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Review

Out of hospital cardiac arrest: Past, present, and future

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Abstract

Advances in resuscitation following out-of-hospital cardiac arrest (OHCA) provide an opportunity to improve public health. This review reflects on past developments, present status, and future possibilities using the science-education-implementation framework of the Utstein Formula and the clinical framework of the links in the chain of survival. With the discovery of CPR and defibrillation in the mid 20th century, resuscitation developed a scientific construct for progress. Systems of emergency community response provided operational efficiency to treat OHCA.

Contemporary resuscitation involves integrated interventions in the chain of survival: early recognition, early CPR, early defibrillation, expert and timely advanced life support and hospital care, and multidimensional rehabilitation. Implementation of scientific advances is especially challenging given the unexpected nature of OHCA, the need for time-sensitive interventions, and the substantial collective of stakeholders involved in the chain of survival. Systematic measurement provides the foundation to evaluate performance and guide implementation initiatives. For many systems, telecommunicator CPR and high-performance CPR by emergency professionals are accessible, near-term programs to improve OHCA outcome. Smart technologies that activate, coordinate, and/or coach community “volunteers” to accelerate early CPR and defibrillation have conceptual promise, though robust implementation has been achieved by only a handful of systems. Longer-term strategies may leverage technology to develop a high-fidelity “life-detector” or engineer and disseminate a specialized consumer defibrillator designed to bridge care until arrival of professional response.

Keywords: History of resuscitation, Emergency medical services, Out of hospital cardiac arrest, Cardiac arrest, Resuscitation, Defibrillation, CPR, Cardiopulmonary resuscitation

Introduction

Out-of-hospital sudden cardiac arrest (OHCA) is a leading cause of mortality among adults, accounting for millions of deaths worldwide.[1] OHCA is most often caused by a primary cardiac event that can be the initial clinical manifestation of heart disease. OHCA can occur at all ages, though most persons experiencing OHCA are older – with an average age in the mid-sixties. Unless treated within minutes of onset, OHCA is uniformly fatal. However, timely and coordinated interventions can be lifesaving.[2] In communities with high-performing emergency medical services (EMS), survival overall is 20%; and survival from ventricular fibrillation can exceed 50%.[3]

The principles of successful resuscitation involve links in the chain of survival to include early recognition and emergency medical services (EMS) activation, early CPR, early defibrillation, expert advanced resuscitation and post-resuscitation care, and supported recovery.[2] Because of the time-dependent nature of resuscitation, the early links to recognize OHCA, provide CPR, and deliver defibrillation are the foundational “basics” needed to improve community survival. Yet operational strategies to achieve these concepts are not uniform and in large part explain system-specific outcome disparity. In this

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article we review past developments, current perspectives, and future potentials in OHCA resuscitation, recognizing the variable relevance of programs in resource challenged regions of the world.[4]

Past

A heterogeneous, often unfounded, collection of resuscitation therapies have been practiced over the centuries with accounts of resuscitation recordedas far back as the Bible's Old Testament and in ancient Egyptian texts.[5] In the 19th and early 20th centuries a variety of e techniques in ventilation and circulation were promoted with little or no evidence of effectiveness. Beginning in the mid 20th century, however, a biological and clinical understanding cardiopulmonary resuscitation (CPR) along with defibrillation and the time dependent nature of these interventions emerged. Throughout the past seven decades, progress was facilitated by the International Lisiason Committee on Resuscitation (LCOR), the American Heart Association (AHA) and European Resuscitation Council's (ERC) periodic evidence based reviews of the scientific literature and updated recommendations for resuscitation.

Defibrillation

Electrical countershock to achieve defibrillation was developed in animal models and first successfully used in a human in 1947.[6] Defibrillation originally required open-chest thoracotomy and direct myocardial paddle contact, often performed in concert with direct cardiac massage, but subsequently advanced to external chest defibrillation.[7] Use of external defibrillation was almost exclusively a hospital intervention until the 1970s when prehospital EMS incorporated rhythm analysis and defibrillation into the scope of practice for paramedic emergency responders.[8] In the 1980s, technology was developed to automate rhythm analysis – and the automated external defibrillator or "AED" became a standard practice enabling rescuers not trained in rhythm interpretation to deliver a shock.[9] The development markedly expanded the pool of persons who could provide defibrillation and led to earlier access to lifesaving therapy. In the United States, the FDA subsequently authorized AEDs for sale to and use by the general public.[10]

CPR

Cardiopulmonary resuscitation – the action of compressing the chest and providing rescue breaths – was a serendipitous discovery. In the 1950s, three researchers – William Kouwenhoven, Guy Knickerbocker, and James Jude – observed a pulsatile rise in blood pressure each time defibrillator paddles were pressed to the chest as part of an animal study investigating defibrillation.[11] This observation provided the conceptual foundation that chest compression can produce forward blood flow and support some measure of circulation during OHCA, providing a viable alternative to open chest cardiac massage. In a landmark report involving 20 hospitalized patients – all who presented with VF, 70% were successfully resuscitated with the combination of chest compressions and external chest defibrillation, underscoring the potential for these therapies.[11] In a parallel series of investigations, James Elam and Peter Safar advanced the science of rescue breathing as a means to support oxygenation and ventilation.[12] In 1960, at a meeting of the Maryland Medical Society, chest compressions and positive pressure ventilation were combined into the framework for current-day CPR.[13]

Although the fundamental "why" of CPR – to save lives – is steadfast, the who, how, and what has evolved over the last 60 years. Once the purview of physicians and nurses, CPR is now considered an essential citizen (layperson) skill in many parts of the world, where CPR (and AED use) is taught as part of secondary education. An advancing resuscitation science has produced serial updates designed to refine the best practices of CPR as well as defibrillation, advanced life support, and post resuscitative care.[2]

Community system response

Given the time-dependent nature of resuscitation, evidence-based interventions have often been pushed from hospital to the prehospital environment, to be delivered at their earliest opportunity. Dr. Frank Pantridge first described the Belfast mobile intensive care experience in 1967, highlighting the lifesaving potential for OHCA.[14] The results motivated other communities around the world. These systems typically have a common activation call-number whereby a trained call-receiver or "telecommunicator" can simultaneously assess the circumstance, coach callers to deliver care, and dispatch professional response. There is a range of system models, staffed by various profiles of professionals with different operational response strategies. Regardless of the model, emergency activation of a designated response has become the standard for most communities. In our own community of Seattle and King County, telecommunicators assertively provide telephone CPR instructions to callers, while a tiered response of professional providers is simultaneously activated, consisting of a first tier of EMT firefighters equipped with AEDs and a second tier provided by paramedics with advanced life support skills.

Utstein style for reporting

A critical challenge to resuscitation is how to evaluate and compare treatment strategies among systems of care given the variable circumstances, presentation, and outcomes used to report experience. In 1990, an international group of resuscitation stakeholders convened in Stavanger, Norway at the Utstein Abbey to consider a common set of definitions that could be used to achieve a universal platform for scientific evaluation and clinical reporting.[15] The original comparator group – characterized by bystander-witnessed OHCA presenting with an initial rhythm of VF – serves as an essential focus of community response given its favorable prognosis and the relevance of each link in the chain of survival. The Utstein template has been refined and updated periodically to incorporate new knowledge and perspectives, and it continues to be an essential framework.[16–18]

Evidence evaluation

Resuscitation is a complex condition that brings together a wide range of stakeholders involved in science, operations, clinical medicine, advocacy, and policy. Beginning in 1992, ILCOR was convened to translate scientific evidence into clinical resuscitation guidelines.[19,20] ILCOR is comprised of a collection of individuals and organizations from around the world who conduct a rigorous evidence review to help update the science of resuscitation, the product of which is disseminated to the respective regional resuscitation councils. The process produces periodic updated emergency cardiac care guidelines that have become the basis for OHCA care.

In the past 60 years, these developments have contributed to millions of lives saved worldwide. Taken together, they provide a useful context to assess current practice and consider how more lives might be saved.

Present

Summary estimates of OHCA vary depending upon the national or international participants. For example, estimates from the Cardiac Arrest Registry to Enhance Survival (CARES) indicate all-rhythm OHCA survival to hospital discharge of approximately 10% and bystander-witnessed VF survival of about 30%, with most – though not all – survivors having a satisfactory functional status and quality of life.[2] These summary estimates however belie the marked disparity across communities: survival varies more than 3-fold when comparing 10th–90th percentile. Systems in the top decile typically achieve survival to hospital discharge in more than 50% of bystander-witnessed ventricular fibrillation OHCA events, while survival among systems in the lowest decile is typically less than 15%.[3] Thus, important public health progress can be achieved if the causes of outcome disparity were identified and effectively addressed.

OHCA survival depends on translation of scientific understanding to effective education and operational implementation, expressed as the Utstein Survival Formula which is: **Survival = Medical Science X Educational Efficiency X Local Implementation**.[21] Each domain of the Formula can impact a system's overall outcome. The construct provides a useful contemporary framework to understand disparity and in turn advance resuscitation.

Medical science

The links in the chain of survival continue to serve as the scientific paradigm to achieve resuscitation.[2] This paradigm involves a series of time-sensitive, interdependent therapies that collectively provide the best opportunity to "snatch life from the jaws of death". In resuscitation, the dimension of time has an intrinsic and formative influence whereby even seconds can make the difference between life and death. Ultimately, the timing and quality of interventions intersect with the patient's pathophysiology to determine vital outcome. The initial links of recognition, CPR, and defibrillation often determine whether downstream advanced prehospital and hospital therapies will have opportunity to be effective.[22,23]

The investigative pipeline to improve resuscitation is often long, difficult, and expensive. Promising results from basic science and animal models ultimately may not translate to the less-controlled human OHCA circumstance. The reality, however, is that apparently "null" interventions could actually be beneficial; but the choice of study population, dose of intervention, mode of delivery, or selected outcome obscures or undermines the fidelity of the effect.[24,25] There may be opportunities to accelerate progress and success in human resuscitation science by coordinating a pipeline of promising therapies, with proactive regulatory review and efficient field evaluation. In our own community of Seattle, survival from out of hospital cardiac arrest with a shockable rhythm has increased through adherence to guideline-based best practices from 14% in 1970 to 51% in 2019 *(unpublished data provided by Catherine Counts, Seattle Fire Department)*.

Despite the challenges involved in resuscitation research, new science continues to accelerate, making individual mastery near impossible.[26] Fortunately, the science of resuscitation undergoes regular review by ILCOR.[27] Representative resuscitation councils interpret and translate the science into guidelines that serve to inform practice. Consequently, the clinical science of resuscitation is routinely updated and generally widely accessible.

Educational efficiency

Resuscitation education increases awareness, imparts essential skills, and encourages self-efficacy.[28] The age of virtual learning – prompted in part by the COVID-19 pandemic – has posed opportunity and challenge for resuscitation education.[29] Although still an effective means of education, the traditional physical classroom, textbook, and group didactic is no longer essential. Instead web-based, individualized education can likewise achieve cognitive competency.

Resuscitation, however, also involves psychomotor skills. Competency requires these skills to be supported by frequent practice, even if these "hands-on" sessions are brief, a strategy sometimes referred to as low-dose, high-frequency psychomotor training.[30–32] Moreover, professional resuscitation involves not just individual skills but the need to perform collectively as a team.[33]

Advocacy, policy, and legislation can have an important role in education and preparedness. One-day events such as Restart-A-Heart can engage hundreds of thousands in training worldwide.[34] School-based CPR-AED training is now a legislative requirement in some parts of the world and engages a ready learner in lifelong awareness and a skillset that can multiply as they share their experience.[35–37] Other legislative examples involve occupational requirements that advance AED access (for example on commercial aircraft) or require telecommunicator CPR training at emergency communication centers.[38,39]

Collectively, these strategies have the potential to expand access and advance training, providing a more effective means for education and preparedness for all.

Implementation: putting science into action

Implementation is typically a local activity. To this end, successful resuscitation often demands nearby laypersons activate an emergency call to prompt professional response, provide early "bystander CPR", and potentially retrieve and apply an AED. Advanced downstream care collectively requires clinical acumen, technical skills, and organizational commitment to assure optimal opportunity for survival and recovery. Differences in real-world operational performance across the links help to explain system outcome disparities.[40,41]

As an example, bystander CPR is a well-established scientific concept supported by resuscitation guidelines. However, the proportion of eligible OHCA patients who receive bystander CPR varies markedly across communities from 10% to 70% despite its consistent endorsement for decades.[3] A number of programs can affect bystander rates: conventional community training, just-in-time telecommunicator CPR coaching, school-based and occupational training, targeted training with families of high-risk patients, crowd-sourcing social media applications, and other innovative approaches.[35,42–45] Although the example highlights system-based (bystander CPR) disparity, differences in treatment and outcome based on other characteristics (i.e. patient sex, race, education status, or neighborhood of residence) also provide a means to see improvement.[46–48]

Implementation itself involves an evidence-based strategy that engages local stakeholders to advance a treatment program by planning and measuring the program process, while leveraging an understanding of the local, regional, and national factors that may support or impede implementation.[49–57] Program implementation is especially challenging in resuscitation given the spectrum of multiple stakeholders. Increasingly, there are resources that inform implementation strategies to improve resuscitation. Organizations such as the Resuscitation Academy, Global Resuscitation Alliance, and the National Highway Traffic Safety Adinistration provide no-cost (open source) tools designed for community program improvement.[58–60]

A better understanding of best practices can occur when measurement is extended to incorporate qualitative and quantitative aspects of real-world interventions beyond "yes-no" categorical classification typically captured by base registries. Such investigation often underscores the stark difference between scientific efficacy and real-world performance. For example, research highlighted the substantial variation in CPR quality by EMS measured by quantitative terms such as compression, rate, depth and pauses, and in turn provided goals for high-performance professional CPR metrics.[61–65] In summary, implementation of evidence-based therapies is increasingly recognized as a key strategy to address disparity and improve OHCA survival.[66]

Future

Given advances in medical science and communication technologies, the future of resuscitation is promising. There are some near-term developments that provide iterative and accessible advances in community resuscitation. Fiscal resources will be an important consideration in their adoption. Support should consider public and private sources, though public investment is essential and justified given the public health toll of OHCA.

Measurement: knowing what to improve

The past decade has highlighted the usefulness of investing in standards of measurement to define current best practices and target opportunities for improvement.[18] Currently most communities around the world do not measure their emergency response system's OHCA care, though multiple geopolitical registries provide access to this essential building block for improvement.[67,68] Comprehensive participation in these registries will enable all systems to benefit from measurement and serves as the best assessment of clinical practice and the effective translation of scientific guidelines. Moreover, public reporting by region, demographic, or other "risk factor" will engage public attention, foster accountablity and drive change. Whether resources and willpower can align to achieve comprehensive participation remains unclear but provides a constructive goal for improving care and outcome for all systems. Measurement needs to coupled with opportunities to advance each link in the chain of survival.

Activation, early CPR, and early defibrillation

Arrest recognition

Early recognition by lay rescuers is a key initial step that has the greatest potential impact on public health given the dominant prognostic role of time. Only about half of OHCA events are witnessed. Approximately half of witnessed OHCA present with a shockable initial rhythm, a key determinant of outcome. In contrast, only a small fraction of unwitnessed events present with a shockable rhythm; instead asystole is often the initial rhythm, arguably the terminal phase of what might have started as a ventricular fibrillation arrest. Thus a "life detector" that could identify cardiac arrest in an accurate and timely manner could transform resuscitation by functionally converting what might have been an unrecognized (effectively unwitnessed) arrest to a rapidly-recognized witnessed event. Increasingly, portable and/or ubiquitous technologies can assess abnormal breathing using the microphone in a smart device, evaluate the ECG rhythm using a smartwatch, and determine pulse rate using video of the face.[69–71] These technologies can be integrated with emergency alert and response. However, their adoption requires exceptional fidelity such that activation is limited to true life-threatening circumstance.

Telecommunicator interface

Many parts of the world have a "universal" call number for medical emergencies that connects callers with a telecommunicator trained to identify OHCA and coach CPR. There is immense opportunity to leverage this resource to more comprehensively and more quickly identify OHCA.[72–74] The telecommunicator also has the potential to affect the quality of bystander CPR and access to an AED.[75] Widespread adoption of established performance metrics that prioritizes measurement and telecommunicator feedback could increase timely recognition and bystander CPR performance.[42]

Technology affords the potential to supplement the human interface between the caller and telecommunicator. Specifically, artificial intelligence may help with OHCA recognition, appreciating that at least a quarter of OHCA is not recognized early by the telecommunicator or bystander. Artificial intelligence "listening" to words, phrases, and intonation of the exchange to determine in real-time the possibility of OHCA could aid the telecommunicator in difficult cases.[76] Such artificial intelligence also provides potential for real-time language translation that could overcome communication challenges.[77] Video communication may also aid the caller-rescuer team to identify and perform high-quality CPR.[78]

Early CPR

The emergency communication center also enables activation of the community to respond to suspected OHCA. This crowdsourcing strategy uses an integrated geospatial smartphone application to alert nearby volunteer citizens to respond to the scene to provide CPR and/or AED application.[44] The strategy has accelerated quickly in some regions of the world. The response includes not just public settings but now is expanded to incorporate residential locations, transforming the potential impact of these volunteer response programs given the majority of OHCA occurs in the home.[79–82] Such a response may incorporate other lifesaving adjuncts – specifically the AED – so that the volunteer response can provide CPR and early defibrillation.[83] This all-access crowdsourcing strategy has conceptual appeal but requires leadership, investment, and community engagement to truly have public health impact. Finally, ubiquitous personal technology (smart phone or watch) may be able to measure and report compression characteristics to help coach CPR.[84,85]

Early defibrillation

The interval from collapse to initial shock is a strong predictor of survival. Thus, the basic but formidable challenge is to deliver a relatively scarce resource – defibrillation – to the patient more quickly. The challenge is that OHCA is an unexpected event, making timely access to defibrillation difficult. Consequently, first responder AED, law enforcement AED, and public access defibrillation programs have incrementally improved survival by shortening the interval from collapse-to-defibrillation.[86–89] And yet there is a remarkable opportunity to achieve earlier defibrillation as the majority of shockable OHCA receives initial defibrillation more than 8 min after collapse.[90] In many communities, bystanders provide early CPR in well over half of OHCA; however less than 5% receive early AED, even when multiple rescuers are on site.[3,4,67,75] Hence there are often willing early rescuers providing CPR who lack access to lifesaving defibrillation.

One general strategy to reduce the interval to defibrillation is to more efficiently harness the current network of available AEDs. The strategy may be advanced via an accurate, accessible AED registry that links in real-time to the rescuer.[91] The registry must coordinate the locations of the OHCA event, the rescuer, and the accessible AED to direct the optimal response. Integrated crowdsourcing strategies using geospatial technology have promise and could enable smart responses that bring the AED to the patient though the potential has yet to be realized.[2] Drone AED delivery may also impact community resuscitation by reducing the defibrillation response interval, though the strategy must consider the optimal deployment model, regulatory and operational oversight, and program expense.[92–94] Other operational methods that integrate AED delivery as a scarce resource have potential; for example, a program that equips prevalent transportation services (cabs or ride service, delivery vehicles).[95]

Current AEDs are designed for "industrial use" whereby they are engineered and powered for sustained and repeated high-fidelity operation. Yet we know that in most public access events, the AED delivers a single shock as this initial shock is either successful or professional response arrives.[96] Should we be implementing a lower-cost, all-access bridge device that is engineered to address the need for layperson defibrillation, especially in the residential setting where most OHCA occurs?[97]

From a public health perspective, a widely deployed "personal lifesaver" could address the ongoing substantial and missed opportunity to save more lives through early defibrillation. Imagine a true layperson AED that is engineered more modestly, providing only a single shock, typically delivered during the electrical phase. Deployment does not deter conventional EMS response, assuring the current standard of care. The challenge is to achieve broad deployment, a strategy that would undoubtedly require a lower cost.

Progress requires engineering and regulatory innovation. A new layperson AED would not serve professional organizations or even public access programs but instead define a new market whereby the device is engineered as a bridge, appreciating that the new device may achieve lower operational fidelity. As public health context, we should consider CPR. Bystanders do not achieve high-performance metrics that are the standard for professional rescuers, and yet we know imperfect early CPR effort by laypersons substantially improves the likelihood of survival. By analogy, a new consumer-designed and priced AED bridge device that operated successfully, for example, in 95% instead of the 99% industry standard would represent an enormous advance for the 95% while the 5% would retain the current standard of care. Dissemination of low-cost consumer AEDs as a public health intervention (like fire safety home equipment) could address the challenge of timely defibrillation inherent in OHCA. We must consider and create solutions with a public health lens to truly transform resuscitation outcomes.

Advanced resuscitation

Current strategies of professional-rescuer resuscitation generally follow an algorithmic one-size-fits-all approach. However, OHCA occurs via heterogeneous acute mechanisms (i.e. ischemia, primary electrical disturbance, hypoxia) among persons with variable chronic disease states and manifests a time-dependent evolving pathophysiology, which in turn influences prognosis.[98,99] The heterogeneous and time-dependent pathophysiology suggests the opportunity for a more directed and specific treatment strategy tailored to the individual patient.[100] Indeed, experimental models demonstrate that individualized therapy that matches acute physiology with specific treatment can improve resuscitation.[101–103]

Rescuers use the patient's ECG rhythm and vital status to guide clinical decision making.[2] Yet the provider is typically blinded to this information for large stretches of resuscitation during CPR. As a consequence, treatment decisions and therapies may not align with the patient's physiological needs. Ongoing investigation highlights the ability to predict rhythm and vital status during active compressions, potentially enabling more targeted therapy.[104,105] Other modalities that evaluate flow, oxygenation, and cellular respiration may also help inform for example the composition, dose, and/or sequence of CPR, drug treatment, and defibrillation.[106,107]

As stakeholders consider their own system, strategies of advanced resuscitation may depend on their particular resources and expertise – the concept of local implementation. Survival may benefit from strategies that assure field provider expertise to enable dedicated onsite field effort rather than a rush to hospital transport.[108] Conversely, early hospital transport for highly-technical, advanced interventions such as those involving extracorporeal membrane oxygenation (ECMO) may offer survival benefit for a distinct subset.[109–112] ECMO provides the ability to control systemic perfusion and potentially correct the underlying pathology. Real-world considerations of cost, expertise, timely access, and system coordination will help determine the balance of benefit and risk for the different advanced strategies.[113] Such decisions that direct programmatic focus need to consider opportunity cost, understanding that investment in early links are important if downstream interventions are to affect outcome.

Post cardiac arrest care and recovery

Early hospital-based care such as cardiac catheterization and targeted temperature management, close hemodynamic and neurological monitoring, and delayed neuro-prognostication are key components in the successfully resuscitated patient.[114] Future developments may further define pathophysiology, incorporate more specific diagnostic strategies, or refine treatment protocols, potentially incorporating methods of perfusion and brain protection.[115] For example, whole-body CT imaging may identify etiology including acute coronary occlusion that may support catheterization among resuscitated patients without acute ST segment elevation myocardial infarction.[116] In addition, trials are ongoing to address the optimal degree and duration of targeted temperature management, and multidisciplinary approaches to assess neurological prognosis.[117] Advances in risk stratification may also impact the use of implantable defibrillator use and other medical treatments to improve secondary prevention. To achieve optimal recovery, survivors and their families often have a range of emotional and medical needs that can best be addressed by a multidisciplinary health team. Quality and quantity of life may be improved based on better understanding the ideal model of convalescence care and recovery.

The promise ahead

The ability to translate scientific understanding into real-world clinical practice through implementation provides an opportunity to advance OHCA resuscitation. A key characteristic of this progress is accountable partnerships across stakeholder organizations. The ability to widely share and learn from these experiences provides the platform for improvement. Ongoing innovation involving the domains of science, education, and implementation provide an interdependent opportunity to accelerate progress, save more lives, and positively impact global health.

Conflict of interest

The authors of the article Out of Hospital Cardiac Arrest: Past, Present, and Future have no conflicts of interest to report.

CRediT authorship contribution statement

All authors for the submitted article Out of Hospital Cardiac Arrest: Past, Present, and Future contributed to the writing and made significant input to the final version. The idea for the article was conceived by Mickey Eisenberg and he is listed as the senior author. The final version was mostly provided by Tom Rea the first author.

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