon's research came after 200 years of experiments in artificial respiration. In 1953, Karpovich was able to list 105 published methods recommended for adults and 12 for infants.<sup>1</sup> With the cacophony caused by the advocates of so many methods, and with none being truly effective, it is no wonder that confusion, argument, and controversy ruled. Many of the experiments by Gordon and others were done with tracheal tubes in place, thanks to the inventiveness of Kuhn,<sup>54</sup> Magill,<sup>55,56</sup> and Mackintosh<sup>57</sup> and thus the problem of obstructed airway was never taken into account. Even if the airway was not obstructed, these techniques resulted in air exchanges well below that which was needed to sustain life. In the early 1950s, the world awaited a better method.

### The kiss of life

James Elam was the first contemporary investigator to prove that expired air was sufficient to maintain adequate

oxygenation, when he used mouth-to-nose breathing on patients with acute poliomyelitis paralysis during an epidemic in Minnesota in 1946.<sup>58</sup> These episodes invariably occurred at times of equipment failure or when patients arrived in the hospital with acute respiratory paralysis.

Elam chose mouth-to-nose ventilation because he believed it was the obvious thing to do in such emergencies. He described his first experience in detail:<sup>59</sup>

I had just gotten to Minneapolis . . . and I was browsing around to get acquainted with the ward when along the corridor came a gurney racing – a nurse pulling it and two orderlies pushing it and the kid on it was blue. I went into total reflex behavior. I stepped out in the middle of the corridor, stopped the gurney, grabbed the sheet, wiped the copious mucous [sic] off his mouth and face, tilted his head back, took a big breath, sealed my lips around his nose, and inflated his lungs. In four breaths. I kept on because they had to do a tracheostomy. He was just totally unable to swallow; he had bulbar polio.

With a zealot's passion he spoke of the value of mouth-to-nose ventilation whenever he could, drawing attention to the ineffectiveness of the Holger Nielsen method. To prove that exhaled air was adequate to oxygenate a non-breathing person, Elam obtained permission to do studies on postoperative surgical patients before they recovered from ether anesthesia. The tracheal tube was left in place and succinyl choline was continued as a drip. Elam found by blowing into the tube with his expired air that normal arterial oxygen saturation could be maintained in the patients. After he had published his results in 1954,<sup>60</sup> the US Army Chemical Center in Edgewood, Maryland, recognized the potential value of Elam's findings as a method for ventilating victims of nerve gas (anticholinesterase) poisoning. Although impressed by a successful technique that required no respiration equipment, the Army could not endorse the technique without the blessing of the National Research Council. The Red Cross, meanwhile, was unconvinced that expired air resuscitation was superior to other techniques: manual methods continued to prevail.<sup>61</sup>

By good fortune, Peter Safar joined James Elam on a long car journey from an anesthesia meeting in Kansas City to their homes in Baltimore in October 1956; their 2 days together led to a collaboration that was to change resuscitation practice for ever. Safar was stimulated to become involved in resuscitation research and began a series of experiments on curarized volunteers to see if mouth-to-mouth artificial respiration was effective. By the spring of 1957, he had proved conclusively three essential points in relation to artificial ventilation:<sup>62</sup> first, simply tilting a person's head backward would usually open the airway; second, most existing manual ventilation techniques provided little air, whereas mouth-to-mouth provided



excellent artificial ventilation; third, mouth-to-mouth resuscitation could be performed easily and effectively.

Review (ethics) committees did not exist at the time of Safar's experiments on human subjects; the chief investigator was responsible for ensuring the safety of subjects and for the ethical conduct of research. Safar was well aware of the potential risks. He went to great lengths to explain the experiment to the subjects, instituted multiple safeguards to ensure their safety, and supervised each experiment himself. The volunteers were heavily sedated and thus were not conscious of their paralysis, which generally lasted 1 to 3 hours. All subjects breathed a combination of 50% oxygen and 50% nitrous oxide and were closely monitored. No one was allowed to remain in a non-breathing state for more than 90 seconds, and the high oxygen content of the blood (from breathing 50% oxygen) made this safe.<sup>62</sup>

Within a year, Elam, Safar, and Gordon convinced the world to switch from manual to mouth-to-mouth methods.<sup>63</sup> A 1958 issue of *J. Am. Med. Assoc.* contains the following endorsement:<sup>64</sup>

Skilful performance of expired air breathing is an easily learned, lifesaving procedure. It has revived many victims unresponsive to other methods and has been proved in real emergencies under field conditions. Information about expired air breathing should be disseminated as widely as possible.

The invention of the self-inflating bag valve mask by Ruben in 1957 provided a key advance in artificial ventilation that was independent of compressed gas and the aesthetic drawbacks of the mouth to mouth method.<sup>65,66</sup> It became, and remains, the optimal method for healthcare professionals to provide artificial ventilation in the emergency situation.

### The search for artificial circulation

Probably the first mention of chest compression to treat cardiac arrest appeared in a dental journal – written by John Hill, an English surgeon, in 1868.<sup>67</sup> He treated patients aged 72, 12, and 8 – all of whom were recognized as having lost both respiration and circulation as a result of chloroform. The front of the chest was compressed forcibly three times each 15 seconds, and the inspiration that followed a rapid release was used to administer ammonia (now known to be a potent vasoconstrictor!). All survived; the younger child regained a pulse only after 15 minutes of treatment and relapsed once – but nevertheless made a slow recovery over several days. Better known is the 1883 recommendation of Professor Franz Koenig to use

sternal compression for artificial ventilation.<sup>68</sup> Eight years later, Dr. Friedrich Maass, one of his assistants, performed compressions in two patients intentionally to counter chloroform-induced cardiac arrest.<sup>69</sup> One case involved an 18-year-old man who had lost his pulse during induction of anesthesia and was regarded as dead. Maass initially tried a slow rate of chest compressions to simulate respirations, but, when the situation did not improve, he increased the rate to 120 compressions per minute and noted a carotid pulse. Within 25 minutes the patient achieved a spontaneous pulse and blood pressure. After the man recovered Maass operated on him without complications. Maass concluded: “*So long as compression is applied at the speed of the patient's breathing, slow deterioration. When compression is speeded up, gradual improvement follows. . .*” Maass later described his technique thus:

One steps to the left side of the patient facing his head, and presses deep in the heart region with strong movements . . . The frequency of compression is 120 or more per minute. The effectiveness of the efforts is recognized from the artificially produced carotid pulse and the constriction of the pupils.

External chest compressions survived, predominantly in Germany, for several more decades,<sup>70</sup> but it was used in association with the inefficient methods of artificial ventilation by then in vogue and failed to become well established. Case reports were not widely available because they were published only in German or French, but more importantly the technique could not be successful in most cases of cardiac arrest until defibrillation was developed. No therapy, regardless how innovative, was likely to gain widespread acceptance if it rarely or ever succeeded. Moreover, the relationship between heart disease, ventricular fibrillation, and sudden death was not appreciated until well into the twentieth century. As a result, the role of chest compression to support an artificial circulation was largely ignored until it was rediscovered in 1960.

Open chest cardiac massage was also introduced relatively late, despite the cardiac arrests that occurred during anesthesia. Although Moritz Schiff had practiced and described the technique under experimental conditions and chloroform anesthesia in 1874,<sup>71,72</sup> the first recorded attempt in man was by Niehans in Berne – recorded by a colleague in 1903.<sup>73</sup> But the first definite success had occurred 2 years earlier in Tromsø: it was described only after Igelsrud told a colleague of it when he visited the USA.<sup>74</sup> Interest in open cardiac massage continued for a while. Green in 1906<sup>75</sup> described 40 cases that were by then in the literature, of which nine had been “entirely successful” and eight others had shown transient recovery of pulse and respiration. But

it was never a procedure that, by itself, would have a high success rate, nor could it be widely applied.

The accidental rediscovery of artificial circulation occurred in William Kouwenhoven's laboratory at Johns Hopkins University in Baltimore.<sup>76</sup> Kouwenhoven and Guy Knickerbocker were studying fibrillation in the hearts of anesthetized dogs. In one series of experiments they wanted to determine how long they could leave a dog's heart fibrillating and still achieve defibrillation successfully. On this particular occasion they had taken an anesthetized dog and inserted a catheter into the femoral artery to measure its arterial blood pressure. While observing the dog's fallen arterial pressure, Knickerbocker applied the defibrillator's paddles to the animal. He noticed a blip on the blood pressure indicator. The force of the application of the paddles to the dog's chest had caused a pulsation of blood and a momentary increase in arterial pressure apparently. Knickerbocker called Kouwenhoven over, and they both observed the phenomenon. By repeatedly applying the paddles, they were able to extend the period of time the dog's heart was in fibrillation from approximately 1 minute to several minutes and still successfully achieve defibrillation.

Several weeks after the initial observation, James Jude, a surgical resident at the time, joined the team. All three soon realized that they could use their hands to apply pressure to the chest and achieve artificial circulation. At first it was not at all evident where to compress the chest. Should it be side to side? front to back? on the upper chest? lower chest? Through a series of experiments in late 1958 the team discovered that the best procedure was to apply rhythmic pressure on the lower part of the sternum and press straight down using the heel of the hand. Other locations led to higher rates of complications, including lacerations of the liver, stomach, or lungs. They repeatedly measured actual arterial pressures and through trial and error discovered that the optimal depth of compression should be 1 to 2 inches and the best rate of compression was approximately 60 to 80 per minute.<sup>61</sup> Their success with dogs led the three experimenters to consider trying the technique on humans. Jude and other residents began applying the experimental results to living patients. The first person to have this lifesaving procedure, recalled Jude, was described as follows:<sup>77,78</sup>

... rather an obese female who was having a cholecystectomy and was being held in the emergency room just before surgery. The patient went into cardiac arrest as a result of fluothane anesthetic ... This woman had no blood pressure, no pulse, and ordinarily we would have opened up her chest and done direct cardiac massage. Instead, since we weren't in the operating room, we applied external cardiac massage and they immediately switched back to

straight oxygen in ventilation. Her blood pressure and pulse came back at once. We didn't have to open up her chest. They went ahead and did the operation on her, and she recovered completely.

In 1960 the three investigators reported their findings on 20 cases of in-hospital cardiac arrest.<sup>76,79</sup> Fourteen of the 20 patients (70%) survived and were discharged from the hospital. Many of the patients were in cardiac arrest as a result of anesthesia. Three patients were documented to be in ventricular fibrillation. The duration of chest compression varied from less than 1 minute to 65 minutes. The article was very clear: chest compression buys time until the external defibrillator arrives on the scene. As the authors write in the article: "*Anyone, anywhere, can now initiate cardiac resuscitative procedures. All that is needed is two hands.*" However, respiration or ventilation received relatively little attention in the 1960 article. Many of the patients had been intubated. Soon, however, chest compression formally 'married' mouth-to-mouth ventilation: the couple's new name was CPR.

## The birth of cardiopulmonary resuscitation

### Ventilation and compression combined

Between 1958 and 1961 artificial respiration was combined with artificial circulation to create CPR. The period began with demonstrations that mouth-to-mouth ventilation was effective for artificial respiration and chest compression was effective for artificial circulation. Now all that was needed was the formal connection of the two techniques to create CPR as it is practiced today. And that took place at the scientific level when Safar, Hackett, Jude, and Kouwenhoven presented their findings at the Maryland Medical Society meeting held on September 16, 1960 in Ocean City. In the opening remarks the moderator said: "*Our purpose today is to bring to you, then, this new idea.*" It was so new that it was still without a name. The moderator stated that the two techniques "*cannot be considered any longer as separate units, but as parts of a whole and complete approach to resuscitation.*"<sup>80</sup> In his remarks Safar stressed the importance of combining ventilation and circulation. He presented convincing data that chest compression alone did not provide effective ventilation; that required mouth-to-mouth respiration.

To promote CPR, Jude, Knickerbocker, and Safar began a world speaking tour. In 1962 Gordon, along with David Adams, produced a 27-minute training film called *The Pulse of Life*. The film was used in CPR classes and viewed by millions of students. For the film, Gordon and Adams devised the easy to remember mnemonic of A, B, and