European Resuscitation Council Guidelines for Resuscitation 2010 Section 3. Electrical therapies: Automated external defibrillators, defibrillation, cardioversion and pacing

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Summary of changes since 2005 Guidelines

The most important changes in the 2010 European Resuscitation Council (ERC) guidelines for electrical therapies include:

- The importance of early, uninterrupted chest compressions is emphasised throughout these guidelines.
- Much greater emphasis on minimising the duration of the pre-shock and post-shock pauses. The continuation of compressions during charging of the defibrillator is recommended.
- Immediate resumption of chest compressions following defibrillation is also emphasised; in combination with continuation of compressions during defibrillator charging, the delivery of defibrillation should be achievable with an interruption in chest compressions of no more than 5 s.
- Safety of the rescuer remains paramount, but there is recognition in these guidelines that the risk of harm to a rescuer from a defibrillator is very small, particularly if the rescuer is wearing gloves. The focus is now on a rapid safety check to minimise the pre-shock pause.
- When treating out-of-hospital cardiac arrest, emergency medical services (EMS) personnel should provide good-quality CPR while a defibrillator is retrieved, applied and charged, but routine delivery of a pre-specified period of CPR (e.g., 2 or 3 min) before rhythm analysis and a shock is delivered is no longer recommended. For some emergency medical services that have already fully implemented a pre-specified period of chest compressions before defibrillation, given the lack of convincing data either supporting or refuting this strategy, it is reasonable for them to continue this practice.
- The use of up to three-stacked shocks may be considered if ventricular fibrillation/pulseless ventricular tachycardia (VF/VT)

occurs during cardiac catheterisation or in the early post-operative period following cardiac surgery. This three-shock strategy may also be considered for an initial, witnessed VF/VT cardiac arrest when the patient is already connected to a manual defibrillator.
- Electrode pastes and gels can spread between the two paddles, creating the potential for a spark and should not be used

Introduction

The chapter presents guidelines for defibrillation using both automated external defibrillators (AEDs) and manual defibrillators. There are only a few differences from the 2005 ERC Guidelines. All healthcare providers and lay responders can use AEDs as an integral component of basic life support. Manual defibrillation is used as part of advanced life support (ALS) therapy. Synchronised cardioversion and pacing options are included on many defibrillators and are also discussed in this chapter.

Defibrillation is the passage of an electrical current across the myocardium of sufficient magnitude to depolarise a critical mass of myocardium and enable restoration of coordinated electrical activity. Defibrillation is defined as the termination of fibrillation or, more precisely, the absence of VF/VT at 5 s after shock delivery; however, the goal of attempted defibrillation is to restore an organised rhythm and a spontaneous circulation.

Defibrillator technology is advancing rapidly. AED interaction with the rescuer through voice prompts is now established and future technology may enable more specific instructions to be given by voice prompt. The evolving ability of defibrillators to assess the rhythm whilst CPR is in progress is an important advance and enables rescuers to assess the rhythm without interrupting external chest compressions. In the future, waveform analysis may also enable the defibrillator to calculate the optimal time at which to give a shock.

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A vital link in the Chain of Survival

Defibrillation is a key link in the Chain of Survival and is one of the few interventions that have been shown to improve outcome from VF/VT cardiac arrest. The previous guidelines published in 2005 rightly emphasized the importance of early defibrillation with minimum delay.[1,2]

The probability of successful defibrillation and subsequent survival to hospital discharge declines rapidly with time[3,4] and the ability to deliver early defibrillation is one of the most important factors in determining survival from cardiac arrest. For every minute delay in defibrillation, in the absence of bystander CPR, survival from witnessed VF decreases by 10–12%.[4,5] EMS systems do not generally have the capability to deliver defibrillation through traditional paramedic responders within the first few minutes of a call and the alternative use of trained lay responders to deliver prompt defibrillation using AEDs is now widespread. EMS systems that have reduced time to defibrillation following cardiac arrest using trained lay responders have reported greatly improved survival to hospital discharge rates,[6–9] some as high as 75% if defibrillation is performed within 3 min of collapse.[10] This concept has also been extended to in-hospital cardiac arrests where staff, other than doctors, are also being trained to defibrillate using an AED before arrival of the cardiac arrest team.[11]

When bystander CPR is provided, the fall in survival is more gradual and averages 3–4% per minute from collapse to defibrillation[3,4,12]; bystander CPR can double[3,4,13] or triple[14] survival from witnessed out-of-hospital cardiac arrest. Resuscitation instructions given by the ambulance service before the arrival of trained help increase the quantity and quality of bystander CPR[15,16] and use of video instructions by phone may improve performance further.[17,18]

All healthcare providers with a duty to perform CPR should be trained, equipped, and encouraged to perform defibrillation and CPR. Early defibrillation should be available throughout all hospitals, outpatient medical facilities and public areas of mass gathering (see Section 2).[19] Those trained in the use of an AED should also be trained to deliver high-quality CPR before arrival of ALS providers so that the effectiveness of early defibrillation can be optimised.

Automated external defibrillators

Automated external defibrillators are sophisticated, reliable computerised devices that use voice and visual prompts to guide lay rescuers and healthcare professionals to safely attempt defibrillation in cardiac arrest victims. Some AEDs combine guidance for defibrillation with guidance for the delivery of optimal chest compressions. Use of AEDs by lay or non-healthcare rescuers is covered in Section 2.[19]

In many situations, an AED is used to provide initial defibrillation but is subsequently swapped for a manual defibrillator on arrival of EMS personnel. If such a swap is done without considering the phase the AED cycle is in, the next shock may be delayed, which may compromise outcome.[20] For this reason, EMS personnel should leave the AED connected while securing airway and IV access. The AED should be left attached for the next rhythm analysis and, if indicated, a shock delivered before the AED is swapped for a manual defibrillator.

Currently many manufacturers use product-specific electrode to defibrillator connectors, which necessitates the defibrillation pads also being removed and replaced with a pair compatible with the new defibrillator. Manufacturers are encouraged to collaborate and develop a universal connector that enables all defibrillation pads to be compatible with all defibrillators. This will have significant patient benefit and minimise unnecessary waste.

In-hospital use of AEDs

At the time of the 2010 Consensus on CPR Science Conference there were no published randomised trials comparing in-hospital use of AEDs with manual defibrillators. Two lower level studies of adults with in-hospital cardiac arrest from shockable rhythms showed higher survival to hospital discharge rates when defibrillation was provided through an AED programme than with manual defibrillation alone.[21,22] One retrospective study[23] demonstrated no improvements in survival to hospital discharge for in-hospital adult cardiac arrest when using an AED compared with manual defibrillation. In this study, patients in the AED group with initial asystole or pulseless electrical activity (PEA) had a lower survival to hospital discharge rate compared with those in the manual defibrillator group (15% versus 23%; $p = 0.04$). A manikin study showed that use of an AED significantly increased the likelihood of delivering three shocks but increased the time to deliver the shocks when compared with manual defibrillators.[24] In contrast, a study of mock arrests in simulated patients showed that use of monitoring leads and fully automated defibrillators reduced time to defibrillation when compared with manual defibrillators.[25]

Delayed defibrillation may occur when patients sustain cardiac arrest in unmonitored hospital beds and in outpatient departments.[26] In these areas several minutes may elapse before resuscitation teams arrive with a defibrillator and deliver shocks. Despite limited evidence, AEDs should be considered for the hospital setting as a way to facilitate early defibrillation (a goal of <3 min from collapse), especially in areas where healthcare providers have no rhythm recognition skills or where they use defibrillators infrequently. An effective system for training and retraining should be in place.[11] Enough healthcare providers should be trained to enable achievement of the goal of providing the first shock within 3 min of collapse anywhere in the hospital. Hospitals should monitor collapse-to-first shock intervals and monitor resuscitation outcomes.

Shock in manual versus semi-automatic mode

Many AEDs can be operated in both manual and semi-automatic mode but few studies have compared these two options. The semi-automatic mode has been shown to reduce time to first shock when used both in-hospital[27] and pre-hospital[28] settings, and results in higher VF conversion rates,[28] and delivery of fewer inappropriate shocks.[29] Conversely, semi-automatic modes result in less time spent performing chest compressions[29,30] mainly because of a longer pre-shock pause associated with automated rhythm analysis. Despite these differences, no overall difference in return of spontaneous circulation (ROSC), survival, or discharge rate from hospital has been demonstrated in any study.[23,27,28] The defibrillation mode that affords the best outcome will depend on the system, skills, training and ECG recognition skills of rescuers. A shorter pre-shock pause and lower total hands-off-ratio increases vital organ perfusion and the probability of ROSC.[31–33] With manual defibrillators and some AEDs it is possible to perform chest compressions during charging and thereby reduce the pre-shock pause to less than 5 s. Trained individuals may deliver defibrillation in manual mode but frequent team training and ECG recognition skills are essential.

Automated rhythm analysis

Automated external defibrillators have microprocessors that analyse several features of the ECG, including frequency and amplitude. Developing technology should soon enable AEDs to provide information about frequency and depth of chest compressions dur-

ing CPR that may improve basic life support (BLS) performance by all rescuers.[34,35]

Automated external defibrillators have been tested extensively against libraries of recorded cardiac rhythms and in many trials in adults[36,37] and children.[38,39] They are extremely accurate in rhythm analysis. Although most AEDs are not designed to deliver synchronised shocks, all AEDs will recommend shocks for VT if the rate and R-wave morphology and duration exceeds preset values. Most AEDs require a 'hands-off' period while the device analyses the rhythm. This 'hands-off' period results in interruption to chest compressions for varying but significant periods of time[40]; a factor shown to have significant adverse impact on outcome from cardiac arrest.[41] Manufacturers of these devices should make every effort to develop software that minimises this analysis period to ensure that interruptions to external chest compressions are kept to a minimum.

Strategies before defibrillation

Minimising the pre-shock pause

The delay between stopping chest compressions and delivery of the shock (the pre-shock pause) must be kept to an absolute minimum; even 5–10 s delay will reduce the chances of the shock being successful.[31,32,42] The pre-shock pause can easily be reduced to less than 5 s by continuing compressions during charging of the defibrillator and by having an efficient team coordinated by a leader who communicates effectively. The safety check to ensure that nobody is in contact with the patient at the moment of defibrillation should be undertaken rapidly but efficiently. The negligible risk of a rescuer receiving an accidental shock is minimised even further if all rescuers wear gloves.[43] The post-shock pause is minimised by resuming chest compressions immediately after shock delivery (see below). The entire process of defibrillation should be achievable with no more than a 5 s interruption to chest compression.

Safe use of oxygen during defibrillation

In an oxygen-enriched atmosphere, sparking from poorly applied defibrillator paddles can cause a fire.[44–49] There are several reports of fires being caused in this way and most have resulted in significant burns to the patient. There are no case reports of fires caused by sparking where defibrillation was delivered using adhesive pads. In two manikin studies the oxygen concentration in the zone of defibrillation was not increased when ventilation devices (bag-valve device, self-inflating bag, modern intensive care unit ventilator) were left attached to a tracheal tube or the oxygen source was vented at least 1 m behind the patient's mouth.[50,51] One study described higher oxygen concentrations and longer washout periods when oxygen is administered in confined spaces without adequate ventilation.[52]

The risk of fire during attempted defibrillation can be minimised by taking the following precautions:

- Take off any oxygen mask or nasal cannulae and place them at least 1 m away from the patient's chest.
- Leave the ventilation bag connected to the tracheal tube or supraglottic airway device. Alternatively, disconnect any bag-valve device from the tracheal tube or supraglottic airway device and remove it at least 1 m from the patient's chest during defibrillation.
- If the patient is connected to a ventilator, for example in the operating room or critical care unit, leave the ventilator tubing (breathing circuit) connected to the tracheal tube unless chest compressions prevent the ventilator from delivering adequate tidal volumes. In this case, the ventilator is usually substituted by a ventilation bag, which can itself be left connected or detached and removed to a distance of at least 1 m. If the ventilator tubing is disconnected, ensure it is kept at least 1 m from the patient or, better still, switch the ventilator off; modern ventilators generate massive oxygen flows when disconnected. During normal use, when connected to a tracheal tube, oxygen from a ventilator in the critical care unit will be vented from the main ventilator housing well away from the defibrillation zone. Patients in the critical care unit may be dependent on positive end expiratory pressure (PEEP) to maintain adequate oxygenation; during cardioversion, when the spontaneous circulation potentially enables blood to remain well oxygenated, it is particularly appropriate to leave the critically ill patient connected to the ventilator during shock delivery.
- Minimise the risk of sparks during defibrillation. Self-adhesive defibrillation pads are less likely to cause sparks than manual paddles.

Some early versions of the LUCAS external chest compression device are driven by high flow rates of oxygen which discharges waste gas over the patient's chest. High ambient levels of oxygen over the chest have been documented using this device, particularly in relatively confined spaces such as the back of the ambulance and caution should be used when defibrillating patients while using the oxygen-powered model.[52]

The technique for electrode contact with the chest

Optimal defibrillation technique aims to deliver current across the fibrillating myocardium in the presence of minimal transthoracic impedance. Transthoracic impedance varies considerably with body mass, but is approximately 70–80 Ω in adults.[53,54] The techniques described below aim to place external electrodes (paddles or self-adhesive pads) in an optimal position using techniques that minimise transthoracic impedance.

Shaving the chest

Patients with a hairy chest have poor electrode-to-skin electrical contact and air trapping beneath the electrode. This causes high impedance, reduced defibrillation efficacy, risk of arcing (sparks) from electrode-to-skin and electrode to electrode and is more likely to cause burns to the patient's chest. Rapid shaving of the area of intended electrode placement may be necessary, but do not delay defibrillation if a shaver is not immediately available. Shaving the chest *per se* may reduce transthoracic impedance slightly and has been recommended for elective DC cardioversion with monophasic defibrillators,[55] although the efficacy of biphasic impedance-compensated waveforms may not be so susceptible to higher transthoracic impedance.[56]

Paddle force

If using paddles, apply them firmly to the chest wall. This reduces transthoracic impedance by improving electrical contact at the electrode–skin interface and reducing thoracic volume.[57] The defibrillator operator should always press firmly on handheld electrode paddles, the optimal force being 8 kg in adult and 5 kg in children 1–8 years using adult paddles.[58] Eight kilogram force may be attainable only by the strongest members of the cardiac arrest team and therefore it is recommended that these individuals apply the paddles during defibrillation. Unlike self-adhesive pads, manual paddles have a bare metal plate that requires a conductive material placed between the metal and patient's skin to improve electrical

contact. Use of bare-metal paddles alone creates high transthoracic impedance and is likely to increase the risk of arcing and worsen cutaneous burns from defibrillation.

Electrode position

No human studies have evaluated the electrode position as a determinant of ROSC or survival from VF/VT cardiac arrest. Transmyocardial current during defibrillation is likely to be maximal when the electrodes are placed so that the area of the heart that is fibrillating lies directly between them (i.e. ventricles in VF/VT, atria in AF). Therefore, the optimal electrode position may not be the same for ventricular and atrial arrhythmias.

More patients are presenting with implantable medical devices (e.g., permanent pacemaker, implantable cardioverter defibrillator (ICD)). Medic Alert bracelets are recommended for these patients. These devices may be damaged during defibrillation if current is discharged through electrodes placed directly over the device.[59,60] Place the electrode away from the device (at least 8 cm)[59] or use an alternative electrode position (anterior-lateral, anterior-posterior) as described below.

Transdermal drug patches may prevent good electrode contact, causing arcing and burns if the electrode is placed directly over the patch during defibrillation.[61,62] Remove medication patches and wipe the area before applying the electrode.

Placement for ventricular arrhythmias and cardiac arrest

Place electrodes (either pads or paddles) in the conventional sternal-apical position. The right (sternal) electrode is placed to the right of the sternum, below the clavicle. The apical paddle is placed in the left mid-axillary line, approximately level with the V6 ECG electrode or female breast. This position should be clear of any breast tissue. It is important that this electrode is placed sufficiently laterally. Other acceptable pad positions include

- Placement of each electrode on the lateral chest walls, one on the right and the other on the left side (bi-axillary).
- One electrode in the standard apical position and the other on the right upper back.
- One electrode anteriorly, over the left precordium, and the other electrode posteriorly to the heart just inferior to the left scapula.

It does not matter which electrode (apex/sternum) is placed in either position.

Transthoracic impedance has been shown to be minimised when the apical electrode is not placed over the female breast.[63] Asymmetrically shaped apical electrodes have a lower impedance when placed longitudinally rather than transversely.[64]

Placement for atrial arrhythmias

Atrial fibrillation is maintained by functional re-entry circuits anchored in the left atrium. As the left atrium is located posteriorly in the thorax, electrode positions that result in a more posterior current pathway may theoretically be more effective for atrial arrhythmias. Although some studies have shown that antero-posterior electrode placement is more effective than the traditional antero-apical position in elective cardioversion of atrial fibrillation,[65,66] the majority have failed to demonstrate any clear advantage of any specific electrode position.[67,68] Efficacy of cardioversion may be less dependent on electrode position when using biphasic impedance-compensated waveforms.[56] The following electrode positions all appear safe and effective for cardioversion of atrial arrhythmias:

- Traditional antero-apical position.
- Antero-posterior position (one electrode anteriorly, over the left precordium, and the other electrode posteriorly to the heart just inferior to the left scapula).

Respiratory phase

Transthoracic impedance varies during respiration, being minimal at end-expiration. If possible, defibrillation should be attempted at this phase of the respiratory cycle. Positive end expiratory pressure (PEEP) increases transthoracic impedance and should be minimised during defibrillation. Auto-PEEP (gas trapping) may be particularly high in asthmatics and may necessitate higher than usual energy levels for defibrillation.[69]

Electrode size

The Association for the Advancement of Medical Instrumentation recommends a minimum electrode size of for individual electrodes and the sum of the electrode areas should be a minimum of 150 cm^2.[70] Larger electrodes have lower impedance, but excessively large electrodes may result in less transmyocardial current flow.[71]

For adult defibrillation, both handheld paddle electrodes and self-adhesive pad electrodes 8–12 cm in diameter are used and function well. Defibrillation success may be higher with electrodes of 12 cm diameter compared with those of 8 cm diameter.[54,72]

Standard AEDs are suitable for use in children over the age of 8 years. In children between 1 and 8 years use paediatric pads with an attenuator to reduce delivered energy or a paediatric mode if they are available; if not, use the unmodified machine, taking care to ensure that the adult pads do not overlap. Use of AEDs is not recommended in children less than 1 year.

Coupling agents

If using manual paddles, disposable gel pads should be used to reduce impedance at the electrode–skin interface. Electrode pastes and gels can spread between the two paddles, creating the potential for a spark and should not be used. Do not use bare electrodes without gel pads because the resultant high transthoracic impedance may impair the effectiveness of defibrillation, increase the severity of any cutaneous burns and risk arcing with subsequent fire or explosion.

Pads versus paddles

Self-adhesive defibrillation pads have practical benefits over paddles for routine monitoring and defibrillation.[73–77] They are safe and effective and are preferable to standard defibrillation paddles.[72] Consideration should be given to use of self-adhesive pads in peri-arrest situations and in clinical situations where patient access is difficult. They have a similar transthoracic impedance[71] (and therefore efficacy)[78,79] to manual paddles and enable the operator to defibrillate the patient from a safe distance rather than leaning over the patient as occurs with paddles. When used for initial monitoring of a rhythm, both pads and paddles enable quicker delivery of the first shock compared with standard ECG electrodes, but pads are quicker than paddles.[80]

When gel pads are used with paddles, the electrolyte gel becomes polarised and thus is a poor conductor after defibrillation. This can cause spurious asystole that may persist for 3–4 min when used to monitor the rhythm; a phenomenon not reported with self-adhesive pads.[74,81] When using a gel pad/paddle combination confirm a diagnosis of asystole with independent ECG electrodes rather than the paddles.

Fibrillation waveform analysis

It is possible to predict, with varying reliability, the success of defibrillation from the fibrillation waveform.[82–101] If optimal defibrillation waveforms and the optimal timing of shock delivery can be determined in prospective studies, it should be possible to prevent the delivery of unsuccessful high energy shocks and minimise myocardial injury. This technology is under active development and investigation but current sensitivity and specificity is insufficient to enable introduction of VF waveform analysis into clinical practice.

CPR versus defibrillation as the initial treatment

A number of studies have examined whether a period of CPR prior to defibrillation is beneficial, particularly in patients with an unwitnessed arrest or prolonged collapse without resuscitation. A review of evidence for the 2005 guidelines resulted in the recommendation that it was reasonable for EMS personnel to give a period of about 2 min of CPR (i.e. about five cycles at 30:2) before defibrillation in patients with prolonged collapse (>5 min).[1] This recommendation was based on clinical studies where response times exceeded 4–5 min, a period of 1.5–3 min of CPR by paramedics or EMS physicians before shock delivery improved ROSC, survival to hospital discharge[102,103] and one year survival[103] for adults with out-of-hospital VF/VT compared with immediate defibrillation. In some animal studies of VF lasting at least 5 min, CPR before defibrillation improved haemodynamics and survival.[103–106] A recent ischaemic swine model of cardiac arrest showed a decreased survival after pre-shock CPR.[107]

In contrast, two randomized controlled trials, a period of 1.5–3 min of CPR by EMS personnel before defibrillation did not improve ROSC or survival to hospital discharge in patients with out-of-hospital VF/VT, regardless of EMS response interval.[108,109] Four other studies have also failed to demonstrate significant improvements in overall ROSC or survival to hospital discharge with an initial period of CPR,[102,103,110,111] although one did show a higher rate of favourable neurological outcome at 30 days and one year after cardiac arrest.[110]

The duration of collapse is frequently difficult to estimate accurately and there is evidence that performing chest compressions while retrieving and charging a defibrillator improves the probability of survival.[112] For these reasons, in any cardiac arrest they have not witnessed, EMS personnel should provide good-quality CPR while a defibrillator is retrieved, applied and charged, but routine delivery of a pre-specified period of CPR (e.g., 2 or 3 min) before rhythm analysis and a shock is delivered is not recommended. Some EMS systems have already fully implemented a pre-specified period of chest compressions before defibrillation; given the lack of convincing data either supporting or refuting this strategy, it is reasonable for them to continue this practice.

In hospital environments, settings with an AED on-site and available (including lay responders), or EMS-witnessed events, defibrillation should be performed as soon as the defibrillator is available. Chest compressions should be performed until just before the defibrillation attempt (see Section 4 advanced life support).[113]

The importance of early, uninterrupted chest compressions is emphasised throughout these guidelines. In practice, it is often difficult to ascertain the exact time of collapse and, in any case, CPR should be started as soon as possible. The rescuer providing chest compressions should interrupt chest compressions only for ventilations, rhythm analysis and shock delivery, and should resume chest compressions as soon as a shock is delivered. When two rescuers are present, the rescuer operating the AED should apply the electrodes whilst CPR is in progress. Interrupt CPR only when it is necessary to assess the rhythm and deliver a shock. The AED operator should be prepared to deliver a shock as soon as analysis is complete and the shock is advised, ensuring no rescuer is in contact with the victim.

Delivery of defibrillation

One-shock versus three-stacked shock sequence

A major change in the 2005 guidelines was the recommendation to give single rather than three-stacked shocks. This was because animal studies had shown that relatively short interruptions in external chest compression to deliver rescue breaths[114,115] or perform rhythm analysis[33] were associated with post-resuscitation myocardial dysfunction and reduced survival. Interruptions in external chest compression also reduced the chances of converting VF to another rhythm.[32] Analysis of CPR performance during out-of-hospital[34,116] and in-hospital[35] cardiac arrest also showed that significant interruptions were common, with chest compressions comprising no more than 51–76%[34,35] of total CPR time.

With first shock efficacy of biphasic waveforms generally exceeding 90%,[117–120] failure to cardiovert VF successfully is more likely to suggest the need for a period of CPR rather than a further shock. Even if the defibrillation attempt is successful in restoring a perfusing rhythm, it is very rare for a pulse to be palpable immediately after defibrillation and the delay in trying to palpate a pulse will further compromise the myocardium if a perfusing rhythm has not been restored.[40]

Subsequent studies have shown a significantly lower hands-off-ratio with the one-shock protocol[121] and some,[41,122,123] but not all,[121,124] have suggested a significant survival benefit from this single-shock strategy. However, all studies except one[124] were before-after studies and all introduced multiple changes in the protocol, making it difficult to attribute a possible survival benefit to one of the changes.

When defibrillation is warranted, give a single shock and resume chest compressions immediately following the shock. Do not delay CPR for rhythm reanalysis or a pulse check immediately after a shock. Continue CPR (30 compressions:2 ventilations) for 2 min until rhythm reanalysis is undertaken and another shock given (if indicated) (see Section 4 advanced life support).[113] This single-shock strategy is applicable to both monophasic and biphasic defibrillators.

If VF/VT occurs during cardiac catheterisation or in the early post-operative period following cardiac surgery (when chest compressions could disrupt vascular sutures), consider delivering up to three-stacked shocks before starting chest compressions (see Section 8 special circumstances).[125] This three-shock strategy may also be considered for an initial, witnessed VF/VT cardiac arrest if the patient is already connected to a manual defibrillator. Although there are no data supporting a three-shock strategy in any of these circumstances, it is unlikely that chest compressions will improve the already very high chance of return of spontaneous circulation when defibrillation occurs early in the electrical phase, immediately after onset of VF.

Waveforms

Historically, defibrillators delivering a monophasic pulse had been the standard of care until the 1990s. Monophasic defibrillators deliver current that is unipolar (i.e. one direction of current flow) (Fig. 3.1). Monophasic defibrillators were particularly susceptible to waveform modification depending on transthoracic impedance. Small patients with minimal transthoracic impedance received considerably greater transmyocardial current than larger patients,
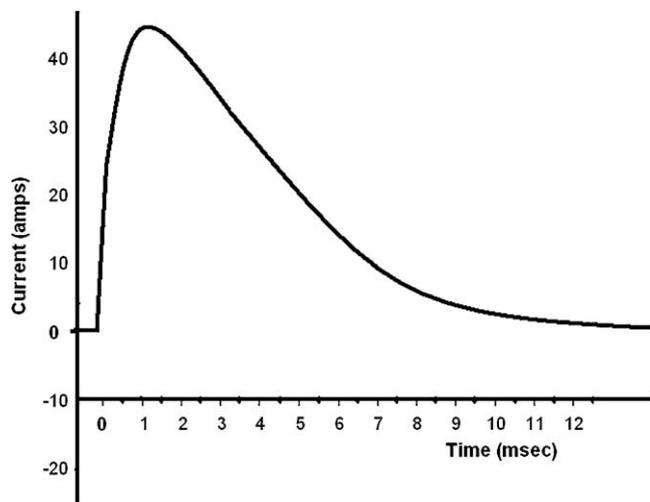
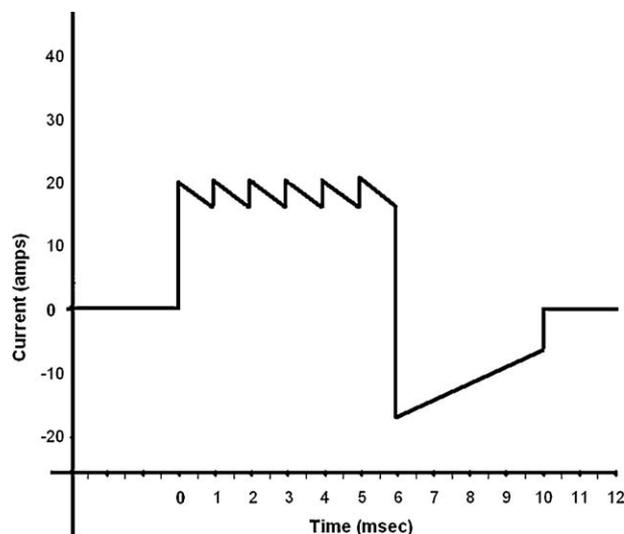**Fig. 3.1.** Monophasic damped sinusoidal waveform (MDS).

Fig. 3.3. Rectilinear biphasic waveform (RLB).

where not only was the current less, but the waveform lengthened to the extent that its efficacy was reduced.

Monophasic defibrillators are no longer manufactured, and although many will remain in use for several years, biphasic defibrillators have now superseded them. Biphasic defibrillators deliver current that flows in a positive direction for a specified duration before reversing and flowing in a negative direction for the remaining milliseconds of the electrical discharge. There are two main types of biphasic waveform: the biphasic truncated exponential (BTE) (Fig. 3.2) and rectilinear biphasic (RLB) (Fig. 3.3). Biphasic defibrillators compensate for the wide variations in transthoracic impedance by electronically adjusting the waveform magnitude and duration to ensure optimal current delivery to the myocardium, irrespective of the patient's size.

A pulsed biphasic waveform has recently been described in which the current rapidly oscillates between baseline and a positive value before inverting in a negative pattern. This waveform is also in clinical use. It may have a similar efficacy as other biphasic waveforms, but the single clinical study of this waveform was not performed with an impedance compensating device.[126,127] There are several other different biphasic waveforms, all with no clinical evidence of superiority for any individual waveform compared with another.

All manual defibrillators and AEDs that allow manual override of energy levels should be labelled to indicate their waveform (monophasic or biphasic) and recommended energy levels for attempted defibrillation of VF/VT.
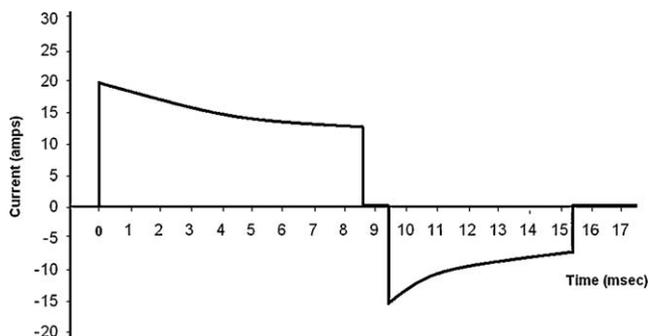
Monophasic versus biphasic defibrillation

Although biphasic waveforms are more effective at terminating ventricular arrhythmias at lower energy levels, have demonstrated greater first shock efficacy than monophasic waveforms, and have greater first shock efficacy for long duration VF/VT,[128–130] no randomised studies have demonstrated superiority in terms of neurologically intact survival to hospital discharge.

Some,[119,128–133] but not all,[134] studies suggest the biphasic waveform improves short-term outcomes of VF termination compared with monophasic defibrillation.

Biphasic waveforms have been shown to be superior to monophasic waveforms for elective cardioversion of atrial fibrillation, with greater overall success rates, using less cumulative energy and reducing the severity of cutaneous burns,[135–138] and are the waveform of choice for this procedure.

Multiphasic versus biphasic defibrillation

A number of multiphasic waveforms (e.g. triphasic, quadriphasic, multiphasic) have also been trialled in animal studies. Animal data suggest that multiphasic waveforms may defibrillate at lower energies and induce less post-shock myocardial dysfunction.[139–141] These results are limited by studies of short duration of VF (approximately 30 s) and lack of human studies for validation. At present, there are no human studies comparing a multiphasic waveform with biphasic waveforms for defibrillation and no defibrillator currently available uses multiphasic waveforms.

Energy levels

Defibrillation requires the delivery of sufficient electrical energy to defibrillate a critical mass of myocardium, abolish the wavefronts of VF and enable restoration of spontaneous synchronized electrical activity in the form of an organised rhythm. The optimal energy for defibrillation is that which achieves defibrillation whilst causing the minimum of myocardial damage.[142] Selection of an appropriate energy level also reduces the number of repetitive shocks, which in turn limits myocardial damage.[143]

Optimal energy levels for both monophasic and biphasic waveforms are unknown. The recommendations for energy levels are based on a consensus following careful review of the current literature. Although energy levels are selected for defibrillation, it is the transmyocardial current flow that achieves defibrilla-

Fig. 3.2. Biphasic truncated exponential waveform (BTE).

tion. Current correlates well with successful defibrillation and cardioversion.[144] The optimal current for defibrillation using a monophasic waveform is in the range of 30–40 A. Indirect evidence from measurements during cardioversion for atrial fibrillation suggests that the current during defibrillation using biphasic waveforms is in the range of 15–20 A.[137] Future technology may enable defibrillators to discharge according to transthoracic current; a strategy that may lead to greater consistency in shock success. Peak current amplitude, average current and phase duration all need to be studied to determine optimal values and manufacturers are encouraged to explore further this move from energy-based to current-based defibrillation.

First shock

Monophasic defibrillators

There are no new published studies looking at the optimal energy levels for monophasic waveforms since publication of the 2005 guidelines. First shock efficacy for long duration cardiac arrest using monophasic defibrillation has been reported as 54–63% for a 200 J monophasic truncated exponential (MTE) waveform[129,145] and 77–91% using a 200 J monophasic damped sinusoidal (MDS) waveform.[128–130,145] Because of the lower efficacy of this waveform, the recommended initial energy level for the first shock using a monophasic defibrillator is 360 J. Although higher energy levels risk a greater degree of myocardial injury, the benefits of earlier conversion to a perfusing rhythm are paramount. Atrioventricular block is more common with higher monophasic energy levels, but is generally transient and has been shown not to affect survival to hospital discharge.[146] Only one of 27 animal studies demonstrated harm caused by attempted defibrillation using high energy shocks.[147]

Biphasic defibrillators

Relatively few studies have been published in the past 5 years on which to refine the 2005 guidelines. There is no evidence that one biphasic waveform or device is more effective than another. First shock efficacy of the BTE waveform using 150–200 J has been reported as 86–98%.[128,129,145,148,149] First shock efficacy of the RLB waveform using 120 J is up to 85% (data not published in the paper but supplied by personnel communication).[130] First shock efficacy of a new pulsed biphasic waveform at 130 J showed a first shock success rate of 90%.[126] Two studies have suggested equivalence with lower and higher starting energy biphasic defibrillation.[150,151] Although human studies have not shown harm (raised biomarkers, ECG changes, ejection fraction) from any biphasic waveform up to 360 J,[150,152] several animal studies have suggested the potential for harm with higher energy levels.[153–156]

The initial biphasic shock should be no lower than 120 J for RLB waveforms and 150 J for BTE waveforms. Ideally, the initial biphasic shock energy should be at least 150 J for all waveforms.

Manufacturers should display the effective waveform dose range on the face of the biphasic defibrillator; older monophasic defibrillators should also be marked clearly with the appropriate dose range. If the rescuer is unaware of the recommended energy settings of the defibrillator, use the highest setting for all shocks.

Second and subsequent shocks

The 2005 guidelines recommended either a fixed or escalating energy strategy for defibrillation. Subsequent to these recommendations, several studies have demonstrated that although an escalating strategy reduces the number of shocks required to restore an organised rhythm compared with fixed-dose biphasic defibrillation, and may be needed for successful defibrillation,[157,158] rates of ROSC or survival to hospital discharge are not signifi-

cantly different between strategies.[150,151] Conversely, a fixed-dose biphasic protocol demonstrated high cardioversion rates (>90%) with a three-shock fixed dose protocol but the small number of cases did not exclude a significant lower ROSC rate for recurrent VF.[159] Several in-hospital studies using an escalating shock energy strategy have demonstrated improvement in cardioversion rates (compared with fixed dose protocols) in non-arrest rhythms with the same level of energy selected for both biphasic and monophasic waveforms.[135,137,160–163]

Monophasic defibrillators

Because the initial shock has been unsuccessful at 360 J, second and subsequent shocks should all be delivered at 360 J.

Biphasic defibrillators

There is no evidence to support either a fixed or escalating energy protocol. Both strategies are acceptable; however, if the first shock is not successful and the defibrillator is capable of delivering shocks of higher energy it is reasonable to increase the energy for subsequent shocks.

Recurrent ventricular fibrillation

If a shockable rhythm recurs after successful defibrillation with ROSC, give the next shock with the energy level that had previously been successful.

Other related defibrillation topics

Defibrillation of children

Cardiac arrest is less common in children. Common causes of VF in children include trauma, congenital heart disease, long QT interval, drug overdose and hypothermia.[164–166] Ventricular fibrillation is relatively rare compared with adult cardiac arrest, occurring in 7-15% of paediatric and adolescent arrests.[166–171] Rapid defibrillation of these patients may improve outcome.[171,172]

The optimal energy level, waveform and shock sequence is unknown but as with adults, biphasic shocks appear to be at least as effective as, and less harmful than, monophasic shocks.[173–175] The upper limit for safe defibrillation is unknown, but doses in excess of the previously recommended maximum of 4 J kg^{-1} (as high as 9 J kg^{-1}) have defibrillated children effectively without significant adverse effects.[38,176,177]

The recommended energy levels for manual monophasic defibrillation are 4 J kg^{-1} for the initial shock and subsequent shocks. The same energy levels are recommended for manual biphasic defibrillation.[178] As with adults, if a shockable rhythm recurs, use the energy level for defibrillation that had previously been successful.

For defibrillation of children above the age of 8 years, an AED with standard electrodes is used and standard energy settings accepted. For defibrillation of children between 1 and 8 years, special paediatric electrodes and energy attenuators are recommended; these reduce the delivered energy to a level that approaches that of the energy recommended for manual defibrillators. When these electrodes are not available, an AED with standard electrodes should be used. For defibrillation of children below 1 year of age, an AED, is not recommended; however, there are a few case reports describing the use of AEDs in children aged less than 1 year.[179,180] The incidence of shockable rhythms in infants is very low except when there is cardiac disease[167,181,182]; in these rare cases, if an AED is the only defibrillator available, its use should be considered (preferably with dose attenuator).

Cardioversion

If electrical cardioversion is used to convert atrial or ventricular tachyarrhythmias, the shock must be synchronised to occur with the R wave of the electrocardiogram rather than with the T wave: VF can be induced if a shock is delivered during the relative refractory portion of the cardiac cycle.[183] Synchronisation can be difficult in VT because of the wide-complex and variable forms of ventricular arrhythmia. Inspect the synchronisation marker carefully for consistent recognition of the R wave. If needed, choose another lead and/or adjust the amplitude. If synchronisation fails, give unsynchronised shocks to the unstable patient in VT to avoid prolonged delay in restoring sinus rhythm. Ventricular fibrillation or pulseless VT requires unsynchronised shocks. Conscious patients must be anaesthetised or sedated before attempting synchronised cardioversion.

Atrial fibrillation

Optimal electrode position has been discussed previously, but anterolateral and antero-posterior are both acceptable positions. Biphasic waveforms are more effective than monophasic waveforms for cardioversion of AF[135–138]; and cause less severe skin burns.[184] When available, a biphasic defibrillator should be used in preference to a monophasic defibrillator. Differences in biphasic waveforms themselves have not been established.

Monophasic waveforms

A study of electrical cardioversion for atrial fibrillation indicated that 360 J monophasic damped sinusoidal (MDS) shocks were more effective than 100 or 200 J MDS shocks.[185] Although a first shock of 360 J reduces overall energy requirements for cardioversion,[185] 360 J may cause greater myocardial damage and skin burns than occurs with lower monophasic energy levels and this must be taken into consideration. Commence synchronised cardioversion of atrial fibrillation using an initial energy level of 200 J, increasing in a stepwise manner as necessary.

Biphasic waveforms

More data are needed before specific recommendations can be made for optimal biphasic energy levels. Commencing at high energy levels has not shown to result in more successful cardioversion rates compared to lower energy levels.[135,186–191] An initial synchronised shock of 120–150 J, escalating if necessary is a reasonable strategy based on current data.

Atrial flutter and paroxysmal supraventricular tachycardia

Atrial flutter and paroxysmal SVT generally require less energy than atrial fibrillation for cardioversion.[190] Give an initial shock of 100 J monophasic or 70–120 J biphasic. Give subsequent shocks using stepwise increases in energy.[144]

Ventricular tachycardia

The energy required for cardioversion of VT depends on the morphological characteristics and rate of the arrhythmia.[192] Ventricular tachycardia with a pulse responds well to cardioversion using initial monophasic energies of 200 J. Use biphasic energy levels of 120–150 J for the initial shock. Consider stepwise increases if the first shock fails to achieve sinus rhythm.[192]

Pacing

Consider pacing in patients with symptomatic bradycardia refractory to anti-cholinergic drugs or other second line therapy (see Section 4).[113] Immediate pacing is indicated especially when the block is at or below the His-Purkinje level. If transthoracic pacing is ineffective, consider transvenous pacing. Whenever a diagnosis of asystole is made, check the ECG carefully for the presence of P waves because this will likely respond to cardiac pacing. The use of epicardial wires to pace the myocardium following cardiac surgery is effective and discussed elsewhere. Do not attempt pacing for asystole unless P waves are present; it does not increase short or long-term survival in- or out-of-hospital.[193–201] For haemodynamically unstable, conscious patients with bradyarrhythmias, percussion pacing as a bridge to electrical pacing may be attempted, although its effectiveness has not been established.

Implantable cardioverter defibrillators

Implantable cardioverter defibrillators (ICDs) are becoming increasingly common as the devices are implanted more frequently as the population ages. They are implanted because a patient is considered to be at risk from, or has had, a life-threatening shockable arrhythmia and are usually embedded under the pectoral muscle below the left clavicle (in a similar position to pacemakers, from which they cannot be immediately distinguished). On sensing a shockable rhythm, an ICD will discharge approximately 40 J through an internal pacing wire embedded in the right ventricle. On detecting VF/VT, ICD devices will discharge no more than eight times, but may reset if they detect a new period of VF/VT. Patients with fractured ICD leads may suffer repeated internal defibrillation as the electrical noise is mistaken for a shockable rhythm; in these circumstances, the patient is likely to be conscious, with the ECG showing a relatively normal rate. A magnet placed over the ICD will disable the defibrillation function in these circumstances.

Discharge of an ICD may cause pectoral muscle contraction in the patient, and shocks to the rescuer have been documented.[202] In view of the low energy levels discharged by ICDs, it is unlikely that any harm will come to the rescuer, but the wearing of gloves and minimising contact with the patient whilst the device is discharging is prudent. Cardioverter and pacing function should always be re-evaluated following external defibrillation, both to check the device itself and to check pacing/defibrillation thresholds of the device leads.

Pacemaker spikes generated by devices programmed to unipolar pacing may confuse AED software and emergency personnel, and may prevent the detection of VF.[203] The diagnostic algorithms of modern AEDs are insensitive to such spikes.

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