



Demystifying Defibrillators



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DESPITE ENORMOUS MEDICAL ADVANCES, cardiac arrest still ranks as a leading cause of death in the 21st century. Sudden cardiac death accounts for a quarter of all human deaths. During cardiac arrest, the heart's rhythmic electrical beat becomes disturbed, resulting in a cessation of blood flow throughout the body and eventual death unless the rhythm is restored within a limited time by electrical shock.

Modern compact defibrillators that provide these life saving shocks to the heart can on occasion be witnessed not only in health care facilities but also in some public facilities, commercial airlines and at many businesses for their employees.

Conceptual Development

A series of electrical shocks to the chest is necessary for restoring the heart's normal rhythmic process during ventricular fibrillation. This concept of an electrical shock to the heart to cease its erratic rhythm rests in part on early developments in understanding the electrophysiological basis of fibrillation.

In 1775, a Danish physician, Peter Christian Abilgaard, described a series of experiments using chickens whose hearts were stopped by an electric current through their bodies. He noticed the birds could be revived by another series of shocks to their breasts. His were the first recorded accounts of fibrillation and defibrillation.

Seventy-five years later, Carl Ludwig, a German physician, physiologist and professor at the University of Leipzig, and his student, M. Hoffa, were the first to document the onset of ventricular fibrillation induced by electrical stimulation of a dog's heart. Hoffa utilized a kymograph for the first time to record arrhythmic wave patterns associated with fibrillation.

Later in 1887, John A. Mac William, a British physiologist was able to differentiate between ventricular and atrial fibrillation. He suggested for the first time that ventricular fibrillation might cause sudden death. Mac William also discovered that, unlike ventricular fibrillation, atrial fibrillation could be initiated and arrested with vagus nerve stimulation.

Subsequently in 1899, Swiss physiologists J. L. Prevost and F. Batelli reported that while a weak alternating current (AC) or direct current (DC) stimulus can produce fibrillation, a stronger electrical stimulus applied directly to the exposed canine heart could arrest ventricular fibrillation and restore normal sinus rhythm.

These findings of cardiac faradizations were replicated in 1940 by Carl J. Wiggers at Case Western Reserve University in Cleveland, Ohio. Wiggers provided the first mechanistic explanation for ventricular fibrillation produced by electrical stimulation. Today these are known as Wiggers stage I, Wiggers stage II, etc. He also further refined the animal model

of defibrillation.

Claude S. Beck, a thoracic surgeon at the University hospital in Cleveland adjacent to Case Western Reserve was familiar with Carl Wiggers' work on ventricular fibrillation with dogs. Dr. Beck pioneered cardiac surgery to improve circulation in damaged heart muscles. During open-heart surgery in 1947, the patient, a 14-year-old boy, went into ventricular fibrillation and Dr. Beck first applied heart massage unsuccessfully. An experimental defibrillator was brought into the operating room from Dr. Beck's research laboratory and 1500 volts were applied to the boy's exposed heart, restoring the normal cardiac rhythm.

This defibrillator was a large monstrosity operated from conventional AC wall sockets using a bulky step-up transformer. Two metal paddles had to be positioned on either side of the heart and voltage applied for $\frac{1}{4}$ to $\frac{1}{2}$ second. Not a lot was known at that time about the amount of voltage necessary to restore a normal sinus rhythm.

This was the first documented and published success of a human patient resuscitated during ventricular fibrillation. Beck's success encouraged the medical community to adopt defibrillation for cardiac resuscitation.

Then, in 1956, Paul M. Zoll, a cardiologist at Harvard Medical School, demonstrated the lifesaving benefits of employing defibrillation on a closed chest. He applied 15-ampere AC currents that produced 710 volts across the chest for 150 milliseconds. Zoll went on later in the 1950s to develop an external pacemaker for closed chest.

Coinciding with these experimental and clinical trials were attempts by the medical and engineering communities to develop a satisfactory defibrillator. In the first half of the 20th century, many linemen were electrocuted during the power companies' electrification of America. Inspired by these grim statistics and some research funding from Consolidated Edison of New York, William B. Kouwenhoven, an electrical engineer and William Henry Howell, a physician at Johns Hopkins University, began to study the ravages of electric shock. In 1933 Kouwenhoven and Hopkins neurologist Orthello Langworthy demonstrated that an internally applied alternating current could be used to produce a counter shock that reversed ventricular fibrillation in dogs.

Eventually, Kouwenhoven and Langworthy revolutionized cardiovascular resuscitation. Together with cardiovascular physiologist William Milnor, Kouwenhoven began evaluating various electrical parameters in the 1950s that would restore a normal sinus rhythm during closed chest shocks to dogs. Kouwenhoven and Milnor soon discovered that electrical stimulation was more effective and required less voltage if current flow followed a vertical rather than a horizontal path through the heart.

Eventually, after repeated testing on dogs, Kouwenhoven assembled a 200-pound machine on wheels that delivered AC shocks from two electrodes, one positioned over the suprasternal notch and the other over the apex of the heart. In addition to the Hopkins AC Defibrillator, Kouwenhoven went on to later develop and refine the Mine Safety Portable.

Other Efforts

There were early attempts by other individuals to develop electrical apparatus for cardiac resuscitation. During the 1930s, Albert S. Hyman devised a machine to produce an electric shock to the heart by a needle inserted into the patient's chest wall. This device turned out to be more of a primitive pacemaker than a defibrillator. The electricity was produced by a hand-operated magneto (DC generator). The device was never approved by the medical community.



Then in 1949, electrical engineer John A. Hoops designed and built a vacuum tube cardiac stimulator for doctors Wilfred Bigelow and John C. Callaghan that utilized a catheter electrode. The stimulating electrode was to be introduced to the heart via the right external jugular vein.

This device was never employed for medical service with a human patient.

During the 1960s, Bernard Lown of Harvard School of Public Health and K. William Edmark of the University of Washington demonstrated that direct current could be employed for ventricular defibrillation. These DC defibrillators were safer and portable permitting their use outside of hospitals. The portability issue becomes a primary concern in reaching out to patients during ventricular defibrillation. The normal sinus rhythm has to be restored within minutes if the patient is to survive.

Two cardiologists in Northern Ireland realized the potential life-saving benefit of bringing a portable defibrillator to the patient. Doctors J. Frank Pantridge and John S. Geddes equipped an old ambulance with a portable defibrillator and thus established the first mobile intensive care unit in 1966. Two 12-volt car batteries powered the defibrillator, which was operated by a physician and a nurse.

Subsequently, paramedic teams have come to occupy and operate the emergency medical equipment in these mobile units. Defibrillation by emergency medical technicians (EMTs) without the presence of physicians was first employed at Portland, Oregon in 1969. The personnel in these units are in communication with a hospital's intensive care unit, receiving transmitted EKG recordings from the patient en route and receiving emergency medical advice as needed.

In the latter part of the 20th century, intelligent computer chip circuitry has on some occasions partially obviated the need for medical advice when a health specialist is inaccessible. During the 1980s, the computer industry incorporated electronic circuits into defibrillators along with computer algorithms that recognized ventricular fibrillation. These "smart" defibrillators, also known as automatic external defibrillators (AED), interpret the patient's rhythm from the EKG signal - recorded off the same stimulating electrodes that can deliver a series of shocks to restore normal cardiac rhythm. The EKG signal is analyzed with a combination of signal parameters including rate and amplitude criteria.



In addition, the QRS (electrocardiographic) waveform is also analyzed as to its slope, morphology, power spectrum density, and time away from the isoelectric baseline for preset levels defined as abnormal. Samples of the EKG are taken at 2-4 second intervals. If any abnormal complexes are detected for more than double the frequency of any other QRS for three consecutive checks, the AED will be ready to deliver a shock. Voice-chip technology is also incorporated into these devices to prompt the operator by verbally coaching procedures.

The operator must stand clear during the shock phase and administered cardio-pulmonary resuscitation (CPR) to the patient during periods of EKG analysis. The AEDs have a reported sensitivity of 76-96 percent in reliably detecting ventricular fibrillation and specificity (correctly identifying non-ventricular rhythms) of close to 100 percent.

Implantable Defibrillators

Implantable defibrillators were also developed in the 1980s. Rushing a portable defibrillator to an individual in ventricular distress is usually too late. Michael Mirowski and Morton M. Mower at Johns Hopkins Hospital developed a miniaturized defibrillator for implantation.

This first generation of implantable defibrillators was the size of a portable compact disc player and used electrodes directly contacting the heart. Implantation was performed only as a last resort for open-heart surgery. With time, implantable defibrillators were reduced in size by developing computer chip technology. The latest implantable defibrillators are small enough to be placed under the skin over the chest. Their circuitry is housed in a

titanium chassis that also serves as a return current pathway for a fine wire electrode threaded through a vein to the heart. Consequently, open-heart surgery is longer required.

Battery life on these devices is in excess of eight years following the adoption of utilizing biphasic stimulation pulses. This industry standard has also been adopted for AEDs. The biphasic pulse is more physiologically effective, as well as resulting in longer battery life and a substantially reduced recycle time to build up successive charges. In addition, EKG information is recorded, stored on the chip and downloaded later to a computer for diagnostic analysis and troubleshooting.

However, only a small fraction of patients with potential heart disease come to the attention of a cardiologist before their first attack. Twenty percent of ventricular fibrillation cases occur in individuals with no previous diagnoses of heart disease.

Ventricular fibrillation is still the leading cause of death in adults. Defibrillators will be needed until medical science better understands ventricular fibrillation and can prevent it. In the meantime, defibrillators are not quite ready to be relegated to a museum.

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