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Part 3: Defibrillation

International Liaison Committee on Resuscitation

The 2005 Consensus Conference considered questions related to the sequence of shock delivery and the use and effectiveness of various waveforms and energies. These questions have been grouped into the following categories: (1) strategies before defibrillation; (2) use of automated external defibrillators (AEDs); (3) electrode-patient interface; (4) use of the electrocardiographic (ECG) waveform to alter management; (5) waveform and energy levels for the initial shock; (6) sequence after failure of the initial shock (i.e. second and subsequent shocks; and (7) other related topics.

The International Guidelines 2000[1] state that defibrillation should be attempted as soon as ventricular fibrillation (VF) is detected, regardless of the response interval (i.e. time between collapse and arrival of the AED). If the response interval is >4—5 min, however, there is evidence that 1.5—3 min of CPR before attempted defibrillation may improve the victim's chance of survival. The data in support of out-of-hospital AED programmes continue to accumulate, and there is some evidence supporting the use of AEDs in the hospital. Analysis of the VF waveform enables prediction of the likelihood of defibrillation success; with this information the rescuer can be instructed to give CPR or attempt defibrillation. This technology was developed by analysis of downloads from AEDs; it has yet to be applied prospectively to improve defibrillation success and is not available outside research programmes.

All new defibrillators deliver a shock with a biphasic waveform. There are several varieties of biphasic waveform, but the best variant and the optimal energy level and shock strategy (fixed versus escalating) have yet to be determined. Biphasic devices achieve higher first-shock success rates than monophasic defibrillators. This fact, combined with the knowledge that interruptions to chest compressions are harmful, suggests that a one-shock strategy (one shock followed immediately by CPR) may be preferable to the traditional three-shock sequence for VF and pulseless ventricular tachycardia (VT).

Strategies before defibrillation

Precordial thump
W59,W166B

Consensus on science. No prospective studies have evaluated the use of the precordial (chest) thump. In three case series (LOE 5)[2—4] VF or pulseless VT was converted to a perfusing rhythm by a precordial thump. The likelihood of conversion of VF decreased rapidly with time (LOE 5).[4] The conversion rate was higher for unstable or pulseless VT than for VF (LOE 5).[2—6]

Several observational studies indicated that an effective thump was delivered by a closed fist from a height of 5—40 cm (LOE 5).[3,4,6—8] Other observational studies indicated that additional tachyarrhythmias, such as unstable supraventricular tachycardia (SVT), were terminated by precordial thump (LOE 5).[9,10] Potential complications of the precordial thump include rhythm deteriorations, such as rate acceleration of VT, conversion of VT into VF, complete heart block, and asystole (LOE 5;[3,5,6,8,11,12] LOE 6[13]). Existing data do not enable an accurate estimate of the likelihood of these complications.

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Treatment recommendation. One immediate precordial thump may be considered after a monitored cardiac arrest if an electrical defibrillator is not immediately available.

CPR before defibrillation
W68,W177

Consensus on science. In a before—after study (LOE 4)[14] and a randomised trial (LOE 2),[15] 1.5—3 min of CPR by paramedics or EMS physicians before attempted defibrillation improved return of spontaneous circulation (ROSC) and survival rates for adults with out-of-hospital VF or VT when the response interval (ambulance dispatch to arrival) and time to defibrillation was ≥4—5 min. This contrasts with the results of another trial in adults with out-of-hospital VF or VT, in which 1.5 min of paramedic CPR before defibrillation did not improve ROSC or survival to hospital discharge (LOE 2).[16] In animal studies of VF lasting ≥5 min, CPR (often with administration of adrenaline (epinephrine)) before defibrillation improved haemodynamics and survival rates (LOE 6).[17—21]

Treatment recommendation. A 1.5- to 3-min period of CPR before attempting defibrillation may be considered in adults with out-of-hospital VF or pulseless VT and EMS response (call to arrival) intervals >4—5 min. There is no evidence to support or refute the use of CPR before defibrillation for in-hospital cardiac arrest.

Use of AEDS

AED programmes
W174,W175

Consensus on science. A randomised trial of trained lay responders in public settings (LOE 2)[22] and observational studies of CPR and defibrillation performed by trained professional responders in casinos (LOE 5)[23] and lay responders in airports (LOE 5)[24] and on commercial passenger aircraft (LOE 5)[25,26] showed that AED programmes are safe and feasible and significantly increase survival from out-of-hospital VF cardiac arrest if the emergency response plan is effectively implemented and sustained. In some studies defibrillation by trained first responders (e.g. firefighters or police officers) has improved survival rates from witnessed out-of-hospital VF sudden cardiac arrest (LOE 2;[27] LOE 3;[28,29] LOE 4;[30,31] LOE 5[32]). In other studies AED defibrillation by trained first-responders has not improved survival.[14,33]

Approximately 80% of out-of-hospital cardiac arrests occur in a private or residential setting (LOE 4).[34] However, there are insufficient data to support or refute the effectiveness of home AED programmes.

Treatment recommendation. Use of AEDs by trained lay and professional responders is recommended to increase survival rates in patients with cardiac arrest. Use of AEDs in public settings (airports, casinos, sports facilities, etc.) where witnessed cardiac arrest is likely to occur can be useful if an effective response plan is in place. The response plan should include equipment maintenance, training of likely responders, coordination with local EMS systems, and programme monitoring. No recommendation can be made for or against personal or home AED deployment.

AED Programme quality assurance and maintenance
W178

Consensus on science. No published trials evaluated specifically the effectiveness of AED programme quality improvement efforts to further improve survival rates. Case series and reports suggest that potential improvements can be made by reviewing AED function (rhythm analysis and shock), battery and pad readiness, operator performance, and system performance (e.g. mock codes, time to shock, outcomes) (LOE 5).[35—42]

Treatment recommendation. AED programmes should optimise AED function (rhythm analysis and shock), battery and pad readiness, operator performance, and system performance (e.g. mock codes, time to shock, outcomes).

AED use in hospitals
W62A

Consensus on science. No published randomised trials have compared AEDs with manual defibrillators in hospitals. One study of adults with in-hospital cardiac arrest with shockable rhythms showed higher survival-to-hospital discharge rates when defibrillation was provided through an AED than by manual defibrillation alone (LOE 4).[43] In an animal model, use of an AED substantially interrupted and delayed chest compressions compared with manual defibrillation (LOE 6).[44] 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 (LOE 6).[45] 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 (LOE 7).[46]

Treatment recommendation. Use of AEDs is reasonable to facilitate early defibrillation in hospitals.

Electrode-patient interface

Electrode pad/paddle position and size
W63A,W63B,W173A

Consensus on science.

Position. No studies of cardiac arrest in humans have evaluated the effect of pad/paddle position on defibrillation success or survival rates. Most studies evaluated cardioversion (e.g. atrial fibrillation [AF]) or secondary end points (e.g. transthoracic impedance [TTI]).

Placement of paddles or electrode pads on the superior-anterior right chest and the inferior-lateral left chest were effective (paddles studied in AF, LOE 2;[47] pads studied in AF, LOE 3;[48] effect of pad position on TTI, LOE 3[49]). Alternative paddle or pad positions that were reported to be effective were apex-posterior (pads studied in VF and AF, LOE 4;[50] effect of pad position on TTI, LOE 3[49]), and anteroposterior (paddles studied in AF, LOE 2;[51] pads studied in AF, LOE 2;[52] LOE 3;[53] effect of pad position on TTI, LOE 3[49]). One study showed lower TTI with longitudinal placement of the apical paddle (LOE 3).[54] Placement of the pad on the female breast increased impedance and may decrease efficacy of defibrillation (LOE 5).[55] High-voltage alternating current (e.g. from high power lines) interfered with AED analysis (LOE 6).[56]

Size. One human study (LOE 3)[57] and one animal study (LOE 6)[58] documented higher defibrillation success rates with larger paddles: 12.8-cm paddles were superior to 8-cm paddles. Eight studies (LOE 3;[53,57,59,60] LOE 5[61] LOE 6[55,62,63]) demonstrated that increased pad size decreased TTI. In one canine study, significantly increased myocardial damage was reported after defibrillation with small (4.3 cm) electrodes compared with larger (8 and 12 cm) electrodes (LOE 6).[64]

Treatment recommendation. Paddles and electrode pads should be placed on the exposed chest in an anterolateral position. Acceptable alternative positions are anteroposterior (paddles and pads) and apex-posterior (pads). In large-breasted patients it is reasonable to place the left electrode pad (or paddle) lateral to or underneath the left breast. Defibrillation success may be higher with 12-cm electrodes than with 8-cm electrodes. Small electrodes (4.3 cm) may be harmful (myocardial injury can occur).

Self-adhesive defibrillation pads versus paddles
W71

Consensus on science. One randomised trial (LOE 2)[65] and two retrospective comparisons (LOE 4)[50,66] showed that TTI is similar when either pads or paddles are used. One prospective comparison of pads and paddles (LOE 3)[67] showed lower TTI when paddles were applied at an optimal force of 8 kg compared with pads. One randomised study of chronic AF showed similar effectiveness for self-adhesive pads and manual paddles when monophasic damped sinusoidal or BTE waveforms were evaluated separately (LOE 7).[68] Several studies (LOE 5;[69–71] LOE 6[72]) showed the practical benefits of pads over paddles for routine monitoring and defibrillation, prehospital defibrillation, and perioperative defibrillation.

Treatment recommendation. Self-adhesive defibrillation pads are safe and effective and are an acceptable alternative to standard defibrillation paddles.

Waveform analysis

VF waveform analysis has the potential to improve the timing and effectiveness of defibrillation attempts; this should minimise interruptions in precordial compressions and reduce the number of unsuccessful high-energy shocks, which cause postresuscitation myocardial injury. The technology is advancing rapidly but is not yet available to assist rescuers.

Prediction of shock success from VF waveform
W64A,W64B,W64C,W65A

Consensus on science. Retrospective analyses of the VF waveform in clinical and animal studies and theoretical models (LOE 4;[73–82] LOE 6[83–93]) suggest that it is possible to predict with varying reliability the success of defibrillation from the fibrillation waveform. No studies evaluated specifically whether treatment can be altered by the prediction of defibrillation success to improve survival from cardiac arrest.

Initial shock waveform and energy levels

Several related questions were reviewed. Outcome after defibrillation has been studied by many

investigators. When evaluating these studies the reviewer must consider the setting (e.g. out-of-hospital versus in-hospital), the initial rhythm (e.g. VF/pulseless VT), the duration of arrests (e.g. out-of-hospital with typical EMS response interval versus electrophysiology study with 15-s arrest interval), and the specific outcome measured (e.g. termination of VF at 5 s).

Biphasic versus monophasic waveforms for ventricular defibrillation
W61A,W61B,W172

Consensus on science. In three randomised cardiac arrest studies (LOE 2),[94–96] a re-analysis of one of these studies (LOE 2),[97] two observational cardiac arrest studies (LOE 4),[98,99] a meta-analysis of seven randomised trials in the electrophysiology laboratory (LOE 1),[100] and multiple animal studies, defibrillation with a biphasic waveform, using equal or lower energy levels, was at least as effective for termination of VF as monophasic waveforms. No specific waveform (either monophasic or biphasic) was consistently associated with a greater incidence of ROSC or higher hospital discharge rates from cardiac arrest than any other specific waveform. One retrospective study (LOE 4)[99] showed a lower survival-to-hospital-discharge rate after defibrillation with a biphasic truncated exponential (BTE) waveform when compared with a monophasic truncated exponential (MTE) device (20% versus 39.7%, $P = .01$), but survival was a secondary end point. This study had multiple potential confounders, including the fact that CPR was provided to more subjects in the MTE group.

No direct comparison of the different biphasic waveforms has been reported as of 2005.

Treatment recommendation. Biphasic waveform shocks are safe and effective for termination of VF when compared with monophasic waveform shocks.

Energy level for defibrillation
W60A,W60B

Consensus on science. Eight human clinical studies (LOE 2;[94] LOE 3;[101] LOE 5;[95,96,98,99,102,103]) described initial biphasic selected shock energy levels ranging from 100 to 200 J with different devices but without demonstrating an optimal energy level clearly. These human clinical studies also described use of subsequent selected shock energy levels with different devices for shock-refractory VF/VT ranging from 150 to 360 J but without demonstrating an optimal energy level clearly.

Seven more laboratory studies (LOE 7)[104–110] in stable patients evaluated termination of induced VF with energy levels of 115–200 J.

Neither human clinical nor laboratory studies demonstrated evidence of significantly greater benefit or harm from any energy level used currently. One human study showed an increased incidence of transient heart block following two or more 320-J monophasic damped sine wave (MDS) shocks when compared with an equal number of 175-J MDS shocks, but there was no difference in long-term clinical outcome (LOE 2).[111]

Only one of the reviewed animal studies showed harm caused by attempted defibrillation with doses in the range of 120–360 J in adult animals; this study indicated that myocardial damage was caused by higher-energy shocks (LOE 6).[112]

One in-hospital study of 100 patients in VF compared MDS shocks of low (200–240 J), intermediate (300–320 J), and high (400–440 J) energy (LOE 2).[113] First-shock efficacy (termination of VF for $\geq$5 s) was 39% for the low-energy group, 58% for the intermediate-energy group, and 56% for the high-energy dose group. These differences did not achieve statistical significance. A study of electrical cardioversion for AF indicated that 360-J MDS shocks were more effective than 100- or 200-J MDS shocks (LOE 7).[114] Cardioversion of a well-perfused myocardium, however, is not the same as defibrillation attempted during VF cardiac arrest, and any extrapolation should be interpreted cautiously.

Treatment recommendation. There is insufficient evidence for or against specific selected energy levels for the first or subsequent biphasic shocks. With a biphasic defibrillator it is reasonable to use 150–200 J with BTE waveforms or 120 J with the rectilinear biphasic waveform for the initial shock. With a monophasic waveform defibrillator, an initial shock of 360 J is reasonable.

Second and subsequent shocks

Fixed versus escalating energy
W171

Consensus on science. Only one small human clinical study (LOE 3)[101] compared fixed energy with escalating energies using biphasic defibrillators. The study did not identify a clear benefit for either strategy.

Treatment recommendation. Nonescalating- and escalating-energy biphasic waveform defibrillation can be used safely and effectively to terminate VF of both short and long duration.

One-shock protocol versus three-shock sequence
W69A,W69B,W69C

Consensus on science. No published human or animal studies compared a one-shock protocol with a three-stacked shock sequence for any outcome. The magnitude of success of initial or subsequent shocks depended on the specific group of patients, the initial rhythm, and the outcome considered. Shock success was defined as termination of VF for ≥5 s after the shock. Resuscitation success can include ROSC and survival to hospital discharge. Only shock success is cited below.

First-shock success. Six studies of defibrillation in out-of-hospital cardiac arrest reported first-shock success in patients whose initial rhythm was shockable (VF/pulseless VT):

- In studies that used a 200-J MDS waveform, the first-shock success rate was 77—91% (LOE 2;[94,97] LOE 5[95,99]). In studies that used a 200-J MTE waveform, the first-shock success rate was 54—63% (LOE 4).[97,99]
- In studies that used a 150-J BTE waveform[97,99,115,116] and one study that used a 200-J BTE waveform,[95] the first-shock success rate was 86—98%.[95,97,99,115,116]
- The first-shock success rate with a 120-J rectilinear biphasic waveform was 85% (according to L.J. Morrison, MD, in oral discussion at the 2005 Consensus Conference).[94]

Although the first-shock success rate was relatively high in patients with out-of-hospital cardiac arrest with an initial rhythm of VF, the average rate of ROSC with the first shock (for MDS, MTE, and BTE waveforms) was 21% (range 13—23%) (LOE 5).[99]

Second- and third-shock success rates. Six studies of defibrillation in out-of-hospital cardiac arrest reported the shock success (defined above) rate of the first shock and subsequent two shocks (if the initial shock was unsuccessful) for patients whose initial rhythm was VF/pulseless VT. The figures below refer to only those patients who remained in VF after the first shock, and they represent the proportion of these cases successfully defibrillated by either the second or third shock.

In two studies that used the MDS waveform with increasing energy levels (200 J to 200—300 J to 360 J), the combined shock success of the second and/or third shocks when the first shock failed was 68—72% (LOE 5).[94,99] In two studies that used the MTE waveform with increasing energy levels (200 J to 200—360 J), the combined shock success of the second and third shocks when the first shock failed was 27—60% (LOE 5).[97,99]

In four studies that used the fixed-energy 150-J BTE waveform, the combined shock success of the second and third shocks when the first shock failed was 50—90% (LOE 5).[97,99,115,116]

In the one study that used a rectilinear waveform with increasing energy levels (120 J to 150—200 J), the combined success rate of the second and third shocks when the first shock failed was 85% (LOE 5).[94]

One study of defibrillation for out-of-hospital cardiac arrest in which the initial rhythm was VF reported a 26% rate of ROSC with the initial series of up to three shocks (for BTE waveforms) combined with pre-shock or post-shock CPR or both (LOE 5).[116]

Treatment recommendation. Priorities in resuscitation should include early assessment of the need for defibrillation (Part 2. Adult Basic Life Support), provision of CPR until a defibrillator is available, and minimisation of interruptions in chest compressions. Rescuers can optimise the likelihood of defibrillation success by optimising the performance of CPR, timing of shock delivery with respect to CPR, and the combination of waveform and energy levels. A one-shock strategy may improve outcome by reducing interruption of chest compressions. A three-stacked shock sequence can be optimised by immediate resumption of effective chest compressions after each shock (irrespective of the rhythm) and by minimising the hands-off time for rhythm analysis.

Related defibrillation topics

Defibrillator data collection
W66

Consensus on science. Collection of data from defibrillators enables a comparison of actual performance during cardiac arrests and training events. The results of three observational studies (LOE 5)[117—119] suggest that the rate and depth of external cardiac compressions and ventilation rate were at variance with current guidelines.

Treatment recommendation. Monitor/defibrillators modified to enable collection of data on compression rate and depth and ventilation rate may be useful for monitoring and improving process and outcomes after cardiac arrest.

Oxygen and fire risk during defibrillation
W70A,W70B

Consensus on science. Several case reports (LOE 5)[120–125] described instances of fires ignited by sparks from poorly attached defibrillator paddles in the presence of an oxygen-enriched atmosphere. The oxygen-enriched atmosphere rarely extends >0.5 m in any direction from the oxygen outflow point, and the oxygen concentration returns quickly to ambient when the source of enrichment is removed (LOE 5;[122] LOE 6[126]). The most severe fires were caused when ventilator tubing was disconnected from the tracheal tube and then left adjacent to the patient's head during attempted defibrillation (LOE 5).[121,123,125] In at least one case a spark generated during defibrillation ignited oxygen delivered by a simple transparent face mask that was left in place (LOE 5).[120]

In a manikin study (LOE 6)[126] there was no increase in oxygen concentration anywhere around the manikin when the ventilation device was left attached to the tracheal tube, even with an oxygen flow of 15 L min^{-1}.

Treatment recommendation. Rescuers should take precautions to minimise sparking (by paying attention to pad/paddle placement, contact, etc) during attempted defibrillation. Rescuers should try to ensure that defibrillation is not attempted in an oxygen-enriched atmosphere.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.resuscitation.2005.09.017.

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