REVIEW ARTICLE

John A. Jarcho, M.D., *Editor*

Lay Responder Care for an Adult with Out-of-Hospital Cardiac Arrest

William J. Brady, M.D., Amal Mattu, M.D., and Corey M. Slovis, M.D.

From the Department of Emergency Medicine, University of Virginia Health System, Albemarle County Fire Rescue, Charlottesville (W.J.B.); the Department of Emergency Medicine, University of Maryland School of Medicine, Baltimore (A.M.); and the Department of Emergency Medicine, Vanderbilt University Medical Center, the Metro Nashville Fire Department, and the Nashville International Airport Department of Public Safety — all in Nashville (C.M.S.). Address reprint requests to Dr. Brady at the Department of Emergency Medicine, University of Virginia Health System, P.O. Box 800699, Charlottesville, VA 22908, or at wjbrady@virginia.edu.

N Engl J Med 2019;381:2242-51.
DOI: 10.1056/NEJMra1802529

Out-of-hospital cardiac arrest is a major public health issue.[1-5] In the United States, an estimated 155,000 persons per year are treated by emergency medical services (EMS) for out-of-hospital cardiac arrest, and approximately 8% survive.[6] In Europe, annual occurrence is estimated to be 128,000 to 275,000 persons, and approximately 10% survive.[3,7,8] Substantial variations exist, both within countries and across the globe, with respect to data collection and reporting methods and with respect to survival and neurologic outcome.[3-11]

A key concept in the successful treatment of patients with out-of-hospital cardiac arrest is the strategy known as the "chain of survival," which emphasizes a system-of-care approach that includes early access to care and consists of five key links: early recognition of cardiac arrest and activation of the emergency-response system; immediate, high-quality cardiopulmonary resuscitation (CPR); rapid defibrillation; basic and advanced EMS; and advanced life support and postarrest care.[12] Research in cardiac arrest resuscitation has affirmed that the most important links in the chain of survival are the earliest ones — recognition of cardiac arrest and initiation of CPR, both of which are performed largely by lay bystanders.[13]

Lay rescuers therefore play a major role in the resuscitation of people with out-of-hospital cardiac arrest. Physicians have a role in helping to make the lay public aware of the importance of bystander contribution to favorable outcomes. In addition, although physicians are not directly involved in bystander response to cardiac arrest, they should know how to support these resuscitation efforts, encourage appropriate education for lay providers, and advocate for placement of automated external defibrillators (AEDs) for public access.

THE CONCEPT OF PREARRIVAL CARE

The first components of the chain of survival can be termed "prearrival care" (Fig. 1), defined here as basic medical interventions initiated by bystanders before trained medical providers arrive on the scene. These components include recognition of cardiac arrest and call for emergency assistance, initiation of CPR, and use of an AED. Prearrival care is associated with substantial improvements in survival and neurologic status.[14-17] Bystander-initiated CPR significantly increases the chance of survival; application of an AED also markedly increases the chance of survival.[15,16] The combination of bystander CPR and AED use has a synergistic positive effect on outcome.[17] The delivery of prearrival care — and its effect on a patient's neurologically intact survival — is time-sensitive (Fig. 2); for every minute that a person with out-of-hospital cardiac arrest goes without CPR and defibrillation, the chance of survival decreases by 7 to 10%.[19]

Unfortunately, bystander CPR is provided in less than 50% of cases[20]; AEDs are

used even less often, in no more than 25% of appropriate patients, even though they are frequently available in public places.[21,22] Data from the Cardiac Arrest Registry to Enhance Survival show considerable variation among 132 U.S. counties with respect to survival (ranging from 3.4 to 22%) and neurologic outcome (ranging from 0.8 to 21.0%); these variations in outcome are attributed partially to varying frequencies of bystander CPR performance and AED use.[11] Regional and national education and awareness efforts have resulted in increased bystander intervention and associated improvements in outcome,[16,23] but considerable work will be required to overcome the many remaining barriers.[24]

LAY RECOGNITION OF CARDIAC ARREST

One of the primary reasons for infrequent bystander intervention in out-of-hospital cardiac arrest is that lay rescuers may fail to recognize cardiac arrest. Cardiac arrest may be mistaken for syncope or seizure. Furthermore, persons with cardiac arrest may have continued gasping respirations for several minutes,[25] which can confuse lay rescuers and lead to delays in bystander care.[26] To overcome this confusion, the 2010 American Heart Association (AHA) Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care eliminated the "look, listen, and feel" approach for bystanders, which it had previously emphasized, and instead recommended immediate activation of the emergency-response system and initiation of chest compressions for any adult who is unresponsive and either is not breathing or is having gasping respirations.[27] To further simplify the initial assessment for the lay provider, the 2015 guidelines from the AHA,[28] the European Resuscitation Council (ERC),[29] and the International Liaison Committee on Resuscitation (ILCOR)[30] recommend that bystanders should suspect cardiac arrest and begin CPR whenever a person is unresponsive and not breathing normally.[28-30]

Educational efforts should be targeted at helping the lay public understand that persons with cardiac arrest can initially have seizurelike activity or abnormal respirations and that every effort should be made to minimize delays in initiating care. Abnormal breathing can involve either the absence of respirations or agonal respirations (slow and deep breaths, often with a gasping quality). If the lay rescuer does not realize that cardiac arrest is present, algorithms used by the emergency communications center dispatcher can aid in identification of the medical emergency; the appropriate response can then be initiated and telephone guidance provided.

INTERVENTIONS ASSISTED BY THE EMERGENCY COMMUNICATIONS CENTER DISPATCHER

Recognition of a medical emergency, including collapse with possible cardiac arrest, should be followed by prompt activation of the emergency-response system.[12] In many areas, the emergency-response system is activated by a call to an emergency communications center. The first responsibility of personnel at the emergency communications center is to dispatch appropriate EMS units to the scene of the medical emergency. Once EMS units have been activated, the dispatcher can then provide additional resources to assist the lay responder in providing appropriate prearrival care. Impediments to the implementation of dispatcher instructions by the lay responder include language barriers, emotional stress, and lack of awareness of the importance of prearrival care.

The dispatcher in the emergency communications center can begin by assisting the caller in determining whether cardiac arrest has occurred. In general, dispatchers are able to identify the presence of cardiac arrest in approximately 70% of cases,[31-33] and once they recognize the presence of cardiac arrest, they can provide instructions for resuscitation if the callers are willing to perform CPR. A dispatcher's verbal approach to the caller influences the likelihood that the bystander will perform CPR before the arrival of EMS. Specific phrases such as "We are going to do CPR" and "We need to do CPR" imply a sense of futurity and obligation and are more likely to result in the bystander performing CPR.[34] Dispatcher directions also increase rates of return of spontaneous circulation, survival, and favorable neurologic status among survivors of cardiac arrest.[35,36]

In addition to guiding CPR, the dispatcher may be able to direct the caller to the location of the closest registered AED. This strategy of identifying and deploying the closest AED has been

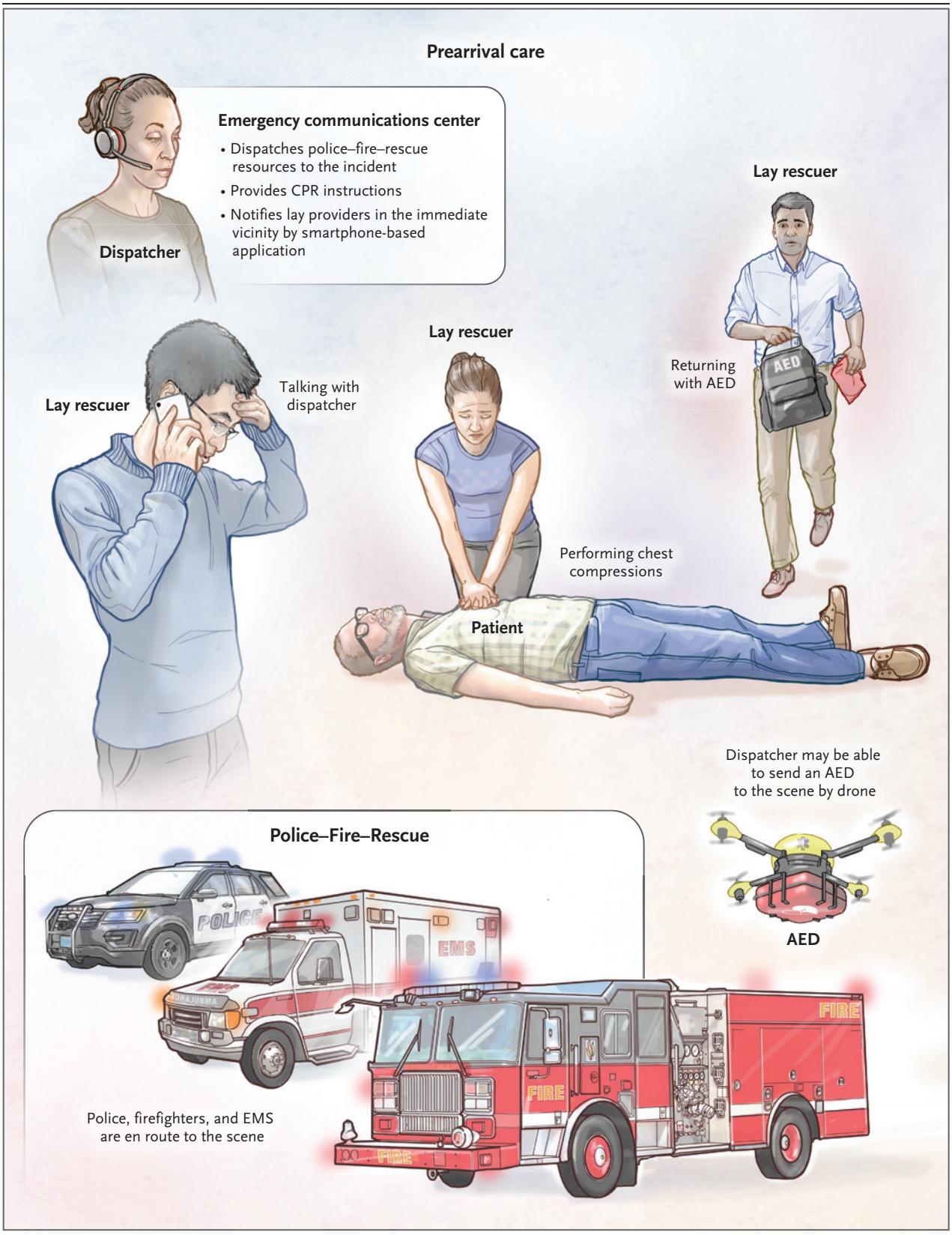

Figure 1 (facing page). Components of Prearrival Care.
A patient having an out-of-hospital cardiac arrest is attended to by a lay rescuer performing chest compressions while a second lay rescuer talks with a person at the emergency communications center who is dispatching police, fire, and rescue resources to the site and providing cardiopulmonary resuscitation (CPR) instructions. The emergency center dispatcher also uses a smartphone-based application to notify lay providers in the immediate vicinity that a person is in cardiac arrest. A third lay rescuer is returning to the patient with an automated external defibrillator (AED); the emergency center dispatcher has also sent an AED to the scene by drone while police, fire, and rescue units respond to the scene in emergency mode, with lights and sirens activated. EMS denotes emergency medical services.

quite successful in simulation studies[37] but has been found to be less effective in studies of real-world dispatch programs.[38,39] In one analysis, among cardiac arrests in which the dispatchers knew that publicly accessible AEDs were available and informed bystanders of their location (which was a minority of the total number of cardiac arrests), AEDs were successfully retrieved and used in only 14% of the cases.[39] One practical issue in whether an AED is used is that typically at least two rescuers must be present — one to perform CPR and another to retrieve the AED.

While instructions are being relayed by telephone, the dispatcher can alert others in the community about the cardiac arrest through text messaging and other smartphone-based applications. This approach notifies lay responders who have voluntarily agreed to join these digital response efforts of an occurrence of out-of-hospital cardiac arrest in their immediate vicinity, provides information about the arrest and location, and, in some cases, alerts them to the presence of adjacent public-access AEDs.[40] Although this is a new strategy, early investigations are promising; studies have shown increased frequency of early CPR and associated improved survival and functional status among survivors.[41,42] This strategy is formally supported by the AHA.[43]

Finally, the dispatcher may have the ability to send an AED to the scene by drone. This approach is still investigational, but early system modeling suggests that an AED can arrive at the scene considerably earlier by drone than by standard EMS vehicle, with the time to arrival at the scene of the cardiac arrest reduced by 6 minutes in urban settings and by 19 minutes in rural settings.[44-46]

CARDIOPULMONARY RESUSCITATION

CPR is a method of external chest compressions and artificial respirations that provides perfusion to vital organs during cardiac arrest until definitive treatment is available. There are two basic approaches to CPR: the conventional method, which is performed with both chest compressions and ventilations, and a newer method, termed compression-only CPR, which is performed with only chest compressions.

Some debate remains regarding the benefits of traditional CPR as compared with compression-only CPR.[28-30] Central oxygen saturation levels are likely to be normal at the moment of cardiac arrest; because several minutes may pass before oxygen saturations fall to critical levels, immediate initiation of ventilations may not be necessary. In addition, bystander mouth-to-mouth ventilations are often ineffective and unlikely to provide any meaningful oxygenation for the patient; they can produce excessive intrathoracic pressure with negative effect on perfusion. Furthermore, ventilations can detract from high-quality chest compressions and timely defibrillation. The benefits of lay rescuer ventilations early in cardiac arrest, particularly if the ventilations are delivered by untrained bystanders, are therefore questionable. Studies comparing patients who received conventional CPR with those who received compression-only CPR have shown no significant difference in survival.[47-49]

Compression-only CPR is associated with better acceptance and engagement by lay rescuers,[50] who may hesitate to provide conventional CPR because of fear of performing the procedure incorrectly, concern about victim regurgitation during mouth-to-mouth ventilations, or anxiety regarding disease transmission.[51,52] To overcome these barriers, in 2010 the AHA endorsed compression-only CPR for untrained lay rescuers; the 2015 AHA, ERC, and ILCOR guidelines continue to support this recommendation.[28-30] Nonetheless, the ability to perform CPR remains a concern for the public. In a recent survey[53] of participants in CPR training sessions in the United States, trainees were asked about their willingness to perform CPR on various persons having a cardiac arrest (male and female adolescents, a middle-aged woman, and

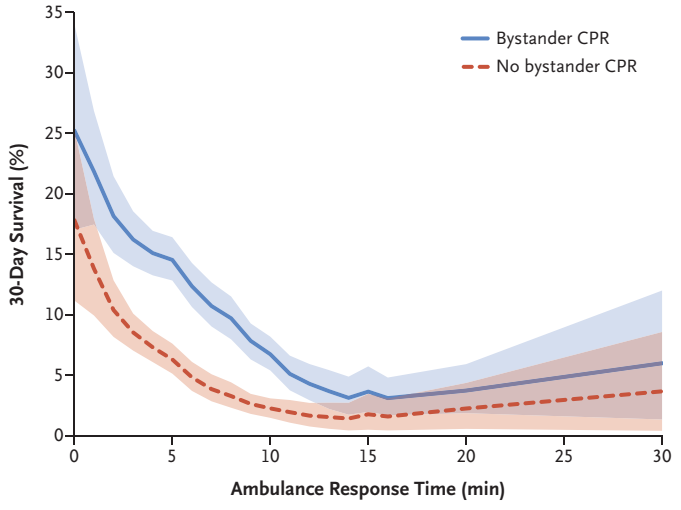

Figure 2. Survival of Patients with Out-of-hospital Cardiac Arrest Relative to Fire–Rescue Response Time and Lay versus EMS Intervention.

Shown is 30-day survival among patients who received bystander CPR and those who did not receive prearrival intervention, according to EMS response time. Shaded areas represent 95% confidence intervals. The 30-day survival was higher among patients who received bystander CPR than among those who did not. Reprinted, with permission, from Rajan et al.[18]

an elderly man) as well as their potential specific concerns about doing so. Less than 65% of participants said that they were moderately or extremely likely to perform CPR on the victims. The most commonly expressed concerns included the possibility of causing injury to the patient, a lack of appropriate CPR training, the need to unclothe a female patient's chest and expose her breasts, and the fear of sexual assault accusations.

Regardless of the method used, the importance of bystander CPR has been shown in numerous studies. In a 2010 report of 10,681 cases of out-of-hospital cardiac arrest, Rea et al. found that 22.1% of patients who received bystander CPR, as compared with 7.8% of patients who did not receive bystander care, survived.[54] A meta-analysis including 142,740 patients from 79 studies showed markedly higher survival among patients with out-of-hospital cardiac arrest who received bystander CPR than among those who did not (16.1% vs. 3.9%); in this same analysis, among persons receiving bystander CPR, the number needed to treat to save one life ranged from 24 to 36.[1] A 2019 study in Sweden that compared three time periods from 2000 to 2017 assessed the frequency of conventional and compression-only CPR and 30-day survival; the authors noted that performance of compression-only CPR before EMS arrival increased by 6 times, and the survival rate doubled, over the course of the study.[55]

Bystander CPR can prolong the time period within which successful resuscitation can occur and can thus allow for longer EMS response times.[14-16,18] One potential mechanism by which CPR extends the successful resuscitation time period is by prolonging the presence of the shockable cardiac arrest rhythms — ventricular fibrillation and pulseless ventricular tachycardia. A study of 2772 patients in the London Ambulance Service database showed that the percentage of shockable rhythm cases was 48% among patients with witnessed cardiac arrest who received bystander CPR, as compared with 27% among those who did not receive bystander CPR; a similar trend was noted in cases of unwitnessed cardiac arrest (31% vs. 18%).[56] Similar results were noted among 34,125 patients included in the Swedish Cardiac Arrest Register over a 14-year period; furthermore, fewer defibrillation attempts were needed to achieve return of spontaneous circulation in patients who had received bystander CPR.[57] The benefit of bystander CPR increased as the time to initial defibrillation increased.[58]

Feedback devices that support and encourage providers to perform high-quality chest compressions are in use by professional rescuers both in and outside the hospital setting. At this time, real-time feedback for the lay rescuer is limited to AED-delivered audible prompts that provide CPR instructions. Many AEDs also have audible alert sounds that provide a rhythm and cadence to assist the lay rescuer in performing an appropriate rate of chest compressions.

AUTOMATED EXTERNAL DEFIBRILLATORS

AEDs are portable devices that automatically analyze the cardiac rhythms of patients with cardiac arrest and deliver defibrillatory shocks if either ventricular fibrillation or ventricular tachycardia is detected. Rhythm diagnosis is not a component of lay bystander care; for the lay provider, the only distinction between shockable and nonshockable rhythm presentations is provided by an audible message from the AED stating "shock advised," which indicates that either ventricular

fibrillation or ventricular tachycardia has been detected by the device. Among persons with out-of-hospital cardiac arrest, shockable initial rhythms (noted in 7.7 to 32.0% of patients) occur significantly less often than nonshockable rhythms and are associated with a better prognosis than nonshockable rhythms.[59-63]

Operation of the AED by either trained or untrained rescuers is guided by audible prompts from the unit as well as graphical directions on the device. Although AED design differs slightly by manufacturer, the basic elements of operation are the same in the various devices. The user is instructed to turn the device on and to bare the patient's chest. The defibrillator pads must be opened and their protective backing removed; they are then positioned on the patient's chest according to the graphics shown on the AED. The AED then analyzes the patient's cardiac rhythm, and if a shockable rhythm is detected, the user is instructed to press a button that delivers the defibrillatory shock. AEDs can be deployed in public locations for use by lay providers as part of a public-access defibrillation program.

The potential lifesaving advantages of AEDs in public locations have been investigated extensively. In a recent systematic review of 41 studies of public-access defibrillation, the median percentage of patients who survived to hospital discharge was 53.0% when defibrillation was performed by lay first responders as compared with 28.6% when defibrillation was performed by EMS personnel (Fig. 3).[64] In 2018, the Resuscitation Outcomes Consortium investigators reported the results of a comparison of defibrillation with a bystander-applied AED and defibrillation by EMS in nearly 50,000 out-of-hospital cardiac arrests in nine U.S. regions.[65] The investigators reported that 66.5% of patients in whom defibrillation was performed by bystanders, as compared with 43.0% in whom defibrillation was performed by EMS, survived to hospital discharge; in addition, hospital discharge with a favorable neurologic outcome was more commonly seen among patients in whom defibrillation had been performed by bystanders than among those in whom defibrillation had been performed by EMS (57.1% vs. 32.7%). Among all observed out-of-hospital cardiac arrests, bystanders applied an AED in 15.9% of cases.[65] The benefit of bystander AED-delivered defibrillation increased as EMS response times became longer.[65] In 2019, Nehme et al. reported

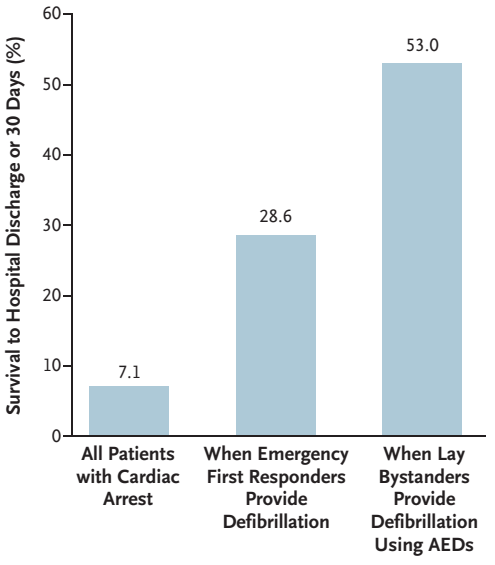

Figure 3. Survival after Cardiac Arrest, with Defibrillatory Shock Delivered by Bystander-Accessible AED or EMS Device.

Survival to discharge or to 30 days is significantly higher when an AED is available and used by lay providers for defibrillation in a person with cardiac arrest before EMS arrival than when defibrillation is delivered by EMS providers. Adapted from www.sca-aware.org/sca-news/bystander-use-of-aeds-could-double-the-number-of-survivors, with data from Baekgaard et al.[64] and Berdowski et al.[2]

the results of a study[66] of out-of-hospital cardiac arrest defibrillation performed by bystanders, first responders, and paramedics, and reported the resultant outcomes for an 18-year period (2000–2017). When comparing the initial (2000–2002) and final (2015–2017) 2-year segments of the study period, the authors noted an overall increase in the number of patients in whom defibrillation was performed by bystanders (from 2.0% to 11.2%) and first responders (from 3.8% to 8.2%). Over this same period, they reported a significant increase in survival to hospital discharge regardless of whether defibrillation was performed by bystanders, first responders, or paramedics ($P<0.001$ for all three groups); however, the increase was greater among patients in whom defibrillation was performed by bystanders (from 6.7% to 55.5%) than among patients in whom defibrillation was performed by first responders (from 10.5% to 37.8%) and paramedics (11.6% to 28.8%).

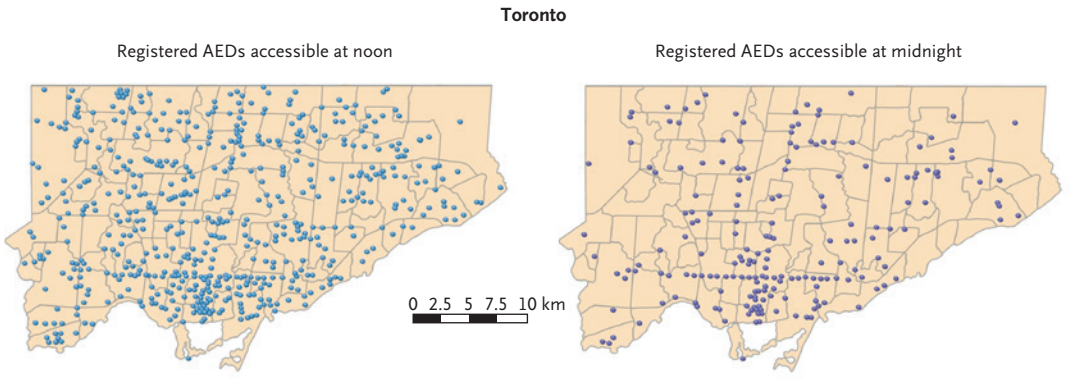

Figure 4. Public AED Accessibility in Toronto at Noon and Midnight.
Of a total of 737 registered AEDs in Toronto, 707 (95.9%) were available at noon and 228 (30.9%) were available at midnight. The AEDs included in these maps were available at least 5 days a week at their respective examined times. Reprinted, with permission, from Sun et al.[72]).

AEDs are especially useful when placed in public places where there is a reasonable probability of a witnessed cardiac arrest within a defined period of time.[67] The AHA and ERC recommend that AEDs are best placed in locations such as airports, rail terminals, casinos, and sports arenas[29,30] or in locations in which there is at least one cardiac arrest every 5 years.[29] AED placement in commercial aircraft is required by many nations, including the United States. Unfortunately, placement of AEDs in private homes has not been shown to be beneficial; in one study of more than 7000 high-risk patients (those who had previous anterior myocardial infarctions), placement of an AED in the home did not improve overall survival.[68] Estimates of the cost-effectiveness of public-access AEDs vary, ranging from approximately $40,000 to $80,000 per quality-adjusted life-year (QALY) gained when AEDs are placed in shopping malls or sports arenas to more than $1 million per QALY gained for AEDs placed in less densely populated areas.[69]

Although AEDs offer many benefits, there are challenges to their use by lay providers. Studies suggest that even in regions in which active efforts have been made to position public-access AEDs widely, less than 10% of out-of-hospital cardiac arrests occur within 100 m of an AED.[38,70] Furthermore, many AEDs that are installed in the community are located inside buildings such as schools, business offices, and sports facilities that are not accessible to the public during evenings, at night, or on weekends[71,72] (Fig. 4). In addition, when the ability of untrained laypersons to operate AEDs was evaluated, substantial variation in ability was observed.[73] Both graphical and audible directions for defibrillator pad placement are important.[74] Finally, although AED use is potentially lifesaving, operating an AED may cause the bystander to be distracted from performing CPR.[75]

LAY PROVIDER EDUCATION

To provide effective bystander care, a layperson must be able to recognize the presence of cardiac arrest, call for help, begin CPR, and use an AED (if one is readily available).[12] Unfortunately, the ability of lay bystanders to recognize cardiac arrest and perform CPR is not uniform across communities, which has resulted in variable application of bystander CPR. It is estimated that only approximately 2.4% of the U.S. population undergoes CPR training each year. Areas with low rates of CPR training correspond to regions of the U.S. in which the outcome of cardiac arrest is less favorable.[76]

Training should include provision of information as well as deliberate practice, with a focus on repetition with feedback, until mastery is obtained.[77] Traditional CPR classroom courses normally take 3 to 4 hours and require an on-scene instructor. To maximize the number of laypersons trained in CPR, many innovative teaching methods are being studied or are already in use,

including installation of CPR kiosks in public locations (Fig. 5), mass training of hundreds or thousands of people in stadiums, instructional role-playing games, and use of virtual reality programs.[12,78,79] Courses that use videos ranging in length from 60 seconds to 8 minutes may be effective in training people to perform compression-only CPR.[80] A 4-minute kiosk-based training session, including video instruction and practice sessions with feedback, appears to be more effective than video instruction alone.[81]

Many national and international organizations have called for universal CPR training. The World Health Organization has endorsed the "Kids Save Lives" training initiative, which recommends that school-age children receive 2 hours of CPR training annually.[78] The AHA has a stated goal of training 20 million people per year in CPR by 2020,[80] and ILCOR has launched the "All Citizens of the World Can Save a Life" program to increase CPR training and performance.[82]

Figure 5. Chest Compression Training Kiosk at Baltimore–Washington International Airport.

CPR training kiosks are currently deployed in many high-traffic public locations to train people such as air travelers awaiting a flight or audience members attending a public event.

CONCLUSIONS

The report "Strategies to Improve Cardiac Arrest Survival: A Time to Act" of the Institute of Medicine (IOM, now the National Academy of Medicine) recommends that physicians ". . . foster a culture of action through public awareness and training" in cardiac arrest management.[51] Physicians should support this approach by encouraging the public to participate in prearrival care, endorsing appropriate lay provider education, and advocating for placement of public-access AEDs. Physicians should also make the public aware of the substantial effect bystander care has on survival.

The IOM report also refers to "The Power of Multiple Initiatives" — the benefit of approaching this major public health issue from multiple strategic directions simultaneously with education, training, and resource implementation.[51] The multiple-initiatives approach emphasizes cardiac arrest recognition, call for assistance, CPR performance, and AED application.[51] If these prearrival measures are initiated early in out-of-hospital cardiac arrest, they have the potential to significantly increase the likelihood of meaningful survival.

Dr. Brady reports receiving grant support from Siemens Medical Solutions. No other potential conflict of interest relevant to this article was reported.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

REFERENCES

1. Sasson C, Rogers MAM, Dahl J, Kellermann AL. Predictors of survival from out-of-hospital cardiac arrest: a systematic review and meta-analysis. Circ Cardiovasc Qual Outcomes 2010;3:63-81.
2. Berdowski J, Berg RA, Tijssen JGP, Koster RW. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. Resuscitation 2010;81:1479-87.
3. 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.
4. 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.
5. Ong MEH, Shin SD, De Souza NNA, 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.
6. Rea TD, Eisenberg MS, Sinibaldi G, White RD. Incidence of EMS-treated out-of-hospital cardiac arrest in the United States. Resuscitation 2004;63:17-24.
7. Atwood C, Eisenberg MS, Herlitz J, Rea TD. Incidence of EMS-treated out-of-

hospital cardiac arrest in Europe. Resuscitation 2005;67:75-80.
8. Hawkes C, Booth S, Ji C, et al. Epidemiology and outcomes from out-of-hospital cardiac arrests in England. Resuscitation 2017;110:133-40.
9. Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. JAMA 2008;300:1423-31.
10. Zive D, Koprowicz K, Schmidt T, et al. Variation in out-of-hospital cardiac arrest resuscitation and transport practices in the Resuscitation Outcomes Consortium: ROC Epistry-Cardiac Arrest. Resuscitation 2011;82:277-84.
11. Girotra S, van Diepen S, Nallamothu BK, et al. Regional variation in out-of-hospital cardiac arrest survival in the United States. Circulation 2016;133:2159-68.
12. Kronick SL, Kurz MC, Lin S, et al. Systems of care and continuous quality improvement: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2015; 132:Suppl 2:S397-S413.
13. Deakin CD. The chain of survival: not all links are equal. Resuscitation 2018; 126:80-2.
14. Kragholm K, Wissenberg M, Mortensen RN, et al. Bystander efforts and 1-year outcomes in out-of-hospital cardiac arrest. N Engl J Med 2017;376: 1737-47.
15. Nakahara S, Tomio J, Ichikawa M, et al. Association of bystander interventions with neurologically intact survival among patients with bystander-witnessed out-of-hospital cardiac arrest in Japan. JAMA 2015;314:247-54.
16. Malta Hansen C, Kragholm K, Pearson DA, et al. Association of bystander and first-responder intervention with survival after out-of-hospital cardiac arrest in North Carolina, 2010-2013. JAMA 2015; 314:255-64.
17. Sayre MR, Berg RA, Cave DM, Page RL, Potts J, White RD. Hands-only (compression-only) cardiopulmonary resuscitation: a call to action for bystander response to adults who experience out-of-hospital sudden cardiac arrest: a science advisory for the public from the American Heart Association Emergency Cardiovascular Care Committee. Circulation 2008;117: 2162-7.
18. Rajan S, Wissenberg M, Folke F, et al. Association of bystander cardiopulmonary resuscitation and survival according to ambulance response times after out-of-hospital cardiac arrest. Circulation 2016; 134:2095-104.
19. Link MS, Atkins DL, Passman RS, et al. Electrical therapies: automated external defibrillators, defibrillation, cardioversion, and pacing: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2010;122:Suppl 3:S706-S719.
20. Mozaffarian D, Benjamin EJ, Go AS, et al. Heart disease and stroke statistics — 2015 update: a report from the American Heart Association. Circulation 2015; 131(4):e29-e322.
21. Agerskov M, Nielsen AM, Hansen CM, et al. Public access defibrillation: great benefit and potential but infrequently used. Resuscitation 2015;96:53-8.
22. 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.
23. Iwami T, Kitamura T, Kiyohara K, Kawamura T. Dissemination of chest compression-only cardiopulmonary resuscitation and survival after out-of-hospital cardiac arrest. Circulation 2015;132: 415-22.
24. Case R, Cartledge S, Siedenburg J, et al. Identifying barriers to the provision of bystander cardiopulmonary resuscitation (CPR) in high-risk regions: a qualitative review of emergency calls. Resuscitation 2018;129:43-7.
25. Bobrow BJ, Zuercher M, Ewy GA, et al. Gasping during cardiac arrest in humans is frequent and associated with improved survival. Circulation 2008;118:2550-4.
26. Brinkrolf P, Metelmann B, Scharte C, Zarbock A, Hahnenkamp K, Bohn A. Bystander-witnessed cardiac arrest is associated with reported agonal breathing and leads to less frequent bystander CPR. Resuscitation 2018;127:114-8.
27. Field JM, Hazinski MF, Sayre MR, et al. Executive summary: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2010; 122:Suppl 3:S640-S656.
28. Kleinman ME, Brennan EE, Goldberger ZD, et al. 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-S435.
29. Perkins GD, Handley AJ, Koster RW, et al. European Resuscitation Council guidelines for resuscitation 2015. 2. Adult basic life support and automated external defibrillation. Resuscitation 2015;95:81-99.
30. Travers AH, Perkins GD, Berg RA, et al. 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-S83.
31. Møller TP, Andréll C, Viereck S, Todorova L, Friberg H, Lippert FK. Recognition of out-of-hospital cardiac arrest by medical dispatchers in emergency medical dispatch centres in two countries. Resuscitation 2016;109:1-8.
32. Viereck S, Møller TP, Ersbøll AK, et al. Recognising out-of-hospital cardiac arrest during emergency calls increases bystander cardiopulmonary resuscitation and survival. Resuscitation 2017;115:141-7.
33. Viereck S, Møller TP, Rothman JP, Folke F, Lippert FK. Recognition of out-of-hospital cardiac arrest during emergency calls — a systematic review of observational studies. Scand J Trauma Resusc Emerg Med 2017;25:9.
34. Riou M, Ball S, Whiteside A, et al. 'We're going to do CPR': a linguistic study of the words used to initiate dispatcher-assisted CPR and their association with caller agreement. Resuscitation 2018;133: 95-100.
35. Ro YS, Shin SD, Lee YJ, et al. Effect of dispatcher-assisted cardiopulmonary resuscitation program and location of out-of-hospital cardiac arrest on survival and neurologic outcome. Ann Emerg Med 2017;69(1):52.e1-61.e1.
36. 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.
37. Riyapan S, Lubin J. Emergency dispatcher assistance decreases time to defibrillation in a public venue: a randomized controlled trial. Am J Emerg Med 2016;34: 590-3.
38. 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.
39. Gardett I, Broadbent M, Scott G, Clawson JJ, Olola C. Availability and use of an automated external defibrillator at emergency medical dispatch. Prehosp Emerg Care 2019;23:683-90.
40. 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.
41. Pijls RWM, Nelemans PJ, Rahel BM, Gorgels APM. A text message alert system for trained volunteers improves out-of-hospital cardiac arrest survival. Resuscitation 2016;105:182-7.
42. Lee SY, Shin SD, Lee YJ, et al. Text message alert system and resuscitation outcomes after out-of-hospital cardiac arrest: a before-and-after population-based study. Resuscitation 2019;138:198-207.
43. 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(8):e87-e108.
44. 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;24:124-9.
45. Pulver A, Wei R, Mann C. Locating AED enabled medical drones to enhance cardiac arrest response times. Prehosp Emerg Care 2016;20:378-89.
46. Boutilier JJ, Brooks SC, Janmohamed A, et al. Optimizing a drone network to deliver automated external defibrillators. Circulation 2017;135:2454-65.
47. Hüpfl M, Selig HF, Nagele P. Chest-compression-only versus standard cardiopulmonary resuscitation: a meta-analysis. Lancet 2010;376:1552-7.
48. Bobrow BJ, Spaite DW, Berg RA, et al. Chest compression-only CPR by lay rescuers and survival from out-of-hospital cardiac arrest. JAMA 2010;304:1447-54.
49. Panchal AR, Bobrow BJ, Spaite DW, et al. Chest compression-only cardiopulmonary resuscitation performed by lay rescuers for adult out-of-hospital cardiac arrest due to non-cardiac aetiologies. Resuscitation 2013;84:435-9.
50. Ewy GA, Sanders AB. Alternative approach to improving survival of patients with out-of-hospital primary cardiac arrest. J Am Coll Cardiol 2013;61:113-8.
51. Graham R, McCoy MA, Schultz AM, eds. Strategies to improve cardiac arrest survival: a time to act. Washington, DC: National Academies Press, 2015.
52. Virkkunen I, Kujala S, Ryynänen S, et al. Bystander mouth-to-mouth ventilation and regurgitation during cardiopulmonary resuscitation. J Intern Med 2006;260:39-42.
53. Becker TK, Gul SS, Cohen SA, et al. Public perception towards bystander cardiopulmonary resuscitation. Emerg Med J 2019;36:660-5.
54. Rea TD, Cook AJ, Stiell IG, et al. Predicting survival after out-of-hospital cardiac arrest: role of the Utstein data elements. Ann Emerg Med 2010;55:249-57.
55. Riva G, Ringh M, Jonsson M, et al. Survival in out-of-hospital cardiac arrest after standard cardiopulmonary resuscitation or chest compressions only before arrival of emergency medical services: nationwide study during three guideline periods. Circulation 2019;139:2600-9.
56. Dowie R, Campbell H, Donohoe R, Clarke P. 'Event tree' analysis of out-of-hospital cardiac arrest data: confirming the importance of bystander CPR. Resuscitation 2003;56:173-81.
57. Nordberg P, Hollenberg J, Herlitz J, Rosenqvist M, Svensson L. Aspects on the increase in bystander CPR in Sweden and its association with outcome. Resuscitation 2009;80:329-33.
58. Gilmore CM, Rea TD, Becker LJ, Eisenberg MS. Three-phase model of cardiac arrest: time-dependent benefit of bystander cardiopulmonary resuscitation. Am J Cardiol 2006;98:497-9.
59. Bunch TJ, White RD, Friedman PA, Kottke TE, Wu LA, Packer DL. Trends in treated ventricular fibrillation out-of-hospital cardiac arrest: a 17-year population-based study. Heart Rhythm 2004;1:255-9.
60. Herlitz J, Andersson E, Bång A, et al. Experiences from treatment of out-of-hospital cardiac arrest during 17 years in Göteborg. Eur Heart J 2000;21:1251-8.
61. Polentini MS, Pirrallo RG, McGill W. The changing incidence of ventricular fibrillation in Milwaukee, Wisconsin (1992-2002). Prehosp Emerg Care 2006;10:52-60.
62. Luo S, Zhang Y, Zhang W, Zheng R, Tao J, Xiong Y. Prognostic significance of spontaneous shockable rhythm conversion in adult out-of-hospital cardiac arrest patients with initial non-shockable heart rhythms: a systematic review and meta-analysis. Resuscitation 2017;121:1-8.
63. Song J, Guo W, Lu X, Kang X, Song Y, Gong D. The effect of bystander cardiopulmonary resuscitation on the survival of out-of-hospital cardiac arrests: a systematic review and meta-analysis. Scand J Trauma Resusc Emerg Med 2018;26:86-96.
64. 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.
65. Pollack RA, Brown SP, Rea T, et al. Impact of bystander automated external defibrillation use on survival and functional outcomes in shockable observed public cardiac arrests. Circulation 2018;137:2104-13.
66. Nehme Z, Andrew E, Bernard S, Haskins B, Smith K. Trends in survival from out-of-hospital cardiac arrests defibrillated by paramedics, first responders and bystanders. Resuscitation 2019;143:85-91.
67. 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.
68. 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.
69. 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.
70. 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.
71. 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.
72. Sun CLF, 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.
73. Andre AD, Jorgenson DB, Froman JA, Snyder DE, Poole JE. Automated external defibrillator use by untrained bystanders: can the public-use model work? Prehosp Emerg Care 2004;8:284-91.
74. Bødtker H, Rosendahl D. Correct AED electrode placement is rarely achieved by laypersons when attaching AED electrodes to a human thorax. Resuscitation 2018;127:e12-e13.
75. Nishi T, Takei Y, Kamikura T, Ohta K, Hashimoto M, Inaba H. Improper bystander-performed basic life support in cardiac arrests managed with public automated external defibrillators. Am J Emerg Med 2015;33:43-9.
76. Anderson ML, Cox M, Al-Khatib SM, et al. Rates of cardiopulmonary resuscitation training in the United States. JAMA Intern Med 2014;174:194-201.
77. Cheng A, Nadkarni VM, Mancini MB, et al. Resuscitation education science: educational strategies to improve outcomes from cardiac arrest: a scientific statement from the American Heart Association. Circulation 2018;138(6):e82-e122.
78. Semeraro F, Frisoli A, Loconsole C, et al. Kids (learn how to) save lives in the school with the serious game Relive. Resuscitation 2017;116:27-32.
79. Chang MP, Gent LM, Sweet M, Potts J, Ahtone J, Idris AH. A novel educational outreach approach to teach Hands-Only Cardiopulmonary Resuscitation to the public. Resuscitation 2017;116:22-6.
80. Bobrow BJ, Vadeboncoeur TF, Spaite DW, et al. The effectiveness of ultrabrief and brief educational videos for training lay responders in Hands-Only Cardiopulmonary Resuscitation: implications for the future of citizen cardiopulmonary resuscitation training. Circ Cardiovasc Qual Outcomes 2011;4:220-6.
81. Heard DG, Andresen KH, Guthmiller KM, et al. Hands-only cardiopulmonary resuscitation education: a comparison of on-screen with compression feedback, classroom, and video education. Ann Emerg Med 2019;73:599-609.
82. 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.