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,

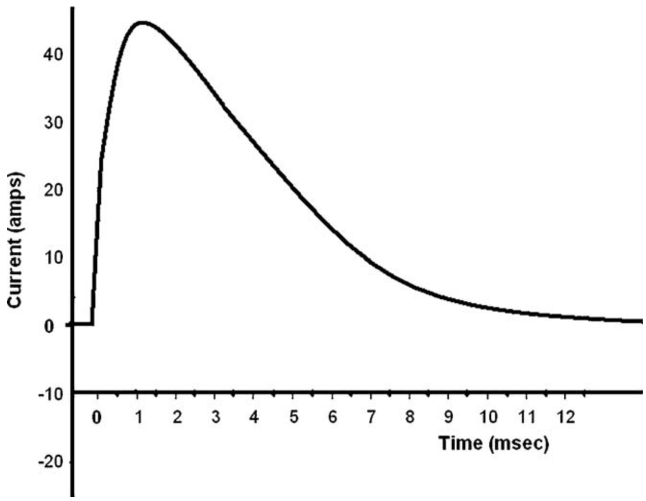

Fig. 3.1. Monophasic damped sinusoidal waveform (MDS).

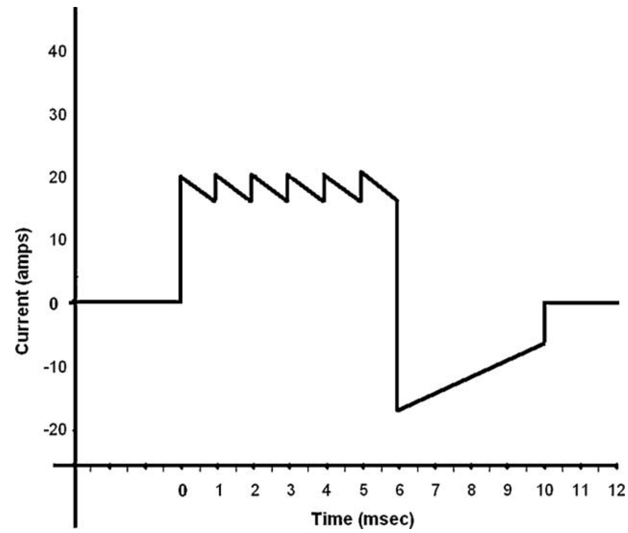

Fig. 3.3. Rectilinear biphasic waveform (RLB).

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.

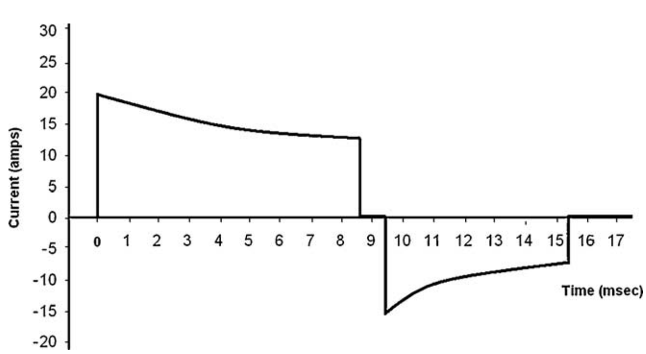

Fig. 3.2. Biphasic truncated exponential waveform (BTE).

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 defibrillation. 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 significantly 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).