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Invited Commentary

Advancements in Cardiopulmonary Resuscitation: Increasing Circulation and Improving Survival

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Clinicians, as well as lay people, have realized the importance of resuscitative maneuvers throughout recorded history. Cardiopulmonary resuscitation has evolved from a relatively primitive technique to one now dictated by data from evidence based medicine. Recent advancements include changes in life support guidelines, the development of an impedance threshold device, and the initiation of therapeutic hypothermia. We can only expect continued advancements in cardiopulmonary resuscitation through new technology with resultant improved outcomes.

THE INCIDENCE OF WITNESSED out-of-hospital cardiac arrest in the United States is approximately 165,000 cases/year.[1] Treatment requires effective cardiopulmonary resuscitation (CPR) and transfer to a definitive care facility. Recent advancements include changes in life support guidelines, the development of an impedance threshold device, and the initiation of therapeutic hypothermia. The ultimate goal of these advancements is to improve survival and patient outcomes.

History of Cardiopulmonary Resuscitation

An understanding of the advancements in CPR begins with an appreciation of the contributions of countless individuals over the past two centuries. The first reference to resuscitation appears in the second book of Kings: "And when Elisha came into the house, the child was dead... and he went up... and put his mouth upon his mouth ... and the flesh of the child waxed warm ... and the child sneezed seven times and opened his eyes."[2] The Talmud tells the story of assisting a newborn animal by "holding up the young and blowing air into its nostrils."[3] Swiss physician Paracelsus used fireside bellows placed in the nostrils of both animals and humans for respiration in 1530.[4] Belgian anatomist Andreas Vesalius[5] wrote in 1543 in De Fabrica Humani Corporis, "But so that life may in some measure be restored to the animal, you must attempt an opening in the trunk of the rough vein (trachea) and pass into it a tube of rush or reed, and you must blow into this so that the lung may expand and the animal draw breath."

By the late 18th century, humane societies were formed to aid in the resuscitation of victims of drowning. Attempts at clearing the airway included such crude efforts as rolling the patient over a barrel. The Dutch Humane Society, established in 1773, advocated the use of mouth to mouth resuscitation. The Royal Humane Society of London, founded in 1774, abandoned the use of mouth to mouth resuscitation because it was felt that air exhaled by the rescuer was toxic and could be harmful to the victim. The fireside bellow to nostril method was "restored" and became the method of choice for ventilation. In 1837, it was realized that ventilation by bellows could cause overinflation of the lungs and this method was soon abandoned. Henry Silvester, in 1861, described a method of ventilation by lifting the victim's arms above the head and then lowering them and pressing them against the chest. Endotracheal intubation was described in a letter by W. Cullen stating that "it is very practical to introduce directly into the glottis and trachea a crooked tube."[4] The effect of respirations on the heart was first noted by John Hunter. He observed that when ventilation stopped, the heart stopped, and when ventilation resumed,

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the heart beat resumed. From this, he determined that the beating heart "must therefore depend immediately on the application of air to the lungs."[4]

Electricity was discovered in the mid-1700s and in 1780, Luigi Galvani observed that electricity could cause muscle tissue to contract. In 1795, the Humane Society of New York accepted the use of electricity in resuscitation and proclaimed it was "a most powerful agent, a very proper remedy."[4] French physiologists Prevost and Battelli found in 1899 that the heart could be defibrillated by electricity. Carl Wiggers, physiologist at Western Reserve University, realized that circulatory support was required to deliver oxygen to the tissues. Before this, cardiac massage was considered dangerous as it could potentially cause return of ventricular fibrillation. Wiggers recommended cardiac massage before defibrillation. Dr. Claude Beck, while a surgery resident at Johns Hopkins in 1920, told the story of a patient who went into cardiac arrest while on the operating table. At that time, tools for resuscitation were not available in the hospital, so the fire department was called to aid in resuscitation of the patient. The patient was ultimately pronounced dead. After this, he stated "The experience left me with a conviction that we were not doing our best for the patient."[6] In 1937, Beck developed a sequence of steps for the treatment of cardiac arrest during surgery, which included cardiac massage and defibrillation.[6]

Austrian born physician Peter Safar has become known as the "Father of cardiopulmonary resuscitation."[6] He focused his efforts on educating the general public and established the "ABCs" of CPR by integrating airway, breathing, and circulation.[6] Dr. Safar had the fortune of meeting publisher and toymaker Asmund Laerdal. Laerdal had actually saved his own 2-year-old son from drowning and became interested in creating medical training aids. In 1960, Laerdal created a mannequin for CPR education named Resusci Anne. His company was renamed as Laerdal Medical and in addition to producing Resusci Anne, the company also made CPR training films and published CPR materials. Dr. Safar wrote "Without Asmund Laerdal, CPR would never have been implemented so rapidly and so widely. Millions have been influenced by his products, thousands by his thoughts."[7]

Cardiopulmonary Resuscitation Guideline Changes

The first CPR guidelines were published in the mid-1960s and have undergone numerous revisions since new evidence based medicine has become available. The most recent changes in lay rescuer CPR and healthcare provider basic and advanced life support are too numerous to detail here, but a few of these deserve discussion. The common theme that has emerged from research in this area is modifications that improve cardiac output and circulation.

The newest guidelines emphasize the importance of effective chest compressions by maintaining a rate of 100 compressions/minute, allowing full recoil of the chest, and minimizing interruptions. Before this, there was no real emphasis placed on the quality or rate of compressions. Rescuers are encouraged to use two hands instead of just one for chest compressions in children. Effective chest compressions translate into improved blood flow to perfuse the heart and the brain.[8]

Another important change is an increase in the ratio of chest compressions to ventilations for adults and children (Table 1). These changes ensure that all rescuers deliver a longer series of uninterrupted compressions. This also simplifies the information for rescuers to learn and to remember.[8]

A recent study suggests that ventilations might be eliminated from future recommendations. In an observational study of 4068 patients with witnessed out-of-hospital cardiac arrest, 11 per cent received cardiac resuscitation without ventilation, 18 per cent received conventional CPR, and 72 per cent received no resuscitation. Any type of resuscitation resulted in a more favorable neurologic outcome compared with no resuscitation ($P < 0.0001$). Cardiac resuscitation without ventilation *versus* conventional CPR resulted a more favorable neurologic outcome in patients with apnea ($P = 0.0195$), in patients with a shockable rhythm ($P = 0.041$), and when resuscitation began within 4 minutes ($P = 0.0221$). From these findings, it was interpreted that cardiac resuscitation without ventilation is the preferred method of resuscitation for out of hospital cardiac arrest.[9] If any additional evidence supports these findings, they may be reflected in the next set of guidelines to be published in 2010.

Previously, lay rescuers were advised to check for signs of circulation after delivering rescue breaths. This step resulted in a delay in chest compressions and has been eliminated. Additionally, healthcare providers no longer deliver a stacked sequence of three shocks to treat ventricular fibrillation or pulseless ventricular tachycardia. Instead, rescuers should deliver a single shock followed

TABLE 1. *Chest Compression to Ventilation Ratios*[8]

		2000 Guidelines	2005 Guidelines
Adult/older child	1 Rescuer	15:2	30:2
	2 Rescuer	15:2	30:2
Infant/younger child	1 Rescuer	5:1	30:2
	2 Rescuer	5:1	15:2

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immediately by chest compressions. If the shock fails, chest compressions are more valuable than delivering another shock. If the shock is successful, it takes several seconds for the heart to begin beating effectively and chest compressions during this time period will "prime the pump." Lastly, drugs should be administered during CPR and not in a "drug-CPR-shock" cycle.[8]

In regards to chest compressions, rate and depth of compressions are both important. Two recent studies have demonstrated that healthcare providers do not follow current published CPR guidelines. In a 2005 study by Abella et al.,[10] chest compression rates were measured during cardiac arrests to determine in-hospital compliance with the current recommended compression rate of 100 compressions/minute (cpm). Compression rates of < 80 cpm and < 70 cpm were observed 36.9 per cent and 21.7 per cent of the time, respectively. Rates were between 90 and 110 cpm only 31.4 per cent of the time.[10] In a second study by Abella et al.,[11] compression rates were < 90 cpm and < 80 cpm for 28.1 per cent and 12.8 per cent of compression time segments, respectively. Compression depth was too shallow for 37.4 per cent of compressions. A minimum chest compression depth of 38 mm is presently recommended. Mean no-flow fraction, or fraction of time during which no chest compressions were performed during the arrest, was 0.24. A 10 second pause every minute would result in a no-flow fraction of 0.16. From these studies, it can be seen that CPR provided by hospital professionals is often inconsistent and inadequate. Too many interruptions lead to wasted valuable time that should be used for chest compressions. The importance of education, monitoring, and feedback can not be overstated.[11]

Impedance Threshold Device

Recently, an Impedance Threshold Device (ITD) has shown potential in augmenting cardiac output during CPR and could be a tool for use during chest compressions (Fig. 1). CPR alone is inefficient. Cardiac output may only be 20 per cent of normal and cardiac perfusion may only be 5 per cent of normal.[12] An ITD is a one-way valve that attaches inline with an endotracheal tube (ETT) or a facemask that selectively inhibits air from entering the chest during chest wall recoil between each compression. During CPR with conventional respiratory equipment, the negative pressure generated during chest wall recoil preferentially augments air entering the thoracic cavity via the lungs. If this inflow is impeded with the use of an ITD, the negative pressure of chest wall recoil preferentially increases cardiac return to the heart. By increasing venous return, cardiac output and perfusion will be increased resulting in improved survival.

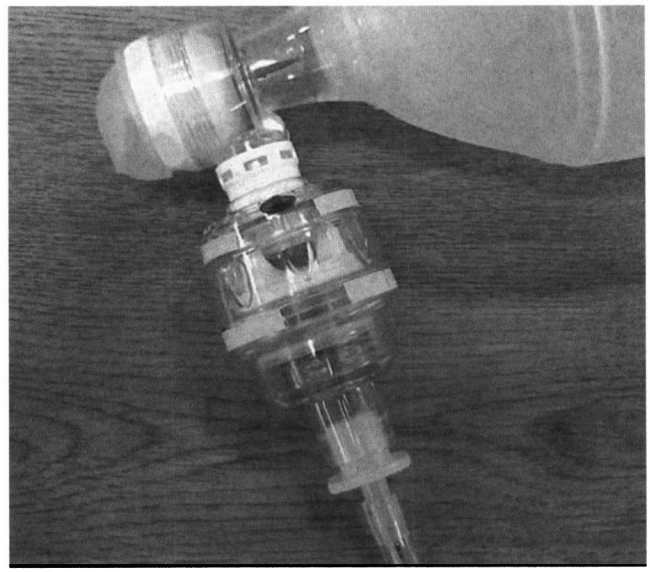


FIG. 1. Impedance Threshold Device.

The use of an ITD during cardiopulmonary resuscitation has been evaluated in several studies. Plaisance et al.[13] measured intratracheal pressure, as a substitute for intrathoracic pressure, in patients receiving CPR with either an active ITD or a sham ITD. Mean maximum negative intratracheal pressure during decompression was lower with an active ITD compared with a sham ITD on both a facemask ($P = 0.003$) and on an ETT ($P = 0.0009$). This study showed that an active ITD resulted in a significantly lower intratracheal (or intrathoracic) pressure.[13]

In another study by Plaisance et al.,[14] venous return and CPR efficiency was compared using CPR alone and CPR with an ITD. CPR performed with an ITD resulted in higher mean maximal end-tidal CO_2 ($P < 0.001$), higher coronary perfusion pressure ($P < 0.001$), and higher diastolic arterial pressure ($P < 0.001$). Additionally, return of spontaneous circulation was observed in two of 10 patients after 26.5 minutes with CPR without an ITD *versus* four of 11 patients after 19.8 minutes with CPR with an ITD ($P < 0.05$). The use of an ITD lead to a higher diastolic arterial pressure, improved perfusion, and improved outcome.[14]

In 2005, Auferheide et al.[15] compared the use of a sham ITD *versus* an active ITD in patients receiving out-of-hospital CPR. Intensive care unit admission rates were 17 per cent with a sham ITD *versus* 25 per cent with an active ITD ($P = 0.13$). Subgroup analysis of patients presenting with pulseless electrical activity revealed an intensive care unit admission rate of 20 per cent with a sham ITD *versus* 52 per cent with an active ITD ($P = 0.018$). The use of an ITD with conventional CPR more than doubled short-term

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survival rates in patients presenting with pulseless electrical activity.[15]

Hypothermia to Improve Neurologic Outcome

Therapeutic hypothermia has proven beneficial in patients receiving CPR. Cardiac arrest results in global cerebral ischemia and resultant neurologic damage. During reperfusion, free radicals are produced leading to secondary brain injury. A reduction in free radical production and cerebral oxygen consumption have been attributed to therapeutic hypothermia.[16] The original CPR guidelines used hypothermia to treat patients with apparent anoxic brain injury after resuscitation, but this fell out of favor in future guidelines. Now, this therapy has come full circle.

The Hypothermia after Cardiac Arrest Study Group,[16] in 2002, studied neurologic outcome and mortality in patients who underwent therapeutic hypothermia after cardiac arrest due to ventricular fibrillation. Patients who had been successfully resuscitated after cardiac arrest were assigned to hypothermia (bladder temperature of 32–34° C over 24 hours) or normothermia. Fifty-five per cent of survivors in the hypothermia group had good neurologic outcome as compared with 39 per cent of patients in the normothermia group ($P = 0.009$). Mortality at 6 months was 41 per cent in the hypothermia group *versus* 55 per cent in the normothermia group ($P = 0.02$). This study has reevaluated and reinforced the use of therapeutic hypothermia in CPR.[16]

Conclusion

Clinicians as well as lay people have realized the importance of resuscitative maneuvers throughout recorded history. CPR has evolved from a relatively primitive technique to one now dictated by data from evidence based medicine. Researchers continue to test and refine these techniques for optimal patient outcome. Current research efforts now focus on chest compression delivery techniques, the development of an impedance threshold device, and therapeutic hypothermia. We can only expect continued advancements in CPR through new technology with resultant improved outcomes.

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