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ILCOR Summary Statement

Optimizing outcomes after out-of-hospital cardiac arrest with innovative approaches to public-access defibrillation: A scientific statement from the International Liaison Committee on Resuscitation ☆

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Abstract
Out-of-hospital cardiac arrest is a global public health issue experienced by ≈3.8 million people annually. Only 8% to 12% survive to hospital discharge. Early defibrillation of shockable rhythms is associated with improved survival, but ensuring timely access to defibrillators has been a significant challenge. To date, the development of public-access defibrillation programs, involving the deployment of automated external defibrillators into the public space, has been the main strategy to address this challenge. Public-access defibrillator programs have been associated with improved outcomes for out-of-hospital cardiac arrest; however, the devices are used in <3% of episodes of out-of-hospital cardiac arrest. This scientific statement was commissioned by the International Liaison Committee on Resuscitation with 3 objectives: (1) identify known barriers to public-access defibrillator use and early defibrillation, (2) discuss established and novel strategies to address those barriers, and (3) identify high-priority knowledge gaps for future research to address. The writing group undertook systematic searches of the literature to inform this statement. Innovative strategies were identified that relate to enhanced public outreach, behavior change approaches, optimization of static public-access defibrillator deployment and housing, evolved automated external defibrillator technology and functionality, improved integration of public-access defibrillation with existing emergency dispatch protocols, and exploration of novel automated external defibrillator delivery vectors. We provide evidence- and consensus-based policy suggestions to enhance public-access defibrillation and guidance for future research in this area.
Keywords: AHA scientific statements, Cardiopulmonary resuscitation, Defibrillators, First aid, Heart arrest, Out-of-hospital cardiac arrest

Introduction

Out-of-hospital cardiac arrest (OHCA) is a time-sensitive, life-threatening emergency that occurs millions of times every year.[1] Data from countries around the world with emergency medical services (EMS) in place suggest a global average of 82.1 EMS-attended OHCAs per 100 000 people per annum. Ten percent (range, 6%–22%) of people who experience OHCA can expect to survive with a favorable neurological outcome.[2] The probability of survival after OHCA can be markedly increased if immediate cardiopulmonary resuscitation (CPR) is provided and an automated external defibrillator (AED) is used.[3,4] Ventricular fibrillation (VF) and pulseless ventricular tachycardia (pVT) are amenable to defibrillation but deteriorate to nonshockable rhythms over time. The chances of survival from cardiac arrest fall rapidly for every minute that defibrillation is delayed.[5–7] Median response time intervals for professional EMS responders after a call for help are often >6 minutes, even in developed urban settings with optimized EMS.[8] The vision of the International Liaison Committee on Resuscitation (ILCOR) is "saving more lives globally through resuscitation."[9] If this vision is to be realized, more patients must receive the benefit of

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early defibrillation. The objectives of this scientific statement are to identify known barriers to public-access AED use, discuss both established and novel strategies to address those barriers, and identify high-priority knowledge gaps to be addressed by future research.

Methods

This scientific statement was commissioned by ILCOR. Members of the writing group were selected for their expertise in public-access defibrillation and to establish broad representation from member councils around the world. The statement was coordinated through a series of teleconference meetings and online collaboration from September 2018 through January 2020. The writing group agreed on the overall scope and identified author groups to lead the development of individual sections. The section leaders undertook a series of literature searches relevant to the scope of their section. They used MEDLINE and Embase, with hand searching of reference lists in all citations identified. They completed all original database searches between October and December 2018 or later, with supplementation of the original searches if section authors learned of more recent citations during the writing process. Policy suggestions and critical knowledge gaps are highlighted in the text.

Background

Automated external defibrillators

The introduction of defibrillation into clinical practice is credited to Claude Beck, MD, who, in 1947, performed open-chest defibrillation during surgery on a 14-year-old boy, who survived.[10] Paul Zoll, MD, and colleagues followed with the introduction of closed-chest defibrillation in 1956,[11] and the first out-of-hospital defibrillator was used in an ambulance in Ireland in 1966 by Frank Pantridge, MD.[12] These early defibrillators were bulky machines designed to be operated by health care professionals in a hospital setting. It took decades for defibrillator technology to evolve in such a way that the device became portable and could feasibly be used by laypeople. When these devices were placed in public settings with the goal of having laypeople use them on people who experience sudden cardiac arrest, the concept of public-access defibrillation was born.

AEDs were first made available for public use in the 1980s[13–15] (Fig. 1). AEDs are automated in that they can independently analyze a patient's cardiac rhythm. They are external in that electrode pads associated with an AED are placed on the chest, in contrast to internal defibrillation facilitated by implantable cardioverter defibrillators. They are defibrillators in that they pass an electric current across the myocardium to depolarize muscle and convert a dysrhythmia back to a normal sinus rhythm.[16]

Many AEDs today are compact and user-friendly. Once powered on, many have voice and visual prompts guiding the user to attach the adhesive electrode pads to the chest of an unconscious person. Once the pads are connected, some devices have voice prompts that guide the user in CPR. Some devices can provide feedback on the quality of the CPR provided. At appropriate points in the CPR algorithm, AEDs automatically analyze the patient's cardiac rhythm. AEDs use proprietary algorithms to detect VF and pVT.[17] When tested against rhythm libraries, they function reasonably well in the diagnosis of VF and pVT, with a sensitivity of >95% and a specificity of 95%.[18,19]

In addition to analysis of the rhythm, AEDs provide defibrillation to terminate VF and pVT. If the device detects VF or pVT, it can deliver a shock either automatically or by instructing the rescuer to press a button. Initially, monophasic shock waveforms were used, but all current AEDs use biphasic waveforms, which more predictably terminate VF. VF termination with a single shock is now seen in 90% with biphasic shocks.[20–23] All current AEDs use repeated single shocks in their algorithms rather than multiple sequential, or stacked, shocks. AEDs have evolved over time to include many more features than just automated rhythm detection and defibrillation. Most AEDs designed for public use include auditory and visual cues to guide the user through the steps of CPR and defibrillation. Some devices also include sensors to measure various aspects of CPR quality, including compression depth, recoil, and rate.[24–26] The data from these sensors give users real-time feedback on the quality of the CPR being provided, and many store these data for later review. Many AEDs facilitate download of resuscitation data, including the ECG and CPR quality measures; some of the newest models can transmit these data over the internet via Wi-Fi or cellular connection. Several manufacturers have developed software that accepts data downloaded from the AED to create a debriefing report that is suitable for clinical, research, or quality assurance purposes.[27] Electrocardiographic data from the AED may document the earliest rhythm, contribute to the diagnosis of cause, and suggest treatments (eg, implantable cardioverter defibrillator).[28]

Most contemporary AED algorithms involve pausing chest compressions to facilitate an undistorted electrocardiographic signal for the machine to analyze. This is problematic because chest compression pauses are associated with poorer outcomes.[29,30] Some devices now include technology to allow analysis of the cardiac rhythm while CPR is ongoing.[31] Improvements in technology have reduced charging times and included algorithms to facilitate charging during chest compressions, resulting in a shortened preshock pause.[32]

Public-access defibrillation

Public-access defibrillation is the use of AEDs in the community by members of the public to facilitate bystander resuscitation and early defibrillation. Early public-access AED programs involved the placement of static AEDs in high-traffic public spaces (eg, airports,[33,34] sporting grounds,[35] casinos36) and in places where EMS response is often delayed (eg, aircraft),[33,37] along with the provision of basic life support education to employees. Observational studies report relatively high survival rates for those experiencing OHCA defibrillated at these locations.[33,36,37] There were no incidents of inappropriate shocks or injuries to employees. Early success with this type of strategy prompted implementation in other locations such as subway systems,[38] government buildings,[39] and large public events (eg, marathons)[40] and to a wider range of rescuers. Most contemporary public-access AED programs continue to deploy static AEDs. Oversight and management of these programs is heterogeneous, with some being managed by municipal government, some by EMS, some by fire departments, and some by other types of organizations.

Effectiveness of public-access AED programs

The ILCOR "2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations" recommends the implementation of public-access AED programs.[41,42] Only 1 randomized controlled trial

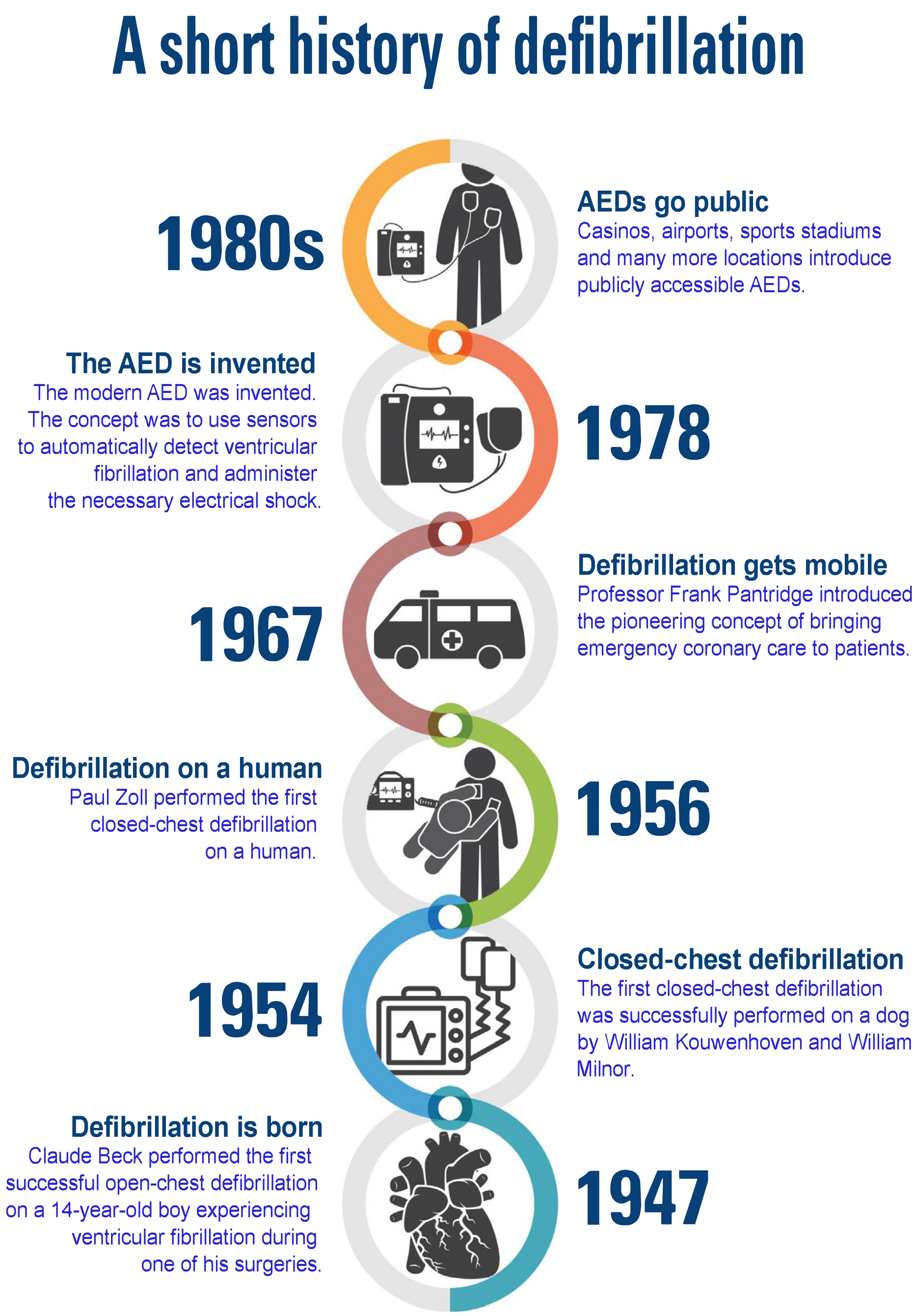

Fig. 1 – A short history of defibrillation. AED indicates automated external defibrillator.

has evaluated the impact of a public-access AED program involving laypeople. The PAD trial (Public Access Defibrillation), published by Hallstrom et al[43] in 2004, was a cluster randomized controlled trial involving 993 community units (eg, shopping malls, recreation centers, hotels, apartment complexes) in the United States and Canada. Community units were randomly assigned to either a CPR-only response system or a CPR-plus-AED system. Volunteer responders in each community unit were trained in CPR, and each site developed an emergency response plan. Community units randomized to the AED group were supplied with static AED units, and volunteers were trained in AED operation. There were 135 definite cardiac arrests during the 21-month study period. The addition of AED training resulted in greater AED use (34.4% versus 1.9%) and shorter times to first rhythm assessment (average, 2.7 minutes faster). The use of AEDs increased survival to hospital discharge (30 survivors of 128 arrests versus 15 of 107; risk ratio, 2.0 [95% CI, 1.07–3.77]; P = 0.03). Functional status at hospital discharge did not differ among survivors in treatment groups as measured by the Cerebral Performance Category.[43]

Systematic reviews on the effectiveness of bystander AED use have been published.[44,45] For example, Holmberg and colleagues[45] identified 44 observational studies comparing bystander AED use with no bystander AED use in regard to clinical outcomes for patients with OHCA. Meta-analysis of 6 observational studies without critical risk of bias demonstrated that bystander AED use was associated with increased odds of survival to hospital discharge (all rhythms

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odds ratio, 1.73 [95% CI, 1.36–2.18]; shockable rhythms odds ratio, 1.66 [95% CI, 1.54–1.79]) and favorable neurological outcome (all rhythms odds ratio, 2.12 [95% CI, 1.36–3.29]; shockable rhythms odds ratio, 2.37 [95% CI, 1.58–3.57]).[45] The number needed to treat ranged from 10 (95% CI, 7–19) to 30 (95% CI, 19–60) for all rhythms and 9 (95% CI, 7–10) to 18 (95% CI, 15–22) for shockable rhythms, depending on baseline survival.

The same systematic review identified 10 studies with reasonable quality exploring the cost-effectiveness of public-access AEDs. Seven of the 10 estimated a cost-effectiveness ratio of <$100 000 (US dollars in 2016) per quality-adjusted life-year. When AEDs are placed at locations with high footfall or population density such as airports, large aircraft, and casinos, cost-effectiveness estimates have ranged from US $30 000 to $50 000 per year of life saved.[46,47] Estimates were found to be heavily influenced by the incidence of cardiac arrest in the population studied, the estimate of public-access AED effectiveness used in the study, and the rate of actual use of AEDs when available. A more recent study, not included in the Holmberg systematic review, used a societal perspective and model inputs based on a review of the literature.[48] An incremental cost-effectiveness ratio of US $53 797 per quality-adjusted life-year for public-access AED programs was calculated, consistent with other cost-effective health care interventions.[49,50] Innovative strategies that guide bystanders to the AED location and increase the probability of device use are expected to improve the cost-benefit ratio of public-access AED programs.

Underuse of public-access AEDs

Unfortunately, public-access AEDs are rarely used during OHCA. Overall, <3% of OHCAs have an AED applied before EMS arrival.[4,7,8] AEDs are more likely to be used in public settings compared with a private residential setting (15.3% versus 1.3%).[51] The "chain of public-access AED," conceptualized by Ringh and colleagues,[52] identifies points on the pathway between collapse and AED use where potential barriers exist (Fig. 2).

Innovative approaches to public-access defibrillation

In the 4 decades since public-access defibrillation was first conceived, many lives have been saved. An analysis from the Resuscitation Outcomes Consortium estimated that on the basis of current use, ≈474 lives are saved every year in Canada and the United States alone.[4] In this study, only 2.1% of people experiencing OHCA had the advantage of AED application before EMS arrival. The potential public health benefits to be gained from increased AED application rates are substantial. The identification of knowledge gaps and viable new strategies to increase early defibrillation should guide our future work. It is unlikely that any individual strategy for improving public-access defibrillation will be sufficient. Rather, we propose a multilayered approach aimed at improving various steps on the pathway from cardiac arrest occurrence to early defibrillation and successful resuscitation (Fig. 3). Next, we identify specific barriers to early defibrillation for patients who experience OHCA, innovative approaches to address those barriers, and critical knowledge gaps to guide future research.

Improving early detection of cardiac arrest

Recognition of cardiac arrest is a critical first step toward successful retrieval and use of an AED. Most cardiac arrests, however, occur in a residential setting, where they often go unwitnessed. With no opportunity for early CPR or defibrillation, death is almost certain.

Innovative technology applications such as wearables (eg, clothing, watches), smart speakers, and machine learning could be used to minimize the occurrence of unwitnessed and untreated cardiac arrest. The latest iterations of consumer wearable devices have rhythm detection capability. Coupled with other sensors and capabilities in these devices—including location awareness, accelerometers, and photoplethysmographs—remote alerting of bystanders or EMS when sensors suggest that a cardiac emergency is occurring (eg, heart rate of 0 or >250 bpm, acceleration-deceleration event [a

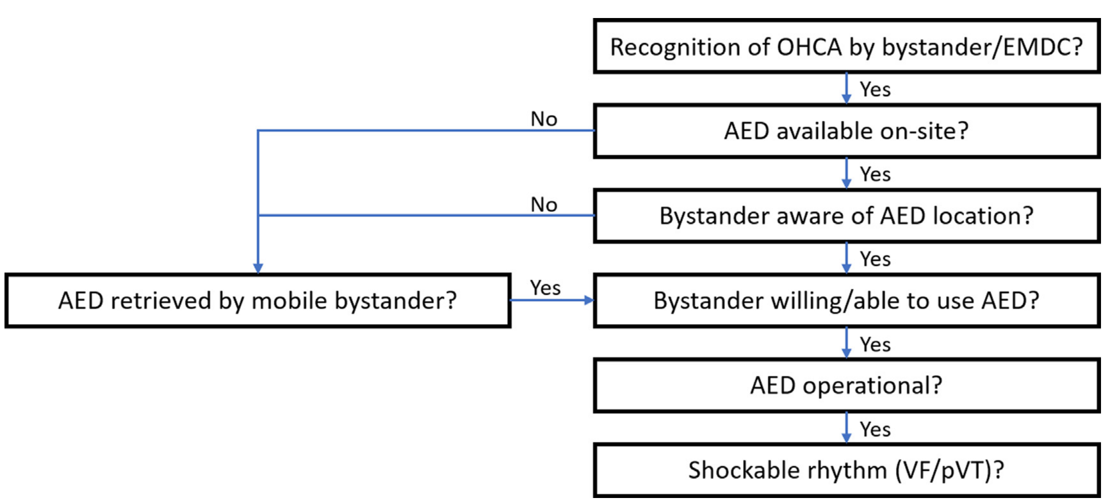

Fig. 2 – Flowchart for use of AEDs: chain of public-access defibrillation. AED indicates automated external defibrillator; EMDC, emergency medical dispatch center; OHCA, out-of-hospital cardiac arrest; pVT, pulseless ventricular tachycardia; and VF, ventricular fibrillation. Reproduced from Ringh et al[52] with permission from John Wiley & Sons Inc. Copyright © 2018, the Association for the Publication of the Journal of Internal Medicine.

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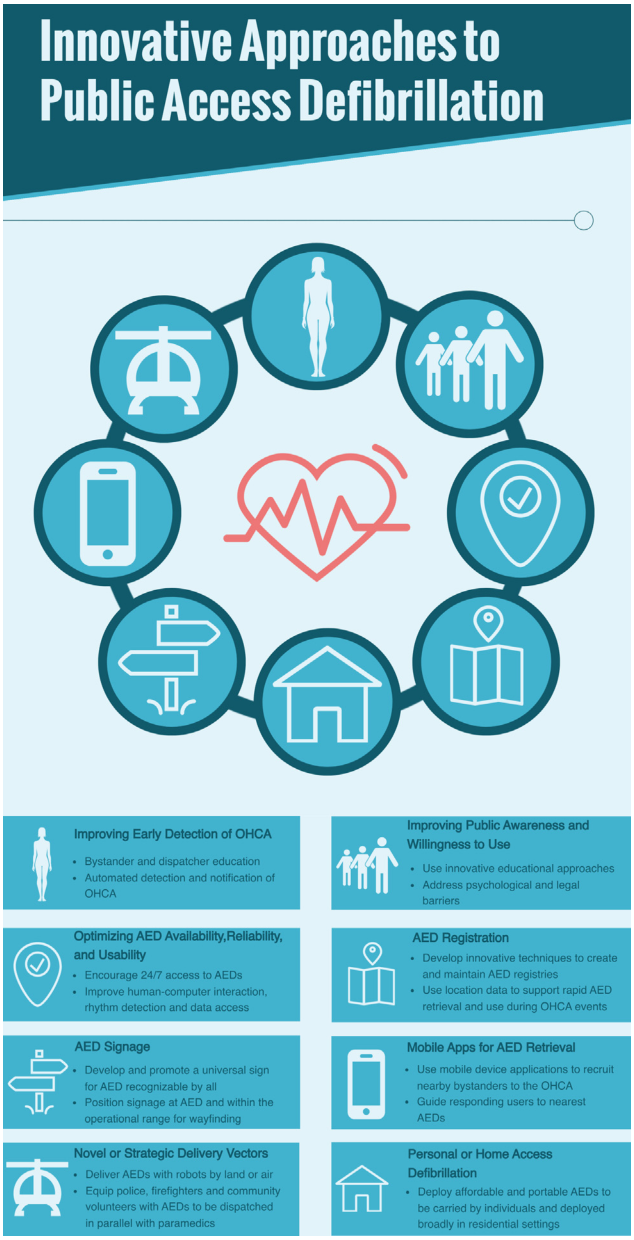

Fig. 3 – A multifaceted approach to improving public-access defibrillation in the future. AED indicates automated external defibrillator; and OHCA, out-of-hospital cardiac arrest.

fall] or zero motion, failure of the user to respond to prompts from the device) becomes a possibility. Innovations in automated video analysis, smart speakers, and machine learning may lead to the development of systems capable of "contactless" early cardiac arrest recognition without the use of wearable sensors.

A recent study involving the review of cardiac arrest events captured on video (eg, security camera feed, personal recordings on mobile devices, mass media footage) demonstrated that people who experience sudden cardiac arrest tend to display stereotypical behaviors.[53] Authors reviewed videos posted to online media-sharing platforms and observed that people experiencing OHCA often touched their face before transitioning from an upright position to a horizontal position on the ground, followed by an absence of movement. The application of machine learning, along with conventional methods of video analysis such as background subtraction, optical flow algorithms, motion detection, person tracking, and behavior analysis, may support the development of systems able to automatically detect medical emergencies and notify bystanders and EMS.[53] In another study using machine learning and sound signal processing, investigators developed a prototype contactless system to detect agonal breathing. Their system was able to detect agonal breathing with a sensitivity of 97.24% (95% CI, 96.86–97.61) and a specificity of 99.51% (95% CI, 99.35–99.67). Using smart speakers and a mobile phone, they demonstrated a false-positive rate of 0% to 0.22% over 164 hours of recorded sleep in 35 different bedrooms.[54] Once fully developed, these systems could automatically trigger an emergency response and facilitate timely CPR and defibrillation for patients who experience OHCA without a human witness.

Knowledge gap

We suggest the development and scientific evaluation of technology-based strategies for early warning of impending cardiac arrest and detection of cardiac arrest when it occurs to facilitate automatic triggering of an emergency response and early defibrillation.

Improving public awareness and willingness to use

Public awareness of AED function and location is generally low.[55] Few laypeople considered using an AED when presented with simulated or hypothetical cardiac arrest scenarios.[56,57] Several other studies have demonstrated that AED recognition and awareness of function among laypeople are poor, ranging from 19% to 43%.[56–59] Most respondents in these studies did not know that AEDs were intended for use by laypeople. In a nationally representative survey from the United Kingdom, fewer than half were aware of the location of the nearest AED.[60]

Self-reported willingness to use AEDs is low across several studies.[55,59,60] Low levels of willingness to use AEDs have been associated with a lack of awareness and training, a fear of causing harm, and, less often, fears of legal liability.[55] Surveyed laypeople report preferring to wait for experienced help to arrive rather than initiating resuscitation themselves.[61] Only 2% of survey respondents in a study from Southampton, UK, could have integrated the essential steps required for successful AED use, namely the knowledge of AED function and location and the willingness to retrieve and use it.[62]

Training is consistently identified as a factor associated with improved bystander awareness of AED function and location, along with increased willingness to use an AED when required.[55] Several factors, including prior training, awareness that AEDs provide voice prompts to guide resuscitation, and knowledge that bystander intervention cannot cause additional harm, were positively associated with actual bystander CPR and AED use among interviewed witnesses to real cardiac arrests.[63] Significant variability exists in how recommendations for AED training have been adopted both within and across different countries and regions.[64,65] In a recent UK survey, bystanders who received AED training in the 5 years before the survey were >5 times as likely to use an AED as those having no prior training.[60] CPR training is more widespread than AED training.[60,66] Media campaigns and initiatives to provide targeted information about AEDs have shown short-term increases in reported willingness to use an AED.[55] AED training is an important factor in multimodal programs designed to increase AED use. Initiatives, including training, expansion of AED numbers, and development of a registry linked to emergency dispatch, were associated with an increase in public-place bystander defibrillation in Denmark from 1.2% in 2001 to 15.3% in 2012, with a similar program in Victoria, Australia, preceding an almost 11-fold increase in the use of AEDs from 1.7% to 18.5% between 2002 and 2013.[51,67]

Using behavior change theory to increase AED use

The most successful behavior change interventions are those underpinned by established behavior change theories. A systematic review of health campaigns in general found that few campaigns used or reported established behavior change theories in planning and evaluating interventions, but those that did were associated with better outcomes.[68] To date, most attempts to increase AED use through public outreach have not involved strategies based on a specific theoretical framework of changing human behavior.[51,69–73] Some evidence suggests, however, that this approach may be helpful in the establishment of public-access defibrillation programs.[74] The PAD trial showed that training and equipping volunteers to attempt early defibrillation within a structured response system increased the number of survivors to hospital discharge after OHCA in public locations.[43] A retrospective analysis of the program from a social marketing perspective suggested that the observed improvement of outcomes could have been further enhanced by an assessment of the community awareness of the health problem and the community's willingness to change behavior before designing and implementing social marketing programs for behavior change.[74]

Social marketing is an example of a theory-based behavior change approach. Social marketing aims to have members of a target audience voluntarily change a particular behavior for the benefit of individuals, groups, or society.[68,75,76] Although a full review of behavior change theory and frameworks is outside the scope of this scientific statement, writing group members acknowledge that well-recognized and validated approaches such as social marketing[68,75,76] and the behavior change wheel[77] are likely to optimize outcomes of a public-access AED strategy implementation.

Policy suggestion

We suggest that a validated behavior change framework be used to guide the development and implementation of interventions to increase public-access defibrillation. We encourage the engagement of experts in behavior change, implementation, or knowledge translation to guide program development.

Creating a culture of action through innovative methods of public messaging

The US Institute of Medicine published a comprehensive report called Strategies to Improve Cardiac Arrest Survival: A Time to Act.[78] This report identifies the need to develop and implement "strategies to better educate members of the public about what cardiac arrest is, how to identify it, and how to respond to it." In the age of the internet and social media, the opportunities for messaging are limitless; however, more data are required to develop best practices. In a scientific statement from the American Heart Association titled "Use of Mobile Devices, Social Media, and Crowdsourcing as Digital Strategies to Improve Emergency Cardiovascular Care,"[79] the authors describe the American Heart Association's success with past social media education campaigns, including "Hands-Only CPR" and "Call Fast, Call 9–1-1." These campaigns were viewed by hundreds of thousands of people, but the impact on behavior change and OHCA outcomes is unknown.

Knowledge gap

We suggest research to guide the design, implementation, and assessment of innovative public messaging strategies to increase bystander CPR and AED use.

Global awareness days

Coordinated and promoted by ILCOR, the first annual World Restart a Heart Day occurred on October 16, 2018.[80] This day was designed to draw the world's attention to sudden cardiac arrest and the importance of bystander resuscitation. The vision for the day involves public outreach, training events, and media events organized and implemented by regional resuscitation councils, with ILCOR motivating the regional councils and supporting them with shared resources. It is estimated that as a result of World Restart a Heart Day in October 2018, >67 000 people worldwide were trained in CPR. Events included such activities as a hands-only CPR mobile tour; promotional events and CPR training in schools, airports, bus stations, and hospitals; and a social media awareness campaign.[81] The importance of AED use in conjunction with CPR should be emphasized in future iterations of this event.

Engaging and empowering children

Although children are not the most likely demographic group to find themselves in the position of being a bystander to cardiac arrest, there is an opportunity to build a generation of global citizens who can recognize cardiac arrest, perform CPR, and confidently use an AED. Strategies aimed at children can promote CPR and AED use as important safety skills, no different from the school-based education currently delivered on other emergency situations such as fire, natural disasters, and active shooters.

There has been a concerted effort by several national resuscitation councils to increase CPR training in schools.[82] Much of the work to date has focused on teaching children about cardiac arrest and CPR. The "Kids Save Lives" initiative has a demonstrated impact in promoting training in school-aged children.[83] The program was launched in 2014 by the European Patient Safety Foundation, the European Resuscitation Council, ILCOR, and the World Federation of Societies of Anesthesiologists, with the intent of promoting resuscitation training worldwide. The initiative recommends educating children beginning at 12 years of age or earlier for at least 2 h/y.[84] This program has been broadly adopted across several European countries[85–87] and is now also supported by the World Health Organization.

Reported outcomes from various programs aiming to educate children about cardiac arrest response are encouraging.[88–91] A notable study from Denmark demonstrates that children can become vectors for further knowledge translation after being trained.[90] Investigators distributed 35 000 home training kits, which included inflatable resuscitation manikins, to schoolchildren. After training the children, investigators encouraged them to take the kits home and train as many people as they could. Through this mechanism, an additional 17 140 individuals received training. This mechanism could be explored to promote AED awareness and training.

Recently, legislation mandating CPR training in schools has been approved in many US states and several European countries. More than 35 US states have signed on for implementation, and there are efforts to reach all 50 states. Although AED training is not explicitly a component of the CPR in Schools movement, it is being adopted as a dual resuscitation package in some areas.[82] After many years of lobbying the government in the United Kingdom, the UK Resuscitation Council and the British Heart Foundation announced that the government has agreed to implement first aid and CPR training into the curriculum for all primary and secondary school students in England.[92] In addition, all school councils in Scotland agreed to establish a "nation of lifesavers" and in 2019 launched efforts to ensure that every secondary school graduate will have had CPR training.

Although this is a promising step, data from Denmark and Canada suggest that legislation does not guarantee that training will occur. The Denmark data suggest that even after 8 years of legislated CPR education in schools there, most children do not receive the training.[93] Mandatory CPR training was legislated in Ontario, Canada, in 1999. A survey of schools in that province conducted a decade later found that only 51% of the schoolchildren were educated in CPR, and only 6% were educated in AED training.[94] The survey highlighted barriers to implementation despite the legislation. Teachers reported that the mandated 4-hour CPR training course was too long, too costly, and too difficult to fit into the already full curriculum.

AED training for children was not included in most of the education initiatives identified by our literature review. Available data suggest that AED use by children as young as 11 years of age is feasible.[95] Teaching AED use in school could help demystify and demedicalize AEDs at an early stage, increasing the chances of AED recognition and use during an emergency later in life.

Knowledge gap

We suggest that future research be conducted to determine optimal AED educational programs for schoolchildren.

We suggest that investigators measure long-term skill retention and the probability of providing resuscitation in future cardiac arrest events as key outcomes when evaluating educational programs.

Policy suggestion

We suggest that all future CPR training for children and adults include the recognition and use of AEDs.

Addressing psychological barriers and injury

The bystander effect, in which a person is less likely to offer help to a person when there are other people in the vicinity, has long been thought to play a role in preventing bystanders from acting. Although this effect has not been specifically investigated in the context of cardiac arrest, some data suggest that it may be less pronounced in situations that are clearly recognized as emergencies or when bystanders are known to one another.[96] In an Australian survey of willingness to perform CPR in a hypothetical scenario, a small percentage of respondents indicated that the presence of someone else who could help would make them less likely to perform CPR.[97] The bystander effect as it relates to AED retrieval and use should be directly addressed in public messaging and training.

Performing CPR and using an AED may be a distressing and traumatic experience for lay rescuers. Bystanders involved in OHCAs may experience ongoing psychological problems after the event, including flashbacks and feelings of guilt if the patient died or the outcome was unknown.[98] A Canadian study analyzed the psychological reactions of 15 lay rescuers after participating in real cardiac arrest events.[99] Participants reported that despite being trained, their emotional response at the time of the event limited their ability to recognize cardiac arrest and act promptly. They also had difficulties processing the event, reporting psychological sequelae such as flashbacks or intrusive change to memories.

Some data suggest that the incidence of significant psychological injury is fairly uncommon. The North American PAD trial, which included 239 EMS-treated cardiac arrests, documented 4 volunteers (<2%) who reported psychological stress requiring intervention.[100] In an online survey of 189 Dutch volunteer first responders who attended a cardiac arrest, 41% perceived no/mild short-term psychological impact, 46% perceived a bearable impact, and 13% perceived a severe impact.[101] None experienced symptoms related to posttraumatic stress disorder 4–6 weeks after performing bystander CPR.

Bystanders have reported that the presence of an AED and the audio instructions provided by the device were calming influences and facilitated good-quality CPR.[63] Other studies suggest that prior training may mitigate the stress of a resuscitation event.[100] Receiving debriefing from trained medical personnel could help bystanders cope with and reflect on the incident and improve confidence that they could act again in the future.[102] One public-access AED program managed by a paramedic service in Canada has created a structured program called the Lay Responder Postarrest Support Model, which includes 3 stages. Stage 1 is identifying and engaging lay responders; stage 2 involves debriefing the lay responders; and stage 3 involves follow-up and referral for professional support for those lay responders exhibiting symptoms of posttraumatic stress or other distress.[103] The impact of formal debriefing for lay bystanders is unknown.

Knowledge gap

We suggest research to evaluate the effectiveness of different bystander follow-up models with respect to bystander wellness, psychological outcomes, and quality improvement.

Policy suggestion

We suggest that CPR and AED training programs directly address potential psychological barriers to action during an OHCA. We suggest that public-access AED programs implement a system of lay responder follow-up to support bystander wellness and quality assurance.

Addressing perceived and real legal barriers

Bystander concerns over legal and liability issues can negatively influence bystander attitudes at the time of an emergency.[55–57,66,104] In 2006, the American Heart Association recommended key components to improve public-access AED programs.[105] Among 13 suggested elements of a successful program were provisions for civil liability protection for lay rescuers and those who provide AEDs.[105,106] Most US states offer immunity from civil liability under Good Samaritan laws, although such laws differ in scope.[106–109] Seventeen US states mandate AED placement in schools, but arrangements and funding to support the law are lacking in many places.[108] Organizations can also be influenced by perceived liability when planning for response to cardiac arrest emergencies. In one survey, a US school refused to have an AED on site despite state-level legislation requiring it to do so, citing liability concerns.[110] Some initiatives at the federal level grant immunity from civil liability not only to lay rescuers but also to AED device owners under certain circumstances.[111]

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The Chase McEachern Act in Ontario, Canada, protects from civil liability the defibrillator user, the owner of the equipment, and the premises on which it is located, as well as health care professionals outside a health care facility.[112] Other countries such as South Korea, Taiwan, and Japan also have Good Samaritan laws that protect bystander rescuers from civil liability when performing CPR or using an AED.[71,113,114] In the United Kingdom, the Social Action, Responsibility, and Heroism Act 2015[115] is intended to protect individuals who act in a responsible and heroic manner in the best interests of society during an emergency. There is no information on its use in case law related to a cardiac arrest event to date. In Australia, Good Samaritan legislation protects volunteers and laypeople who assist others. Although protective laws such as these are in place in several jurisdictions, awareness and understanding of them among the public are not known. More important, their effect on public-access AED use is not known.

Knowledge gap

We suggest that future research determine the effect of legislation on willingness to use and actual use of AEDs during OHCA.

Optimizing AED availability, reliability, and usability

Many factors can affect AED availability at the time of a cardiac arrest. Key issues relate to the proximity of AEDs to cardiac arrest events in the community, the ability of bystanders to locate the nearest available AED at the time of an emergency in a timely manner, and AED accessibility.

The importance of AED proximity to OHCA

People who experience OHCA with a nearby AED are 3 times more likely to receive bystander defibrillation and twice as likely to survive as those without an AED nearby.[116,117] Unfortunately, AEDs are rarely close enough for timely retrieval.[116,118] Data from various urban areas have estimated that only 3% to 25% of OHCAs occur within 100 m of an AED.[118–123] In a study of 4169 cardiac arrest calls to the South Central Ambulance Service, which serves both rural and urban areas in the United Kingdom, only 6% of the cardiac arrest locations during the day and <2% of the cardiac arrest locations during the night were within 100 m of a registered AED.[124] The problem of poor availability is compounded by the fact that even when a registered AED is in close proximity to a cardiac arrest, most go unrecognized and unused.[122,124] In a study from Copenhagen, AEDs were used 35.7% of the time when arrests occurred immediately adjacent to the AED and only 13.7% of the time when arrests occurred 200 m from the AED in a public setting.[117] Fredman et al[121] observed 47 cases in which an AED was available within 100 m of an OHCA; emergency dispatch notified callers about the nearby AED in only 2 (4%) cases.

Despite the importance of ensuring proximity, the placement of AEDs in the community has traditionally occurred in a haphazard way. Placement decisions are often left to the owners of the AED and are not coordinated centrally within a community. Many communities have AEDs in areas that are relatively low risk for OHCA while leaving higher-risk areas unserviced.[55,118,125] Although low–socioeconomic status communities are associated with a higher incidence of OHCA,[126,127] they are also associated with lower AED availability,[128,129] bystander CPR,[130–133] and survival.[134]

Optimizing the geographic distribution of AEDs

We identified multiple publications demonstrating innovative data-driven approaches to optimizing AED deployment. Several have used geographic cardiac arrest data to guide AED placement. For instance, density maps of OHCAs, which simply plot OHCA locations on a map, can identify higher-risk locations for cardiac arrest and optimal locations for AEDs. This technique has been used to support effective urban coverage[135] and to identify rural locations where a particular need exists.[136] Several investigations have determined risk or comparative risk for cardiac arrest by location or building type so that AED deployment can be prioritized to those locations.[64,118,137–140] Operations research techniques such as optimization modeling have been used effectively to determine optimal sites for AED placement.[118] These types of analyses typically involve a mathematical model using a cardiac arrest data set with arrest locations, current AED locations, and a set of constraints (eg, an arbitrary coverage range of AEDs, potential locations for future AEDs, number of new AEDs available for placement). The output of such models can be used to assess current AED deployment in terms of hot spot coverage, identify optimal (as defined by constraints in the model) locations for new AEDs, and test deployment strategies through simulation. Using optimization modeling, Sun and colleagues[141] determined that placing AEDs at high-visibility locations with 24-hour accessibility such as coffee shops and automated teller machines (which also tend to exist in high–population density areas) can significantly improve AED availability. Optimization modeling may also guide ideal positioning of AEDs within buildings. An analysis by Chan[142] used optimization modeling to compare the placement of AEDs servicing high-rise buildings in the lobby versus in an elevator. The optimal placement depended on the risk of OHCA per floor, the number of floors in the building, and the risk of OHCA in the lobby, underground areas, and street-level areas.

Policy suggestion

We suggest coordinated, data-driven, regional strategies to optimize deployment of AED resources on the basis of cardiac arrest risk and site accessibility. We suggest that public-access AED programs prioritize deployment of new defibrillators in locations deemed to be at highest risk for the occurrence of cardiac arrest and underserved by available AEDs. Determination of cardiac arrest risk should be assessed with local cardiac arrest data if available.

Improving detection of shockable rhythms

Although rhythm library sensitivity and specificity are excellent, field tracings are often not as clear and include CPR artifact, patient movement, and poor adherence of the pads.[143] In one study, overall sensitivity for coarse VF averaged across all AED brands tested was >98% (lower 95% confidence bound, 98%), and specificity for all nonshockable rhythms was 98% (lower 95% confidence bound, >97%).[144] Not all devices included in this analysis achieved >98% sensitivity, however, and data from some defibrillators in the study came from <5 shocks with the device. It should also be noted that data in this study were derived from a limited number of device models; therefore, the results may not be generalizable to all AEDs, including newer defibrillators available on the market today. Other studies reporting sensitivities ranging from 84% to 91.2% suggest that there is room for improvement in the algorithms that AEDs use to detect shockable rhythms.[145–147] More sophisticated filtering techniques are becoming available. Some have published data from simulation studies[148] and real OHCA cases.[149] Machine learning and neural networks may also improve diagnostic accuracy and could be used to optimize future AEDs.[150]

Knowledge gap

We suggest that future development of AED technology focus on improving the diagnostic accuracy of VF and pVT detection algorithms during cardiac arrest, both with and without CPR artifact.

Improving data transfer from AEDs to hospital-based health care professionals

Patients treated with an AED who achieve return of spontaneous circulation before EMS are on site often arrive at the hospital without any data from the AED. In fact, the information that an AED shock was given may be lost in the chain of communication to the treating physician. Even if this fact is recognized by physicians, accepting an AED shock as proxy for a shockable rhythm may be inaccurate, given the (small) false-positive rate. Such cases, when information about prehospital AED shocks and the ECG from the AED are omitted from the medical record, may involve missed indications for an implantable cardioverter defibrillator. Patients with primary arrhythmias are at risk of recurrence of cardiac arrest.[151] Retrieval of the AED tracings from the prehospital setting is challenging because of multiple barriers to obtaining them. Heterogeneity in cable connectors and download software programs across manufacturers means that downloads from the prehospital setting are almost never accomplished.

Policy suggestion

We suggest that AED manufacturers develop a standardized process for AED data retrieval to improve sharing with prehospital and hospital-based health care professionals. Because of the critical importance of this data in the clinical care of survivors, we suggest that this feature be mandated by regulatory bodies.

Addressing human/computer interaction barriers

Improvements can be made to all aspects of AED design (casing, controls, user prompts) to encourage successful use. Errors during AED use are rare but are most commonly attributed to the interaction between the operator and the device rather than to the device itself. In a study of actual OHCA events, errors included continuing chest compressions during AED analysis, failing to deliver a shock when instructed by the machine, and removing the AED prematurely, which prevented shock delivery.[144] Simulation studies suggest that fully automated AEDs (in which shock is delivered without the need for the operator to press a button) increase operator safety[152] and compliance with AED instructions, reducing the time to successful defibrillation.[153] In simulation studies, untrained bystanders were often able to successfully deliver a shock,[154] but device-specific differences in design have been observed to affect the time required to power on a device, the accuracy of AED pad placement, and whether CPR was initiated after rhythm analysis.[155,156]

Knowledge gap

We suggest that research be conducted to identify novel AED design features that facilitate the proper use of AEDs by laypeople and improve both the quality of resuscitation provided and the outcomes for patients with OHCA.

Ensuring 24/7 access to resuscitation-ready AEDs

Many OHCAs occur outside normal working hours,[157] and many AEDs are not available at these times.[55,120,158] AED coverage decreases by 53% to 60% during the evening, nighttime, and weekends,[120,123,124] which is when 61.8% of all cardiac arrests in public locations occur.[158]

Policy suggestion

We suggest that all AEDs be installed in locations with 24-hour accessibility.

In making this suggestion, we acknowledge that there are costs and practical considerations that may prevent some AED owners from providing 24-hour access for the public. A public-access AED with accessibility during some of the day is better than no public-access AED at all; therefore, our suggestion should not deter prospective owners from having one even if providing 24-hour public access is not possible.

AEDs require regular maintenance to ensure 24/7 availability because the units themselves have shelf lives, batteries and pads must be replaced before their expiry dates, and AEDs not monitored and routinely checked as recommended by the manufacturer may lapse into disrepair. Published data from the US Food and Drug Administration on AED adverse events demonstrated that 1150 failed defibrillation attempts were reported between 1993 and 2008.[159] Of these, the unit gave a low-battery warning in 54 cases, was never powered on in 37 cases, and failed to deliver a recommended shock in 524 cases. Poorly maintained AEDs represent a potential threat to life when these devices are required in an OHCA situation. The quality of maintenance of AEDs in real-world settings varies, with many not associated with any individual responsible for maintenance (24%) or having no formal plans in place for maintenance (18%) or replacement (24%).[55,160]

Policy suggestion

We suggest that AEDs be checked regularly according to manufacturer instructions and be resuscitation ready at all times.

AED cabinets can support device readiness by ensuring AED availability through device protection and facilitation of remote monitoring to support device readiness. Various cabinets are available on the market, ranging from boxes that simply hold the AED in place on a wall to internet-connected devices with advanced antitheft technology and environmental control. Some AED cabinets are weatherproof and equipped with sensors for internal temperature and humidity, along with thermostat-controlled heating elements. These cabinets can store defibrillators in high-visibility outdoor settings in a variety of climates. Some cabinets are internet connected, facilitating remote monitoring of AED-readiness status (eg, battery, pads), internal climate (eg, temperature, humidity), and AED deployment. These cabinets can send messages to owners or caretakers of the AED when the AED is not ready, is outside the ideal operating temperature or humidity range, or is removed from the cabinet. Some cabinets and peripheral devices for AEDs are enabled with a global positioning system and can trigger automated calls and 2-way voice communication between the user and local emergency dispatchers.

Theft of AEDs is rare. In the PAD trial, of the 1716 community AEDs deployed, only 20 were stolen over a period of ≈3 years (0.3% loss per year).[100] In a more recent survey of public-access defibrillation programs in 51 US cities, only 9 AED thefts were reported.[161] Despite this low risk, many cabinets have antitheft features. These include locks, audible alarms, automated photo capture of the person removing the AED, and "break in case of emergency" glass to deter frivolous access. Locked cabinets often have a keypad requiring users to enter a numeric passcode before being granted access. The prospective AED user either must know the keypad code ahead of time (eg, private installations) or must call emergency dispatch to learn the code. The magnitude of the impact of locked

AED cabinets on the delay to defibrillation and clinical outcomes is not known. It is reasonable to expect that locked AED cabinets might introduce significant delay in accessing the defibrillator in an emergency.

Policy suggestion

We suggest against the use of locked AED cabinets. If locked cabinets are used, we suggest that simple instructions on how to access the AED should be clearly visible on or near the cabinet. Every effort should be made to minimize delay caused by the unlocking procedure.

"Smart kiosks" are becoming commonplace, especially in urban centers, and can be found in both outdoor and indoor environments. They typically display information about the local setting, advertisements, and public announcements on a video screen. Some smart kiosks have such features as Wi-Fi hot spots, charging stations, and emergency call support. Some communities use these kiosks as locations for AEDs. These novel public utilities provide an excellent opportunity to increase the visibility of the AED, increase public engagement and education, and facilitate remote monitoring of the AED to support security and readiness.

AED registration

OHCAs clustered at high-incidence sites constitute only a small percentage of all OHCAs.[64,162] True onsite defibrillation is therefore a relatively rare occasion,[4] such that it is usually necessary to transport the AED to the scene of the arrest.[117,124] Because there is generally no consistency in where AEDs are located in one community versus the next, novel approaches to AED location intelligence, techniques to improve wayfinding, guidance from emergency dispatch, and new AED delivery vectors require consideration.

AED registries serve as the backbone of many novel solutions developed to facilitate rapid identification of the nearest resuscitation-ready AED in an emergency. AED registries, holding information on location and accessibility, may facilitate AED retrieval by enabling rapid identification of the nearest device.[163] Cataloging the location of the device, along with other important information such as battery status, AED expiry date, and the contact information of the person responsible for that particular device, can facilitate maintenance and successful use when required.

The coverage of an AED registry is likely to depend on the size and health care setting of the region. There are a few examples of national AED registries in smaller countries. The first national AED registry was established in Denmark.[116] Microsoft and the British Heart Foundation recently announced a partnership to build a national cloud-based registry of all AEDs in the United Kingdom and to make these data available to all ambulance services in the country.[164] This will complement other available national databases.

Registries have traditionally been developed and maintained by organizations such as EMS agencies that play some role in placing AEDs in the community. One challenge with AED registry development has been ensuring that all AEDs in the community, not just those placed by EMS agencies or regional authorities, are included. If a registry is incomplete, any solutions using the registry data to guide users to an AED in an emergency may not be guiding users to the nearest AED.[163] Several innovative applications of technology aim to improve the completeness of AED registries. The MyHeartMap Challenge was a crowdsourcing innovation competition that aimed to locate and map AEDs in Philadelphia.[165] This was a public tournament to organize public reporting of AED locations. Participation was incentivized with a US $10 000 prize for the person who was able to locate, photograph, and geotag the most AEDs in Philadelphia. During an 8-week time frame, 313 teams and individuals registered for the competition. Participants located 857 unique AEDs, 614 of which were not previously registered.

Mobile device applications (apps) such as GoodSAM (United Kingdom)[166] and PulsePoint AED (United States)[167] can crowdsource the development and maintenance of AED registries. Both apps allow users to photograph AEDs and upload their locations so that they can be verified and added to the local AED registry by hosting EMS or public safety agencies. Some jurisdictions have made AED registration mandatory through legislation in an attempt to develop comprehensive AED databases. For example, a 2010 review of US AED legislation demonstrated that 30 states required notification or registration of AEDs with state or local EMS authorities.[106] The effect of mandatory registration legislation on actual registration of AEDs, AED use, and patient outcomes, however, is not known. In a study from Washington State, where state law mandates AED registration, 13 of 22 (59%) OHCAs involving the application of a public-access AED involved AEDs that were not previously registered with local EMS agencies.[168] Ensuring that registry data, including AED location, remain valid over time is a challenge for current and future registries. As the Internet of Things develops and internet connectivity of AEDs, peripherals, and cabinets becomes more common, future registries may be able to incorporate real-time location and status updates for registered AEDs.

Knowledge gap

We suggest that future system design innovations enhance connectivity among AEDs, registries, emergency dispatchers, and potential users so that real-time location and readiness data can be integrated into the emergency community response.

Policy suggestion

We suggest that the location of all AEDs in a community be known to the local emergency dispatch through the development of national, regional, or local AED registries. We suggest that AED location and status information be current and accessible to emergency dispatchers and available AED-locating systems such as mobile device apps.

AED signage

Immediate identification of the nearest AED is of key importance to shorten the delay to its retrieval and use during an emergency. Contemporary AED signs are heterogeneous, with significant variability in coloring, iconography, and other aspects of design. Several published surveys have demonstrated limited understanding of the meaning of many AED signs in current use.[59,169–171] In an effort to address this heterogeneity and poor recognition, ILCOR formed an international working group to develop an AED sign with the intent to encourage global uptake and universality. The primary purpose of the sign was to indicate the presence of an AED with high visibility and easy recognition from a distance. The ILCOR sign was developed and tested for understanding according to the specifications of the International Organization for Standardization 3864–3 and 9186–1. The results of this evaluation have not been published in a peer-reviewed journal but are included as a supplemental appendix here (Supplemental Appendix 1). The large abbreviation with the meaning of "Automated External Defibrillator" can be customized with local language to enhance understanding. This sign was

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adopted and endorsed by the general assembly of ILCOR in 2008 (Supplemental Appendix 2).

In the United Kingdom, new signage developed with public consultation was found to support understanding of the function of AEDs, and survey respondents perceived that the sign encouraged AED use.[171] It is unknown whether one type of sign versus another is associated with different probability of AED use.

As of 2020, two-thirds of AEDs have no signage at their location. Almost none have peripheral signage at a distance from the AED that could guide rescuers to its location.[172] Regardless of sign characteristics, poor placement, and suboptimal visibility of signs, even in high-use areas, there is a documented limitation with current deployment of AED signs.[172] It is not known which configuration of signs in the environment around an AED is optimal.

On the basis of opinion, the writing group achieved consensus that having a universal AED sign, adopted broadly around the world, should be pursued and could improve recognition and effectiveness of the sign. However, the writing group could not achieve consensus on suggesting broad adoption of the current ILCOR-endorsed sign or any other specific design. Some members felt that a suggestion to broadly implement the current ILCOR sign could have beneficial effects through a reduction in design heterogeneity and an improvement in global recognition. Others felt that this scientific statement should not include a recommendation for any specific design in the absence of evidence to suggest superiority of one design over another.

Knowledge gaps

Future research should identify signage characteristics, designs, and deployment strategies that maximize the probability of AED identification and retrieval by members of the general public.

We suggest that the current ILCOR-endorsed AED sign design, adopted in 2008, be revisited to ensure that it is consistent with contemporary International Organization for Standardization standards and develop an evidence base for effectiveness against alternative designs.

Policy suggestions

We suggest the following:

After reassessment and evaluation of the current ILCOR sign and alternative designs, ILCOR should work to implement a universal evidence-based and International Organization for Standardization–compliant AED sign that promotes recognition and successful retrieval of AEDs around the world.

There is insufficient evidence to suggest one AED sign over another.

Regardless of the signage used, signs should be visible where the AED is stored and within the presumed operational radius of the AED (with a minimum of 200 m).

Signage should indicate the direction and distance to the AED.

Signage should be a sufficient size to be identifiable from a distance of at least 50 m (requiring lettering of ≈12 cm in height).

The AED cabinet should be illuminated at night, and, whenever possible, exterior signs should have supplementary lighting or at least be made of photoluminescent material.

Signage should be properly maintained; we suggest that all signs associated with the AED be inspected at the same time that the AED undergoes its routine checks (at least annually).

Mobile apps for AED retrieval

Global positioning system–equipped mobile devices with advanced computing capabilities have become ubiquitous. The evolution of the personal mobile device has provided new opportunities to improve public-access defibrillation. Some apps are passive, with AED locations simply overlaid on digital mapping software such as Google Maps. These apps allow users to locate all AEDs within a registry on the map, when required. Research to date suggests that these types of passive AED map apps may have a limited impact on improving AED retrieval. In a simulation study from Quebec, Canada, researchers found that a passive AED mapping app improved time to AED retrieval compared with having no guidance at all but was not as effective as verbal instructions from an emergency call taker.[173] In another simulation study from Japan, a passive AED mapping app did not improve time to AED retrieval.[174]

Other, more sophisticated systems are able to link networks of community volunteers with local emergency dispatch centers to facilitate AED retrieval, bystander CPR, and AED use. Many EMS systems are now using mobile phone text messages or notifications through apps, sent to lay responders and off-duty health care professionals within a predetermined distance of a suspected OHCA to encourage bystander CPR and AED use before ambulance arrival.[166,167,175–179] The location of registered mobile phone users can be instantly identified by a mobile phone positioning system.[180] Subsequent integration with AED registries enables dispatch of lay or professional responders to suspected OHCA and AEDs nearby. Some apps have advanced functionality, including just-in-time CPR instruction and capabilities for video linking with dispatch.[166] These systems have some variability in methodology, but there are universal aspects. The systems are triggered by certain emergency call criteria, either automatically or through action by the emergency call taker. The location of the arrest is compared with the location of registered mobile app users (facilitated by the location services of their mobile devices and communication with the app server). Some systems can differentiate between users of different status (eg, layperson, off-duty professional). Once mobile app users are identified within the activation radius of the system, the app server sends a notification to those devices. Many apps display a map showing the location of the OHCA and nearby AEDs. Some systems also bypass the dispatch center by enabling a witness to alert nearby lay responders directly via the app.[166]

Although these systems are being used with increasing frequency, evidence of improved outcome is limited. Observational studies have shown that mobile phone alerting of community responders facilitates AED attachment and defibrillation in selected populations.[175] A pilot study that used a smartphone application in the same study area showed significantly longer effective distances for the lay volunteers assigned to AED retrieval but a low AED attachment rate.[177] In a study from Switzerland, a smartphone-based system was compared with a location-based text message system and was found to be more efficient in terms of dispatching lay responders for CPR.[181] In a randomized controlled trial in Sweden, a mobile phone positioning system (not integrated with an AED registry) significantly increased bystander CPR rates (62% in the group associated with mobile device app notifications and 48% in the control group without mobile device app notifications being sent). Survival to 30 days was higher in the mobile app notification group compared with the control group (11.2% versus 8.6%), but this was not

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statistically significant.[178] A large North American survey about the public perception of this type of crowdsourcing approach demonstrated widespread acceptability.[182]

Although mobile device apps are an appealing mechanism for increasing AED use, potential risks include threats to patient privacy; the engagement of untrained, anonymous volunteers in some of the solutions; and psychological harm to volunteers summoned to the scene of a critically ill or dead person. Data on these potential risks are lacking.

In addition, there are technical challenges related to integrating these apps into existing dispatch systems, and many of them are associated with significant costs for setup and maintenance. Despite these theoretical risks, the writing group felt that the use of such systems is reasonable on the basis of their potential to increase bystander engagement during cardiac arrest. Randomized controlled trials underway in Scandinavia (NCT02992873), France (NCT03633370), Canada, and the United States (the PulsePoint randomized controlled trial, [NCT04806958]) will provide more data on the effectiveness of mobile apps to increase early defibrillation for OHCA.

Knowledge gap

Further scientific evaluation of mobile device apps to crowdsource bystander CPR and AED use is required to determine effectiveness, cost-effectiveness, and the balance of risks and benefits for patients with OHCA.

Policy suggestion

We suggest that the implementation of mobile device apps to crowdsource CPR and early defibrillation is reasonable where resources are available.

Novel or strategic delivery vectors for AEDs

Dispatch-assisted AED locating and coaching

This strategy involves emergency dispatchers guiding callers or other potential rescuers in the vicinity of an OHCA to retrieve and use a nearby AED. Unfortunately, there is a paucity of research on this strategy. Although dispatch-assisted CPR has been associated with increased survival,[183,184] most cases are not associated with AED retrieval.[4,55,185–187] Real-time visualization of AED locations on the computer-assisted dispatch system displayed during a cardiac arrest call has been suggested as a method to direct bystanders to nearby AEDs.[168] Studies from Sweden and Denmark tested this approach. Dispatchers were instructed to refer to available AEDs within a 100-m distance of OHCA emergencies. Unfortunately, this had a limited effect on AED referral.[121,122] This task may be too complex for dispatchers to manage while also having to dispatch professional rescuers to the scene and support telephone-assisted CPR as a priority. Machine learning and artificial intelligence may hold promise as tools to assist dispatchers with OHCA recognition and AED referral by process automatization and reduction of dispatcher cognitive workload.[188]

Knowledge gap

We suggest that future studies explore innovative dispatch strategies to facilitate efficient guidance of bystanders to the nearest available AED and successful use of the device.

Strategies using firefighters and police

The past 2 decades have seen the trial and adoption of dispatched AED programs using fire and police services.[189–192] The only clinical trial[193] supports most of the observational findings, which report that firefighters and police provided the first shock in 6% to 53% of OHCA cases they attend[15,194] and a reduction in time to first defibrillation.[189,190] Only the largest observational studies, however, report corresponding improvements in OHCA survival.[189,191,192] A recent systematic review reported an overall survival to hospital discharge or a 30-day survival of 28% (median; range, 9%–76%) among those defibrillated by firefighters or police using AEDs before ambulance arrival.[44] The need for wider coverage and faster response has seen these programs extended to the mobilization of other health care professionals who do not routinely practice in the prehospital setting (eg, home care nurses,[195] off-duty nurses, physicians181).

Policy suggestion

We suggest that firefighters, police, and community health care professionals be considered vectors for mobile AED deployment to enhance early defibrillation in communities.

Community volunteer responder programs

Community volunteer responder programs, involving a mixture of layperson volunteers and off-duty health care professional volunteers, have evolved primarily in countries outside North America.[196] These programs typically involve trained volunteers who are dispatched to a variety of potential medical emergencies such as trauma, stroke, loss of consciousness, and cardiac arrest in communities outside densely populated urban settings, which tend to have longer paramedic response times. Community volunteer responders provide an additional tier of organized response to medical emergencies. Because community volunteer responders are embedded in their target communities, they are often closer to the emergencies than the nearest paramedic unit. The Sandpiper Trust Wildcat program in Aberdeenshire, Scotland, is a community program that has focused specifically on responding to OHCA.[197] Although there is a paucity of research on the effectiveness of such programs for OHCA, they represent a particularly attractive strategy to address the problem of OHCA in residential settings, where penetration of conventional AED strategies has been poor.

Knowledge gap

We suggest that research on community responder models be done to determine the feasibility, scalability, effectiveness, and cost-effectiveness of volunteer community responder programs with respect to early CPR, defibrillation, and survival after OHCA.

Robots as novel delivery vectors for AEDs

The development of land-based robots and unmanned aerial vehicles, or drones, for civilian applications is being pursued by numerous companies and academic organizations. Potential applications for this emerging technology include surveillance, package delivery, and delivery of medical products and devices. Although regulatory approval of autonomous robots and drones to routinely deliver goods and services is pending in most jurisdictions, robotic delivery of AEDs to the scene of an OHCA may become a reality in the near future. Several investigators have explored the use of unmanned vehicles for the purpose of delivering AEDs to the scene of OHCA. Robots carrying an AED payload could potentially be dispatched simultaneously with the conventional emergency response, with the goal of delivering an AED to the scene for immediate bystander use. Potential users of the delivered AED could be coordinated through emergency dispatch or through a mobile device app.

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Although some work has been done with land-based robots in this context,[198] most innovations involve drones. Drones could deliver an AED to the ground by landing at the site, by using a winch to lower the AED to the site while the drone hovers, or by jettisoning the AED and having it land safely by parachute. Studies using drone flights to simulated or historical OHCA locations have demonstrated that the time interval between the emergency call and having an AED on the scene can be reduced compared with a conventional ambulance response.[199–201] One of these studies involved a fully autonomous drone that could travel to locations specified by operators and deliver the AED without direct human control.[200] In a region-specific analysis using historical cardiac arrest data from several urban and rural regions around Toronto, ON, Canada, optimization modeling and simulated drone base placements demonstrated that an optimized drone network could potentially reduce delay to AED delivery compared with a conventional EMS response.[202]

Although this strategy could improve access to early defibrillation, significant regulatory and logistical challenges must be overcome before it is a feasible strategy. A recent study involving a simulated cardiac arrest with a manikin in an indoor setting and volunteer bystanders who were informed of an impending drone delivery before the simulation had begun demonstrated that drone delivery can introduce clinically significant hands-off time when there is only 1 bystander on the scene. Among 4 scenarios involving only 1 bystander, the median hands-off time attributed to AED retrieval from the drone (≈50 m away) was 1 minute 34 seconds (range, 75–110 seconds).[203] This delay is likely underestimated. It is probably longer in real-world settings where large buildings, unanticipated drone arrival, poor lighting, adverse weather conditions, or complex terrain may pose challenges. Strategies involving multipurpose drones (eg, public safety functions, package delivery) or multiple emergency medical payload items (eg, epinephrine for anaphylaxis, tourniquets for bleeding control, naloxone for opioid overdose) may improve the cost-benefit ratio for this type of strategy.

Knowledge gap

We suggest that further research be undertaken to develop and evaluate the clinical and cost-effectiveness of robotic delivery systems for AEDs. Future work should consider how best to coordinate the AED delivery with emergency dispatch and potential users in the vicinity of the cardiac arrest to ensure that AED delivery translates quickly into successful AED use.

Personal and home-access defibrillation

The AED has evolved from its beginnings as a heavy, expensive piece of hospital equipment designed for medical professionals to a more portable, lower-cost, and user-friendly device intended for laypeople. Most contemporary devices, however, are still too bulky and heavy to be practical accoutrements for the general public that might be carried routinely in a briefcase, backpack, or purse. The high purchase price of conventional devices is also a potential barrier to widespread uptake of AEDs as personal or household first-aid items. Accordingly, most public-access devices are purchased by organizations rather than individuals, and most are stored in wall cabinets rather than carried by a person. In what may be a critical juncture in the technological evolution of AEDs, several start-up companies are developing smaller, inexpensive, and in some cases single-use AEDs that will be marketed as consumer products for the individual. The target price point of at least 1 single-use defibrillator in development will be in the range of many household smoke detectors on the market today. Some innovators aim to miniaturize the AED enough to integrate it as a mobile phone peripheral (eg, phone case). Future work is required to develop this technology, explore the feasibility of deployment (including an understanding of the market), and determine the effectiveness of strategies that incorporate this new technology broadly.

Most (60%–80%) OHCAs occur in residential settings[4,204–210]; however, access to early defibrillation in this setting is almost nonexistent.[211] AED deployment in the home has been studied in the past with results that dissuaded further research and broad implementation of this strategy. The HAT trial (Home Automated External Defibrillator) randomized 7001 patients with anterior wall myocardial infarction to receive CPR training for spouses or companions and a home AED versus CPR training alone. The number of at-home cardiac arrest events in the trial was low: Only 133 events occurred in the home of study patients, and only 71 of these were witnessed. An AED was applied in only 32 patients in the intervention group. Of 21 unresponsive patients with AED data available in this group, only 13 had VF, 12 received a shock, and 4 survived long term. There was no impact of the intervention on the primary outcome of death resulting from any cause among this group of post–myocardial infarction patients (6.5% versus 6.4%).[212]

The HAT trial did not use a cost-effectiveness methodology, but the low event rate, low witnessed rate, and underuse of the AEDs even when witnessed cardiac arrest occurred raised doubts about the cost-effectiveness and public health benefit of deploying AEDs in this manner. However, the analysis, which focused on a population in whom >90% did not have cardiac arrest, may have missed an important benefit for patients who experience cardiac arrest in residential settings. Investigators report that among people who experienced cardiac arrest in the home with an AED available, survival was 12% (18.3% for witnessed events). This relatively high proportion is closer to that usually observed for patients with OHCA in public settings, where conditions are generally more favorable for being witnessed and receiving early bystander intervention.[213] There were also several occurrences of study AEDs being used for neighbors experiencing cardiac arrest, and these instances were not included in the evaluation of effectiveness. The positive influence that the AEDs might have had on the delivery of chest compressions is unknown because the study did not report CPR quality measures or the proportion of patients with cardiac arrest receiving CPR. It is unknown whether devices used in the study included CPR coaching or quality feedback. The HAT trial does not provide evidence to support AEDs in the home for post–myocardial infarction patients, and the potential benefit of modern AEDs deployed in homes and neighborhoods for the broader population of people who experience cardiac arrest in these settings remains unknown.

Knowledge gap

We suggest that innovative strategies to improve outcomes for those who experience OHCA in the residential settings are required. The feasibility and potential impact of novel AED technologies that lower cost, improve portability, or otherwise encourage purchase by individual consumers or households should be explored.

Summary and conclusions

Despite imperfect implementation, public-access defibrillation has saved countless lives. AEDs remain underused so that many sal-

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vageable individuals die without the benefit of having an AED available to them. There are multiple barriers to more consistent AED use; however, there are also multiple opportunities to address those barriers with new approaches to public-access AED program implementation, including changing the behavior of potential users; improving availability; improving integration with existing emergency dispatch; enhancing AED housing, signage, and device technology; and exploring novel AED delivery vectors. We summarize specific policy suggestions made in this scientific statement in Table 1. We also identify the knowledge gaps for future research in Table 2. Continued evolution of our approach to public-access defibrillation with increased early CPR, rhythm detection, and defibrillation will improve cardiac safety in our communities and ultimately increase survival after OHCA.

Article information

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the

Table 1 – Summary of Policy Suggestions to Improve Public-Access Defibrillation Implementation.

Statement section	Suggestions
Improving Public Awareness and Willingness to Use	We suggest that a validated behavior change framework be used to guide the development and implementation of interventions to increase public-access defibrillation. We encourage the engagement of experts in behavior change, implementation, or knowledge translation to guide program development.
	We suggest that all future CPR training for children and adults include the recognition and use of AEDs.
	We suggest that CPR and AED training programs directly address potential psychological barriers to action during an OHCA. We suggest that public-access AED programs implement a system of lay responder follow-up to support bystander wellness and quality assurance.
Optimizing AED Availability, Reliability, and Usability	We suggest coordinated, data-driven, regional strategies to optimize deployment of AED resources on the basis of cardiac arrest risk and site accessibility.
	We suggest that public-access AED programs prioritize deployment of new defibrillators in locations deemed to be at highest risk for the occurrence of cardiac arrest and underserved by available AEDs. Determination of cardiac arrest risk should be assessed with local cardiac arrest data if available.
	We suggest that AED manufacturers develop a standardized process for AED data retrieval to improve sharing with prehospital and hospital-based health care professionals. Because of the critical importance of these data in the clinical care of survivors, we suggest that this feature be mandated by regulatory bodies.
	We suggest that all AEDs be installed in locations with 24-h accessibility.
	We suggest that AEDs be checked regularly according to the manufacturer's instructions and be resuscitation-ready at all times.
	We suggest against the use of locked AED cabinets. If locked cabinets are used, we suggest that simple instructions on how to access the AED should be clearly visible on or near the cabinet. Every effort should be made to minimize delay caused by the unlocking procedure.
	We suggest that the location of all AEDs in a community be known to the local emergency dispatch through the development of national, regional, or local AED registries. We suggest that AED location and status information be current and accessible to emergency dispatchers and available AED-locating systems such as mobile device apps.
AED Signage	We suggest the following:
	After reassessment and evaluation of the current ILCOR sign and alternative designs, ILCOR should work to implement a universal evidence-based and International Organization for Standardization–compliant AED sign that promotes recognition and successful retrieval of AEDs around the world.
	There is insufficient evidence to suggest one AED sign over another.
	Regardless of the signage used, signs should be visible where the AED is stored and within the presumed operational radius of the AED (with a minimum of 200 m).
	Signage should indicate the direction and distance to the AED.
	Signage should be a sufficient size to be identifiable from a distance of at least 50 m (requiring lettering of ≈12 cm in height).
	The AED cabinet should be illuminated at night, and, whenever possible, exterior signs should have supplementary lighting or at least be made of photoluminescent material.
	Signage should be properly maintained; we suggest that all signs associated with the AED be inspected at the same time that the AED undergoes its routine checks (at least annually).
Mobile Apps for AED Retrieval	We suggest that the implementation of mobile device apps to crowdsource CPR and early defibrillation is reasonable where resources are available.
Novel or Strategic Delivery Vectors for AEDs	We suggest that firefighters, police, and community health care professionals be considered vectors for mobile AED deployment to enhance early defibrillation in communities.

AED indicates automated external defibrillator; app, application; CPR, cardiopulmonary resuscitation; ILCOR, International Liaison Committee on Resuscitation; and OHCA, out-of-hospital cardiac arrest.

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Table 2 – Summary of Knowledge Gaps Identified by the Writing Group and Suggestions for Future Research Priorities in Public-Access Defibrillation.

Statement section	Suggestion
Improving Early Detection of Cardiac Arrest	We suggest the development and scientific evaluation of technology-based strategies for early warning of impending cardiac arrest and detection of cardiac arrest when it occurs to facilitate automatic triggering of an emergency response and early defibrillation.
Improving Public Awareness and Willingness to Use	We suggest research to guide the design, implementation, and assessment of innovative public messaging strategies to increase bystander CPR and AED use.
	We suggest that future research be conducted to determine optimal AED educational programs for schoolchildren.
	We suggest that investigators measure long-term skill retention and the probability of providing resuscitation in future cardiac arrest events as key outcomes when evaluating educational programs.
	We suggest research to evaluate the effectiveness of different bystander follow-up models with respect to bystander wellness, psychological outcomes, and quality improvement.
	We suggest that future research determine the effect of legislation on willingness to use and actual use of AEDs during OHCA.
Optimizing AED Availability, Reliability, and Usability	We suggest that future development of AED technology focus on improving the diagnostic accuracy of VF and pVT detection algorithms during cardiac arrest, both with and without CPR artifact.
	We suggest that research be conducted to identify novel AED design features that facilitate the proper use of AEDs by laypeople and improve both the quality of resuscitation provided and the outcomes for patients with OHCA.
AED Registration	We suggest that future system design innovations enhance connectivity among AEDs, registries, emergency dispatchers, and potential users so that real-time location and readiness data can be integrated into the emergency community response.
AED Signage	Future research should identify signage characteristics, designs, and deployment strategies that maximize the probability of AED identification and retrieval by members of the general public.
	We suggest that the current ILCOR-endorsed AED sign design, adopted in 2008, be revisited to ensure that it is consistent with contemporary International Organization for Standardization standards and develop an evidence base for effectiveness against alternative designs.
Mobile Apps for AED Retrieval	Further scientific evaluation of mobile device apps to crowdsource bystander CPR and AED use is required to determine effectiveness, cost-effectiveness, and the balance of risks and benefits for patients with OHCA.
Novel or Strategic Delivery Vectors	We suggest that future studies explore innovative dispatch strategies to facilitate efficient guidance of bystanders to the nearest available AED and successful use of the device.
	We suggest that research on community responder models be done to determine the feasibility, scalability, effectiveness, and cost-effectiveness of volunteer community responder programs with respect to early CPR, defibrillation, and survival after OHCA.
	We suggest that further research be undertaken to develop and evaluate the clinical and cost-effectiveness of robotic delivery systems for AEDs. Future work should consider how best to coordinate the AED delivery with emergency dispatch and potential users in the vicinity of the cardiac arrest to ensure that AED delivery translates quickly into successful AED use.
Personal and Home-Access Defibrillation	We suggest that innovative strategies to improve outcomes for those who experience OHCA in the residential settings are required. The feasibility and potential impact of novel AED technologies that lower cost, improve portability, or otherwise encourage purchase by individual consumers or households should be explored.

AED indicates automated external defibrillator; app, application; CPR, cardiopulmonary resuscitation; ILCOR, International Liaison Committee on Resuscitation; OHCA, out-of-hospital cardiac arrest; pVT, pulseless ventricular tachycardia; and VF, ventricular fibrillation.

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Writing Group Disclosures

Writing group member	Employment	Research grant	Other research support	Speakers' bureau/ honoraria	Expert witness	Ownership interest	Consultant/ advisory board	Other
Steven C. Brooks	Queen's University; Kingston Health Sciences Centre (Canada)	Canadian Institutes of Health Research (RCT testing effectiveness of the PulsePoint mobile device app to crowdsource bystander CPR and AED use for individuals with out-of-hospital cardiac arrest)†; Canadian Institutes of Health Research (meeting support grant to support a meeting called Rethink PAD for Healthy Cities, which aims to develop community-wide interventions to increase defibrillator public-access in cities)†	None	None	None	None	None	None
Gareth R. Clegg	University of Edinburgh (United Kingdom)	None	None	None	None	None	None	None
Janet Bray	Monash University (Australia)	None	None	None	None	None	None	None
Charles D. Deakin	University Hospital Southampton (United Kingdom)	None	None	None	None	Prometheus Medical Ltd†	None	None
Rudolph W. Koster	Academic Medical Center (the Netherlands)	Stryker (grants for personnel, material for resuscitation studies, including AEDs)†; COACT study VUMC Amsterdam (DSMB; uncompensated)*	None	None	None	None	Stryker*; HeartSine*	None
Mark S. Link	UT Southwestern Medical Center	None	None	None	None	None	None	None
Raina M. Merchant	University of Pennsylvania	None	None	None	None	None	None	None
Laurie J. Morrison	Rescu, Li Ka Shing Knowledge Institute, St Michael's Hospital, University of Toronto (Canada)	None	None	None	None	None	None	None
Marcus E.H. Ong	Singapore General Hospital, Singapore, and Health Services and Systems Research, Duke–NUS Medical School, Singapore (Singapore)	None	None	None	None	None	None	None
Michael Parr	Liverpool Hospital, University of New South Wales and Macquarie University Hospital, Macquarie University (Australia)	None	None	None	None	None	None	None

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Gavin D. Perkins	Warwick Medical School and University Hospitals NHS Foundation Trust (United Kingdom)	Resuscitation Council UK (Fund UK OHCAO registry, which monitors cardiac arrest survival and PAD use)*; British Heart Foundation (Fund UK OHCAO registry, which monitors cardiac arrest survival and PAD use)*	None	None	None	None	None	None
Jaime Pezo-Morales	InterAmerican Heart Foundation (Peru)	None	None	None	None	None	None	None
Mattias Ringh	Karolinska Institutet, Center for Resuscitation Science, Stockholm (Sweden)	Stockholm County (Post Doctoral Fellowship)*; Stockholm County (research support)*	None	None	None	None	None	None
Christopher M. Smith	University of Warwick, Warwick Medical School (United Kingdom)	National Institute for Health Research (Doctoral Research Fellow: UK government funding for a PhD at the University of Warwick)†	None	None	None	None	None	Resuscitation Council (UK) (volunteer role on the Executive Committee and Community and Ambulance Resuscitation subcommittee; unpaid role, travel expenses to meetings paid)*
Tzong-Luen Wang	Fu Jen Catholic University Hospital (Singapore)	None	None	None	None	None	None	None

This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit. A relationship is considered to be "significant" if (a) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (b) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

*Modest.

†Significant.

Reviewer Disclosures

Reviewer	Employment	Research grant	Other research support	Speakers' bureau/ honoraria	Expert witness	Ownership interest	Consultant/ advisory board	Other
Ilan Goldenberg	University of Rochester Medical Center	None	None	None	None	None	None	None
Ines P. Koerner	Oregon Health and Sciences University	NIH (R21 to investigate mechanisms of neurogenesis after cardiac arrest)*	None	None	None	None	None	None
Russell V. Luepker	University of Minnesota School of Public Health	None	None	None	None	None	None	None
Robert Silbergleit	University of Michigan	None	None	None	None	None	None	None

This table represents the relationships of reviewers that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all reviewers are required to complete and submit. A relationship is considered to be "significant" if (a) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (b) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

*Significant.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2021.11.032.

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REFERENCES

1. Berdowski J, Berg RA, Tijssen JG, Koster RW. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. Resuscitation 2010;81:1479–87. https://doi.org/10.1016/j. resuscitation.2010.08.006.
2. Dyson K, Brown SP, May S, et al. International variation in survival after out-of-hospital cardiac arrest: a validation study of the Utstein template. Resuscitation 2019;138:168–81. https://doi.org/10.1016/j.resuscitation.2019.03.018.
3. Pollack RA, Brown SP, Rea T, et al. Impact of bystander automated external defibrillator use on survival and functional outcomes in shockable observed public cardiac arrests. Circulation 2018;137:2104–13. https://doi.org/10.1161/CIRCULATIONAHA.117.030700.
4. Weisfeldt ML, Sitlani CM, Ornato JP, et al. Survival after application of automatic external defibrillators before arrival of the emergency medical system: evaluation in the Resuscitation Outcomes Consortium population of 21 million. J Am Coll Cardiol 2010;55:1713–20. https://doi.org/10.1016/j.jacc.2009.11.077.
5. Blom MT, Beesems SG, Homma PC, et al. Improved survival after out-of-hospital cardiac arrest and use of automated external defibrillators. Circulation 2014;130:1868–75. https://doi.org/10.1161/CIRCULATIONAHA.114.010905.
6. Drennan IR, Lin S, Thorpe KE, Morrison LJ. The effect of time to defibrillation and targeted temperature management on functional survival after out-of-hospital cardiac arrest. Resuscitation 2014;85:1623–8. https://doi.org/10.1016/j.resuscitation.2014.07.010.
7. Hawkes C, Booth S, Ji C, et al. Epidemiology and outcomes from out-of-hospital cardiac arrests in England. Resuscitation 2017;110:133–40. https://doi.org/10.1016/j.resuscitation.2016.10.030.
8. Buick JE, Drennan IR, Scales DC, et al. Improving temporal trends in survival and neurological outcomes after out-of-hospital cardiac arrest. Circ Cardiovasc Qual Outcomes 2018;11. https://doi.org/10.1161/CIRCOUTCOMES.117.003561.
9. Perkins GD, Neumar R, Monsieurs KG, et al. The International Liaison Committee on Resuscitation: review of the last 25 years and vision for the future. Resuscitation 2017;121:104–16. https://doi.org/10.1016/j.resuscitation.2017.09.029.
10. Beck CS, Pritchard WH, Feil HS. Ventricular fibrillation of long duration abolished by electric shock. J Am Med Assoc 1947;135:985. https://doi.org/10.1001/jama.1947.62890150005007a.
11. Zoll PM, Linenthal AJ, Gibson W, Paul MH, Norman LR. Termination of ventricular fibrillation in man by externally applied electric countershock. N Engl J Med 1956;254:727–32. https://doi.org/10.1056/NEJM195604192541601.
12. Pantridge JF, Geddes JS. A mobile intensive-care unit in the management of myocardial infarction. Lancet 1967;2:271–3. https://doi.org/10.1016/s0140-6736(67)90110-9.
13. Weaver WD, Hill DL, Fahrenbruch C, et al. Automatic external defibrillators: importance of field testing to evaluate performance. J Am Coll Cardiol 1987;10:1259–64. https://doi.org/10.1016/s0735-1097(87)80128-6.
14. Stults KR, Brown DD, Kerber RE. Efficacy of an automated external defibrillator in the management of out-of-hospital cardiac arrest: validation of the diagnostic algorithm and initial clinical experience in a rural environment. Circulation 1986;73:701–9. https://doi.org/10.1161/01.cir.73.4.701.

15. Weaver WD, Hill D, Fahrenbruch CE, et al. Use of the automatic external defibrillator in the management of out-of-hospital cardiac arrest. N Engl J Med 1988;319:661–6. https://doi.org/10.1056/NEJM198809153191101.
16. Nichol G, Sayre MR, Guerra F, Poole J. Defibrillation for ventricular fibrillation: a shocking update. J Am Coll Cardiol 2017;70:1496–509. https://doi.org/10.1016/j.jacc.2017.07.778.
17. Link MS, Atkins DL, Passman RS, et al. Part 6: electrical therapies: automated external defibrillators, defibrillation, cardioversion, and pacing: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care [published correction appears in Circulation. 2011;123:e235]. Circulation 2010;122(suppl 3):S706–19. https://doi.org/10.1161/CIRCULATIONAHA.110.970954.
18. Kerber RE, Becker LB, Bourland JD, et al. Automatic external defibrillators for public access defibrillation: recommendations for specifying and reporting arrhythmia analysis algorithm performance, incorporating new waveforms, and enhancing safety: a statement for health professionals from the American Heart Association Task Force on Automatic External Defibrillation, Subcommittee on AED Safety and Efficacy. Circulation 1997;95:1677–82. https://doi.org/10.1161/01.cir.95.6.1677.
19. Cecchin F, Jorgenson DB, Berul CI, et al. Is arrhythmia detection by automatic external defibrillator accurate for children? Sensitivity and specificity of an automatic external defibrillator algorithm in 696 pediatric arrhythmias. Circulation 2001;103:2483–8. https://doi.org/10.1161/01.cir.103.20.2483.
20. van Alem AP, Chapman FW, Lank P, Hart AA, Koster RW. A prospective, randomised and blinded comparison of first shock success of monophasic and biphasic waveforms in out-of-hospital cardiac arrest. Resuscitation 2003;58:17–24. https://doi.org/10.1016/s0300-9572(03)00106-0.
21. Morrison LJ, Dorian P, Long J, et al. Out-of-hospital cardiac arrest rectilinear biphasic to monophasic damped sine defibrillation waveforms with advanced life support intervention trial (ORBIT). Resuscitation 2005;66:149–57. https://doi.org/10.1016/j.resuscitation.2004.11.031.
22. Kudenchuk PJ, Cobb LA, Copass MK, Olsufka M, Maynard C, Nichol G. Transthoracic Incremental Monophasic Versus Biphasic Defibrillation by Emergency Responders (TIMBER): a randomized comparison of monophasic with biphasic waveform ascending energy defibrillation for the resuscitation of out-of-hospital cardiac arrest due to ventricular fibrillation. Circulation 2006;114:2010–8. https://doi.org/10.1161/CIRCULATIONAHA.106.636506.
23. Leng CT, Paradis NA, Calkins H, et al. Resuscitation after prolonged ventricular fibrillation with use of monophasic and biphasic waveform pulses for external defibrillation. Circulation 2000;101:2968–74. https://doi.org/10.1161/01.cir.101.25.2968.
24. Fernando SM, Vaillancourt C, Morrow S, Stiell IG. Analysis of bystander CPR quality during out-of-hospital cardiac arrest using data derived from automated external defibrillators. Resuscitation 2018;128:138–43. https://doi.org/10.1016/j.resuscitation.2018.05.012.
25. Talikowska M, Tohira H, Finn J. Cardiopulmonary resuscitation quality and patient survival outcome in cardiac arrest: a systematic review and meta-analysis. Resuscitation 2015;96:66–77. https://doi.org/10.1016/j.resuscitation.2015.07.036.
26. Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: adult basic life support and cardiopulmonary resuscitation quality: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2015;132(suppl 2):S414–35. https://doi.org/10.1161/CIR.0000000000000259.
27. Bleijenberg E, Koster RW, de Vries H, Beesems SG. The impact of post-resuscitation feedback for paramedics on the quality of cardiopulmonary resuscitation. Resuscitation 2017;110:1–5. https://doi.org/10.1016/j. resuscitation.2016.08.034.
28. Cross BJ, Link MS. Erroneous shock by an AED: importance of obtaining AED tracing to prevent inappropriate ICD implantation. HeartRhythm Case Rep 2015;1:62–3. https://doi.org/10.1016/j.hrcr.2015.02.002.
29. Christenson J, Andrusiek D, Everson-Stewart S, et al. Chest compression fraction determines survival in patients with out-of-hospital ventricular fibrillation. Circulation 2009;120:1241–7. https://doi.org/10.1161/CIRCULATIONAHA.109.852202.
30. Cheskes S, Schmicker RH, Christenson J, et al. Perishock pause: an independent predictor of survival from out-of-hospital shockable cardiac arrest. Circulation 2011;124:58–66. https://doi.org/10.1161/CIRCULATIONAHA.110.010736.
31. Affatato R, Li Y, Ristagno G. See through ECG technology during cardiopulmonary resuscitation to analyze rhythm and predict defibrillation outcome. Curr Opin Crit Care 2016;22:199–205. https://doi.org/10.1097/MCC.0000000000000297.
32. Cheskes S, Schmicker RH, Verbeek PR, et al. The impact of peri-shock pause on survival from out-of-hospital shockable cardiac arrest during the Resuscitation Outcomes Consortium PRIMED trial. Resuscitation 2014;85:336–42. https://doi.org/10.1016/j.resuscitation.2013.10.014.
33. O'Rourke MF, Donaldson E, Geddes JS. An airline cardiac arrest program. Circulation 1997;96:2849–53. https://doi.org/10.1161/01.cir.96.9.2849.
34. Caffrey SL, Willoughby PJ, Pepe PE, Becker LB. Public use of automated external defibrillators. N Engl J Med 2002;347:1242–7. https://doi.org/10.1056/NEJMoa020932.
35. Wassertheil J, Keane G, Fisher N, Leditschke JF. Cardiac arrest outcomes at the Melbourne Cricket Ground and shrine of remembrance using a tiered response strategy: a forerunner to public access defibrillation. Resuscitation 2000;44:97–104. https://doi.org/10.1016/s0300-9572(99)00168-9.
36. Valenzuela TD, Roe DJ, Nichol G, Clark LL, Spaite DW, Hardman RG. Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos. N Engl J Med 2000;343:1206–9. https://doi.org/10.1056/NEJM200010263431701.
37. Page RL, Joglar JA, Kowal RC, et al. Use of automated external defibrillators by a U.S. airline. N Engl J Med 2000;343:1210–6. https://doi.org/10.1056/NEJM200010263431702.
38. Gianotto-Oliveira R, Gonzalez MM, Vianna CB, et al. Survival after ventricular fibrillation cardiac arrest in the Sao Paulo metropolitan subway system: first successful targeted automated external defibrillator (AED) program in Latin America. J Am Heart Assoc 2015;4:e002185. https://doi.org/10.1161/JAHA.115.002185.
39. Kilaru AS, Leffer M, Perkner J, et al. Use of automated external defibrillators in US federal buildings: implementation of the Federal Occupational Health public access defibrillation program. J Occup Environ Med 2014;56:86–91. https://doi.org/10.1097/JOM.0000000000000042.
40. Webner D, DuPrey KM, Drezner JA, Cronholm P, Roberts WO. Sudden cardiac arrest and death in United States marathons. Med Sci Sports Exerc 2012;44:1843–5. https://doi.org/10.1249/MSS.0b013e318258b59a.
41. Perkins GD, Travers AH, Berg RA, et al. Part 3: adult basic life support and automated external defibrillation: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Resuscitation 2015;95:e43–69. https://doi.org/10.1016/j.resuscitation.2015.07.041.
42. Travers AH, Perkins GD, Berg RA, et al. Part 3: adult basic life support and automated external defibrillation: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Circulation 2015;132(suppl 1):S51–83. https://doi.org/10.1161/CIR.0000000000000272.
43. Hallstrom AP, Ornato JP, Weisfeldt M, et al. Public-access defibrillation and survival after out-of-hospital cardiac arrest. N Engl J Med 2004;351:637–46. https://doi.org/10.1056/NEJMoa040566.

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44. Bækgaard JS, Viereck S, Møller TP, Ersbøll AK, Lippert F, Folke F. The effects of public access defibrillation on survival after out-of-hospital cardiac arrest: a systematic review of observational studies. Circulation 2017;136:954–65. https://doi.org/10.1161/CIRCULATIONAHA.117.029067.
45. Holmberg MJ, Vognsen M, Andersen MS, Donnino MW, Andersen LW. Bystander automated external defibrillator use and clinical outcomes after out-of-hospital cardiac arrest: a systematic review and meta-analysis. Resuscitation 2017;120:77–87. https://doi.org/10.1016/j.resuscitation.2017.09.003.
46. Winkle RA. The effectiveness and cost effectiveness of public-access defibrillation. Clin Cardiol 2010;33:396–9. https://doi.org/10.1002/clc.20790.
47. Nichol G, Valenzuela T, Roe D, Clark L, Huszti E, Wells GA. Cost effectiveness of defibrillation by targeted responders in public settings. Circulation 2003;108:697–703. https://doi.org/10.1161/01.CIR.0000084545.65645.28.
48. Andersen LW, Holmberg MJ, Granfeldt A, James LP, Caulley L. Cost-effectiveness of public automated external defibrillators. Resuscitation 2019;138:250–8. https://doi.org/10.1016/j.resuscitation.2019.03.029.
49. Cappato R, Curnis A, Marzollo P, et al. Prospective assessment of integrating the existing emergency medical system with automated external defibrillators fully operated by volunteers and laypersons for out-of-hospital cardiac arrest: the Brescia Early Defibrillation Study (BEDS). Eur Heart J 2006;27:553–61. https://doi.org/10.1093/eurheartj/ehi654.
50. Moran PS, Teljeur C, Masterson S, O'Neill M, Harrington P, Ryan M. Cost-effectiveness of a national public access defibrillation programme. Resuscitation 2015;91:48–55. https://doi.org/10.1016/j.resuscitation.2015.03.017.
51. Hansen SM, Hansen CM, Folke F, et al. Bystander defibrillation for out-of-hospital cardiac arrest in public vs residential locations. JAMA Cardiol 2017;2:507–14. https://doi.org/10.1001/jamacardio.2017.0008.
52. Ringh M, Hollenberg J, Palsgaard-Moeller T, et al. COSTA Study Group (research collaboration between Copenhagen, Oslo, Stockholm, and Amsterdam). The challenges and possibilities of public access defibrillation. J Intern Med 2018;283:238–56. https://doi.org/10.1111/joim.12730.
53. Douma MJ. Automated video surveillance and machine learning: leveraging existing infrastructure for cardiac arrest detection and emergency response activation. Resuscitation 2018;126:e3. https://doi.org/10.1016/j. resuscitation.2018.02.010.
54. Chan J, Rea T, Gollakota S, Sunshine JE. Contactless cardiac arrest detection using smart devices. NPJ Digit Med 2019;2:52. https://doi.org/10.1038/s41746-019-0128-7.
55. Smith CM, Lim Choi Keung SN, Khan MO, et al. Barriers and facilitators to public access defibrillation in out-of-hospital cardiac arrest: a systematic review. Eur Heart J Qual Care Clin Outcomes 2017;3:264–73. https://doi.org/10.1093/ehjqcco/qcx023.
56. Schober P, van Dehn FB, Bierens JJ, Loer SA, Schwarte LA. Public access defibrillation: time to access the public. Ann Emerg Med 2011;58:240–7. https://doi.org/10.1016/j.annemergmed.2010.12.016.
57. Gonzalez M, Leary M, Blewer AL, et al. Public knowledge of automatic external defibrillators in a large U.S. urban community. Resuscitation 2015;92:101–6. https://doi.org/10.1016/j.resuscitation.2015.04.022.
58. Kuramoto N, Morimoto T, Kubota Y, et al. Public perception of and willingness to perform bystander CPR in Japan. Resuscitation 2008;79:475–81. https://doi.org/10.1016/j.resuscitation.2008.07.005.
59. Krammel M, Schnaubelt S, Weidenauer D, et al. Gender and age-specific aspects of awareness and knowledge in basic life support. PLoS One 2018;13:e0198918. https://doi.org/10.1371/journal.pone.0198918.
60. Hawkes CA, Brown TP, Booth S, et al. Attitudes to cardiopulmonary resuscitation and defibrillator use: a survey of UK adults in 2017. J Am Heart Assoc 2019;8:e008267. https://doi.org/10.1161/JAHA.117.008267.
61. McDonough A, Callan K, Egizio K, et al. Student perceptions of sudden cardiac arrest: a qualitative inquiry. Br J Nurs 2012;21:523–7. https://doi.org/10.12968/bjon.2012.21.9.523.
62. Brooks B, Chan S, Lander P, Adamson R, Hodgetts GA, Deakin CD. Public knowledge and confidence in the use of public access defibrillation. Heart 2015;101:967–71. https://doi.org/10.1136/heartjnl-2015-307624.
63. Malta Hansen C, Rosenkranz SM, Folke F, et al. Lay bystanders' perspectives on what facilitates cardiopulmonary resuscitation and use of automated external defibrillators in real cardiac arrests. J Am Heart Assoc 2017;6:e004572. https://doi.org/10.1161/JAHA.116.004572.
64. Folke F, Lippert FK, Nielsen SL, et al. Location of cardiac arrest in a city center: strategic placement of automated external defibrillators in public locations. Circulation 2009;120:510–7. https://doi.org/10.1161/CIRCULATIONAHA.108.843755.
65. Haskell SE, Post M, Cram P, Atkins DL. Community public access sites: compliance with American Heart Association recommendations. Resuscitation 2009;80:854–8. https://doi.org/10.1016/j.resuscitation.2009.04.033.
66. Ong ME, Quah JL, Ho AF, et al. National population based survey on the prevalence of first aid, cardiopulmonary resuscitation and automated external defibrillator skills in Singapore. Resuscitation 2013;84:1633–6. https://doi.org/10.1016/j.resuscitation.2013.05.008.
67. Lijovic M, Bernard S, Nehme Z, Walker T, Smith K. Public access defibrillation: results from the Victorian Ambulance Cardiac Arrest Registry. Resuscitation 2014;85:1739–44. https://doi.org/10.1016/j.resuscitation.2014.10.005.
68. Luca NR, Suggs LS. Theory and model use in social marketing health interventions. J Health Commun 2013;18:20–40. https://doi.org/10.1080/10810730.2012.688243.
69. Fordyce CB, Hansen CM, Kragholm K, et al. Association of public health initiatives with outcomes for out-of-hospital cardiac arrest at home and in public locations. JAMA Cardiol 2017;2:1226–35. https://doi.org/10.1001/jamacardio.2017.3471.
70. Boland LL, Formanek MB, Harkins KK, et al. Minnesota Heart Safe Communities: are community-based initiatives increasing pre-ambulance CPR and AED use? Resuscitation 2017;119:33–6. https://doi.org/10.1016/j.resuscitation.2017.07.031.
71. Lee MJ, Hwang SO, Cha KC, Cho GC, Yang HJ, Rho TH. Influence of nationwide policy on citizens' awareness and willingness to perform bystander cardiopulmonary resuscitation. Resuscitation 2013;84:889–94. https://doi.org/10.1016/j.resuscitation.2013.01.009.
72. Nas J, Thannhauser J, Herrmann JJ, et al. Changes in automated external defibrillator use and survival after out-of-hospital cardiac arrest in the Nijmegen area. Neth Heart J 2018;26:600–5. https://doi.org/10.1007/s12471-018-1162-9.
73. Wissenberg M, Lippert FK, Folke F, et al. Association of national initiatives to improve cardiac arrest management with rates of bystander intervention and patient survival after out-of-hospital cardiac arrest. JAMA 2013;310:1377–84. https://doi.org/10.1001/jama.2013.278483.
74. Ragin DF, Holohan JA, Ricci EM, Grant C, Richardson LD. Shocking a community into action: a social marketing approach to cardiac arrests. J Health Soc Policy 2005;20:49–70. https://doi.org/10.1300/J045v20n02_04.
75. Andreasen AR. Marketing social marketing in the social change marketplace. J Public Policy Marketing 2002;21:3–13.
76. Evans WD. How social marketing works in health care. BMJ 2006;332:1207–10. https://doi.org/10.1136/bmj.332.7551.1207-a.
77. Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change

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interventions. Implement Sci 2011;6:42. https://doi.org/10.1186/1748-5908-6-42.
78. Committee on the Treatment of Cardiac Arrest: Current Status and Future Directions; Board on Health Sciences Policy; Institute of Medicine. Strategies to Improve Cardiac Arrest Survival: A Time to Act. National Academies Press; 2015.
79. Rumsfeld JS, Brooks SC, Aufderheide TP, et al. Use of mobile devices, social media, and crowdsourcing as digital strategies to improve emergency cardiovascular care: a scientific statement from the American Heart Association. Circulation 2016;134:e87–e108. https://doi.org/10.1161/CIR.0000000000000428.
80. Böttiger BW, Lockey A, Aickin R, et al. "All citizens of the world can save a life": the World Restart a Heart (WRAH) initiative starts in 2018. Resuscitation 2018;128:188–90. https://doi.org/10.1016/j.resuscitation.2018.04. 015.
81. Böttiger BW, Lockey A, Aickin R, et al. Over 675,000 lay people trained in cardiopulmonary resuscitation worldwide: the "World Restart a Heart (WRAH)" initiative 2018. Resuscitation 2019;138:15–7. https://doi.org/10.1016/j.resuscitation.2019.02.033.
82. American Heart Association. CPR in schools. (Accessed August 5, 2019, at https://cpr.heart.org/AHAECC/CPRAndECC/Programs/CPRIn-Schools/UCM_473194_CPR-In-Schools.jsp).
83. Semeraro F, Wingen S, Schroeder DC, et al. Kids Save Lives: Three years of implementation in Europe. Resuscitation 2018;131:e9–e11. https://doi.org/10.1016/j. resuscitation.2018.08.008.
84. European Patient Safety Foundation. Kids Save Lives website. (Accessed August 5, 2019, at https://www.kids-save-lives.eu/statement.html).
85. Schroeder DC, Ecker H, Wingen S, Semeraro F, Böttiger BW. "Kids Save Lives": resuscitation training for schoolchildren: systematic review [in German]. Anaesthesist 2017;66:589–97. https://doi.org/10.1007/s00101-017-0319-z.
86. Malsy M, Leberle R, Graf B. Germans learn how to save lives: a nationwide CPR education initiative. Int J Emerg Med 2018;11:9. https://doi.org/10.1186/s12245-018-0171-1.
87. Böttiger BW, Semeraro F, Altemeyer KH, et al. Kids Save Lives: school children education in resuscitation for Europe and the world. Eur J Anaesthesiol 2017;34:792–6. https://doi.org/10.1097/EJA.0000000000000713.
88. Cave DM, Aufderheide TP, Beeson J, et al. Importance and implementation of training in cardiopulmonary resuscitation and automated external defibrillation in schools: a science advisory from the American Heart Association. Circulation 2011;123:691–706. https://doi.org/10.1161/CIR.0b013e31820b5328.
89. Drezner JA, Rao AL, Heistand J, Bloomingdale MK, Harmon KG. Effectiveness of emergency response planning for sudden cardiac arrest in United States high schools with automated external defibrillators. Circulation 2009;120:518–25. https://doi.org/10.1161/CIRCULATIONAHA.109.855890.
90. Isbye DL, Rasmussen LS, Ringsted C, Lippert FK. Disseminating cardiopulmonary resuscitation training by distributing 35,000 personal manikins among school children. Circulation 2007;116:1380–5. https://doi.org/10.1161/CIRCULATIONAHA.107.710616.
91. Hazinski MF, Markenson D, Neish S, et al. Response to cardiac arrest and selected life-threatening medical emergencies: the medical emergency response plan for schools: a statement for healthcare providers, policymakers, school administrators, and community leaders. Circulation 2004;109:278–91. https://doi.org/10.1161/01.CIR.0000109486. 45545.AD.
92. Resuscitation Council UK. CPR education in schools in England. (Accessed August 5, 2019, at https://www.resus.org.uk/media/statements/statement-on-cpr-in-english-schools/).
93. Malta Hansen C, Zinckernagel L, Ersbøll AK, et al. Cardiopulmonary resuscitation training in schools following 8 years of mandating legislation in Denmark: a nationwide survey. J Am Heart Assoc 2017;6:e004128. https://doi.org/10.1161/JAHA.116.004128.
94. Hart D, Flores-Medrano O, Brooks S, Buick JE, Morrison LJ. Cardiopulmonary resuscitation and automatic external defibrillator training in schools: "is anyone learning how to save a life?". CJEM 2013;15:270–8. https://doi.org/10.2310/8000.2013.130898.
95. Gundry JW, Comess KA, DeRook FA, Jorgenson D, Bardy GH. Comparison of naive sixth-grade children with trained professionals in the use of an automated external defibrillator. Circulation 1999;100:1703–7. https://doi.org/10.1161/01.cir.100.16.1703.
96. Fischer P, Krueger JI, Greitemeyer T, et al. The bystander-effect: a meta-analytic review on bystander intervention in dangerous and non-dangerous emergencies. Psychol Bull 2011;137:517–37. https://doi.org/10.1037/a0023304.
97. Johnston TC, Clark MJ, Dingle GA, FitzGerald G. Factors influencing Queenslanders' willingness to perform bystander cardiopulmonary resuscitation. Resuscitation 2003;56:67–75. https://doi.org/10.1016/s0300-9572(02)00277-0.
98. Mathiesen WT, Bjørshol CA, Braut GS, Søreide E. Reactions and coping strategies in lay rescuers who have provided CPR to out-of-hospital cardiac arrest victims: a qualitative study. BMJ Open 2016;6:e010671. https://doi.org/10.1136/bmjopen-2015-010671.
99. Mausz J, Snobelen P, Tavares W. "Please. Don't. Die".: a grounded theory study of bystander cardiopulmonary resuscitation. Circ Cardiovasc Qual Outcomes 2018;11:e004035. https://doi.org/10.1161/CIRCOUTCOMES.117.004035.
100. Peberdy MA, Ottingham LV, Groh WJ, et al. Adverse events associated with lay emergency response programs: the Public Access Defibrillation Trial experience. Resuscitation 2006;70:59–65. https://doi.org/10.1016/j.resuscitation.2005.10.030.
101. Zijlstra JA, Beesems SG, De Haan RJ, Koster RW. Psychological impact on dispatched local lay rescuers performing bystander cardiopulmonary resuscitation. Resuscitation 2015;92:115–21. https://doi.org/10.1016/j. resuscitation.2015.04.028.
102. Møller TP, Hansen CM, Fjordholt M, Pedersen BD, Østergaard D, Lippert FK. Debriefing bystanders of out-of-hospital cardiac arrest is valuable. Resuscitation 2014;85:1504–11. https://doi.org/10.1016/j.resuscitation. 2014.08.006.
103. Snobelen PJ, Pellegrino JL, Nevils GS, Dainty KN. Helping those who help. Circ Cardiovasc Qual Outcomes 2018;11:e004702. https://doi.org/10.1161/CIRCOUTCOMES.118.004702.
104. Pei-Chuan Huang E, Chiang WC, Hsieh MJ, et al. Public knowledge, attitudes and willingness regarding bystander cardiopulmonary resuscitation: a nationwide survey in Taiwan. J Formos Med Assoc 2019;118:572–81. https://doi.org/10.1016/j.jfma.2018.07.018.
105. Aufderheide T, Hazinski MF, Nichol G, et al. Community lay rescuer automated external defibrillation programs: key state legislative components and implementation strategies: a summary of a decade of experience for healthcare providers, policymakers, legislators, employers, and community leaders from the American Heart Association Emergency Cardiovascular Care Committee, Council on Clinical Cardiology, and Office of State Advocacy. Circulation 2006;113:1260–70. https://doi.org/10.1161/CIRCULATIONAHA.106.172289.
106. Gilchrist S, Schieb L, Mukhtar Q, et al. A summary of public access defibrillation laws, United States, 2010. Prev Chronic Dis 2012;9:E71.
107. Garritano NF, Willmarth-Stec M. Student athletes, sudden cardiac death, and lifesaving legislation: a review of the literature. J Pediatr Health Care 2015;29:233–42. https://doi.org/10.1016/j.pedhc.2014.11.006.
108. Sherrid MV, Aagaard P, Serrato S, et al. State requirements for automated external defibrillators in American schools: framing the debate about legislative action. J Am Coll Cardiol 2017;69:1735–43. https://doi.org/10.1016/j.jacc.2017.01.033.
109. Reiner JS, Solomon AJ, Katz RJ. Shock and law. Circulation 2011;124:1391–4. https://doi.org/10.1161/CIRCULATIONAHA.111.040519.

110. Thornton MD, Cicero MX, McCabe ME, Chen L. Automated external defibrillators in high schools: disparities persist despite legislation. Pediatr Emerg Care 2020;36:419–23. https://doi.org/10.1097/PEC.0000000000001335.
111. Brooks SC, Scales DC, Pinto R, et al. The postcardiac arrest consult team: impact on hospital care processes for out-of-hospital cardiac arrest patients. Crit Care Med 2016;44:2037–44. https://doi.org/10.1097/CCM.0000000000001863.
112. Andrew E, Nehme Z, Wolfe R, Bernard S, Smith K. Long-term survival following out-of-hospital cardiac arrest. Heart 2017;103:1104–10. https://doi.org/10.1136/heartjnl-2016-310485.
113. Wang TH, Wu HW, Hou PC, Tseng HJ. The utilization of automated external defibrillators in Taiwan. J Formos Med Assoc 2019;118(pt 1):148–51. https://doi.org/10.1016/j.jfma.2018.02.006.
114. Mitamura H. Public access defibrillation: advances from Japan. Nat Clin Pract Cardiovasc Med 2008;5:690–2. https://doi.org/10.1038/ncpcardio1330.
115. Mumma BE, Diercks DB, Wilson MD, Holmes JF. Association between treatment at an ST-segment elevation myocardial infarction center and neurologic recovery after out-of-hospital cardiac arrest. Am Heart J 2015;170:516–23. https://doi.org/10.1016/j.ahj.2015.05.020.
116. Karlsson L, Malta Hansen C, Wissenberg M, et al. Automated external defibrillator accessibility is crucial for bystander defibrillation and survival: a registry-based study. Resuscitation 2019;136:30–7. https://doi.org/10.1016/j.resuscitation.2019.01.014.
117. Sondergaard KB, Hansen SM, Pallisgaard JL, et al. Out-of-hospital cardiac arrest: probability of bystander defibrillation relative to distance to nearest automated external defibrillator. Resuscitation 2018;124:138–44. https://doi.org/10.1016/j.resuscitation.2017.11.067.
118. Chan TC, Li H, Lebovic G, et al. Identifying locations for public access defibrillators using mathematical optimization. Circulation 2013;127:1801–9. https://doi.org/10.1161/CIRCULATIONAHA.113.001953.
119. Ho CL, Lui CT, Tsui KL, Kam CW. Investigation of availability and accessibility of community automated external defibrillators in a territory in Hong Kong. Hong Kong Med J 2014;20:371–8. https://doi.org/10.12809/hkmj144258.
120. Sun CL, Demirtas D, Brooks SC, Morrison LJ, Chan TC. Overcoming spatial and temporal barriers to public access defibrillators via optimization. J Am Coll Cardiol 2016;68:836–45. https://doi.org/10.1016/j.jacc.2016.03.609.
121. Fredman D, Svensson L, Ban Y, et al. Expanding the first link in the chain of survival: experiences from dispatcher referral of callers to AED locations. Resuscitation 2016;107:129–34. https://doi.org/10.1016/j.resuscitation.2016.06.022.
122. Agerskov M, Nielsen AM, Hansen CM, et al. Public access defibrillation: great benefit and potential but infrequently used. Resuscitation 2015;96:53–8. https://doi.org/10.1016/j.resuscitation.2015.07.021.
123. Hansen CM, Lippert FK, Wissenberg M, et al. Temporal trends in coverage of historical cardiac arrests using a volunteer-based network of automated external defibrillators accessible to laypersons and emergency dispatch centers. Circulation 2014;130:1859–67. https://doi.org/10.1161/CIRCULATIONAHA.114.008850.
124. Deakin CD, Anfield S, Hodgetts GA. Underutilisation of public access defibrillation is related to retrieval distance and time-dependent availability. Heart 2018;104:1339–43. https://doi.org/10.1136/heartjnl-2018-312998.
125. Levy MJ, Seaman KG, Millin MG, Bissell RA, Jenkins JL. A poor association between out-of-hospital cardiac arrest location and public automated external defibrillator placement. Prehosp Disaster Med 2013;28:342–7. https://doi.org/10.1017/S1049023X13000411.
126. Reinier K, Thomas E, Andrusiek DL, et al. Socioeconomic status and incidence of sudden cardiac arrest. CMAJ 2011;183:1705–12. https://doi.org/10.1503/cmaj.101512.
127. Straney LD, Bray JE, Beck B, Bernard S, Lijovic M, Smith K. Are sociodemographic characteristics associated with spatial variation in the incidence of OHCA and bystander CPR rates? A population-based observational study in Victoria, Australia. *BMJ Open* 2016;6:e012434. https://doi.org/10.1136/bmjopen-2016-012434.
128. Lee SY, Do YK, Shin SD, et al. Community socioeconomic status and public access defibrillators: a multilevel analysis. Resuscitation 2017;120:1–7. https://doi.org/10.1016/j.resuscitation.2017.08.012.
129. Dicker B, Garrett N, Wong S, et al. Relationship between socioeconomic factors, distribution of public access defibrillators and incidence of out-of-hospital cardiac arrest. Resuscitation 2019;138:53–8. https://doi.org/10.1016/j.resuscitation.2019.02.022.
130. Sasson C, Keirns CC, Smith DM, et al. Examining the contextual effects of neighborhood on out-of-hospital cardiac arrest and the provision of bystander cardiopulmonary resuscitation. Resuscitation 2011;82:674–9. https://doi.org/10.1016/j.resuscitation.2011.02.002.
131. Chiang WC, Ko PC, Chang AM, et al. Bystander-initiated CPR in an Asian metropolitan: does the socioeconomic status matter? Resuscitation 2014;85:53–8. https://doi.org/10.1016/j.resuscitation.2013.07.033.
132. Ong ME, Wah W, Hsu LY, et al. Geographic factors are associated with increased risk for out-of hospital cardiac arrests and provision of bystander cardio-pulmonary resuscitation in Singapore. Resuscitation 2014;85:1153–60. https://doi.org/10.1016/j.resuscitation.2014.06.006.
133. Dahan B, Jabre P, Karam N, et al. Impact of neighbourhood socio-economic status on bystander cardiopulmonary resuscitation in Paris. Resuscitation 2017;110:107–13. https://doi.org/10.1016/j.resuscitation.2016.10.028.
134. Jonsson M, Härkönen J, Ljungman P, et al. Survival after out-of-hospital cardiac arrest is associated with area-level socioeconomic status. Heart 2019;105:632–8. https://doi.org/10.1136/heartjnl-2018-313838.
135. Zakaria ND, Ong ME, Gan HN, et al. Implications for public access defibrillation placement by non-traumatic out-of-hospital cardiac arrest occurrence in Singapore. Emerg Med Australas 2014;26:229–36. https://doi.org/10.1111/1742-6723.12174.
136. Malcom 3rd GE, Thompson TM, Coule PL. The location and incidence of out-of-hospital cardiac arrest in Georgia: implications for placement of automated external defibrillators. Prehosp Emerg Care 2004;8:10–4. https://doi.org/10.1080/312703002752.
137. Fedoruk JC, Currie WL, Gobet M. Locations of cardiac arrest: affirmation for community Public Access Defibrillation (PAD) program. Prehosp Disaster Med 2002;17:202–5. https://doi.org/10.1017/s1049023x00000509.
138. Frank RL, Rausch MA, Menegazzi JJ, Rickens M. The locations of nonresidential out-of-hospital cardiac arrests in the city of Pittsburgh over a three-year period: implications for automated external defibrillator placement. Prehosp Emerg Care 2001;5:247–51. https://doi.org/10.1080/10903120190939724.
139. Gratton M, Lindholm DJ, Campbell JP. Public-access defibrillation: where do we place the AEDs? Prehosp Emerg Care 1999;3:303–5. https://doi.org/10.1080/10903129908958958.
140. Becker L, Eisenberg M, Fahrenbruch C, Cobb L. Public locations of cardiac arrest. Implications for public access defibrillation. *Circulation* 1998;97:2106–9. https://doi.org/10.1161/01.cir.97.21.2106.
141. Sun CL, Brooks SC, Morrison LJ, Chan TC, Investigators RE. Ranking businesses and municipal locations by spatiotemporal cardiac arrest risk to guide public defibrillator placement. Circulation 2017;135:1104–19. https://doi.org/10.1161/CIRCULATIONAHA.116.025349.
142. Chan TCY. Rise and shock: optimal defibrillator placement in a high-rise building. Prehosp Emerg Care 2017;21:309–14. https://doi.org/10.1080/10903127.2016.1247202.
143. Gong Y, Chen B, Li Y. A review of the performance of artifact filtering algorithms for cardiopulmonary resuscitation. J Healthc Eng 2013;4:185–202. https://doi.org/10.1260/2040-2295.4.2.185.

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144. Zijlstra JA, Bekkers LE, Hulleman M, Beesems SG, Koster RW. Automated external defibrillator and operator performance in out-of-hospital cardiac arrest. Resuscitation 2017;118:140–6. https://doi.org/10.1016/j. resuscitation.2017.05.017.
145. Calle PA, Mpotos N, Calle SP, Monsieurs KG. Inaccurate treatment decisions of automated external defibrillators used by emergency medical services personnel: incidence, cause and impact on outcome. Resuscitation 2015;88:68–74. https://doi.org/10.1016/j.resuscitation.2014.12.017.
146. Israelsson J, Wangenheim BV, Årestedt K, Semark B, Schildmeijer K, Carlsson J. Sensitivity and specificity of two different automated external defibrillators. Resuscitation 2017;120:108–12. https://doi.org/10.1016/j. resuscitation.2017.09.009.
147. Loma-Osorio P, Nuñez M, Aboal J, et al. The Girona Territori Cardioprotegit Project: performance evaluation of public defibrillators. Rev Esp Cardiol (Engl Ed) 2018;71:79–85. https://doi.org/10.1016/j.rec.2017.04.011.
148. Partridge R, Tan Q, Silver A, Riley M, Geheb F, Raymond R. Rhythm analysis and charging during chest compressions reduces compression pause time. Resuscitation 2015;90:133–7. https://doi.org/10.1016/j. resuscitation.2015.02.025.
149. de Graaf C, Beesems SG, Stickney RE, Lank P, Chapman FW, Koster RW. Analyzing heart rhythm during chest compressions in out-of-hospital cardiac arrest patients using new algorithm for automated external defibrillators [abstract 18]. Circulation 2018;138:A18.
150. Figuera C, Irusta U, Morgado E, et al. Machine learning techniques for the detection of shockable rhythms in automated external defibrillators. PLoS One 2016;11:e0159654. https://doi.org/10.1371/journal.pone.0159654.
151. Nielsen AM, Rasmussen LS. The value of ECG downloads from automated external defibrillators. Resuscitation 2010;81:917–8. https://doi.org/10.1016/j.resuscitation.2010.03.020.
152. Hosmans TP, Maquoi I, Vogels C, et al. Safety of fully automatic external defibrillation by untrained lay rescuers in the presence of a bystander. Resuscitation 2008;77:216–9. https://doi.org/10.1016/j.resuscitation.2007.11.017.
153. Monsieurs KG, Vogels C, Bossaert LL, Meert P, Calle PA. A study comparing the usability of fully automatic versus semi-automatic defibrillation by untrained nursing students. Resuscitation 2005;64:41–7. https://doi.org/10.1016/j.resuscitation.2004.07.003.
154. Yeung J, Okamoto D, Soar J, Perkins GD. AED training and its impact on skill acquisition, retention and performance: a systematic review of alternative training methods. Resuscitation 2011;82:657–64. https://doi.org/10.1016/j.resuscitation.2011.02.035.
155. Callejas S, Barry A, Demertsidis E, Jorgenson D, Becker LB. Human factors impact successful lay person automated external defibrillator use during simulated cardiac arrest. Crit Care Med 2004;32(suppl):S406–13. https://doi.org/10.1097/01.ccm.0000139948.46663.3a.
156. Mosesso Jr VN, Shapiro AH, Stein K, Burkett K, Wang H. Effects of AED device features on performance by untrained laypersons. Resuscitation 2009;80:1285–9. https://doi.org/10.1016/j.resuscitation.2009.07.016.
157. Brooks SC, Schmicker RH, Rea TD, et al. Out-of-hospital cardiac arrest frequency and survival: evidence for temporal variability. Resuscitation 2010;81:175–81. https://doi.org/10.1016/j.resuscitation.2009.10.021.
158. Hansen CM, Wissenberg M, Weeke P, et al. Automated external defibrillators inaccessible to more than half of nearby cardiac arrests in public locations during evening, nighttime, and weekends. Circulation 2013;128:2224–31. https://doi.org/10.1161/CIRCULATIONAHA.113.003066.
159. DeLuca Jr LA, Simpson A, Beskind D, et al. Analysis of automated external defibrillator device failures reported to the Food and Drug Administration. Ann Emerg Med 2012;59:103–11. https://doi.org/10.1016/j.annemergmed.2011.07.022.
160. Huig IC, Boonstra L, Gerritsen PC, Hoeks SE. The availability, condition and employability of automated external defibrillators in large city centres in the Netherlands. Resuscitation 2014;85:1324–9. https://doi.org/10.1016/j.resuscitation.2014.05.024.
161. Salerno J, Willson C, Weiss L, Salcido D. Myth of the stolen AED. Resuscitation 2019;140:1. https://doi.org/10.1016/j.resuscitation.2019.04.036.
162. Engdahl J, Herlitz J. Localization of out-of-hospital cardiac arrest in Goteborg 1994–2002 and implications for public access defibrillation. Resuscitation 2005;64:171–5. https://doi.org/10.1016/j.resuscitation.2004.08.006.
163. Fredman D, Ringh M, Svensson L, et al. Experiences and outcome from the implementation of a national Swedish automated external defibrillator registry. Resuscitation 2018;130:73–80. https://doi.org/10.1016/j.resuscitation.2018.06.036.
164. Microsoft. Plan to map UK's network of heart defibrillators using Microsoft Azure could save thousands of lives every year, 2018. (Accessed August 5, 2019, at https://news.microsoft.com/en-gb/2018/08/08/plan-to-map-uks-network-of-heart-defibrillators-using-microsoft-azure-could-save-thousands-of-lives-every-year/).
165. Merchant RM, Asch DA, Hershey JC, et al. A crowdsourcing innovation challenge to locate and map automated external defibrillators. Circ Cardiovasc Qual Outcomes 2013;6:229–36. https://doi.org/10.1161/CIRCOUTCOMES.113.000140.
166. Smith CM, Wilson MH, Ghorbangholi A, et al. The use of trained volunteers in the response to out-of-hospital cardiac arrest: the GoodSAM experience. Resuscitation 2017;121:123–6. https://doi.org/10.1016/j.resuscitation.2017.10.020.
167. Brooks SC, Simmons G, Worthington H, Bobrow BJ, Morrison LJ. The PulsePoint Respond mobile device application to crowdsource basic life support for patients with out-of-hospital cardiac arrest: challenges for optimal implementation. Resuscitation 2016;98:20–6. https://doi.org/10.1016/j. resuscitation.2015.09.392.
168. Rea T, Blackwood J, Damon S, Phelps R, Eisenberg M. A link between emergency dispatch and public access AEDs: potential implications for early defibrillation. Resuscitation 2011;82:995–8. https://doi.org/10.1016/j. resuscitation.2011.04.011.
169. Maes F, Marchandise S, Boileau L, Polain Le, de Waroux JB, Scavée C. Evaluation of a new semiautomated external defibrillator technology: a live cases video recording study. Emerg Med J 2015;32:481–5. https://doi.org/10.1136/emermed-2013-202962.
170. Aagaard R, Grove EL, Mikkelsen R, Wolff A, Iversen KW, Løfgren B. Limited public ability to recognise and understand the universal sign for automated external defibrillators. Heart 2016;102:770–4. https://doi.org/10.1136/heartjnl-2015-308700.
171. Smith CM, Colquhoun MC, Samuels M, Hodson M, Mitchell S, O'Sullivan J. New signs to encourage the use of automated external defibrillators by the lay public. Resuscitation 2017;114:100–5. https://doi.org/10.1016/j. resuscitation.2017.03.012.
172. Sidebottom DB, Potter R, Newitt LK, Hodgetts GA, Deakin CD. Saving lives with public access defibrillation: a deadly game of hide and seek. Resuscitation 2018;128:93–6. https://doi.org/10.1016/j.resuscitation.2018.04.006.
173. Neves Briard J, Grou-Boileau F, El Bashtaly A, Spenard C, de Champlain F, Homier V. Automated external defibrillator geolocalization with a mobile application, verbal assistance or no assistance: a pilot randomized simulation (AED G-MAP). Prehosp Emerg Care 2019;23:420–9. https://doi.org/10.1080/10903127.2018.1511017.
174. Sakai T, Iwami T, Kitamura T, et al. Effectiveness of the new "Mobile AED Map" to find and retrieve an AED: a randomised controlled trial. Resuscitation 2011;82:69–73. https://doi.org/10.1016/j.resuscitation.2010.09.466.
175. Zijlstra JA, Stieglis R, Riedijk F, Smeekes M, van der Worp WE, Koster RW. Local lay rescuers with AEDs, alerted by text messages, contribute to early defibrillation in a Dutch out-of-hospital cardiac arrest dispatch system. Resuscitation

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2014;85:1444–9. https://doi.org/10.1016/j.resuscitation.2014.07.020.
176. Pijls RW, Nelemans PJ, Rahel BM, Gorgels AP. A text message alert system for trained volunteers improves out-of-hospital cardiac arrest survival. Resuscitation 2016;105:182–7. https://doi.org/10.1016/j.resuscitation. 2016.06.006.
177. Berglund E, Claesson A, Nordberg P, et al. A smartphone application for dispatch of lay responders to out-of-hospital cardiac arrests. Resuscitation 2018;126:160–5. https://doi.org/10.1016/j.resuscitation.2018.01.039.
178. Ringh M, Rosenqvist M, Hollenberg J, et al. Mobile-phone dispatch of laypersons for CPR in out-of-hospital cardiac arrest. N Engl J Med 2015;372:2316–25. https://doi.org/10.1056/NEJMoa1406038.
179. Ng YY, Leong SH, Ong ME. The role of dispatch in resuscitation. Singapore Med J 2017;58:449–52. https://doi.org/10.11622/smedj.2017059.
180. Ringh M, Fredman D, Nordberg P, Stark T, Hollenberg J. Mobile phone technology identifies and recruits trained citizens to perform CPR on out-of-hospital cardiac arrest victims prior to ambulance arrival. Resuscitation 2011;82:1514–8. https://doi.org/10.1016/j.resuscitation.2011.07.033.
181. Caputo ML, Muschietti S, Burkart R, et al. Lay persons alerted by mobile application system initiate earlier cardio-pulmonary resuscitation: a comparison with SMS-based system notification. Resuscitation 2017;114:73–8. https://doi.org/10.1016/j.resuscitation.2017.03.003.
182. Dainty KN, Vaid H, Brooks SC. North American public opinion survey on the acceptability of crowdsourcing basic life support for out-of-hospital cardiac arrest with the PulsePoint mobile phone app. JMIR Mhealth Uhealth 2017;5:e63. https://doi.org/10.2196/mhealth.6926.
183. Rea TD, Eisenberg MS, Culley LL, Becker L. Dispatcher-assisted cardiopulmonary resuscitation and survival in cardiac arrest. Circulation 2001;104:2513–6. https://doi.org/10.1161/hc4601.099468.
184. Wu Z, Panczyk M, Spaite DW, et al. Telephone cardiopulmonary resuscitation is independently associated with improved survival and improved functional outcome after out-of-hospital cardiac arrest. Resuscitation 2018;122:135–40. https://doi.org/10.1016/j.resuscitation.2017.07.016.
185. Cone DC, Middleton PM. Are out-of-hospital cardiac arrest survival rates improving? Resuscitation 2015;91:A7–8. https://doi.org/10.1016/j.resuscitation. 2015.03.011.
186. Berdowski J, Kuiper MJ, Dijkgraaf MG, Tijssen JG, Koster RW. Survival and health care costs until hospital discharge of patients treated with onsite, dispatched or without automated external defibrillator. Resuscitation 2010;81:962–7. https://doi.org/10.1016/j.resuscitation.2010.04.013.
187. Deakin CD, Shewry E, Gray HH. Public access defibrillation remains out of reach for most victims of out-of-hospital sudden cardiac arrest. Heart 2014;100:619–23. https://doi.org/10.1136/heartjnl-2013-305030.
188. Blomberg SN, Folke F, Ersbøll AK, et al. Machine learning as a supportive tool to recognize cardiac arrest in emergency calls. Resuscitation 2019;138:322–9. https://doi.org/10.1016/j.resuscitation.2019.01.015.
189. Stiell IG, Wells GA, Field BJ, et al. Improved out-of-hospital cardiac arrest survival through the inexpensive optimization of an existing defibrillation program: OPALS Study phase II: Ontario Prehospital Advanced Life Support. JAMA 1999;281:1175–81. https://doi.org/10.1001/jama.281.13.1175.
190. Berdowski J, Blom MT, Bardai A, Tan HL, Tijssen JG, Koster RW. Impact of onsite or dispatched automated external defibrillator use on survival after out-of-hospital cardiac arrest. Circulation 2011;124:2225–32. https://doi.org/10.1161/CIRCULATIONAHA.110.015545.
191. Nordberg P, Hollenberg J, Rosenqvist M, et al. The implementation of a dual dispatch system in out-of-hospital cardiac arrest is associated with improved short and long term survival. Eur Heart J Acute Cardiovasc Care 2014;3:293–303. https://doi.org/10.1177/2048872614532415.
192. Hasselqvist-Ax I, Nordberg P, Herlitz J, et al. Dispatch of firefighters and police officers in out-of-hospital cardiac arrest: a nationwide prospective cohort trial using propensity score analysis. J Am Heart Assoc 2017;6:e005873. https://doi.org/10.1161/JAHA.117.005873.
193. van Alem AP, Vrenken RH, de Vos R, Tijssen JG, Koster RW. Use of automated external defibrillator by first responders in out of hospital cardiac arrest: prospective controlled trial. BMJ 2003;327:1312. https://doi.org/10.1136/bmj.327.7427.1312.
194. Groh WJ, Newman MM, Beal PE, Fineberg NS, Zipes DP. Limited response to cardiac arrest by police equipped with automated external defibrillators: lack of survival benefit in suburban and rural Indiana: the Police as Responder Automated Defibrillation Evaluation (PARADE). Acad Emerg Med 2001;8:324–30. https://doi.org/10.1111/j.1553- 2712.2001.tb02109.x.
195. Hansen SM, Brøndum S, Thomas G, et al. Home care providers to the rescue: a novel first-responder programme. PLoS One 2015;10:e0141352. https://doi.org/10.1371/journal.pone.0141352.
196. Roberts S, Birgisson N, Julia Chang D, Koopman C. A pilot study on mobile phones as a means to access maternal health education in eastern rural Uganda. J Telemed Telecare 2015;21:14–7. https://doi.org/10.1177/1357633X14545433.
197. Scottish Government. Out-of-hospital cardiac arrest: a strategy for Scotland: review 2015/16 Edinburgh, Scotland, 2015. (Accessed August 5, 2019, at https://www.gov.scot/binaries/content/documents/govscot/publications/progress-report/2016/11/out-hospital-cardiac-arrest-strategy-scotland-review-2015-16/documents/00510496-pdf/00510496-pdf/govscot%3Adocument/00510496.pdf).
198. Arif M, Samani H. AMBUBOT: ambulance robot automated external defibrillator robotic ambulance, 2014. (Accessed August 5, 2019, at https://ieeexplore.ieee.org/document/6778922).
199. Claesson A, Fredman D, Svensson L, et al. Unmanned aerial vehicles (drones) in out-of-hospital-cardiac-arrest. Scand J Trauma Resusc Emerg Med 2016;24:124. https://doi.org/10.1186/s13049-016-0313-5.
200. Claesson A, Bäckman A, Ringh M, et al. Time to delivery of an automated external defibrillator using a drone for simulated out-of-hospital cardiac arrests vs emergency medical services. JAMA 2017;317:2332–4. https://doi.org/10.1001/jama.2017.3957.
201. Pulver A, Wei R, Mann C. Locating AED enabled medical drones to enhance cardiac arrest response times. Prehosp Emerg Care 2016;20:378–89. https://doi.org/10.3109/10903127.2015.1115932.
202. Boutilier JJ, Brooks SC, Janmohamed A, et al. Optimizing a drone network to deliver automated external defibrillators. Circulation 2017;135:2454–65. https://doi.org/10.1161/CIRCULATIONAHA.116.026318.
203. Sanfridsson J, Sparrevik J, Hollenberg J, et al. Drone delivery of an automated external defibrillator: a mixed method simulation study of bystander experience. Scand J Trauma Resusc Emerg Med 2019;27:40. https://doi.org/10.1186/s13049-019-0622-6.
204. Herlitz J, Eek M, Holmberg M, Engdahl J, Holmberg S. Characteristics and outcome among patients having out of hospital cardiac arrest at home compared with elsewhere. Heart 2002;88:579–82. https://doi.org/10.1136/heart.88.6.579.
205. Iwami S, Takeuchi Y, Liu X. Avian-human influenza epidemic model. Math Biosci 2007;207:1–25. https://doi.org/10.1016/j.mbs.2006.08.001.
206. Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. JAMA 2008;300:1423–31. https://doi.org/10.1001/jama.300.12.1423.
207. McNally B, Robb R, Mehta M, et al. Out-of-hospital cardiac arrest surveillance: Cardiac Arrest Registry to Enhance Survival (CARES), United States, October 1, 2005–December 31, 2010. MMWR Surveill Summ 2011;60:1–19.

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208. Ong ME, Shin SD, De Souza NN, et al. Outcomes for out-of-hospital cardiac arrests across 7 countries in Asia: the Pan Asian Resuscitation Outcomes Study (PAROS). Resuscitation 2015;96:100–8. https://doi.org/10.1016/j.resuscitation.2015.07.026.
209. Gräsner JT, Lefering R, Koster RW, et al. EuReCa ONE-27 Nations, ONE Europe, ONE Registry: a prospective one month analysis of out-of-hospital cardiac arrest outcomes in 27 countries in Europe. Resuscitation 2016;105:188–95. https://doi.org/10.1016/j.resuscitation.2016.06.004.
210. Beck B, Bray J, Cameron P, et al. Regional variation in the characteristics, incidence and outcomes of out-of-hospital cardiac arrest in Australia and New Zealand: results from the Aus-ROC Epistry. Resuscitation 2018;126:49–57. https://doi.org/10.1016/j.resuscitation.2018.02.029.
211. Kiyohara K, Nishiyama C, Matsuyama T, et al. Out-of-hospital cardiac arrest at home in Japan. Am J Cardiol 2019;123:1060–8. https://doi.org/10.1016/j.amjcard.2018.12.038.
212. Bardy GH, Lee KL, Mark DB, et al. Home use of automated external defibrillators for sudden cardiac arrest. N Engl J Med 2008;358:1793–804. https://doi.org/10.1056/NEJMoa0801651.
213. Hasselqvist-Ax I, Riva G, Herlitz J, et al. Early cardiopulmonary resuscitation in out-of-hospital cardiac arrest. N Engl J Med 2015;372:2307–15. https://doi.org/10.1056/NEJMoa1405796.

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