Part 6: Electrical Therapies

Automated External Defibrillators, Defibrillation, Cardioversion, and Pacing

2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care

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Overview

This chapter presents guidelines for defibrillation with manual defibrillators and automated external defibrillators (AEDs), synchronized cardioversion, and pacing. AEDs may be used by lay rescuers and healthcare providers as part of basic life support. Manual defibrillation, cardioversion, and pacing are advanced life support therapies.

Defibrillation Plus CPR: A Critical Combination

Early defibrillation is critical to survival from sudden cardiac arrest (SCA) for several reasons[1]: the most frequent initial rhythm in out-of-hospital witnessed SCA is ventricular fibrillation (VF),[2] the treatment for ventricular fibrillation is defibrillation,[3] the probability of successful defibrillation diminishes rapidly over time,[4] and VF tends to deteriorate to asystole over time.[1,5,6]

Several studies have documented the effects of time to defibrillation and the effects of bystander CPR on survival from SCA. For every minute that passes between collapse and defibrillation, survival rates from witnessed VF SCA decrease 7% to 10% if no CPR is provided.[1] When bystander CPR is provided, the decrease in survival rates is more gradual and averages 3% to 4% per minute from collapse to defibrillation.[1,2,5,7] CPR can double[1,3] or triple[4] survival from witnessed SCA at most intervals to defibrillation.

If bystanders provide immediate CPR, many adults in VF can survive with intact neurologic function, especially if defibrillation is performed within 5 to 10 minutes after SCA.[8,9] CPR prolongs VF, delays the onset of asystole,[10–12] and extends the window of time during which defibrillation can occur. Basic CPR alone, however, is unlikely to terminate VF and restore a perfusing rhythm.

New Recommendations to Integrate CPR and AED Use

To treat VF SCA, rescuers must be able to rapidly integrate CPR with use of the AED. To give the victim the best chance of survival, 3 actions must occur within the first moments of a cardiac arrest[1]: activation of the emergency medical services (EMS) system,[2] provision of CPR, and operation of an AED.[3] When 2 or more rescuers are present, activation of EMS and initiation of CPR can occur simultaneously.

Delays to either the start of CPR or the start of defibrillation reduce survival from SCA. In the 1990s, some predicted that CPR could be rendered obsolete by the widespread development of community AED programs. However, Cobb[9] noted that as more of Seattle's first responders were equipped with AEDs, survival rates from SCA unexpectedly fell. This decline was attributed to reduced emphasis on CPR, and there is growing evidence to support this view. Part 5: "Adult Basic Life Support" summarizes the evidence on the importance of provision of high-quality CPR (including chest compressions of adequate rate and depth, allowing full chest recoil after each compression and minimizing interruptions in compressions).

Two critical questions about integration of CPR with defibrillation were evaluated during the 2010 International Consensus Conference on CPR and Emergency Cardiovascular Care.[13] The first question concerned whether CPR should be provided before defibrillation is attempted. The second question concerned the number of shocks to be delivered in a sequence before the rescuer resumes CPR.

Shock First Versus CPR First

When any rescuer witnesses an out-of-hospital arrest and an AED is immediately available on-site, the rescuer should start CPR and use the AED as soon as possible. Healthcare providers who treat cardiac arrest in hospitals and other facilities with AEDs on-site should provide immediate CPR and should use the AED/defibrillator as soon as it is available. These recommendations are designed to support early CPR and early defibrillation, particularly when an AED is available within moments of the onset of SCA.

In studies in which EMS call-to-arrival intervals were 4[9] to 5[8] minutes or longer, 1 ½ to 3 minutes of CPR before defibrillation increased the rate of initial resuscitation (return of spontaneous circulation or ROSC), survival to hospital discharge,[8,9] and 1-year survival[8] when compared with immediate defibrillation

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for VF SCA. However, in 2 randomized controlled trials,[14,15] a period of 1 ½ to 3 minutes of CPR by EMS personnel before defibrillation did not improve ROSC or survival to hospital discharge in patients with out-of-hospital VF or pulseless ventricular tachycardia (VT) compared with immediate defibrillation, regardless of EMS response interval, in systems with low overall survival. In 1 retrospective before/after study,[16] immediate CPR by EMS personnel was associated with no significant difference in survival to discharge but significantly improved neurological status at 30 days or 1 year compared with immediate defibrillation in patients with out-of-hospital VF. In a retrospective observational study,[17] probability of survival was increased if chest compressions were performed during a higher proportion of the initial CPR period as compared to a lower proportion.

When VF is present for more than a few minutes, the myocardium is depleted of oxygen and metabolic substrates. A brief period of chest compressions can deliver oxygen and energy substrates, increasing the likelihood that a shock may terminate VF (defibrillation) and a perfusing rhythm will return (ie, ROSC).[18]

When an out-of-hospital cardiac arrest is not witnessed by EMS personnel, EMS may initiate CPR while checking the ECG rhythm and preparing for defibrillation. There is insufficient evidence to determine if 1 ½ to 3 minutes of CPR should be provided prior to defibrillation. CPR should be performed while a defibrillator is being readied (Class I, LOE B). One cycle of CPR consists of 30 compressions and 2 breaths. When compressions are delivered at a rate of about 100 per minute, 5 cycles of CPR should take roughly 2 minutes (range: about 1 ½ to 3 minutes).

EMS system medical directors may consider implementing a protocol that allows EMS responders to provide CPR while preparing for defibrillation of patients found by EMS personnel to be in VF. In practice, however, CPR can be initiated while the AED is being readied.

With in-hospital SCA, there is insufficient evidence to support or refute CPR before defibrillation. However, in monitored patients, the time from VF to defibrillation should be under 3 minutes. When 2 or more rescuers are present, one rescuer should begin CPR while the other activates the emergency response system and prepares the defibrillator.

1-Shock Protocol Versus 3-Shock Sequence

At the time of the 2010 Consensus Conference, there were 2 new published human studies that compared a 1-shock protocol versus a 3-stacked-shock protocol for treatment of VF cardiac arrest. Evidence from these 2 well-conducted pre/post design[19,20] studies suggested significant survival benefit with the single-shock defibrillation protocol compared with 3-stacked-shock protocols. If 1 shock fails to eliminate VF, the incremental benefit of another shock is low, and resumption of CPR is likely to confer a greater value than another shock. This fact, combined with the data from animal studies documenting harmful effects from interruptions to chest compressions and human studies suggesting a survival benefit with a 1-shock protocol, indicate that it is reasonable to use 1-shock for VF, then immediate CPR (Class IIa, LOE B).

First-shock efficacy for biphasic shocks is comparable or better than 3 monophasic shocks.[21–25] Although the optimal energy level for defibrillation using any of the monophasic or biphasic waveforms has not been determined, a recommendation for higher initial energy when using a monophasic waveform was weighed by expert consensus with consideration of the potential negative effects of a high first-shock energy versus the negative effects of prolonged VF. The consensus was that rescuers using monophasic defibrillators should give an initial shock of 360 J; if VF persists after the first shock, second and subsequent shocks of 360 J should be given. This single dose for monophasic shocks is designed to simplify instructions to rescuers but is not a mandate to recall monophasic AEDs for reprogramming. If the monophasic AED being used is programmed to deliver a different first or subsequent dose, that dose is acceptable.

After shock delivery, the rescuer should not delay resumption of chest compressions to recheck the rhythm or pulse. After about 5 cycles of CPR (about 2 minutes, although this time is not firm), ideally ending with compressions, the AED should then analyze the cardiac rhythm and deliver another shock if indicated (Class I, LOE B). If a nonshockable rhythm is detected, the AED should instruct the rescuer to resume CPR immediately, beginning with chest compressions (Class I, LOE B).

Concern that chest compressions in the presence of a postshock organized rhythm might provoke recurrent VF has been expressed by 1 animal and 2 human studies,[26–28] but this has not been shown to adversely affect survival if the current algorithms are followed.[19,20]

Furthermore, in animal studies, frequent or long interruptions in precordial chest compressions for rhythm analysis[29] or rescue breathing[30,31] were associated with postresuscitation myocardial dysfunction and reduced survival rates. Data from a prospective observational study showed that interruption in chest compressions is associated with a decreased probability of successful conversion of VF to a perfusing rhythm after shock.[32] In a recent clinical observational study of out-of-hospital CPR[33] and an in-hospital study of CPR[34] by healthcare providers, chest compressions were performed only for 51%[33] to 76%[34] of total CPR time.

The rhythm analysis for a 3-shock sequence performed by commercially available AEDs can result in delays of up to 37 seconds between delivery of the first shock and delivery of the first postshock compression.[29] This delay is difficult to justify in light of the first-shock efficacy of >90% reported by current biphasic defibrillators.[28,35–39]

AED manufacturers should seek innovative methods to decrease the amount of time chest compressions are interrupted for AED operation. Training materials for lay rescuers should emphasize the importance of continued CPR until basic or advanced life support personnel take over CPR or the victim begins to move.

Shortening the interval between the last compression and the shock by even a few seconds can improve shock success (defibrillation and ROSC).[18,32,40] Thus, it is reasonable for healthcare providers to practice efficient coordination between CPR and defibrillation to minimize the hands-off interval between stopping compression and administering shock (Class IIa, LOE C). For example, when 2 rescuers are present, the rescuer operating the AED should be prepared to deliver a shock as soon as the compressor removes his or her hands from the victim's chest and all rescuers are "clear" of contact with the victim. Rescue

breathing prior to the shock will increase the time from compression to shock, and thus it is reasonable to proceed immediately to shock without rescue breathing (Class IIa, LOE B).

Defibrillation Waveforms and Energy Levels

The term *defibrillation* (shock success) is typically defined as termination of VF for at least 5 seconds following the shock.[41,42] VF frequently recurs after successful shocks, but this recurrence should not be equated with shock failure.[21,28]

Shock success using the typical definition of *defibrillation* should not be confused with resuscitation outcomes such as restoration of a perfusing rhythm (ROSC), survival to hospital admission, or survival to hospital discharge.[41,43] Since resuscitation outcomes, including survival, depend on many variables in addition to shock delivery, defibrillation programs must strive to improve patient survival, not just shock success.

Modern defibrillators are classified according to 2 types of waveforms: monophasic and biphasic. Monophasic waveform defibrillators were introduced first, but biphasic waveforms are used in almost all AEDs and manual defibrillators sold today. Energy levels vary by type of device and manufacturer.

Monophasic Waveform Defibrillators

Monophasic waveforms deliver current of one polarity (ie, direction of current flow). Monophasic waveforms can be further categorized by the rate at which the current pulse decreases to zero. The monophasic damped sinusoidal waveform (MDS) returns to zero gradually, whereas the monophasic truncated exponential waveform (MTE) current returns abruptly (is truncated) to zero current flow.

Few monophasic waveform defibrillators are being manufactured, but many are still in use, and most use MDS waveforms. As noted above, no specific waveform characteristic (either monophasic or biphasic) is consistently associated with a greater incidence of ROSC or higher survival to hospital discharge rates after cardiac arrest.

Biphasic Waveform Defibrillators

Data from both out-of-hospital and in-hospital studies indicate that lower-energy biphasic waveform shocks have equivalent or higher success for termination of VF than either MDS or MTE monophasic waveform shocks.[21,23,39,44–46] However, the optimal energy for first-shock biphasic waveform defibrillation has not been determined. One study[47] in which a pulsed biphasic waveform was used showed a first-shock success rate of 90%. There is no new evidence regarding the first-shock success rate with the rectilinear biphasic waveform since publication of the 2005 Guidelines. Several randomized[21,23,39] and observational studies[22,48] have shown that defibrillation with biphasic waveforms of relatively low energy (≤200 J) is safe and has equivalent or higher efficacy for termination of VF than monophasic waveform shocks of equivalent or higher energy.[42,49–53]

Evidence from 3 randomized trials[21,23,39] and 3 other human studies[22,42,54] suggests that defibrillation with biphasic waveforms improves the short-term outcome of termination of VF, but no individual study has demonstrated improved survival to discharge using biphasic waveforms when compared with studies using monophasic waveforms. There is no human study to support defibrillation with a multiphasic waveform when compared with any biphasic waveform. Data from animal studies suggest that multiphasic waveforms (triphasic, quadriphasic, or higher) may defibrillate at lower energies and induce less postshock myocardial dysfunction. These results are limited by studies of only short-duration VF (approximately 30 seconds) and lack of human studies for validation of these experimental observations.

Biphasic waveforms are safe and have equivalent or higher efficacy for termination of VF when compared with monophasic waveforms. In the absence of biphasic defibrillators, monophasic defibrillators are acceptable (Class IIb, LOE B). Different biphasic waveforms have not been compared in humans with regard to efficacy. Therefore, for biphasic defibrillators, providers should use the manufacturer's recommended energy dose (eg, initial dose of 120 to 200 J) (Class I, LOE B). If the manufacturer's recommended dose is not known, defibrillation at the maximal dose may be considered (Class IIb, LOE C).

In pediatric defibrillation, there are limited data regarding the lowest effective dose or the upper limit for safe defibrillation. Initial monophasic doses of 2 J/kg are effective in terminating 18% to 50% of VF[55–57] and 48% of VF using similar doses of biphasic energy. [57] However, even with higher energies (up to 9 J/kg), defibrillation has been successful with no clear adverse effects.[58–61] Thus, for pediatric patients, it is acceptable to use an initial dose of 2 to 4 J/kg (Class IIa, LOE C), but for ease of teaching an initial dose of 2 J/kg may be considered. For refractory VF, it is reasonable to increase the dose to 4 J/kg. Subsequent energy levels should be at least 4 J/kg, and higher energy levels may be considered, not to exceed 10 J/kg or the adult maximum dose (Class IIb, LOE C).

Fixed and Escalating Energy

Commercially available biphasic AEDs provide either fixed or escalating energy levels. Multiple prospective human clinical studies[23,52,53] and retrospective studies[21,22,39,48,62,63] have failed to identify an optimal biphasic energy level for first or subsequent shocks. Human studies[50,52] have not demonstrated evidence of harm from any biphasic waveform defibrillation energy up to 360 J, with harm defined as elevated biomarker levels, ECG findings, and reduced ejection fraction. Conversely, several animal studies have shown the potential for myocardial damage with much higher energy shocks.[64–66] Therefore, it is not possible to make a definitive recommendation for the selected energy for subsequent biphasic defibrillation attempts. However, based on available evidence, we recommend that second and subsequent energy levels should be at least equivalent and higher energy levels may be considered, if available (Class IIb, LOE B).

Current-Based Defibrillation

Modern defibrillators deliver current based on stored energy. Because it is accepted that defibrillation is accomplished by the passage of sufficient current through the heart, the concept of current-based defibrillation is appealing. Energy is a nonphysiologic descriptor of defibrillation despite its entrenchment in traditional jargon. Current-based defibrillation has been assessed[67,68] and in 1 study was superior to energy-based defibrillation with monophasic waveforms.[69] This concept merits exploration in light of the variety of biphasic waveforms available that

deliver current in different ways. Peak current amplitude, average current, phasic duration, and phasic current flow need to be examined as determinants of shock efficacy. Transition to current-based defibrillation is timely and should be encouraged.

Clinical studies using MDS waveform shocks have tried to identify the range of current necessary to achieve defibrillation and cardioversion. The optimal current for ventricular defibrillation appears to be 30 to 40 A MDS.[67] Comparable information on current dose for biphasic waveform shocks is under investigation.

Electrodes

Electrode Placement

Data demonstrate that 4 pad positions (anterolateral, anteroposterior, anterior-left infrascapular, and anterior-right-infrascapular)[70] are equally effective to treat atrial or ventricular arrhythmias.[71–75] There are no studies directly pertaining to placement of pads/paddles for defibrillation success with the end point of ROSC. All 4 positions are equally effective in shock success.[71–74,76–82] Any of the 4 pad positions is reasonable for defibrillation (Class IIa, LOE B). For ease of placement and education, anterolateral is a reasonable default electrode placement (Class IIa, LOE C). Alternative pad positions may be considered based on individual patient characteristics.

Lateral pads/paddles should be placed under breast tissue,[83] and hirsute males should be shaved prior to application of pads.[84,85] Ten studies[65,81,86–93] indicated that larger pad/paddle size (8 to 12 cm diameter) lowers transthoracic impedance.

Defibrillation With Implanted Cardioverter Defibrillator

If the patient has an implantable cardioverter defibrillator (ICD) that is delivering shocks (ie, the patient's muscles contract in a manner similar to that observed during external defibrillation), allow 30 to 60 seconds for the ICD to complete the treatment cycle before attaching an AED. Occasionally, the analysis and shock cycles of automatic ICDs and AEDs will conflict.[94] There is the potential for pacemaker or ICD malfunction after defibrillation when the pads are in close proximity to the device.[95,96] One study with cardioversion[95] demonstrated that positioning the pads at least 8 cm away did not produce changes in pacing thresholds or sensing measurements. Pacemaker spikes with unipolar pacing may confuse AED software and may prevent VF detection.[94] The anteroposterior and anterolateral locations are acceptable in patients with these devices. In patients with ICDs or pacemakers, pad/paddle placement should not delay defibrillation. It might be reasonable to avoid placing the pads or paddles over the device (Class IIb, LOE C).

Do not place AED electrode pads directly on top of a transdermal medication patch, (eg, patch containing nitroglycerin, nicotine, analgesics, hormone replacements, antihypertensives) because the patch may block delivery of energy from the electrode pad to the heart and may cause small burns to the skin.[97] If shock delivery will not be delayed, remove medication patches and wipe the area before attaching the electrode pad (Class IIb, LOE C).

If an unresponsive victim is lying in water or if the victim's chest is covered with water or the victim is extremely diaphoretic, it may be reasonable to remove the victim from water and briskly wipe the chest before attaching electrode pads and attempting defibrillation (Class IIb, LOE C). AEDs can be used when the victim is lying on snow or ice (Class IIb, LOE C). Attempt to remove excess chest hair by briskly removing an electrode pad (which will remove some hair) or rapidly shaving the chest in that area provided chest compressions are not interrupted and defibrillation is not delayed.

Electrode Size

In 1993 the Association for the Advancement of Medical Instrumentation recommended a minimum electrode size of 50 cm^2 for individual electrodes.[98] However, advances in electrode design and chemical composition may soon require modification of this recommendation. For adult defibrillation, both handheld paddle electrodes and self-adhesive pad electrodes 8 to 12 cm in diameter perform well, although defibrillation success may be higher with electrodes 12 cm in diameter rather than with those 8 cm in diameter.[86,99] Small electrodes (4.3 cm) may be harmful and may cause myocardial necrosis.[88] When using handheld paddles and gel or pads, rescuers must ensure that the paddle is in full contact with the skin. Even smaller pads have been found to be effective[100] in VF of brief duration. Use of the smallest (pediatric) pads, however, can result in unacceptably high transthoracic impedance in larger children.[93] For adults, an electrode size of 8 to 12 cm is reasonable (Class IIa, LOE B).

Transthoracic Impedance

The average adult human impedance is ≈70 to 80 Ω.[67,86,101] When transthoracic impedance is too high, a low-energy shock will not generate sufficient current to achieve defibrillation.[101–103] To reduce transthoracic impedance, the defibrillator operator should use conductive materials. This is accomplished with the use of gel pads or electrode paste with paddles or through the use of self-adhesive pads. No existing data suggest that one of these modalities is better than the others in decreasing impedance.

Automated External Defibrillators

AEDs are sophisticated, reliable computerized devices that use voice and visual prompts to guide lay rescuers and healthcare providers to safely defibrillate VF and (pulseless) rapid ventricular tachycardia (VT) SCA.[44,46,104,105] In recent clinical trials,[33,34] modified prototype AEDs recorded information about frequency and depth of chest compressions during CPR. These devices are now commercially available and can prompt rescuers to improve CPR performance.

Lay Rescuer AED Programs

Since 1995 the American Heart Association (AHA) has recommended the development of lay rescuer AED programs to improve survival rates from out-of-hospital SCA.[106–108] These programs are also known as public access defibrillation or PAD programs. The goal of these programs is to shorten the time from onset of SCA VF/pulseless VT until CPR and shock delivery by ensuring that AEDs and trained lay rescuers are available in public areas where SCA is likely to occur. To maximize the effectiveness of these programs, the AHA has emphasized the importance of organizing, planning, training, linking with the EMS system, and establishing a process of continuous quality improvement.[109,110]

Studies of lay rescuer AED programs in airports[111] and casinos[112,113] and of first-responder programs with police officers[22,44,46,63,114–116] have shown survival rates of 41% to 74% from out-of-hospital witnessed VF SCA when immediate bystander CPR is provided and defibrillation occurs within about 3 to 5 minutes of collapse.[70,117a] Other studies[117b,118] have demonstrated decreased time intervals from collapse to delivery of the first shock when AEDs were used during adult out-of-hospital cardiac arrest. However, if no decrease in time to defibrillation is achieved, then high survival rates are not observed.[119–121]

In the large prospective randomized trial Public Access Defibrillation Trial (PAD),[122] lay rescuer CPR + AED programs in targeted public settings doubled the number of survivors from out-of-hospital VF SCA when compared with programs that provided early EMS call and early CPR. The programs included a planned response, lay rescuer training, and frequent retraining/practice. In another large population-based study, AED use prior to EMS arrival resulted in a doubling of survival.[123] In a prospective population-based study of >300 000 patients, increased penetration of AEDs resulted in increased defibrillation by bystanders and increased survival compared to historical control.[124]

Lay rescuer AED programs will have the greatest potential impact on survival from SCA if the programs are created in locations where SCA is likely to occur. In the PAD trial, programs were established at sites with a history of at least 1 out-of-hospital cardiac arrest every 2 years or where at least 1 out-of-hospital SCA was predicted during the study period (ie, sites having >250 adults over 50 years of age present for >16 hours/d).[122] Other data suggest that there is benefit when 1 out-of-hospital arrest is likely every 5 years.[125,126]

CPR and AED use by public safety first responders (traditional and nontraditional) is recommended to increase survival rates for SCA (Class I, LOE B). Establishment of AED programs in public locations where there is a reasonable likelihood of witnessed cardiac arrest (eg, airports, casinos, and sports facilities) is recommended (Class I, LOE B).

Because the improvement in survival rates in AED programs is affected by the time to CPR and to defibrillation, it is reasonable for sites that deploy AEDs to establish a response plan, train likely responders in CPR and AED use, maintain equipment, and coordinate with local EMS systems (Class IIa, LOE B).[109,110] Sites without these components are unlikely to demonstrate any improvement in survival rates.[126]

Approximately 80% of out-of-hospital cardiac arrests occur in private or residential settings.[127] One study[128] demonstrated that survival was not improved in homes of high-risk individuals equipped with AEDs compared with homes where only CPR training had been provided.

AEDs are of no value for arrest not caused by VF/pulseless VT, and they are not effective for treatment of nonshockable rhythms that may develop after termination of VF. Nonperfusing rhythms are present in most patients after shock delivery,[22,28,63,129] and in general, CPR is required until a perfusing rhythm returns. Therefore, the AED rescuer should be trained not only to recognize emergencies and use the AED, but also to provide CPR until the AED is retrieved and ready for shock delivery and immediately after shock delivery.

The mere presence of an AED does not ensure that it will be used when SCA occurs. Even in the PAD trial, in which almost 20 000 rescuers were trained to respond to SCA, lay rescuers attempted resuscitation before EMS arrival for only half of the victims of witnessed SCA, and the on-site AED was used for only 34% of the victims who experienced an arrest at locations with AED programs.[122] These findings suggest that lay rescuers need frequent practice to optimize response to emergencies.

It is reasonable for lay rescuer AED programs to implement processes of continuous quality improvement (Class IIa, LOE C). These quality improvement efforts should use both routine inspections and postevent data (from AED recordings and responder reports) to evaluate the following[110,130]:

- Performance of the emergency response plan, including accurate time intervals for key interventions (such as collapse to shock or no shock advisory to initiation of CPR), and patient outcome
- Responder performance
- AED function, including accuracy of the ECG rhythm analysis
- Battery status and function
- Electrode pad function and readiness, including expiration date

Automated Rhythm Analysis

AEDs analyze multiple features of the surface ECG signal, including frequency, amplitude, and some integration of frequency and amplitude, such as slope or wave morphology. Filters check for QRS-like signals, radio transmission, or 50- or 60-cycle interference, as well as loose electrodes and poor electrode contact. The AHA has recommended performance goals for AED arrhythmia analysis algorithms, specifying sensitivity and specificity for various arrhythmias.[131]

AEDs have been tested extensively both in vitro against libraries of recorded cardiac rhythms and clinically in many field trials in adults[131,132] and children.[133–135] They are extremely accurate in rhythm analysis. Although AEDs are not designed to deliver synchronized shocks (ie, cardioversion for VT with pulses), AEDs will recommend a (nonsynchronized) shock for monomorphic and polymorphic VT if the rate and R-wave morphology exceed preset values.

Some devices are programmed to detect spontaneous movement by the patient or others. Prototype defibrillators were used in 2 recent clinical trials evaluating quality of CPR in the out-of-hospital and in-hospital settings, which led to the development of AEDs that prompt rescuers to improve the quality of CPR provided.[33,34]

AED Use in Children

Cardiac arrest is less common in children than adults, and its causes are more diverse.[136–139] Although VF is not a common arrhythmia in children, it is observed in 5% to 15% of pediatric and adolescent arrests.[138,140–143] In these patients rapid defibrillation may improve outcomes.[143,144] The lowest-energy dose for effective defibrillation in infants and children is not known. The upper limit for safe defibrillation is also not known, but doses >4 J/kg (as high as 9 J/kg) have effectively defibrillated children[60,61] and pediatric animal models[145] with no significant

adverse effects. Based on adult clinical data[21,39] and pediatric animal models,[145–147] biphasic shocks appear to be at least as effective as monophasic shocks and are less harmful than monophasic shocks. As noted above, it is acceptable to use an initial dose of 2 to 4 J/kg (Class IIa, LOE C), but for ease of teaching an initial dose of 2 J/kg may be considered. For refractory VF, it is reasonable to increase the dose to 4 J/kg. Subsequent energy levels should be at least 4 J/kg, and higher energy levels may be considered, not to exceed 10 J/kg or the adult maximum dose (Class IIb, LOE C).

Many AEDs can accurately detect VF in children of all ages[133–135] and differentiate shockable from nonshockable rhythms with a high degree of sensitivity and specificity.[133–135] Some AEDs are equipped with pediatric attenuator systems (eg, pad-cable systems or a key) to reduce the delivered energy to a dose suitable for children.

For children 1 to 8 years of age, it is reasonable to use a pediatric dose-attenuator system if one is available (Class IIa, LOE C).[61,148,149] If the rescuer provides CPR to a child in cardiac arrest and does not have an AED with a pediatric attenuator system, the rescuer should use a standard AED.

For infants (<1 year of age), a manual defibrillator is preferred. If a manual defibrillator is not available, an AED with pediatric attenuation is desirable. If neither is available, an AED without a dose attenuator may be used. AEDs with relatively high-energy doses have been successfully used in infants with minimal myocardial damage and good neurological outcomes (Class IIb, LOE C).[150,151]

If an AED program is established in systems or institutions that routinely provide care to children, the program should be equipped with AEDs with a pediatric attenuator system. This statement, however, should not be interpreted as a recommendation for or against AED placement in specific locations where children are present. Ideally, healthcare systems that routinely provide care to children at risk for cardiac arrest should have available manual defibrillators capable of dose adjustment.[148]

In-Hospital Use of AEDs

At the time of the 2010 Consensus Conference, there were no published in-hospital randomized trials of AEDs versus manual defibrillators. Evidence from 1 study with historic controls,[152] 1 case series,[153] and 2 retrospective studies[117,118] indicated higher rates of survival to hospital discharge when AEDs were used to treat adult VF or pulseless VT in the hospital. However, 1 before/after study did not show an improvement in survival to discharge or ROSC when in-hospital AEDs were implemented in noncritical areas of a hospital,[154] and 1 observational study with historical controls observed no improvement in survival to discharge when comparing biphasic AEDs to standard monophasic defibrillators.[155] The Gombotz and Hanefeld studies observed a decrease in the time interval from collapse to first shock delivery as well as increased ROSC and survival.

Defibrillation may be delayed when patients develop SCA in unmonitored hospital beds and in outpatient and diagnostic facilities. In such areas, several minutes may elapse before centralized response teams arrive with the defibrillator, attach it, and deliver shocks.[156] Despite limited evidence, AEDs may be considered for the hospital setting as a way to facilitate early defibrillation (a goal of ≤3 minutes from collapse), especially in areas where staff have no rhythm recognition skills or defibrillators are used infrequently (Class IIb, LOE C).

When hospitals deploy AEDs, first-responding personnel should also receive authorization and training to use an AED, with the goal of providing the first shock for any SCA within 3 minutes of collapse. The objective is to make goals for in-hospital use of AEDs consistent with goals established in the out-of-hospital setting.[157] Early defibrillation capability should be available in ambulatory care facilities, as well as throughout hospital inpatient areas. Hospitals should monitor collapse-to–first shock intervals and resuscitation outcomes.

Fibrillation Waveform Analysis to Predict Outcome

There is evidence that VF waveforms change over time.[158,159] Several retrospective case series, animal studies, and theoretical models suggest that it is possible to predict, with varying reliability, the success of attempted defibrillation by analyzing the VF waveform.[18,40,160–177] However, there are currently no prospective studies that have identified optimal waveforms and/or timing. The value of VF waveform analysis to guide defibrillation management is uncertain (Class IIb, LOE C).

"Occult" Versus "False" Asystole

In certain cases of cardiac arrest, it is difficult to be certain whether the rhythm is fine VF or asystole. In 1989, Losek[178] published a retrospective review of initial shock delivery for 49 children (infants through 19 years of age) in asystole compared with no shock delivery for 41 children in asystole and found no improvement in rhythm change, ROSC, or survival in the group that received the shocks. In 1993, the Nine City High-Dose Epinephrine Study Group published an analysis of 77 asystolic patients who received initial shock compared with 117 who received standard therapy.[179] There was a worse outcome of ROSC and survival for those who received shocks. Thus, it is not useful to shock asystole (Class III, LOE B).

Fire Hazard

Several case reports have described fires ignited by sparks from poorly applied defibrillator paddles in the presence of an oxygen-enriched atmosphere.[180–185] Fires have been reported when ventilator tubing is disconnected from the endotracheal tube and then left adjacent to the patient's head, blowing oxygen across the chest during attempted defibrillation.[181,183,185] It may be reasonable for rescuers to take precautions to minimize sparking during attempted defibrillation; try to avoid defibrillation in an oxygen-enriched atmosphere (Class IIb, LOE C).

The use of self-adhesive defibrillation pads and ensuring good pad–chest-wall contact will likely minimize the risk of sparks igniting during defibrillation. If manual paddles are used, gel pads are preferable to electrode pastes and gels, because the pastes and gels can spread between the 2 paddles, creating the potential for a spark (Class IIb, LOE C).

Synchronized Cardioversion

Synchronized cardioversion is shock delivery that is timed (synchronized) with the QRS complex. This synchronization avoids shock delivery during the relative refractory portion of the cardiac cycle, when a shock could produce VF.[186] For

additional information, see Part 8.3: "Management of Symptomatic Bradycardia and Tachycardia."

Synchronized cardioversion is recommended to treat supraventricular tachycardia due to reentry, atrial fibrillation, atrial flutter, and atrial tachycardia. Synchronized cardioversion is also recommended to treat monomorphic VT with pulses. Cardioversion is not effective for treatment of junctional tachycardia or multifocal atrial tachycardia.

Synchronized cardioversion must not be used for treatment of VF as the device may not sense a QRS wave and thus a shock may not be delivered. Synchronized cardioversion should also not be used for pulseless VT or polymorphic (irregular VT). These rhythms require delivery of high-energy *unsynchronized* shocks (ie, defibrillation doses). Electric therapy for VT is discussed further below. For additional information see Part 8.2: "Management of Cardiac Arrest."

Supraventricular Tachycardias (Reentry Rhythms)

The recommended initial biphasic energy dose for cardioversion of adult atrial fibrillation is 120 to 200 J (Class IIa, LOE A).[187–191] If the initial shock fails, providers should increase the dose in a stepwise fashion. Cardioversion of adult atrial flutter and other supraventricular tachycardias generally requires less energy; an initial energy of 50 J to 100 J is often sufficient.[191] If the initial shock fails, providers should increase the dose in a stepwise fashion.[102] Adult cardioversion of atrial fibrillation with monophasic waveforms should begin at 200 J and increase in a stepwise fashion if not successful (Class IIa, LOE B).[187–189] For cardioversion of SVT in children, use an initial dose of 0.5 to 1 J/kg. If unsuccessful, increase the dose up to 2 J/kg (Class IIb, LOE C). For further information, see Part 14: "Pediatric Advanced Life Support."

Ventricular Tachycardia

The energy dose and timing of shocks for treatment of VT with pulses are determined by the patient's condition and the morphological characteristics of the VT.[192] Pulseless VT is treated as VF (see Part 8.2: "Management of Cardiac Arrest"). Management of stable VT is summarized in Part 8.3: "Management of Symptomatic Bradycardia and Tachycardia." Unstable monomorphic (regular) VT with pulses is treated with synchronized cardioversion. Unstable polymorphic (irregular) VT with or without pulses is treated as VF using *unsynchronized* high-energy shocks (ie, defibrillation doses).

Adult monomorphic VT (regular form and rate) with a pulse responds well to monophasic or biphasic waveform cardioversion (synchronized) shocks at initial energies of 100 J. If there is no response to the first shock, it may be reasonable to increase the dose in a stepwise fashion. No studies were identified that addressed this issue. Thus, this recommendation represents expert opinion (Class IIb, LOE C).

For electric cardioversion in children the recommended starting energy dose is 0.5 to 1 J/kg. If that fails, increase the dose up to 2 J/kg (Class I, LOE C). For further information, see Part 14: "Pediatric Advanced Life Support."

Although synchronized cardioversion is preferred for treatment of an organized ventricular rhythm, for some arrhythmias synchronization is not possible. The many QRS configurations and irregular rates that comprise polymorphic ventricular tachycardia make it difficult or impossible to reliably synchronize to a QRS complex. If there is any doubt whether monomorphic or polymorphic VT is present in the *unstable* patient, do not delay shock delivery to perform detailed rhythm analysis—provide high-energy unsynchronized shocks (ie, defibrillation doses).

The recommended shock doses for high-energy, *unsynchronized* shocks (defibrillation) with a biphasic or monophasic device are those presented earlier in this section (Defibrillation Waveforms and Energy Levels). After shock delivery, the healthcare provider should be prepared to provide immediate CPR (beginning with chest compressions) and follow the ACLS Cardiac Arrest Algorithm if pulseless arrest develops (for further information see Part 8.2: "Management of Cardiac Arrest").

Pacing

Pacing is not recommended for patients in asystolic cardiac arrest. Randomized controlled trials[193–195] and additional studies[196–202] indicate no improvement in the rate of admission to hospital or survival to hospital discharge when paramedics or physicians attempted to provide pacing in asystolic patients in the prehospital or hospital (emergency department) setting. Pacing is not effective for asystolic cardiac arrest and may delay or interrupt the delivery of chest compressions. Pacing for patients in asystole is not recommended (Class III, LOE B).

In symptomatic bradycardia with a pulse, 2 randomized adult trials comparing transcutaneous pacing to drug therapy showed no difference in survival.[203,204] It is reasonable for healthcare providers to be prepared to initiate pacing in patients who do not respond to atropine (or second-line drugs if these do not delay definitive management) (Class IIa, LOE B). Immediate pacing might be considered if the patient is severely symptomatic (Class IIb, LOE C). If the patient does not respond to drugs or transcutaneous pacing, transvenous pacing is probably indicated (Class IIa, LOE C). For further information see Part 8.3: "Management of Symptomatic Bradycardia and Tachycardia."

Maintaining Devices in a State of Readiness

User checklists have been developed to reduce equipment malfunction and operator errors. Failure to properly maintain the defibrillator or power supply is responsible for the majority of reported malfunctions. Many currently available defibrillators do an automated check and display readiness. Checklists are useful when designed to identify and prevent such deficiencies. It is recommended to maintain devices in a state of readiness (Class I, LOE C).

Summary

The recommendations for electrical therapies described in this section are designed to improve survival from SCA and life-threatening arrhythmias. Whenever defibrillation is attempted, rescuers must coordinate high-quality CPR with defibrillation to minimize interruptions in chest compressions and to ensure immediate resumption of chest compressions after shock delivery. The high first-shock efficacy of newer biphasic defibrillators led to the recommendation of single shocks plus immediate CPR instead of 3-shock sequences that were recommended prior to 2005 to treat VF. Further data are needed to refine recommendations for energy levels for defibrillation and cardioversion using biphasic waveforms.

Disclosures

Guidelines Part 6: Electrical Therapies: Writing Group Disclosures

Writing Group Member	Employment	Research Grant	Other Research Support	Speakers' Bureau/Honoraria	Ownership Interest	Consultant/Advisory Board	Other
Mark S. Link	Tufts Medical Center–MD	None	None	None	None	None	None
Dianne L. Atkins	University of Iowa: University and Medical School—Professor *Compensated works sheet editor for the Guidelines 2010 Process. Money is paid approximately 2/3 to my institution and 1/3 to directly me. My salary from my institution is not changed by this reimbursement	None	None	None	None	None	*Serving as defense expert witness
Rod S. Passman	Northwestern University–Associate Professor	None	None	None	None	None	None
Henry R. Halperin	Johns Hopkins University–Professor	†Zoll Circulation	None	None	*Surgivision Lexmed	†Zoll Circulation *Cardiac Concepts	†State of Hawaii *US Department of Justice
Ricardo A. Samson	University of Arizona: clinical care, teaching and research with pediatric cardiology in an academic setting-Professor	None	None	None	None	None	None
Roger D. White	Mayo Clinic–staff physician	None	None	None	None	None	None
Michael T. Cudnik	The Ohio State University Medical Center–Assistant Professor, Dept of Emergency Medicine	†Current Funding AHA Scientist Development Grant. I am the PI on this 4 year project (July 2008-June 2012) that is evaluating the impact of transport distance, transport time, and hospital level factors on survival from CA. There is no perceived conflict with this project. The money from the AHA goes to the Ohio State Research Foundation. Pending Funding R03 Small Research Grant Program, Funding Agency AHRQ. This grant is pending. It is a 1 year project designed to look at the location of current AEDs in the city of Columbus relative to the location of the out of hospital CA in order to determine the optimal location of AEDs in a community. If funded, the money will go to the Ohio State Research Foundation	None	None	None	None	None
Marc D. Berg	University of Arizona/University Physician's Healthcare (UPH): Attending pediatric intensivist and Board Member of UPH. UPH is a physician group of the faculty of the College of Medicine. The Board oversees three distinct entities: the physician group, the UPH managed care plan, and the operations of UPH Hospital.-Associate Prof. of Clinical Pediatrics and Member, BOD	None	None	None	None	None	None
Peter J. Kudenchuk	University of Washington - Medical Professor of Medicine; Contracted Associate Medical Director, King County Emergency Medical Services - Associate Medical Director	Resuscitation Outcomes Consortium (NIH) –multicenter study of resuscitation. Funds come to the University of Washington	None	*Network for Continuing Medical Education, Academy for Healthcare Education, Sanofi-Aventis, Pri-Med, Horiizon CME, with honoraria	*Sanofi-Aventis, Novartis	None	*Occasional expert witness in medical malpractice cases

(*Continued*)

Guidelines Part 6: Electrical Therapies: Writing Group Disclosures, *Continued*

Writing Group Member	Employment	Research Grant	Other Research Support	Speakers' Bureau/Honoraria	Ownership Interest	Consultant/Advisory Board	Other
Richard E. Kerber	University of Iowa Hospitals and Clinics: Staff Cardiologist–Professor of Medicine	None	None	*Occasional speaker at Cardiology Grand Rounds at other hospitals. Usual honorarium is $1000 for such talks, about 3/year. The money is paid by the institution that invites me to speak, and is paid to me personally. I gave a talk several months ago to Philips Medical Co. on my hypothermia research, and provided advice on aspects of defibrillator design $1000 honorarium; one-time event I am a member of a DSMB of a clinical trial of a new Resuscitation product of Zoll. There have been 2 meetings of this DSMB in the past 2 years, & expect subsequent meetings to review/discuss the trial as data are acquired. Compensation so far about $2000	None	*See previous comments about relationships with Philips (one-time) and Zoll (DSMB)	†I have served as an expert witness in lawsuits in the past. Occasionally such suits have involved cardiac resuscitation, although not for several years.

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

*Modest.

†Significant.

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KEY WORDS: arrhythmia ■ automatic external defibrillator ■ cardioversion ■ ventricular fibrillation

Part 6: Electrical Therapies: Automated External Defibrillators, Defibrillation, Cardioversion, and Pacing2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care

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Correction

In the article by Link et al, "Part 6: Electrical Therapies: Automated External Defibrillators, Defibrillation, Cardioversion, and Pacing: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care," which published ahead of print on October 18, 2010, and appeared with the November 2, 2010, issue of the journal (*Circulation.* 2010;122[suppl 3]:S706–S719), a change was needed.

On page S708, in the right column, the first complete paragraph, the third sentence read, "Therefore, for biphasic defibrillators, providers should use the manufacturer's recommended energy dose (120 to 200 J) (Class I, LOE B)." It has been updated to read, "Therefore, for biphasic defibrillators, providers should use the manufacturer's recommended energy dose (eg, initial dose of 120 to 200 J) (Class I, LOE B)."

This correction has been made to the current online version of the article, which is available at http://circ.ahajournals.org/cgi/content/full/122/18_suppl_3/S706.

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