Sudden Cardiac Arrest and Automated External Defibrillators

Mithilesh K. Das, MD; Douglas P. Zipes, MD

Of hospital sudden cardiac arrest (SCA) is the major (approximately 66–94.5%) cause of sudden death worldwide. The remaining causes of sudden death are noncardiac conditions, including epilepsy, alcohol abuse, pulmonary embolism, trauma, cerebrovascular accidents and unknown etiology. The annual occurrence of sudden death is 350,000–450,000 in the United States, 10.5 per 100,000 population in United Kingdom and 37 per 100,000 in Japan. In the United States, there were 341,780 reported cases of out of hospital sudden cardiac death in 1999, which accounted for 47% of all cardiac-related deaths. Identifying the individual at risk for cardiac arrest remains difficult, and approximately 20% of people who suffer from SCA do not have any prior cardiac history. Despite an increase in public awareness and implementation of several programs to rescue individuals from SCA, as well as advances in preventive therapy, the proportion of out-of-hospital SCA has increased 23.5% over the past decade.

Most of the SCAs are reversible if acted upon in a timely and organized fashion. According to the American Red Cross health and safety service, it is estimated that at least 30–50% deaths from SCA could have been prevented if a cardiac chain of survival had been initiated and an automated external defibrillator (AED) had been available for immediate use (within 5 min) at the time of the SCA. Survival from out of hospital cardiac arrest depends upon an urgent and very efficient integrated system of stepwise care, symbolized by the American Heart Association’s (AHA) 4-step of chain of survival: (1) early access to emergency medical system, (2) early initiation of cardiopulmonary resuscitation (CPR), (3) early defibrillation and (4) early advanced life support system.

Early access has been improved in the United States by increasing public awareness of recognizing cardiac arrest, a 911 emergency call system and very organized trained personnel. Prompt initiation of CPR depends upon awareness of cardiac arrest by the public and arrival of emergency medical services (EMS). Immediately after collapse, 75–85% of the patients present with ventricular tachyarrhythmias (mostly ventricular fibrillation). During SCA, speed is essential because survival decreases by approximately 7–10% with each minute after SCA and is 50% at 5 min, 30% at 7 min and becomes as low as 2–5% after 10 min from collapse. Survival rates up to 80–90% have been reported if effective CPR and defibrillation is performed within 1 min of collapse. Ventricular fibrillation (VF) as the presenting rhythm is associated with the majority of survivors of SCA. Therefore, the AHA established a goal of less than 5 min to notify EMS. Despite these efforts, the outcome of SCA has not improved significantly other than in a few communities, because prompt DC cardioversion could not be initiated as a result of delayed arrival of either EMS or equipment for defibrillation. A decade ago, a community-based public access approach to defibrillation was developed for early CPR and more recently, early use of AED by laypersons has emerged as a potentially effective measure prior to arrival of EMS.

The initial goal was to develop an AED that was easy to use by minimally trained, or totally untrained, persons and was reliable in detecting, as well as terminating, ventricular arrhythmias. The initial plan was to place AEDs in locations easily accessible by the public for early defibrillation. Advancements in the technology, including the use of highly efficacious biphasic DC shock, smaller sized devices that were simple to use and required low maintenance, has enabled the placement of AEDs in many locations. The purpose of this review is to discuss the recent advancements in technology and the evolving approaches in the use of AEDs for early and effective defibrillation.

Automated External Defibrillators

In 1994, a conference of the AHA Taskforce on Public Access Defibrillation recommended that an ideal AED should be inexpensive, easy to use, small, lightweight, self
testing, rugged, inexpensive and should be able to deter misuse.\textsuperscript{11} It should also efficiently retrieve and archive the data. Most of the commercially available AEDs in the United States meet these criteria. The modern AEDs administer a DC shock through the chest wall via 2 adhesive electrode/defibrillator pads applied over the cardiac apex and the upper right chest. The built-in computer accesses the patient’s heart rhythm via the defibrillator pad electrodes. The microprocessor in the AED receives the signal, which is filtered to eliminate motion artifacts, ambient electrical interference, radio signals, or poor electrode contact. It takes account of the frequency, amplitude, rate, slope, and integrated waveform to analyze the rhythm. A programmed algorithm is then used to distinguish ‘shockable rhythm’ (ie, ventricular fibrillation (VF) or fast ventricular tachycardia (VT)) from rhythms that do not need a DC shock (ie, sinus tachycardia, asystole). Audible and/or visual prompts guide the user through the process. A DC shock is delivered only for VF and fast VT. Most of the AEDs charge within 10 s and retain the charge for 30 s. The maximum energy delivered depends upon the make of the AED and varies from 200 J biphasic to 360 J biphasic (depending on the manufacture). Most AEDs are now the size of a lunch box and cost between $1,285 and $3,000 in the United States.

**Contemporary AED Technology**

**Microprocessors for Rhythm Analysis and Data Storage**

It is very important that these devices detect the cardiac rhythm with the highest possible accuracy in order to prevent inappropriate shock delivery for any tachycardias other than VF or fast VT. Recent studies have demonstrated a high specificity for the detection of cardiac rhythms not requiring shock therapy. Sensitivity for VF detection ranges from 96% to 100%, and specificity for non-VF rhythms is near 100% in various cardiac arrest situations. Therefore, inappropriate shock delivery is rare and is related mostly to poor interfacing of the electrode with the chest wall or failure of the operator to follow instructions. Failure to deliver an appropriate DC shock most often results in the later stage of cardiac arrest when the VF waveform changes from coarse to fine because the sensitivity for detection of VF is set at 0.01–0.15 mV to prevent false detection during asystole. The contemporary AEDs are also capable of electrogram storage and retrieval for post-event analysis.

**Wave Forms for DC Shocks**

Successful defibrillation depends upon many factors, such as optimal placement of the shock electrodes, appropriate electrode–chest wall contact, chest wall impedance, duration of cardiac arrest, the nature and degree of cardiac pathology, as well as the
amount of energy of the DC current delivered to generate an electrical gradient across the myocardium. The electrical gradient must be sufficient to terminate depolarizing wavefronts as well as to prevent their re-initiation. Monophasic and biphasic waveforms are the 2 types available in commercial defibrillators. In monophasic DC shock the electrical current moves in one direction as the voltage is applied in a single polarity. With biphasic shocks, the direction of current flow is reversed during the shock, and 2 sequential current pulses of opposite polarities are applied in a single shock. Rectilinear biphasic DC shocks are more effective than damped sine wave monophasic shocks for trans-thoracic ventricular defibrillation, particularly in patients with high trans-thoracic impedance. A 130-J truncated exponential biphasic waveform has an efficacy equivalent to a 200-J damped sine wave monophasic waveform for trans-thoracic ventricular defibrillation. Biphasic shocks have been shown to defibrillate with nearly 60% less current than monophasic shocks and are also associated with a significantly better post-resuscitation myocardial function than monophasic DC shocks. For example, a prospective, randomized trial confirmed a significantly higher efficacy of biphasic AEDs in terminating VF compared with monophasic AEDs. A 150-J biphasic AED defibrillated at higher rates with a greater first-shock success rate (89% in one study) compared with monophasic shocks of 200, 300 and 360 J. That type of AED was also associated with improved return of circulation and neurological outcomes compared with a high-energy (200–360-J) monophasic AED.

Therefore, the combination of increased efficacy and decreased current requirements has led to the incorporation of biphasic shocks as the standard practice in AEDs and other semiautomatic and manual defibrillation instruments, as well as in implantable defibrillators. Biphasic shocks have received a category Ia endorsement by the AHA non-progressive protocol of 3 shocks at 150 J (≤200 J), although some devices deliver up to 360 J. However, there is still debate over the optimal biphasic waveform (truncated exponential vs rectilinear) and the optimum energy dose of DC shock for AEDs. Based on the reported data, it is our opinion that biphasic DC shock is at present the most effective form available for cardioversion because it requires less energy for trans-thoracic cardioversion (therefore causes less myocardial damage) and does not depend on chest wall impedance, which is more effective in obese patients. AEDs that deliver a maximum output of 150–200 J are safe and quite effective.

Electrode Pads Self-adhesive pad electrodes that are 8–12 cm in diameter appear to be the optimal size and meet the recommendation of the Association for the Advancement of Medical Instrumentation. Larger electrodes have lower impedance, but excessively large electrodes may result in less transmyocardial current flow.

Batteries The low energy requirement of the biphasic DC shock system has an added advantage over high-energy monophasic devices because it allows the use of lithium batteries, which are smaller in size, energy dense, have a predictable life expectancy, do not need to be recharged and may not need special disposal. Modern AEDs with lithium batteries have a capacity of a 5-year standby, 300 DC shocks or 12-h continuous rhythm monitoring time.

Use of the AED

Single vs Multiple Rescuers SCA occurs when the heart is unable to maintain the circulation effectively and is mostly caused by life-threatening ventricular arrhythmias such as VF or sustained VT and sometimes ventricular asystole. Cardiovascular collapse limits the cerebral and coronary blood flow, resulting in loss of consciousness, collapse and apnea; the victim typically appears lifeless. When only 1 rescuer is present on the scene, after confirming the unresponsiveness of the victim, the AHA’s chain of survival should be activated by calling the EMS. Then the airway should be checked and if the patient does not appear to be breathing, mouth-to-mouth or mouth-to-tube ventilation should be initiated (the protocol for the number of initial assisted breathing varies between countries; eg, 2 assisted breathing in the USA and up to 5 assisted breathing in other countries). Signs of circulation should be checked next and if the pulse is not detected, with the AED treatment algorithm being followed thereafter. If the pulse is detected then breathing should be assisted and the status of circulation should be checked every 30 s to 1 min. When 2 or more rescuers arrive on the scene, all the 3 major components of resuscitation can be carried out simultaneously: activate the EMS, initiate CPR and connect the AED (Fig 2).

AED Operation The AED operator needs to do only 4 things (Fig 3).

1. Turn on the AED: Once the device is activated, electronic voice prompts or a LCD display guide the operator through the subsequent steps, including those required to coordinate concomitant CPR.

2. Attach the pads to the victim’s chest: Single units with 2 self-adhesive pads or 2 separate self-adhesive pads through which current will flow are applied to the right anterior chest below the clavicle and the left chest wall lateral to the nipple. In certain situations, the skin must be dried or shaved, and transdermal medications should be removed. Otherwise, the device may alert the operator to poor electrode contact.

3. Follow the instructions on the AED readout: Most of the devices proceed with this step automatically after pads
are attached and automatic rhythm analysis begins, and only some of the devices require the user to press the ‘Analyze’ button. This process takes up to 15 s, during which time CPR should be stopped and the patient should not be moved. If VF is detected, the device will advise delivery of a defibrillating shock (Fig 4).

4. Keep bystanders away from the patient (to minimize the risk of accidentally shocking someone): The operator has to manually depress the ‘shock’ switch (this feature distinguishes the automated external defibrillator from an automatic device) to defibrillate the victim. Following the shock, the device reanalyzes the rhythm (in some cases this requires an additional operator step). If persistent VF or fast VT is detected, a shock is advised again; this process is repeated until 3 shocks are delivered, at which time the device pauses and instructs that CPR be resumed. After 1 min, analysis of rhythm and another series of 3 shocks may be given until VF is terminated and the device advises, ‘no shock indicated’. In general, 80% of rhythms occurring at the moment of collapse are treatable in this fashion, but becomes less likely as more time passes. If the patient does not have a ‘treatable rhythm,’ the AED will not discharge the electrical shock.

**AED Operation in Special Circumstances**

**Patients With a Pacemaker or an Implantable Cardioverter Defibrillator (ICD)** Shock electrodes should be placed at least 2.5 cm (1 inch) away from the device generator to avoid defibrillation-induced malfunction. Furthermore, the device generator can also block some current to the myocardium during defibrillation, delivering reduced energy to the heart. It is very important to recognize AED and ICD interaction. When an ICD delivers a shock to the patient, the chest wall motion is similar to that produced by AED discharge but of a lesser degree. Once an ICD shock is recognized, 30–60 s should be allowed for the ICD to complete therapy. Antitachycardia pacing to terminate VT can interfere with correct arrhythmia detection by the AED and result in inappropriate ECG analysis. Because some of the defibrillation current flows down the pacemaker leads, pacemakers and ICDs should always be interrogated after resuscitation to rule out any malfunction.

**Patients With Transcutaneous Medicinal Patches** Medication patches (eg, nitroglycerine, clonidine, nicotine) can interfere with current delivery and should be removed and the area wiped clean.

**In a Moving Ambulance** AEDs can be used while transporting the patient in a vehicle, but movement of the vehicle can produce motion artifact and result in a false analysis of the rhythm as VF. If possible, the vehicle should be stopped temporarily for rhythm analysis, especially if the AED prompts for DC shock.

**Use in Children** Unlike adults, the common presenting rhythms leading to SCA in children are asystole or pulseless electrical activity. VF is a presenting rhythm in only 7–19% of the pediatric population. However, when the child is resuscitated, VF as initial rhythm carries a better prognosis than a non-VF rhythm, as does in adults. Adult AEDs are designed for use on adult patients only and are not recommended for use in a victim less than 8 years old or 25 kg (55 lbs) body weight. AEDs designed specifically for children are available and have been approved by the Food and Drug Administration (FDA). Their accuracy in detecting VF is 96–99%. Post-Resuscitation Management The AED should be left attached while waiting for EMS, even after circulation and breathing return. Some of the AEDs continue to monitor the rhythm and prompts if VF recurs. However, it is prudent to check the respiration and circulation prior to delivering shock again. The AED treatment algorithm for ECC (Emergency Cardiovascular Care; American Heart Association) while waiting the arrival of emergency medical personnel recommends that until the EMS arrives the rescuer monitor signs of circulation every 30–60 s and provide artificial respiration if the patient is not breathing spontaneously.

**Wearable Cardioverter Defibrillator** Recently the FDA has approved the wearable cardioverter defibrillator (WCD), which is an external defibrillator worn on the chest that automatically detects and treats ventricular tachyarrhythmias without the need for the commanded shock from a bystander. This allows the patient to ambulate freely. The wearable component of WCD consists of a monitor that automatically detects and treats ventricular tachycardia or fibrillation with an alarm module that clips onto the patient’s belt and alerts the patient to arrhythmias or noise through lights and voice messages. It also gives a warning of an impending shock to prevent any inappropriate shock and also to prevent the bystander from receiving a shock. The wearable vest contains a rechargeable battery pack, an electrode and no further shocks advised (Reproduced with permission from JAMA 2001; 285: 1193–1200).
AED Use in the Treatment of Sudden Cardiac Arrest

with an AED is safe in the hands of lay people and is based on evaluation and sometimes in the real life situation of rescuers with the aid of instructors, video lectures, care-senior care facility workers for CPR and AED use. Training police officers, airline personnel, security guards, and course developed by the AHA prepares lay rescuers such as Elements of the PAD Program

1. Training of rescuers in CPR and AED use: A 4-h course developed by the AHA prepares lay rescuers such as police officers, airline personnel, security guards, and senior care facility workers for CPR and AED use. Training of rescuers with the aid of instructors, video lectures, care-based evaluation and sometimes in the real life situation has been shown to be very effective. The guidelines recognize 3 potential levels of PAD responders.

2. Level 1: Non-traditional Responders: Nontraditional responders are persons other than healthcare personnel who respond to an emergency, but are not expected to perform any action other than CPR during a cardiac arrest scenario. These include firefighters, police, flight attendants, security personnel, sports marshals, ski patrol members, and ferry-boat crews.

3. Level 2: Targeted Responders: Targeted, or worksite responders are employees of companies, corporations, or public facilities with established PAD programs who work in more common areas such as a central reception area and are more likely to witness a SCA. They may also be called ‘citizen responders,’ who frequently participate in PAD programs.

4. Level 3: Responders to Persons at High Risk: Family members and friends living with or visiting persons who are at high-risk for cardiac emergencies are another potential category of responders. They also are taught CPR and the use of an AED. However, many of these high-risk patients have an ICD and therefore may not need resuscitation with an AED. Transtelephonic defibrillation (should not be classified as AED) is a recently introduced method to provide early defibrillation. This is an approach during which a trained family member or other companion attaches adhesive monitor/defibrillator pads of a home unit to the victim. The home unit can transmit the rhythm by telephone circuitry to a remote monitoring station where emergency personnel interpret the rhythm and guide the user in the decision to deliver a shock. The remote station has the capability of charging the home defibrillator unit and delivering the shock as well as voice communication by two-way speakerphone. Similar systems have been successfully used in hospital settings.

2. Physician overseer to help ensure quality: the EMS has the ultimate responsibility to provide emergency care in the community and should oversee the PAD program.

3. Integration with local EMS: PAD program plans may need to be registered with the state EMS in some states in the USA. PAD systems should be able to share event information with EMS. PAD programs must comply with local as well as regional regulation and legislation.

4. Use and maintenance of AEDs: Use and maintenance of AEDs should be according to the manufacturer’s specifications because the most common cause of AED malfunction is lack of maintenance. Therefore, regular system evaluations should be conducted.

AHA/ACC Recommendations for PAD Programs

The AHA ECC Committee and international expert panels recommend routine skills review and practice sessions at least every 6 months. The program director should carefully select AED users who are motivated, available during the expected response period, and capable of performing their duties. A specific response plan should be implemented within each site, targeting a collapse-to-defibrillation time (4–5 min; therefore, AEDs located throughout the facility so that the walk to retrieve an AED is no more than 1.5 min). Frequent unannounced practice drills and evaluations of performance and response time are recommended. The National Heart, Lung, and Blood Institute (NHLBI), in partnership with the AHA and industry, has embarked on a multisite, controlled, prospective clinical trial to determine the efficacy and cost-effectiveness of placing AEDs in a variety of public settings. Such definitive scientific evidence is essential for decision making related to the potentially huge PAD initiative. Final results from the PAD trial are not expected for at least 3 years. The results of a large, controlled, randomized, multicenter, prospective clinical trial will eventually be needed for PAD to be considered a Class I recommendation.

Recommendations for Deployment of PAD Programs

PAD planners recommend the target AED locations as those where there is a high risk of the occurrence of SCA, such as an area where high-risk people congregate/live or where more than 10,000 people (or 1 SCA/1,000 person-year) of 50 years of age gather and where an EMS call-to-shock time of less than 5 min can not be achieved reliably, but a trained layperson can achieve it in >90% of cases. It is recommended that AEDs should be placed at an easily accessible place and close to a phone so that EMS can be contacted urgently. Success of the PAD program depends
upon careful planning, public awareness, proper training, communication with the EMS system, and continuous quality improvement.

Types of Responders and Work Places for the PAD Program

The incidence of cardiac arrest varies in different public areas. Airports, jails, large shopping malls, large industrial sites and sports arenas have been shown to be high incident sites, whereas restaurants, schools, church, motels, hotels, government offices, other entertainment areas and buses are low incident sites. Therefore, extending the training to include bystanders at the higher target areas is expected to be more effective.

AED Use in Airlines  American Airlines trained more than 20,000 flight attendants and became one of the first and they reduced call-to-shock time by 51% (3.5 min).39–41

AED Use by Police Officers  Initial experience with use of AEDs by police officers in 7 suburban municipalities in Allegheny, Pennsylvania revealed a significantly reduced mean defibrillation time (from 11.8±4.7 min to 8.7±3.7 min) as compared with AED use by EMS. Police officers used AEDs in 69% of cases when they arrived before the EMS and they reduced call-to-shock time by 51% (3.5 min).39–41 A similar result was reported from Miami Dade county where there was a higher survival rate after AED use by police officer as compared with a historic control in which there was a higher survival rate after AED use by paramedics.

AED Use by Bystanders  The high specificity of the AED in withholding therapy supports its safety when used in conscious patients as a monitoring device.35,36

Senior Citizens  Seniors can be trained effectively by video-assisted self-instruction or face-to-face teaching. The likelihood that an elderly lay bystander will actually use an AED during a cardiac event may be closely tied to perceptions of his or her ability to operate an AED. Among older laypersons previously trained in AED operation, dispatcher assistance may increase the proportion who can successfully deliver a shock during aVF cardiac arrest.37,48

School Students  A recent study of a mock-cardiac-arrest scenario regarding the use of AED by children as compared with trained emergency medical technicians (EMT) revealed an encouraging result.49 In this study, 15 untrained sixth-grade children were observed and timed in the use of an AED by following only the instructions provided by the device. The mean time to defibrillation by the children was only 23 s longer than by the EMT/paramedics, and operation of the device by all children was correct. The authors concluded that widespread use of AEDs would likely require only modest training.

Future of PAD

The future of PAD is likely to include further improvements in AED design, reduction in the size of the device and making AEDs easier to use and less expensive so that more and more can be employed in the community. Public access to AEDs is increasing, including training nontraditional target bystanders such as children and seniors. Though these people may require telephone-assisted defibrillation by paramedics, it will enable the earliest possible defibrillation in some high-risk places, such as nursing homes.

Neighborhood Heart Watch

We are concerned that the intense pressure to place AEDs in public access places has ignored that fact that 80% of SCAs occur in the home. Therefore we have established a ‘neighborhood heart watch’ initiative, based on the concept of volunteerism in the USA.50 We envision training families in a community in the use of AEDs and CPR, and equipping them with an AED. When the emergency 911 call arrives at the police station, it is also sent to the house closest to where the SCA is taking place, and the neighbor initiates resuscitation of the victim. An alternative to this approach is to distribute ‘lock boxes’, similar to large mailboxes, that contain an AED, to various sites in a community. Nearby neighbors are all given a key to open the lock box and retrieve the AED as needed. Opening the lock box will trigger the 911 call and location, and keep the key in the lock. In that fashion, one always knows who has the AED. Both programs are being trialled in Indianapolis. Although it is likely they will not be cost-effective, they are not very expensive to implement, and if they can save lives, they will be worth the experiment.

Issues Concerning AEDS

Although there will always be a concern regarding appropriate use of AEDs by laypersons, studies have shown a remarkably favorable result of early defibrillation. Therefore, widespread application of PAD will require training nonmedical persons of diverse backgrounds. Legal liability in the use of AEDs by nonmedical persons has been a major concern, potentially limiting the widespread applica-
tion of PAD; but recently several states have approved the use of AED in cardiac arrest situations by laypersons. The Airline Medical Assistance Act of 1998 provided immunity to the airlines, and the Cardiac Arrest Survival Act of 2000 provides federal protection from legal liability for the AED operator. In addition, all states in the United States now have Good Samaritan legislation for protection of bystander operators of an AED.

Home AED As mentioned earlier, 80% of SCAs occur at home rather than in public places, so development of a less expensive (<$1,000) AED may be useful for the many cardiac patients who do not have an ICD. Although such purchases are unlikely to be cost-effective in terms of cost per life-year saved, many concerned individuals may elect to equip their homes with an AED for peace of mind.

Because of the recent advancements in AED technology, including their high sensitivity in recognizing the shockable rhythms of VT and VF, AED use can make a remarkable impact on survival. Though the survival rate for out-of-hospital SCA is still far from desirable, with an increase in public awareness by the media, education in schools and training in CPR and AED use, together with the integration with established emergency care systems, AEDs offer promise of improvement by providing an important link in the cardiac chain of survival.

References


48. Meischke HW, Rea TD, Eisenberg MS, Rowe SM. Intentions to use an automated external defibrillator during a cardiac emergency among a group of seniors trained in its operation. *Heart Lung* 2002; 31: 25–29.
