The Birth of Defibrillation: A Slow March Towards Treating Sudden Death

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Recent years have seen the rapid fine-tuning of external cardiac defibrillation for the treatment of cardiac arrest. However, this rapid advancement conceals the slow march of physiologists over several centuries to address this life threatening state. Frequently, accounts of defibrillation research begin with the turn of the 20th century. However, the birth of the field was rooted millennia earlier, and became the object of scientific investigation a full 150 years before Einthoven received the Nobel Prize for his work developing the electrocardiograph. Early accounts of resuscitation demonstrated an understanding of the necessity of respiration for life, as well as the correlation of respiratory and cardiac function. The eminent danger posed by ventricular fibrillation was noted by the Egyptians as early as 3500 BC, when it was observed that “When the heart trembles, has little power and sinks, the disease is advancing and death is near.” However, it was the discovery of electricity that proved critical to research into heart function, and ultimately, defibrillation. In the mid 18th century, Luigi Galvani made the classic observation that an electrical impulse could cause a frog’s leg to twitch “as though it were seized with tetanus at the very moment when the sparks were discharged.” The excitement generated from Galvani’s experiments led to the almost instantaneous application of electricity to the treatment of cardiac arrest. However, it would take a number of innovative physicians, in roles spanning from basic researchers to public educators, to bring defibrillation from a baseless practice attempted out of desperation, to a scientifically validated, reliable, and widely available procedure. It is the intent of this report to highlight a number of these innovative individuals, and to detail the research that provides a foundation for the rapid advancements in cardiac care seen today.

Introduction

Recent years have seen the rapid fine-tuning of external cardiac defibrillation for the treatment of cardiac arrest. The recent announcement of the Phillips HeartStart Home Defibrillator as one of Fortune Magazine’s “25 Best Products of 2004” can be seen not only as a testament to medicine’s growing response to one of society’s greatest health risks, but also as the culmination of several centuries of discovery in cardiac electrophysiology.

While our ability to respond effectively to sudden death has greatly improved in recent years, it comes as no surprise that the desire to do so is as old as antiquity itself. Reviving someone apparently dead was no doubt a dramatic tale in any time, and countless instances of it are found in mythology and ancient texts. One of the earliest and most widespread written depictions of resuscitation can be found in the Bible, where Elisha was detailed on more than one occasion to raise the dead:

“...And when Elisha was come into the house, behold, the child was dead .... And he went up, and lay upon the child, and put his mouth upon his mouth, and his eyes upon his eyes, and his hands upon his hands: and stretched himself upon the child; and the flesh of the child waxed warm .... And the child sneezed seven times, and the child opened his eyes.” (2 Kings 4:32-35).

While techniques to aid in true cardiac arrest did not emerge until the 18th century, knowledge of ventricular fibrillation – the most common cause of sudden cardiac death – existed more than 3500 years ago. At that time, it was written in the Ebers Papyrus that “When the heart trembles, has little power and sinks, the disease is advancing and death is near...” The link between trembling (fibrillation), little power (poor circulation), and death, was again described by Vesalius as “worm-like” motions of the heart. Vesalius added to this description in 1543, by also noting the correlation between respiration and cardiac function:

“...Indeed, with a slight breath in the case of this living animal the lung will swell to the full extent of the thoracic
cavity, and the heart become strong and exhibits a wondrous variety of motions... And as I... take care that the lung is inflated at intervals, the motion of the heart and arteries does not stop...”.

Electricity
It was the discovery of electricity that proved critical to research into heart function, and ultimately, defibrillation. In the mid 18th century, Luigi Galvani began experimenting with electricity, and made the classic observation in that an electrical impulse could cause a frog’s leg to twitch “as though it were seized with tetanus at the very moment when the sparks were discharged”. This account of “animal electricity” quickly caught the interest of seemingly every scientist in Europe. And while it undoubtedly put great survival pressure on the common frog, the discovery ultimately spawned the field of electrophysiology.

Early Discoveries
The excitement generated from Galvani’s experiments, and the countless experiments that followed, led to the almost instantaneous application of electricity to the treatment of cardiac arrest. While it wouldn’t be until Prevost and Battelli’s work in the turn of the 20th century that true defibrillation would be depicted scientifically, the first case report describing successful resuscitation using electrical shock was made in 1774, when a young woman fell out a second-storey window and was believed by all accounts to be dead. After approximately twenty minutes, a doctor was summoned, who after exhausting all conventional techniques, attempted to apply electricity “to various parts of the body in vain; but upon transmitting a few shocks through the thorax, he perceived a small pulsation’ in a few minutes the child began to breathe with great difficulty, and after some time she vomited.” This account, and many others, were recorded in the register of Royal Humane Society of London, an organization established the very same year to promote resuscitation as a means of saving otherwise healthy people – victims most often of falls, drowning, mining accidents, and lightning.

While doctors across Europe began using electricity as experimental treatment for sudden death, the first report of scientific investigation into this practice was not conducted until a year after the first recorded “save”. In 1775, Dr. Peter Abilgaard published his observations on shock and countershock – a full 124 years before Provost and Battelli’s documentation of ventricular fibrillation and defibrillation. Abilgaard observed that electrical stimuli could, when applied anywhere across the body of a hen, in particular the head, render his animal specimen lifeless, and when applied again across the thorax, restarted the heart:

“With a shock to the head, the animal was rendered lifeless, and arose with a second shock to the chest; however, after the experiment was repeated rather often, the hen was completely stunned, walked with some difficulty, and did not eat for a day and night; then later it was very well and even laid an egg.”

Surprisingly, given the importance of Abilgaard’s observations, few references were made to it in the literature of the time.

A True Beginning
While the study by Abilgaard and the numerous case reports from the Royal Humane Society suggested an early beginning to cardiac arrest research, it was not until the beginning of the 19th century that work began in earnest. The mechanism of cardiac arrest began to be elucidated by Ludwig and Hoffa, who in 1850 were the first to physiologically describe fibrillation in animals, while also noting that electrical shocks can reliably induce the phenomenon. By 1851, chloroform had gained considerable popularity in operating theatres across the world, and numerous cases of sudden death left surgeons hesitant to use the anesthetic. Dr. Steiner was one of the first to investigate chloroform and ether induced cardiac arrest, and published accounts of successful
ventricular pacing in 10 dogs, 14 cats, 6 rabbits, and 1 donkey. Unfortunately, his one attempt at resuscitating a human patient was unsuccessful.9

Work on fibrillation continued by many physiologists in the later half of the 19th century, aided by advances in knowledge of cardiac function and in technology to observe it. John McWilliam made several significant observations about ventricular fibrillation through a series of reports in 188710 and was one of the first to insist that ventricular fibrillation must occur in humankind. Until this point, and in fact for a number of years after, ventricular fibrillation had only been clearly observed in animals, leading many to believe it simply did not occur in mankind.6 McWilliam, however, demonstrated that ventricular fibrillation occurs with greater frequency and severity in larger mammal species, and suggested quite reasonably that the reason ventricular fibrillation had not been clearly identified in humankind was simply that most cases of cardiac arrest occurred out of hospital, where response time exceeded fibrillation duration.10

Around the same time, two other physiologists were studying fibrillation and made some significant discoveries. The focus of Prevost and Battelli’s report was not unlike the conclusions made by McWilliam: the heart’s ventricles could be made to fibrillate with a small amount – as little as 40 Volts – of electricity delivered across the chest wall.5 What was not the focus of this report, but would become the focus of countless reports in the next hundred years was the casual observation – in a footnote – that a second, larger shock (between 240 and 4800 Volts) could often defibrillate the heart. While it is likely that Prevost and Battelli realized the importance of their observation for the animals they studied, they must not have been aware of McWilliams suggestion that ventricular fibrillation is likely a major cause of sudden cardiac arrest in mankind.11 Thus, with what could be the understatement of their professional careers, Prevost and Battelli helped electrophysiology conclude the 19th century with a solid background in ventricular fibrillation and defibrillation – in animals only – setting the stage for rapid advancement in the 20th century.

Development of Defibrillation

While cardiac arrest due to early application of anesthesia prompted research early in the 19th century, the advent of public electricity in the early 20th century prompted further development of the field of cardiac electrophysiology. Spurred by a growing number of employee accidents, in 1926 the Consolidated Electric Company of New York City funded a collaboration at John Hopkins between Orthello Langworthy and Donald Hooker, both physicians, and William Kouwenhoven, an electrical engineer.6 By 1933 the trio had published a summary of their initial research, expanding upon the findings made 30 years earlier made by Prevost and Battelli. Specifically, the group noted that for defibrillation to be successful, the shock must be applied within a few minutes of arrest if no other intervention is made: 99% of cardiac arrests defibrillated after 30 seconds were successfully resuscitated, but after one, two and four minutes the success rates dropped to 90, 27, and zero percent, respectively.8 They also noted that open- and closed-chest cardiac massage could extend this window, an observation that ultimately lead to the chest compressions used in CPR today.

Around the same time that Kouwenhoven and colleagues were developing clinically usable defibrillation techniques, a man who would later be cited as one of the most influential individuals in cardiac resuscitation was completing his internship. During his internship in Cleveland, Ohio, Claude Beck witnessed a number of cardiac arrests during surgery, and stood back with amazement as the surgeon would request that the local fire department be summoned to administer oxygen in an attempt at resuscitation, leaving him feeling, quite fairly, that “we were not doing our best for the patient”.8 He went on to construct his own defibrillator and developed the first in-house cardiac resuscitation team – the precursor to the crash cart team.8 In 1947 Beck achieved the first clearly documented defibrillation, in a young boy undergoing surgery
for a congenital form of funnel chest. Upon noticing ventricular fibrillation, Beck maintained manual heart massage for over 30 minutes before he had an electrocardiograph confirmation and then delivered a shock directly to the heart. The first shock was unsuccessful, procaine was administered to improve the heart’s susceptibility to electricity, and upon a second shock normal sinus rhythm was restored.

Figure 1: Electrocardiogram recorded by Dr. Claude Beck detailing the first documented successful defibrillation of a human. The three tracings demonstrate: a) ventricular fibrillation, b) ventricular fibrillation still present after first shock, c) supraventricular tachycardia following procaine administration and successful second shock.  

Beck went on to fine-tune his device, and in the interest of promoting defibrillation, promising to “furnish this apparatus to anyone who would like to have it for the cost of the various parts”. In 1950 Beck began to educate others in his protocol, establishing a course that trained surgeons, anesthetists, nurses, and dentists from around the world in his protocol, forming the basis of today’s CPR and ACLS courses. By 1961, the advantages of closed chest cardiac and external defibrillation, first suggested by Kouwenhoven 30 years before, were proven clinically by Dr. Paul Zoll. Beck capitalized on the development of external defibrillation as an opportunity to expand his training to the lay public, establishing the Resuscitators of America program to train members of the public in CPR using the now ubiquitous CPR mannequins.

Research continued from the early models designed by Kouwenhoven, Beck and Zoll, refining the amount and type of electricity, the method of delivery, as well as improvements in safety and automation. The advances in cardiac treatment witnessed in just this last generation are substantial, and reveal a history of scientific research spanning over 300 years, and a history of curiosity in the heart’s operation spanning over 3000 years. What will be the future of cardiac resuscitation? The Phillips HeartStart Home Defibrillator is likely just the beginning. When Abilgaard conducted his initial research into “countershock” in 1775, science and society were not ready to appreciate the importance of his work in the context of improving patient care. Perhaps with time we too will find modern research deemed insignificant today shedding light on significant issues of tomorrow.

References