The Effect of the AED and AED Programs on Survival of Individuals, Groups and Populations

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Abbreviations:
AED: automatic external defibrillator
AHA: American Heart Association
CPR: cardiopulmonary resuscitation
EMS: emergency medical services
EMT: emergency medical technician
ILCOR: International Liaison Committee on Resuscitation
NRCPR: National Registry of Cardiopulmonary Resuscitation
OOHCA: out-of-hospital cardiac arrest
PAD: public access defibrillation
PEA: pulseless electrical activity
VF: ventricular fibrillation
VT: ventricular tachycardia

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Abstract

Objective: The automated external defibrillator (AED) is a tool that contributes to survival with mixed outcomes. This review assesses the effectiveness of the AED, consistencies and variations among studies, and how varying outcomes can be resolved.

Methods: A worksheet for the International Liaison Committee on Resuscitation (ILCOR) 2010 science review focused on hospital survival in AED programs was the foundation of the articles reviewed. Articles identified in the search covering a broader range of topics were added. All articles were read by at least two authors; consensus discussions resolved differences.

Results: AED use developed sequentially. Use of AEDs by emergency medical technicians (EMTs) compared to manual defibrillators showed equal or superior survival. AED use was extended to trained responders likely to be near victims, such as fire/rescue, police, airline attendants, and casino security guards, with improvement in all venues but not all programs. Broad public access initiatives demonstrated increased survival despite low rates of AED use. Home AED programs have not improved survival; in-hospital trials have had mixed results. Successful programs have placed devices in high-risk sites, maintained the AEDs, recruited a team with a duty to respond, and conducted ongoing assessment of the program.

Conclusion: The AED can affect survival among patients with sudden ventricular fibrillation (VF). Components of AED programs that affect outcome include the operator, location, the emergency response system, ongoing maintenance and evaluation. Comparing outcomes is complicated by variations in definitions of populations and variables. The effect of AEDs on individuals can be dramatic, but the effect on populations is limited.

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Introduction

As early as 1900, Prevost and Batelli discovered that the conduction of electrical stimuli, if strong enough, could arrest ventricular fibrillation and restore normal sinus rhythm.[1] Beck successfully defibrillated the human heart using internal cardiac paddles in 1947.[2] In 1956, Zoll performed the first successful human external defibrillation,[3] and in 1957, Kouwenhoeven further evaluated closed adult chest compressions and external defibrillation during ventricular fibrillation (VF).[4] Subsequently, prehospital external defibrillation was used by Irish physicians. In addition, external defibrillators were deployed with physicians and nurses who staffed first-aid stations in Atlanta Stadium in 1966 and with emergency medical technicians (EMTs) in Portland, Oregon (USA) in 1969.[5-7]

A series of trials involving automated versions of the external defibrillator were performed with laboratory dogs and hospitalized human subjects,[8] and prehospital versions were tested in Brighton, England in 1980.[9] In 1982, the Food and Drug Administration (FDA) approved clinical trials of automated defibrillator (AED) use by emergency medical technicians (EMTs).[1] Early studies used manual defibrillators and provided a sixteen-hour rhythm recognition training program. Following demonstration that these programs were safe and effective, studies comparing EMT AED use with EMT application of manual defibrillation began. The American Heart Association

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(AHA) endorsed AEDs in 1986,[10] and the American Red Cross added AED training to their cardiopulmonary resuscitation (CPR) curriculum in 1999. Investigators have tested defibrillation in different environments using individuals trained at various degrees of competency, and with different modes of delivery and energy dosages. Because the different snapshots of AED use occurred in various clinical settings and over a long time period, the information regarding AED and AED program effectiveness has been difficult to evaluate in a consolidated and systematic fashion.

Today, the AED is widely used in the resuscitation of individuals in cardiac arrest. This review assesses the effectiveness of the AED and how it has been applied in various settings.

Methods

This review began as part of a project for worksheet development for the International Liaison Committee on Resuscitation (ILCOR) 2010 science review. The worksheet[11] addresses hospital survival in AED programs (EIT-015) and is included in the 2010 ILCOR guidelines.[12] Search strategy in PubMed for the original search was: (AED[tw] OR PAD[tw] OR SAED[tw] OR FAED[tw] OR "automated external defibrillator"[tw] OR "public access defibrillator"[tw] OR defibrillators[mh] OR cardiopulmonary resuscitation[mh] OR heart arrest[mh] OR ventricular fibrillation[mh] OR electric countershock[mh] OR ventricular tachycardia[mh]) AND (program evaluation [mh] OR survival rate [mh] OR survival analysis [mh] OR treatment outcome [mh] OR outcome assessment (health care) [mh] OR time factors [mh]). The search was restricted to RCTs, other clinical trials, meta-analyses, and practice guidelines. Secondary references were derived from review of citations in reviewed articles. The search terms above were used as keywords in various combinations in searching Cochrane and the Defense Technical Information Center (DTIC), which resulted in no new references. CINAHL (http://www.ebscohost.com/academic/cinahl-plus-with-full-text/) was also searched. The original search was conducted in 2009, and was updated using the same criteria in 2010 and 2011. A minimum of two authors reviewed each paper, and consensus discussions resolved disagreements on inclusion and level of evidence, which followed the AHA/ILCOR standards. The original question focused on factors which affected survival in AED programs. However, the broad variations in program design and conduct could not be captured in the worksheet format, so a broader review of the field was undertaken. One author (NAS) joined the team to write this paper.

Results

The Effectiveness and Safety of the AED as a Tool

One early study compared prehospital use of AEDs against manual defibrillation by EMTs with survival to discharge of 17% and 13%, respectively,[13] and another demonstrated similar outcomes between semi-automatic defibrillators and manual defibrillators with good sensitivity and specificity for rhythm recognition with both methods.[14] Cummins (1984) assessed the safety, sensitivity, and effectiveness of the AED when applied by skilled paramedics.[15] AED rhythm interpretation had a sensitivity of 81% and accuracy of 92%. The AED was effective in converting VF or pulseless ventricular tachycardia (VT) to either organized rhythm or asystole 79% of the time.

The 2005 AHA guidelines recommended a single, higher-dose shock for VF/VT for all defibrillators to replace the prior three-shock protocol.[16,17] One study has shown that this protocol shortens pauses in CPR, but did not improve survival.[18] Survival from out-of-hospital cardiac arrest (OOHCA) increased from nine percent with bystander CPR only, to 24% when the AED was applied, to 38% when the AED delivered a shock (OR: 1.75; 95% CI: 1.23-2.50; $P < .002$).[19]

In the public access defibrillation (PAD) study, there were no inappropriate shocks and no device failed to give an indicated shock.[20] The safety of patients and operators during AED use by volunteers and trained laypersons has been studied. Peberdy (2006) documented 27 device-related adverse events; 17 involved theft, three an inability to locate the device, two had ajar batteries, one a wedged electrode wire that prevented opening the lid, one failed circuit board, one dead battery, one electrode warning, and one service warning. Two patient-related adverse events (rib fractures) were associated with resuscitation rather than the AED, and did not affect outcomes. The major impact on laypersons was emotional, which was infrequent (seven adverse events), short-term, and related to the cardiac arrest event rather than operation of the AED.[21]

The AED has been shown to be accurate, efficacious, and able to contribute to patient survival with few adverse effects.

The Application of the AED in Various Settings

The AED has been applied in many study settings. This section reviews studies of AED application in the hospital, prehospital (first responder and EMS), home, and public environments.

In-Hospital—The literature regarding in-hospital AED use is limited. Five relevant investigations were identified.[22-26] Zafari replaced manual, monophasic defibrillators with biphasic defibrillators capable of functioning manually or as an AED (dual function devices). The new devices were set in AED mode in chronic care units, and AEDs were placed in outpatient clinics.[22] The investigation also included an educational program for nursing and medical house staff. Sixty-four defibrillations performed after the program began were compared to historic controls with manual defibrillations. Twenty-seven defibrillations were performed with an AED device and the remaining 37 by a defibrillator in AED mode. An improvement in survival from four percent to 12.8% followed implementation of the program; survival was comparable between the AED and dual function, biphasic defibrillator groups.[22] The separate contribution of education, team reorganization and manual defibrillator cannot be assessed.

Hanefeld reported on the first year of an in-hospital AED program. Fourteen AEDs were installed in areas of a multi-building complex which were not accessible to code carts. AEDs were placed such that the AED was accessible to the team and patients within 30 seconds. During the study period, medical, nursing or other staff responded to 27 witnessed cardiac arrests and applied the AED prior to the arrival of the cardiac arrest team. The median time to activation of the AED was 2.1 minutes compared to 4.7 minutes for the team. A high rate of survival to discharge and return of spontaneous circulation, 55.6% and 88.9% respectively, were noted in the VF/VT group.[23]

Forcina replaced standard defibrillators with devices which could function as an AED or as a manual defibrillator, and assessed survival to discharge following VF/VT and asystole/pulseless electrical activity (PEA) arrests. Time to initial shock was not decreased comparing AED versus standard defibrillation. AED use did not improve outcome for the VF/VT group. Survival of asystole/PEA treated with an AED was worse (15% vs. 23%, $P = .04$) than the standard group. Both VF/VT cohorts received shock in less than three minutes.[24] A recent study of in-hospital AED deployment and use in non-critical care areas showed no significant change in patient outcomes compared to manual defibrillation response.[25] A report from the National Registry of Cardiopulmonary Resuscitation (NRCPR) comparing hospitals using AEDs with those that did not showed equivalent VF outcomes but significantly lower overall survival in the hospitals using AEDs. Both studies demonstrated lower survival among patients with PEA and asystole among the AED group, suggesting delays in treatment among these patients.[25-27]

Prehospital/EMS—Prehospital studies compared first responder and EMS utilization of AEDs versus manual defibrillation, co-response with volunteers, resuscitation algorithms, biphasic/monophasic defibrillation, sequence of shocks, and dosing of energy. Eisenberg (1979, 1980) reported CPR by laypersons and defibrillation by paramedics improved outcomes.[28,29] Vukov showed that EMTs trained in the use of AEDs improved survival with defibrillation compared to AEDs used only to record the rhythm.[30] In 1991, Haynes studied firefighters, peace officers, and public lifeguards in California who, in addition to EMTs, used AEDs, and obtained a 13% survival rate among patients who received defibrillation.[31] White implemented AEDs in an emergency system utilizing policemen and paramedics and reported a survival to discharge of approximately 40% among VF patients.[32] Steill also showed benefit with more rapid response times by EMS personnel equipped with AEDs.[33]

In a 2002 study in Italy, survival tripled when minimally-trained volunteers responded with AEDs in ambulances or police/fire vehicles and a volunteer delivered an AED from a nearby location in addition to the existing EMS response. The multiple levels of responders allowed one to arrive sooner; positive response for a shockable rhythm was doubled and neurologically intact survival increased from 2.4% to 8.4%.[34] Another Italian study showed an increase in neurologically intact one-year survival when AEDs were placed in an existing EMS system of emergency departments and ambulances along with newly-trained volunteers who accessed AEDs at "key locations of public access areas."[35]

Kajino showed success with AEDs used by EMS but there were non-statistically significant differences between monophasic and biphasic versions.[36] A study conducted in Paris by Jost used BLS-trained fire brigade responders to compare the 2000 AHA guidelines for AED use with a protocol based on quicker and fewer shocks and reduced interruption of CPR.[18] The study showed equivocal results of survival to hospital admission; survival to discharge was 13.3% in the study group and 10.6% in the comparison group. Bystander AED use was not reported; approximately 80% of events were witnessed, but bystander CPR was performed in only 21% of events. Only shockable rhythms were included. These studies showed overall success with use of AEDs, but medical training of the AED operator was variable and not always clearly reported.

In the Home—Early AED use by non-medically trained individuals began with high-risk populations in which cardiac arrest occurrence and AED need were likely. In 1989, Eisenberg recruited spouses of survivors of out-of-hospital VF and compared a group trained in AED use to a group trained in CPR.[37] The Home Automated External Defibrillator Trial (HAT) measured survival in a group of high-risk patients who were post-MI (myocardial infarction) and non-implanted cardiac defibrillator (ICD) candidates, and compared home AED against control.[38] In both study arms, no benefit from home AED implementation was shown. Several aspects may have contributed to lack of significant results: low incidence of arrest of cardiac origin, infrequent witnessed arrest, infrequent VF as first rhythm, and a low rate of AED application with misuse in 1/13 cases. Further work is needed to see if home AED use can be beneficial.

Public Access—The ability to treat shockable rhythms without an operator diagnosis led researchers to assess whether AEDs operated by individuals close to a victim might allow faster defibrillation and increased survival. Automatic external defibrillators were placed in locations where rapid EMS arrival was difficult to achieve, where devices could be delivered to the victim by foot, and as mobile AEDs, which could be delivered to the victim by rescuers using vehicles or other transport.

In 1997, O'Rourke conducted an AED program in aircrafts and airport terminals.[39] In 65 months, 27 cardiac arrests occurred on aircraft with only six VF as presenting rhythm, while 19 occurred in terminals with 17 VF events. Among VF patients in aircrafts and terminals, survival to discharge was 33% (2/6) and 24% (4/17), respectively. All survivors had shockable rhythms. Only 16/27 of on-board cardiac arrests were witnessed compared to 19/19 in terminals. The lack of an "attention trigger" could explain the low incidence of VF on aircraft and low survival, because observers may not be able to differentiate between resting and cardiac arrest in a quiet person seated on an aircraft. Despite the low rate of cardiac arrest and AED deployment on-board, AEDs were applied 109 times and used as a monitor 63 times, which gave clinical information to airline medical personnel and reduced flight diversion. Trained American Airlines crew members applied AEDs to 29 cardiac arrest victims over two years, with an overall survival to discharge of 20% (6/29) and of 40% in the VF patients (6/15).[40] Caffrey (2002) implemented AEDs in airports with no specific staff training and obtained a 52% survival to discharge rate in the 21 cardiac arrests that occurred in two years, 20 of which were witnessed and received bystander CPR as well.[41] So-called "Good Samaritans" played a major role in this study.

In the Valenzuela study (2000), casinos functioned as a lab setting in which security officers trained in CPR and AED use were summoned by radio if a collapse was suspected.[42] In these favorable conditions (defined spaces under continuous video review, high density of potential rescuers and devices, and cardiac arrest triggering activity in an elderly population), 149 cardiac arrest cases occurred in 32 months. The association of a short interval from collapse to both CPR (2.9 minutes) and shock (4.4 minutes) led to an overall survival to discharge rate of 38% and VF survival of 53%.

Drezner (2009) surveyed US high schools with at least one AED onsite and an established emergency program.[43] Within the six-month study, 36 out of the 1710 schools responding to the survey reported a case of cardiac arrest in student athletes or older non-students; 97% were witnessed, 94% had bystander CPR performed, and 83% received an AED shock, leading to 64% survival to discharge. Limitations of the study include a survey response of only 11%; only 82% of responding schools actually had AEDs on campus. Automatic external defibrillator placement in schools may be of value, but the low volume of cardiac arrest events reported and poor survey response do not provide enough evidence to validate its use.

Studies have demonstrated that on-site AED deployment results in two outcomes: high survival rate (16%-48%) and low deployment rate.[20,31,34,44-48] In Capucci (2002), on-site AEDs (N = 12) were never used, although mobile devices were delivered to the scene.[34] Cardiac arrests occurring in public places are frequently witnessed, recognized, and treated early, with a high rate of shockable rhythms, but they represent a small portion of OOHCAs, leading to limited use of devices.

Kuisma did not show improved survival-to-discharge in public places compared with EMS despite a shorter "call-to-at patients side" interval.[49] In the PAD trial, a delay in "diagnosis and mobilization of volunteers summoned by way of centralized response system" was hypothesized by authors as a likely cause of disappointing result.[20] Most recently, studies have involved mobile mapping of AED locations and provided SMS text to laypersons, and in both studies, some events had delay in notification. Poor access to the AED device was also reported.[50,51]

Effect of Variables Measured in Programs

In the studies reviewed for this paper, certain variables were measured consistently. However, other variables with substantial effect were considered sporadically. Core Utstein-style variables such as presenting rhythm, return of spontaneous circulation (ROSC), and hospital survival are generally included. The presenting rhythm documents the frequency of ventricular fibrillation, asystole and pulseless electrical activity (PEA) and allows evaluators to compare presenting rhythm with response times.[52] Location may include home, street, nursing home, residential institution, physician office/clinic, education, hospital, recreation/sport, industry, farm, mine/quarry, jail, airport, and lake/river/ocean.[53] Location type affects survival through the characteristics of the individuals, presenting rhythm, time of onset of symptoms prior to activation of the emergency response system, whether the event was witnessed, access to AEDs, and physical barriers to response. Return of spontaneous circulation is typically captured by the transport personnel, and patient outcomes may be obtained through contact with receiving hospitals. While neurological status at discharge is the most meaningful outcome measurement, it is difficult to obtain when the cardiac arrest originates in the prehospital setting.

Dickey studied the in-hospital mortality of patients who were resuscitated from VF outside of the hospital and found that mortality was influenced by pre-arrest patient characteristics including sex, age, prior myocardial infarction, stable angina or chronic cardiac dyspnea, hypertension, diabetes mellitus or cerebrovascular event, drug treatment (digoxin, diuretics, blocking and antiarrhythmic agents), and smoking history.[54] This information is rarely collected among OOHCA patients.

Comparing survival requires assessment of the population studied. Urban populations have different lifestyles, medical history, resources for EMS and first responder systems, and quality and specialization of hospitals than populations of smaller cities and rural areas. Within each population, certain locations favor quick recognition of a cardiac emergency, faster activation and response of the EMS system, and higher rates of bystander CPR and/or AED use. Examples of these locations include airports, casinos, convention centers, and public sporting venues. Furthermore, when assessing bystander AED programs, it is important to document who responds. Relevant categories include volunteers, employees and chance bystanders; some have medical training. Highly mobile groups present problems in defining the parameters of a population.

Discussion

There seems to be little doubt as to the effectiveness of the AED as a tool. However, while the AED is a core component of most cardiac arrest programs, its use has resulted in mixed outcomes. For example, in-hospital studies of AED use demonstrated it to be either more or less effective than manual defibrillation[25] and studies of AEDs in the same California emergency system, during different time periods, yielded survival rates of 13% and 40%.[31,32] Some studies have shown strong benefit in the use of AEDs, while others have shown equivocal results or too few device applications for proper assessment. Most reviews assume that biological disparities between populations are not relevant. This may be partially true in that human physiology has little variation in terms of out-of-hospital cardiac arrest. However, the survival of populations varies greatly based on demographics and illness burden, as supported by Dickey.[54] The following are components of AED programs that affect outcomes:

Operator

Programs that have demonstrated the AED to be an effective tool have a reliable source of responders. Successful projects incorporate recruitment and training of a paid or volunteer team which uses the devices in a system set up to facilitate a prompt response. Programs engaging airline workers and security guards added to trials of police responders and firefighters; while each group was minimally trained in medicine, the program training was sufficient given their vigilance, duty to respond and commitment to the program's success. Survival as high as 40% has been reported when AED was applied by laypersons, 16% when applied by health care workers, and 13% when applied by police.

Alternatively, programs that relied on "faceless, nameless" members of the community showed too low a response rate to cardiac arrests to allow proper assessment. A lower perceived duty to respond among individuals may have contributed to the low rates of response in PAD trials.

Location

There is sufficient evidence to support AED programs in a range of prehospital settings. Locations with high rates of VF, witnessed arrests and rapid response times are likely to increase survival. In a public access defibrillation trial, the highest rates of arrests occurred in fitness centers, golf courses, public transit facilities, and entertainment and meeting complexes, and the lowest rates were in office complexes and hotels.[55] The presence of VF in out-of-hospital cardiac arrest patients varies across time, countries, and settings. Ventricular fibrillation presence ranges from less than 20% in residential communities to over 70% in casinos.[42,56] While AED placements in airports and casinos is effective, there is less impact throughout the community as a whole.[57] There is insufficient evidence to support home AED programs.

A study from Copenhagen evaluated the potential effect of strategic AED placement.[58] According to European Red Cross and AHA guidelines, placement of AEDs is recommended within a 100m radius of one previous cardiac arrest occurring during a two-year or five-year period. Mapping of 74 cardiac arrest events into 100m grids recommended AED placement at major train stations and pedestrian areas. This placement would provide AED availability for 10.6% or 66.8% of arrests and would have required placement of 125 or 1104 AEDs, respectively. In reality, 104 AEDs were placed in an unguided manner in municipal buildings of the city, and none were used during the 2005 study period.[58] Neurologically intact survival of bystander-witnessed arrest treated with an AED increased significantly ($P = .01$) as AED density increased from <1 to ≥ 4 per square kilometer.[56]

"System"
The "System" is the overall environment where the AED is utilized. It involves the public and local stakeholders (including private businesses, government, hospitals, dispatch centers, first responders, and EMS). Systems with high rates of bystander participation in out-of-hospital cardiac arrest have committed stakeholders. Using statistical outcomes of cardiac arrest can drive allocation of resources for equipment and education. As stakeholders promote AED use among the population, the varying degrees of public use of AEDs mentioned previously should be acknowledged. Lack of knowledge of the location of the AED, low comfort level with CPR and AED use, and assumption that a more experienced, trained individual is needed may contribute to the low rates of applying AEDs by the public. Weisfeldt reported 13,769 cases of out-of-hospital cardiac arrest, but AEDs were applied only 289 times.[19] In Kitamura, AEDs were placed by bystanders 462 times in 12,631 witnessed VF cardiac arrest among 312,319 OOHCAs.[56] Among all AED uses, bystanders applied the device in 2.1% of cases, and other contributors included health care workers (32%), lay volunteers (35%), police (26%), and unknown (7%).[57] The impact of bystander AED was reported as 24% survival compared with 9% in CPR alone.[57] There may also be difficulties in access to AEDs, and maintenance of the devices may be inadequate.

Four types of community AED programs exist: (1) traditional responders (e.g., police/fire) with a duty to respond; (2) nontraditional responders (lifeguards/security/airline attendants) with duty to respond; (3) laypersons with CPR and AED training; and (4) minimally trained or untrained citizens applying CPR and an AED.[59] Cost-effectiveness may be higher in programs with mobile AEDs, first responders, strategic placement in high-risk areas, and motivated bystanders/laypersons with a duty to respond.[59-61] The effect of the System is different than that of the location and the operator, and relates to promotion of AED use, interactions among responding public safety and health care organizations, attitudes among the public regarding cardiac arrest, and community ownership.

"Follow-Through"
This component considers device registry and maintenance, evaluation of use and outcomes, ongoing public education and manipulation of resources. Program success requires a system that ensures equipment update and maintenance as well as operator education. Follow-through ensures that an existing AED program does not lose effectiveness over time. Stakeholders need to monitor outcomes and adjust to the dynamics of a prehospital emergency response system that is inclusive of volunteer participation of CPR and AED use.

Definitions
To better understand the effectiveness of AED programs, components must be defined consistently.[62] For example, individuals with a "duty to act" should be identified and categorized specifically among first-responders, EMS providers, public/private employed individuals, bystanders/laypersons, minimally-trained laypersons, and off-duty medical professionals. Populations and specific locations where events occur should be differentiated from others in regards to varying degrees of underlying illnesses within the population, education, socioeconomic resources, and geography, as well as several other variables. For example, population turnover is high at locations such as sports stadiums, where individuals from various cities and/or countries fill and empty over a period of four hours. Similarly, airport population turnover is rapid and affects the city and area in poorly described ways.

Study designs, locations, population and program contributors vary significantly, with many resulting combinations. Therefore it is difficult to compare results, identify the effect of single aspects on overall results of the study, and summarize evidence.

Limitations
As with all review papers, a major limit for this paper is the quality and density of projects relevant to the question. Systematic review or meta-analysis would be desirable, but the inconsistencies in definitions and wide range of programs make these approaches unfeasible. Many AED-based programs exist that have not been prepared for publication, so the full population effect cannot be established. This detailed review has, however, been able to describe groups and interventions most likely to benefit and has assessed the overall limits of AED programs in populations.

Conclusion
When the AED is the appropriate tool, there is no substitute. The AED can reverse clinical death for the individual patient and extend life. However, the limited use of AEDs and the relatively low survival in programs result in little effect on population outcomes. Given the vital impact that AEDs can have, it is disappointing that studies of AED use have yielded mixed results. Causes of variation include strategic placement, training and commitment of the operator, deployment of the device, and the specific populations in which they have been used. Some of the variation demonstrates the limits of the studies, and some the limits of the AED as a solution to the problem. Advancing treatment of cardiac arrest requires optimizing the effectiveness of AED programs and development of alternate modes of treatment of sudden arrest.

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