ILCOR Scientific 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

Steven C. Brooks, MD, MHSc (Co-Chair); Gareth R. Clegg, PhD, MRCP (Co-Chair); Janet Bray, RN, PhD, FAHA; Charles D. Deakin, MD; Gavin D. Perkins, MD; Mattias Ringh, MD, PhD; Christopher M. Smith, MD, MSc; Mark S. Link, MD, FAHA; Raina M. Merchant, MD, MSHP; Jaime Pezo-Morales, MD; Michael Parr, MBBS; Laurie J. Morrison, MD, MSc; Tzong-Luen Wang, MD, PhD, JM; Rudolph Koster, MD, PhD; Marcus E.H. Ong, MBBS, MPH; on behalf of the International Liaison Committee on Resuscitation

Corresponding Author Contact Information:

Steven C. Brooks, MD, MHSc

Queen's University

Department of Emergency Medicine

Kingston General Hospital, Victory 3

76 Stuart Street

Kingston, K7L 2V7 CANADA

Phone: 6134497087

First Alternate Telephone: 011 44 7415 812 796

Fax: 6135481374

Email: steven.brooks@kingstonhsc.ca

<h1>**Abstract**

Out-of-hospital cardiac arrest (OHCA) is a global public health issue with ≈3.8 million victims annually and only 8% to 12% surviving to hospital discharge. It is the quintessential medical emergency. Victims require immediate basic life support to optimize the probability of survival. Early defibrillation of shockable rhythms is associated with improved survival, but one of the greatest challenges in OHCA management has been providing victims with access to immediate defibrillation. Even in optimized emergency medical systems, the median response time for OHCA can be more than 6 minutes. To reduce this delay, public access defibrillation programs involving the strategic deployment of automated external defibrillators (AEDs) in the community have been developed over the past 3 decades. Individuals with little to no training can operate AEDs to support chest compressions and treat shockable cardiac arrest rhythms. Public access defibrillator programs have been associated with improved outcomes for OHCA; however, the devices are used in fewer than 3% of OHCA episodes. If the International Liaison Committee on Resuscitation vision of "saving more lives through resuscitation" is to be realized, more patients must receive the benefit of early defibrillation. This scientific statement was commissioned by the International Liaison Committee on Resuscitation with 3 objectives: (1) Identify known barriers to public access defibrillator use, (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. We identified innovative strategies related to enhanced public outreach, behavior change approaches, optimization of static public access defibrillator deployment and housing, evolved AED technology and functionality, improved integration of public access defibrillation with existing emergency dispatch protocols, and exploration of novel AED delivery vectors. We provide

evidence- and consensus-based policy suggestions to enhance public access defibrillation and guidance for future research in this area. Continued evolution of public access defibrillation implementation to support high-quality chest compressions and improve early defibrillation will enhance cardiac safety in our communities and ultimately increase survival for victims of OHCA.

<h1>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 OHCA per 100,000 people per annum. Ten percent (range 6%–22%) of victims can expect to survive with favorable neurological outcome.[2] The probability of survival after OHCA can be markedly increased if victims receive immediate cardiopulmonary resuscitation (CPR) 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 defibrillation is delayed.[5-7] Median response time intervals for professional EMS responders after a call for help are often more than 6 minutes, even in developed urban settings with optimized EMS.[8] If the International Liaison Committee on Resuscitation (ILCOR) vision of "saving more lives through resuscitation"[9] is to be realized, more patients must receive the benefit of 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.

<h1>**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 their section's scope. 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 (Table 1) and critical knowledge gaps (Table 2) are highlighted in the text.

<h1>**Background**

<h2>***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 healthcare providers 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 victims of sudden cardiac arrest, the concept of public access defibrillation was born.

AEDs were first made available for public use in the 1980s[13-15] (Figure 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 victim's chest, in contrast to internal defibrillation facilitated by implantable cardioverter defibrillators. They are *defibrillators* in that they pass an electrical 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 victim. 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 this data for later review. Many AEDs facilitate download of resuscitation data, including the electrocardiogram (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 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] ECG data from the AED may document the earliest rhythm and contribute to the diagnosis of etiology and suggest treatments (eg, implantable cardioverter defibrillator).[28]

Most contemporary AED algorithms involve pausing chest compressions to facilitate an undistorted ECG 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]

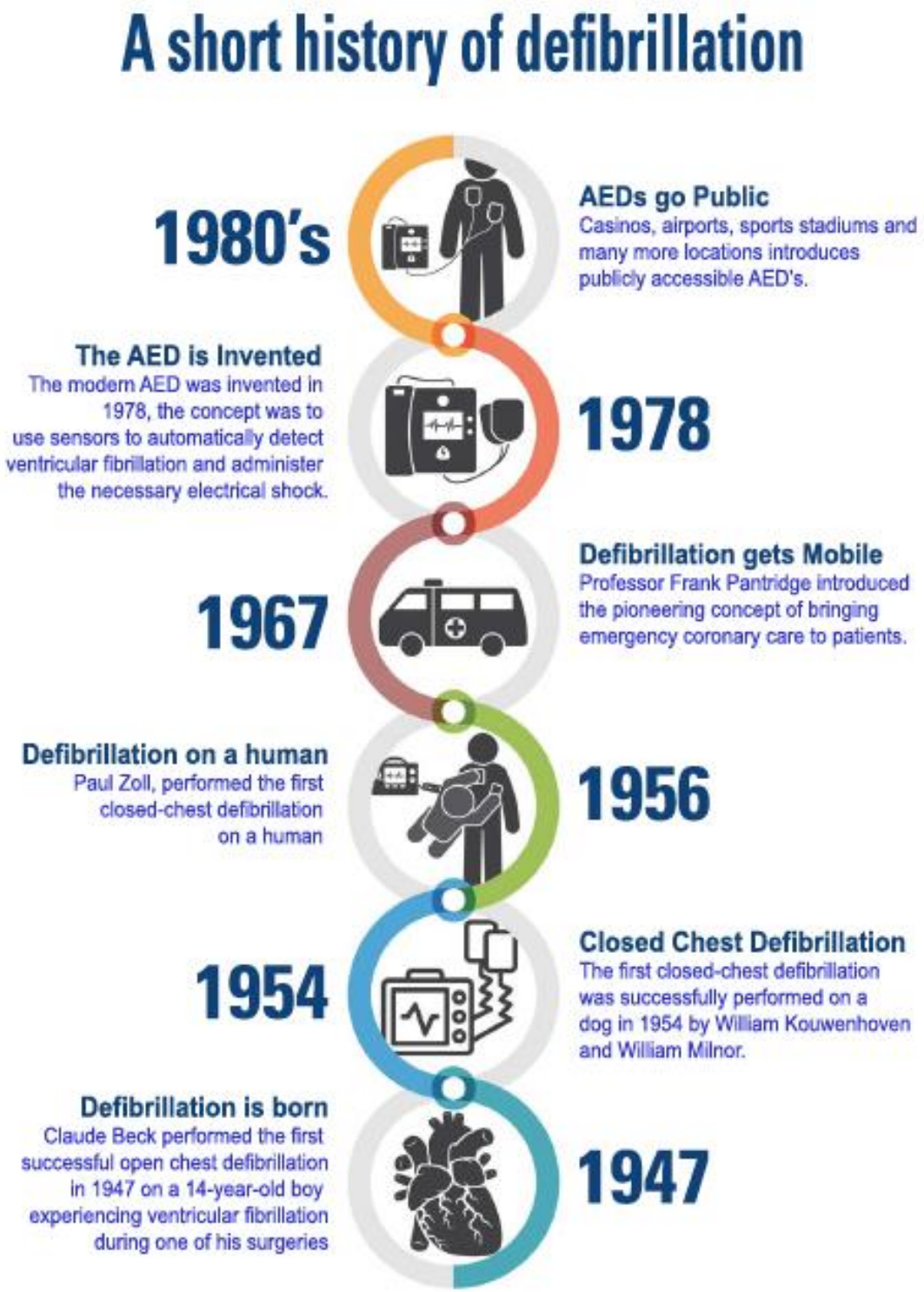


Figure 1. A short history of defibrillation. AED indicates automated external defibrillator.

<h2>***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] casinos[36]) 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 documenting these programs reported relatively high survival rates for victims of OHCA who were 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.

<h3>*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] There has been only one randomized controlled trial (RCT) evaluating the impact of a public access AED program involving laypeople. The Public Access Defibrillation (PAD) Trial, published by Hallstrom et al[43] in 2004, was a cluster RCT involving 993 community units (eg, shopping malls, recreation centers, hotels, apartment complexes) in the United States (US) 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]

In a systematic review, Holmberg and colleagues identified 44 observational studies comparing bystander AED use with no bystander AED use in regard to clinical outcomes for patients with OHCA.[44] 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 odds ratio [OR]: 1.73 [95% CI, 1.36, 2.18], shockable rhythms OR: 1.66 [95% CI, 1.54, 1.79]), and favorable neurological outcome (all rhythms OR: 2.12 [95% CI, 1.36, 3.29], shockable rhythms OR: 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 (in US dollars [USD] 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 $30 000 to $50 000 USD 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 $53 797 USD per quality-adjusted life year for public access AED programs was calculated, consistent with other cost-effective healthcare 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.

<h3>*Underuse of Public Access AEDs*

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

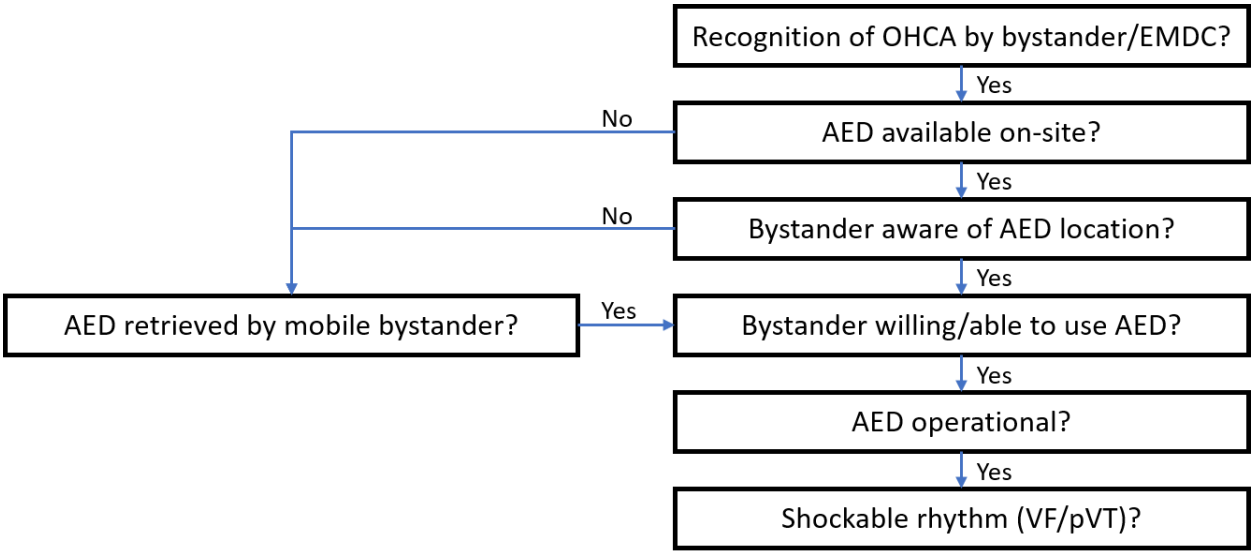
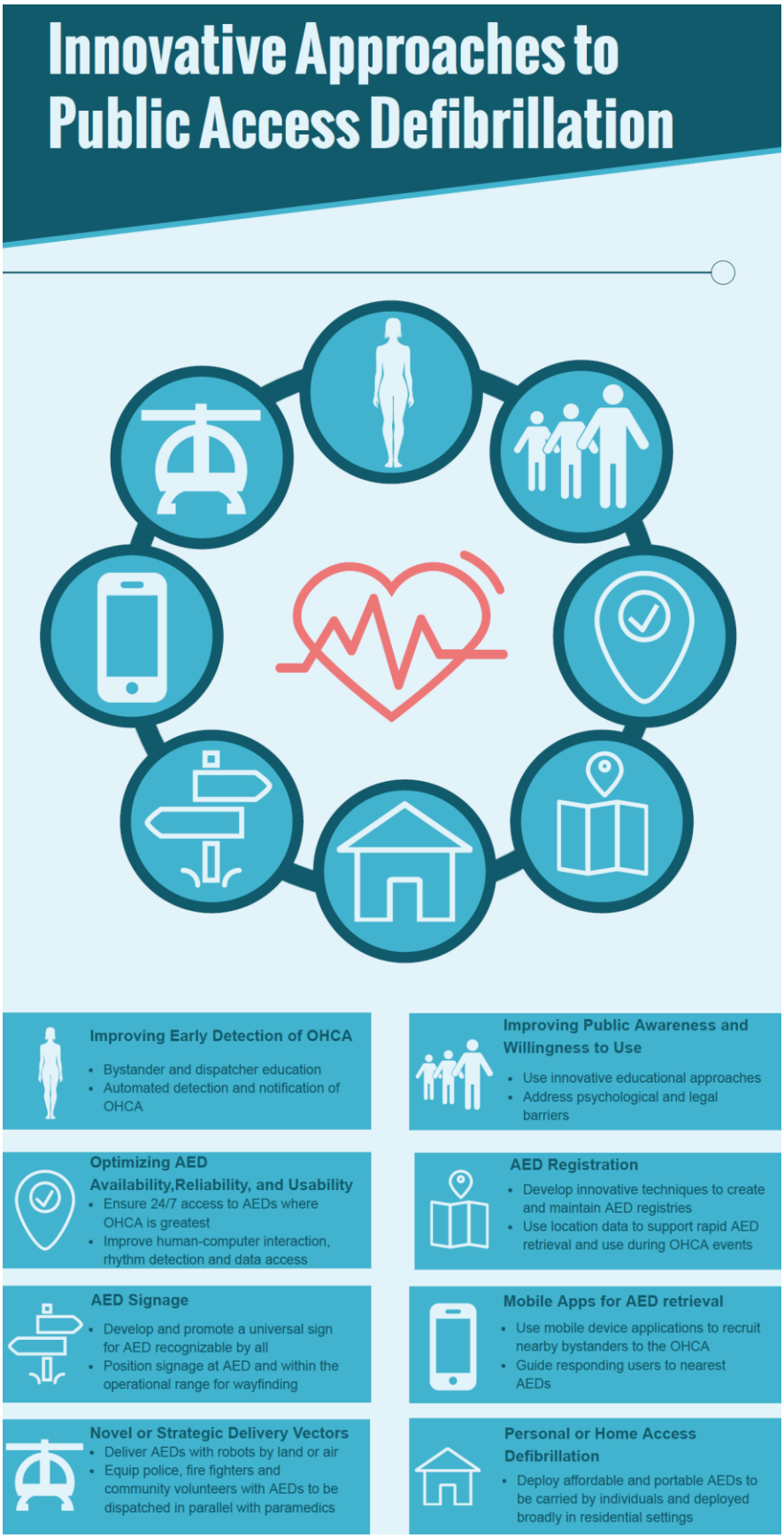


Figure 2. Flowchart for use of AEDs: Chain of Public Access Defibrillation. The challenges and possibilities of public access defibrillation, Ringh M, et al. Copyright © 2018 *Journal of Internal Medicine*. Reproduced with permission of Blackwell Publishing Ltd..[52] AED indicates automated external defibrillator; EMDC, emergency medical dispatch center; OHCA, out-of-hospital cardiac arrest; pVT, pulseless ventricular tachycardia; and VF, ventricular fibrillation.

<h1>**Innovative Approaches to Public Access Defibrillation**

In the 4 decades since public access defibrillation was first conceived, many lives have been saved as a result. 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 victims of 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 (Figure 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.


Innovative Approaches to Public Access Defibrillation
Improving Early Detection of OHCA
• Bystander and dispatcher education
• Automated detection and notification of OHCA
Improving Public Awareness and Willingness to Use
• Use innovative educational approaches
• Address psychological and legal barriers
Optimizing AED Availability,Reliability, and Usability
• Ensure 24/7 access to AEDs where OHCA is greatest
• Improve human-computer interaction, rhythm detection and data access
AED Registration
• Develop innovative techniques to create and maintain AED registries
• Use location data to support rapid AED retrieval and use during OHCA events
AED Signage
• Develop and promote a universal sign for AED recognizable by all
• Position signage at AED and within the operational range for wayfinding
Mobile Apps for AED retrieval
• Use mobile device applications to recruit nearby bystanders to the OHCA
• Guide responding users to nearest AEDs
Novel or Strategic Delivery Vectors
• Deliver AEDs with robots by land or air
• Equip police, fire fighters and community volunteers with AEDs to be dispatched in parallel with paramedics
Personal or Home Access Defibrillation
• Deploy affordable and portable AEDs to be carried by individuals and deployed broadly in residential settings

1

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

<h2>*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 a cardiac emergency is occurring (eg, heart rate of 0 or >250/minute, acceleration-deceleration event [a 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 suffer sudden cardiac arrest tend to display stereotypical behaviors.[53] Authors reviewed videos posted to online media-sharing platforms and observed that OHCA victims 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 demonstrate 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 suffer 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/or detection of cardiac arrest when it occurs to facilitate automatic triggering of an emergency response and early defibrillation.

<h2>*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 is poor, ranging from 19% to 43%.[56-59] The majority of respondents in these studies did not know that AEDs were intended for use by laypeople. In a nationally representative survey from the United Kingdom (UK), 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 a preference to wait for experienced help to arrive rather than initiate resuscitation themselves.[61] Only 2% of survey respondents in a study from Southampton in the United Kingdom 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 more than 5 times as likely to use an AED compared with 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]

<h3>*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, however, suggests 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 its 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.

<h3>*Creating a "Culture of Action" Through Innovative Methods of Public Messaging*

The Institute of Medicine in the United States published a comprehensive report called *Strategies to Improve Cardiac Arrest Survival: A Time to Act.*[78] In this report, they identify 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.

<h3>*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, more than 675 000 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; a social media awareness campaign; and others.[81] The importance of AED use in conjunction with CPR should be emphasized in future iterations of this event.

<h3>*Engaging and Empowering Children*

Although children are not the most likely demographic group to find themselves in the position of 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-age 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 to promote resuscitation training worldwide. The initiative recommends educating children beginning at the age of 12 years or earlier for at least 2 hours per year.[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 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.

<h3>*Addressing Psychological Barriers and Injury*

The *bystander effect*—in which a person is less likely to offer help to a victim 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 or the collapsed victim, 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 when the victim 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% “bearable” impact, and 13% “severe” impact.[101] None

experienced symptoms related to post-traumatic stress disorder 4 to 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 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 post-traumatic 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.

<h3>*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]

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 healthcare professionals outside a healthcare 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 is not known. More importantly, their effect on public access AED use is not known.

Knowledge Gap

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

<h2>***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 fashion, and AED accessibility.

<h3>*The Importance of AED Proximity to OHCA*

OHCA victims 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.[130, 131] Unfortunately, AEDs are rarely close enough for timely retrieval.[130, 132] Data from various urban areas have estimated that only 3% to 25% of OHCAs occur within 100 m of an AED.[132-137] 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.[138] 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.[136, 138] 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.[131] Fredman et al 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.[130]

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, 132, 139] Although low–socioeconomic status communities are associated with a higher incidence of OHCA,[140, 141] they are also associated with lower AED availability,[142, 143] bystander CPR,[144-147] and survival.[148]

<h3>*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[149] and also to identify rural locations where a particular need exists.[150] Several investigations have determined risk or comparative risk for cardiac arrest by location or building so that AED deployment can be prioritized to those locations.[64, 132, 151-154] Operations research techniques such as optimization modeling have been used effectively to determine optimal sites for AED placement.[132] 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, to identify “optimal” (as defined by constraints in the model) locations for new AEDs, and to test deployment strategies through simulation. Using optimization modeling, Sun and

colleagues 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.[155] Optimization modeling may also guide ideal positioning of AEDs within buildings. An analysis by Chan used optimization modeling to compare the placement of AEDs servicing high-rise buildings in the lobby versus in an elevator.[156] 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 based on cardiac arrest risk and site accessibility. We suggest that public access AED programs prioritize deployment of new defibrillators in locations deemed to be at the highest risk for victims of cardiac arrest and underserved by available AEDs. Determination of cardiac arrest risk should be assessed with local cardiac arrest data, if available.

<h3>*Improving Detection of Shockable Rhythms*

While 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.[122] 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%).[116] Not all devices included in this analysis achieved >98% sensitivity, however, and data from some defibrillators in the study came from fewer than 5 shocks with the device. It should also be noted that data in this study were derived from a limited number of device models, and 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.[123-125] More sophisticated filtering techniques are becoming available. Some have published data from simulation studies[126] and real OHCA cases.[127] Machine learning and neural networks may also improve diagnostic accuracy and could be used to optimize future AEDs.[128]

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.

<h3> *Improving Data Transfer from AEDs to Hospital-Based Care Providers*

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.[129] 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 mean 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 healthcare providers. Due to the critical importance of this data in the clinical care of survivors, we suggest that this feature be mandated by regulatory bodies.

<h3>*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 one 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.[116] Simulation studies suggest that fully automated AEDs (where shock is delivered without the need for the operator to press a button) increase operator safety[117] and compliance with AED instructions, reducing the time to successful defibrillation.[118] In simulation studies, untrained bystanders were often able to successfully deliver a shock,[119] 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.[120, 121]

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.

<h3>*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, 134, 158] AED coverage decreases by 53% to 60% during the evening, nighttime, and weekends,[134, 137, 138] 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, and 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. A variety of 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 anti-theft 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 (GPS) 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 percent 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 anti-theft 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 numerical passcode before being granted access. The prospective AED user must either 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.

<h2>*AED Registration*

OHCAs clustered at high-incidence sites constitute only a small percentage of all OHCAs.[64, 162] True on-site defibrillation is therefore a relatively rare occasion,[4] such that it is usually necessary to transport the AED to the scene of the arrest.[131, 138] 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 healthcare 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.[130] 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 $10 000 USD 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 such as GoodSAM (UK)[166] and PulsePoint AED (US)[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 one 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 are current and accessible to emergency dispatchers and available AED-locating systems such as mobile device applications.

<h2>***AED Signage***

AED signage has been proposed as one method to increase general awareness, but several surveys have demonstrated that most people do not understand the meaning of many signs in current use.[59, 169-171] Poor placement and suboptimal visibility of signs, even in high-footfall areas, is another documented limitation with current deployment. 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] In the United Kingdom, new signage developed with public consultation was found to better indicate the function of AEDs and encourage use,[171] but it is unknown whether improved signage translates into increased use of AEDs.

It is also not known which type of signage strategy is optimal. This includes the appearance of the individual signs and the configuration of the signs in the environment around an AED. ILCOR has recommended and disseminated internationally a universal public access AED sign.[170] Recent research has identified the possibility that the electrical shock icon used on the ILCOR sign and many others may inadvertently communicate potential electrical hazard and discourage use.[171]

Knowledge Gap

Future research should identify signage characteristics that maximize the probability of AED identification, retrieval, and successful use.

Policy Suggestion

We suggest that resuscitation councils and communities around the world collaborate to adopt a universal public access AED sign. We suggest that the design be evidence based to support a high degree of recognition among all people and facilitate successful AED use.

Policy Suggestion

We suggest the following:

- Signage 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—where 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).

<h2>*Mobile Applications for AED Retrieval*

GPS-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 applications are passive, with AED locations simply overlaid on digital mapping software like Google Maps. These applications 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 applications may have a limited impact on improving AED retrieval. In one

simulation study from Quebec, researchers found that a passive AED mapping application 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 application 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 healthcare 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 application users (facilitated by the location services of their mobile devices and communication with the application server). Some systems can differentiate between users of different status (eg, layperson, off-duty professional). Once mobile app users are identified within the system's activation radius, the application server sends a notification to those devices. Many applications 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 application.[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 an RCT 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 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 victim. Data on these potential risks are lacking.

In addition, there are technical challenges related to integrating these applications 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 under way in Scandinavia (NCT02992873), France

(NCT03633370), Canada, and the United States (The PulsePoint RCT, not yet registered) will provide more data on the effectiveness of mobile apps to increase early defibrillation for victims of OHCA.

Knowledge Gap

Further scientific evaluation of mobile device applications 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 applications to crowdsource CPR and early defibrillation is reasonable where resources are available.

<h2> Novel or Strategic Delivery Vectors for AEDs

<h3>*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 of victims of OHCA,[183, 184] most cases are not associated with AED retrieval.[4, 55, 185-187] Real-time visualization of AED location 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.[135, 136] 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.

<h3>*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 healthcare professionals who do not routinely practice in the prehospital setting (eg, home care nurses,[195] off-duty nurses, physicians[181]).

Policy Suggestion

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

<h3>*Community Volunteer Responder Programs*

Community volunteer responder programs, involving a mixture of layperson volunteers and off-duty healthcare provider 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, 198] 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 for victims of OHCA.

<h3>*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 application.

Although some work has been done with land-based robots in this context,[199] 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.[200-202] 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.[201] In a region-specific analysis using historical cardiac arrest data from several urban and rural regions around Toronto, 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.[203]

Although this strategy could improve access to early defibrillation for victims of OHCA, 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 and 34 seconds (range 75–110 seconds).[204] 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.

<h2>*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 laypersons. 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 one 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 OHCA occur in residential settings (60%–80%)[4, 205-211]; however, access to early defibrillation in this setting is almost nonexistent.[212] AED deployment in the home has been studied in the past with results that dissuaded further research and broad implementation of this strategy. The Home Automated External Defibrillator (HAT) Trial 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 ventricular fibrillation, 12 received a shock, and 4 survived long term. There was no impact of the intervention on the primary outcome of death from any cause among this group of post–myocardial infarction patients (6.5% versus 6.4%).[213]

The HAT Trial did not employ 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. The analysis, which focused on a population in which >90% did not suffer cardiac arrest, however, may have missed an important benefit for patients who suffer 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 OHCA patients in public settings, where conditions are generally more favorable for being witnessed and receiving early bystander intervention.[214] There were also several occurrences of study AEDs being used for neighbors suffering cardiac arrest, and these instances were not included in the evaluation of effectiveness. The positive influence 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 cardiac arrest patients 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 suffer cardiac 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.

<h1>Summary and Conclusion

Despite imperfect implementation, public access defibrillation has saved countless lives. AEDs remain underused, and many potentially salvageable victims of OHCA 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. 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 for victims of OHCA.

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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 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 are current and accessible to emergency dispatchers and available AED-locating systems such as mobile device applications.
AED Signage	We suggest that resuscitation councils and communities around the world collaborate to adopt a universal public access AED sign. We suggest that the design be evidence based to support a high degree of recognition among all people and facilitate successful AED use. We suggest the following: ● Signage 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—where 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 Applications for AED Retrieval	We suggest that the implementation of mobile device applications 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 healthcare providers be considered vectors for mobile AED deployment to enhance early defibrillation in communities.

AED automated external defibrillator; CPR, cardiopulmonary resuscitation; and OHCA, out-of-hospital cardiac arrest.

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/or 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 and actual use of AEDs during OHCA.
Optimizing AED Availability, Reliability and Usability	We suggest that future research determine the effect of legislation on willingness and actual use of AEDs during OHCA. 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 that maximize the probability of AED identification, retrieval, and successful use.
Mobile Applications for AED Retrieval	Further scientific evaluation of mobile device applications 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 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 for victims of 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; CPR, cardiopulmonary resuscitation; OHCA, out-of-hospital cardiac arrest; pVT, pulseless ventricular tachycardia; and VF, ventricular fibrillation.

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