Defibrillation in clinical practice

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Current Opinion in Critical Care 2009, 15:209–215

Purpose of review

To discuss recent data that may influence defibrillation in clinical practice and improve outcome after cardiac arrest from a shockable rhythm.

Recent findings

Reducing the preshock pause (interval between stopping chest compressions and shock delivery) improves shock success. The preshock pause can be reduced by continuing chest compressions during defibrillator charging and using performance-integrated debriefing to improve the efficiency of the resuscitation team. The findings of a study documenting leakage current during elective cardioversion imply that the risk to healthcare personnel of accidental electrocution during defibrillation has probably been overstated. One study has shown that when more than one shock is required, a strategy of escalating defibrillation energies may be more effective than using a fixed energy. Findings from three recent studies suggest that the precordial thump is ineffective for terminating ventricular fibrillation or ventricular tachycardia.

Summary

A defibrillation strategy that enables rhythm analysis to recognize ventricular fibrillation, defibrillator charging and optimally timed shock delivery with minimal or no interruptions to chest compressions should improve the chances of shock success. Performance debriefing of rescuers and recognizing that the risk to rescuers during defibrillation has been overstated should also help minimize interruptions to chest compressions for shock delivery.

Keywords

cardiopulmonary resuscitation, defibrillation, preshock pause, ventricular fibrillation

Curr Opin Crit Care 15:209–215

1070-5295

Introduction

Although the incidence of ventricular fibrillation is decreasing, the very effective intervention of defibrillation makes it the most treatable of the cardiac arrest rhythms. In Sweden, the incidence of out-of-hospital ventricular fibrillation cardiac arrest has decreased from 33% in 1992 to 26% in 2005 ($P < 0.0001$ for trend) [1•]. At the same time, 1-month survival for patients with shockable rhythms has increased from 12.7% in 1992 to 22.3% in 2005 ($P < 0.0001$ for trend). Strategies to increase the success of defibrillation are evolving continuously. The 2005 consensus on cardiopulmonary resuscitation (CPR) science included several changes to the way defibrillation is achieved, and there is some evidence that survival has improved subsequently [2•,3,4•]. Recently, emphasis has been placed on minimizing the preshock pause, the time between stopping chest compressions and delivery of the shock [5,6••,7•]. Stopping compressions for periods as short as just 10 s seems to reduce the chances of successful defibrillation [8]. This review will discuss potential changes in our clinical practice that might reduce the preshock pause and improve the efficacy of defibrillation. The European Resuscitation Council (ERC) 2005 guidelines advocate a precordial thump in witnessed, monitored ventricular fibrillation cardiac arrests [9]; recent evidence suggests that such an intervention is very unlikely to be successful in ventricular tachycardia or ventricular fibrillation [10••,11••,12•].

Cardiopulmonary resuscitation guidelines 2005: changes to defibrillation practice

Before 2005, the recommended treatment for ventricular fibrillation or pulseless ventricular tachycardia was to give up to three 'stacked' shocks, pausing between each to assess the rhythm, but not restarting chest compressions until after the third shock and, even then, only after a spontaneous circulation had been excluded with a rhythm assessment and pulse check if appropriate. If an automated external defibrillator (AED) is used, allowing for rhythm analysis between each shock, it can take up to 55 s to give three stacked shocks [13]. During this period without chest compressions, the myocardium becomes progressively more acidotic and the quality of the ventricular fibrillation waveform deteriorates, making successful defibrillation much less likely [5,8]. The 2005 consensus on CPR science and guidelines by the ERC and the American Heart Association (AHA) advocated a single shock followed immediately by resumption of chest compressions for 2 min without waiting to check the rhythm [14–16]. In a study from King County, Washington, survival to hospital discharge among a group with out-of-hospital ventricular fibrillation cardiac arrest resuscitated using single shocks and immediate resumption of chest compressions was higher than among a historical group resuscitated using stacked shock and postdefibrillation pulse checks [46% (61/134) versus 33% (122/374), $P = 0.008$] [3,4•]. A more recent study from Copenhagen has also documented higher survival after out-of-hospital cardiac arrest following implementation of the 2005 guidelines. The 30-day survival rate increased from 8.3% (31/372) before implementation to 16% (67/419) ($P = 0.001$) after implementation of the new guidelines [2•]. However, this study included all rhythm cardiac arrests and was also confounded by the introduction of a mechanical CPR device in the postimplementation phase. In a study using swine, immediate postshock compressions resulted in better survival rates compared with a 55-s delay before resuming compressions [17•].

The preshock pause

During ventricular fibrillation, it is now well established that interruptions in chest compressions for periods as short as 10–20 s will reduce the chances of successful defibrillation [5,8]. In an analysis of data downloaded from 60 consecutive in-hospital resuscitations in which a shock was given for ventricular fibrillation, the success (removal of ventricular fibrillation for at least 5 s) was related to the duration of the preshock pause, with adjusted odds ratio (OR) of 1.86 for every 5 s decrease [5]. The reason that shock success is reduced by brief interruptions in chest compressions is not entirely clear. It is known that coronary perfusion pressure declines rapidly when chest compressions are stopped, but it may be that the rapid dilation of the right ventricle and impairment of left ventricular myocyte stretch that occurs at this time makes restoration of a spontaneous circulation less likely [18•].

Use of single shocks will help to reduce the preshock pause, but further changes in defibrillation strategy will reduce this further; these changes include the use of resuscitation team debriefing using downloaded data from a CPR-sensing and feedback-enabled defibrillator, continuing chest compressions during charging and possibly during shock delivery and the use of compression artefact filtering to enable rhythm analysis without stopping chest compressions.

Resuscitation team debriefing

At least two commercially available monitor–defibrillators have the capability of recording data on the quality of CPR. A sternal pad containing an accelerometer and force detector enables the collection of data on depth and rate of compressions, whereas changes in the impedance across self-adhesive defibrillation pads enables ventilation rate to be measured. In a recent study from the University of Chicago Medical Center, data from in-hospital resuscitation attempts were used to inform regular debriefing meetings with resuscitation teams [19••]. Compared with baseline data, the implementation of 'performance-integrated debriefing' reduced the preshock pause, median (interquartile range), from 16.0 (8.5–24.1) to 7.5 (2.8–13.1) s ($P < 0.001$). This implies that efficient team training, which stresses the importance of minimizing the delay between stopping chest compressions and shock delivery, can improve performance and reduce the preshock pause.

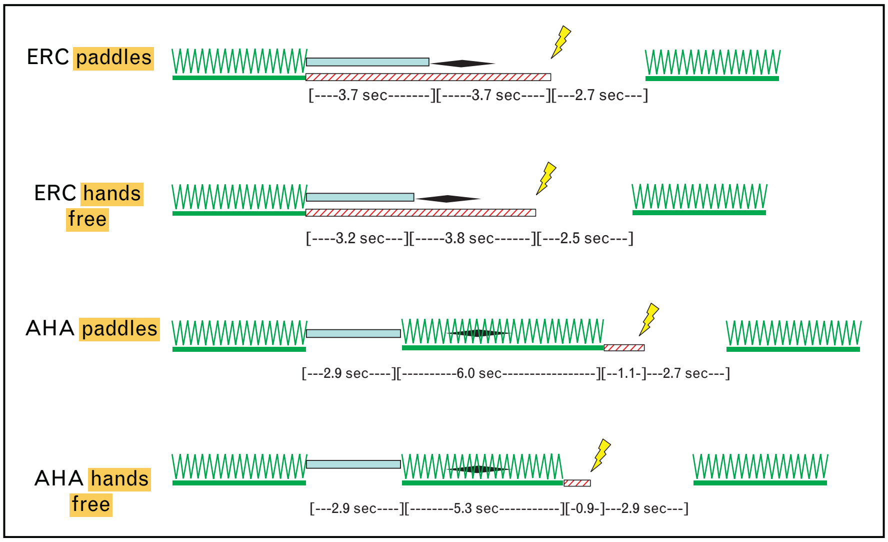
Chest compressions during charging and defibrillation

The 2005 ERC guidelines [15] and advanced life support (ALS) course manual [20] emphasize the importance of safety when using a defibrillator. The guidance indicates that nobody should be touching the patient while the defibrillator is charging and a shock is delivered. A prolonged safety check during defibrillator charging and shock delivery is usually enforced during defibrillator training because of the fear of rescuers receiving serious injuries if they are touching the patient when a shock is given; however, authors of a recent editorial concluded that there are only limited reports of actual harm [7•]. The AHA guidelines [16] and *Advanced Cardiovascular Life Support Provider Manual* advocate resuming chest compressions if the defibrillator takes more than 10 s to charge. Using a manikin and qualified ALS instructors and providers, the effect on the preshock pause of using the AHA and ERC guidelines and manual paddles versus hands-free electrodes has been reported [6••] (Fig. 1). The study was undertaken using a defibrillator with a fast charge time of 2 s. The longest preshock pause of 7.4 s (6.7–11.2) was associated with the ERC paddles technique; the AHA hands-free technique was associated with the shortest preshock pause of 1.5 s (0.8–1.5) (Fig. 2). If using a defibrillator with, for example, a charge time of 7 s, the estimated preshock pause using a hands-free system and the ERC guidelines is 12 s. The current ERC guidelines almost certainly overemphasize the risks of defibrillation, and it is likely that continuing compressions during charging will become standard practice in the future. These data add evidence in support of the trend away from manual paddles to hands-free defibrillation.

Defibrillation risk to the rescuer

A study of current flow through volunteers compressing patients' chests during cardioversion has seriously

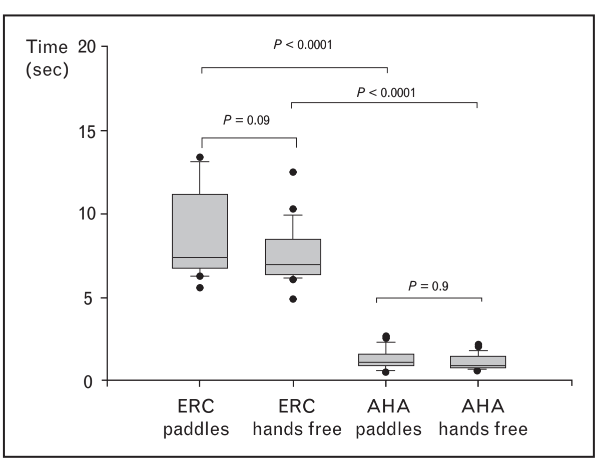
Figure 1 Defibrillation technique comparing European Resuscitation Council with American Heart Association guidelines with either manual paddles or hands-free system



Graphical representation of average (median) times taken to analyse the heart rhythm, charge the defibrillator, perform CPR, deliver shock and resume CPR. AHA, American Heart Association; CPR, cardiopulmonary resuscitation; ERC, European Resuscitation Council. [green zigzag], Chest compressions; [black arrow], defibrillator charging; [hatched bar], preshock pause; [line], scale 2 s; [blue bar], rhythm analysis; [lightning], shock delivered. Reproduced with permission from [6••].

challenged current practice [21••]. Cardioversion using a biphasic defibrillator and anterior–posterior self-adhesive electrode pads was undertaken using energy levels of up to 360 J. During the shock, a volunteer wearing polyethylene medical gloves pressed down on the patient's sternum with a force of 20 pounds. To maximize the possibility of a return current pathway, a conductive wire was connected between the volunteer's thigh and the patient's shoulder. Forty-three shocks in 39 patients were studied. Leakage currents were undetectable for seven shocks. For the remaining 36 shocks, the mean (SD) leakage current was 283 μA (140 μA) with a range of 18.9–907 μA, which is significantly lower than current safety standards for leakage current from medical equipment (Fig. 3). None of the volunteers sensed a shock. An accompanying editorial suggests that the practice of defibrillation during chest compressions should be adopted [22•]. In the absence of confirmatory safety data, this is probably a bit extreme; it is not clear whether different results would be achieved with other types of gloves, and inadvertently, torn gloves could result in the operator receiving a shock. Until we have more data, this study provides reassurance for adopting the strategy of continuing compressions during charging. In the mean time, one safe way of delivering a shock during chest compressions is to use a mechanical CPR adjunct such as the AutoPulse (ZOLL Medical Corporation, Sunnyvale, California, USA) or the LUCAS (Jolife AB, Lund, Sweden) [23•]. Both these devices are currently undergoing prospective multicentre trials to determine their impact on survival after cardiac arrest.

Figure 2 Preshock pause time using American Heart Association technique (stop cardiopulmonary resuscitation, analyse, cardiopulmonary resuscitation and charge, stop cardiopulmonary resuscitation, shock, restart cardiopulmonary resuscitation) and European Resuscitation Council technique (stop cardiopulmonary resuscitation, analyse, charge, shock, restart cardiopulmonary resuscitation) with paddles and hands-free defibrillation systems

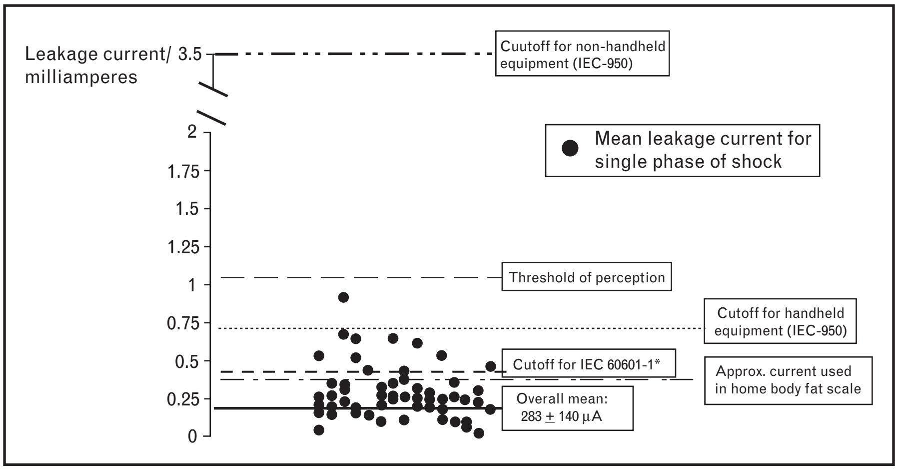


Central bar represents median, box shows 25th and 75th percentiles and whiskers show 10th and 90th percentiles. All outlying data points are shown as circles. Reproduced with permission from [6••].

Removal of compression artefact

The technology of ventricular fibrillation waveform analysis continues to evolve, and eventually, defibrillators will probably have the ability to advise shock delivery

Figure 3 Average leakage current in 36 trials of hands-on defibrillation in relation to several benchmarks of electrical safety



IEC-950 indicates IEC 950 standards for household and business or occupational items, and IEC 60601-1 indicates IEC 60601-1 standards for medical equipment. *This standard is for single-fault conditions. Reproduced with permission from [21••].

only when success is very likely [24•,25•,26••]. One study has also shown that it is possible to improve shock prediction by using an updating algorithm that 'learns' from previous shocks within a resuscitation effort [27•]. The technology to filter out compression artefact enabling ECG analysis without interrupting compressions is continually improving [28•,29•]. Investigators from the Weil Institute of Critical Care Medicine have validated an algorithm on the recordings of ECG and depth of compressions in 229 patients, including 111 instances in which the ECG was corrupted during chest compressions [28•]. A shockable rhythm was identified with a sensitivity of 93% and a specificity of 89%, giving a positive predictive value of 91%. A nonshockable rhythm was identified with a sensitivity of 89%, a specificity of 93% and a positive predictive value of 91% during uninterrupted chest compressions. This has the potential to transform CPR because the rescuer will simply keep compressing the chest until the defibrillator determines the need for a shock or pulse check. The combination of ventricular fibrillation analysis and compression artefact filtering will reduce interruptions in chest compressions to an absolute minimum.

Compressions before defibrillation

A before and after study [30] and a randomized trial [31] documented improved survival after out-of-hospital ventricular fibrillation or ventricular tachycardia if emergency medical services (EMS) personnel gave 1.5–3 min of CPR before attempting defibrillation and when the response time was more than 4–5 min. The 2005 guidelines of the AHA and the ERC both incorporated the recommendation for EMS personnel to give a period of CPR before attempting defibrillation if the response time was more than 4–5 min. The CPR in this recommendation included the provision of ventilation. Bobrow *et al.* [32••] at the University of Arizona Sarver Heart Center advocate a strategy of minimally interrupted cardiac resuscitation (MICR) that is also referred to as cardiocerebral resuscitation. If the initial rhythm is ventricular fibrillation, 200 chest compressions are given before the first shock, followed by 200 postshock chest compressions; tracheal intubation is delayed until after three cycles of chest compressions and rhythm analysis. Intravenous adrenaline (1 mg) is given as soon as possible, ideally within 10 min of arrival of EMS personnel. Outcomes following out-of-hospital cardiac arrests in two metropolitan cities in Arizona were compared before and after MICR training of fire department EMS personnel. Among 886 patients, survival to hospital discharge increased from 1.8% (4/218) before MICR training to 5.4% (36/668) after MICR training [OR, 3.0; 95% confidence interval (CI), 1.1–8.9]. In the subgroup of 174 patients with witnessed cardiac arrest and ventricular fibrillation, survival increased from 4.7% (2/43) before MICR training to 17.6% (23/131) after MICR training (OR, 8.6; 95% CI, 1.8–42.0). The use of historical controls is problematic; there could be several reasons for the better survival rates, and, as discussed above, some improvement in survival has been achieved by simply adopting single shocks and resuming chest compressions immediately [3,4•]. Whether the concept of MICR will be implemented more widely remains to be seen, but, at the very least, there is international consensus on the importance of minimizing interruptions to chest compressions before and after defibrillation.

Defibrillation energy

The 2005 guidelines recommended a single shock instead of a three-stacked-shock strategy for the treatment of ventricular fibrillation or ventricular tachycardia.

Shock energy recommendations vary between defibrillator manufacturers, and it is not clear whether defibrillation energy should be increased if the first defibrillation attempt fails. The Randomized Controlled Trial to Compare Fixed Versus Escalating Energy Regimens for Biphasic Waveform Defibrillation (BIPHASIC) studied 221 out-of-hospital cardiac arrest patients who required at least one shock [33••]. AEDs were randomly programmed to provide, blindly, fixed lower energy (150–150–150 J) or escalating higher energy (200–300–360 J) stacked biphasic shocks. For patients requiring more than one shock, conversion rates (defined as the termination of ventricular fibrillation and the establishment of an organized rhythm within 60 s) differed significantly (fixed lower, 24.7%, versus escalating higher, 36.6%; $P = 0.035$; absolute difference, 11.9%; 95% CI, 1.2–24.4). Ventricular fibrillation termination rates (defined as the termination of ventricular fibrillation for at least 5 s after the shock) were significantly different (71.2 versus 82.5%; $P = 0.027$; absolute difference, 11.3%; 95% CI, 1.6–20.9). First shock success was similar between the fixed lower and escalating higher groups (38.4 versus 36.7%; $P = 0.92$), as were ventricular fibrillation termination rates (86.8 versus 88.8%; $P = 0.81$). There were no differences for survival outcomes or adverse effects. This suggests that, when using a defibrillator with the specific waveform used in the BIPHASIC Trial, patients with ventricular fibrillation benefit from higher biphasic energy levels if multiple defibrillation shocks are required. This study found no harmful effect with higher shock energies. Starting with the highest available energy level for the first shock could, in theory, result in higher success rates, but this requires further study.

The precordial thump

The ERC 2005 guidelines advocate a precordial thump in witnessed, monitored ventricular fibrillation cardiac arrests when a defibrillator is not immediately available [9]. This recommendation is based only on a small case series. The ERC guidelines do not advocate its use in basic life support, partly because it could theoretically provoke ventricular fibrillation in someone who had a perfusing rhythm. This concern was realized recently in a case report from a cardiac catheterization laboratory that documented precipitation of ventricular fibrillation by a precordial thump given to a patient in complete atrioventricular block [34•]. Three recent studies have cast serious doubt on the efficacy of the precordial thump in ventricular tachycardia or ventricular fibrillation [10••, 11••,12•,35••]. Two of these studies involved delivery of a single precordial thump to patients undergoing electrophysiological studies who developed sustained nontolerated ventricular arrhythmias [10••,35••]. In the first study, the precordial thump terminated the ventricular arrhythmia (monomorphic ventricular tachycardia) in just one (1.3%) out of 80 patients (20 monomorphic ventricular tachycardia, 32 polymorphic ventricular tachycardia, 28 ventricular fibrillation) [35••]. In the second study, the precordial thump terminated the tachycardia in just two (1.3%) (polymorphic ventricular tachycardia) out of 155 patients (65 monomorphic ventricular tachycardia, 69 polymorphic ventricular tachycardia, 21 ventricular fibrillation) [10••]. In the third study, the effect of a precordial thump given by prehospital providers as the first intervention after application of defibrillation pads for out-of-hospital cardiac arrest was assessed in 144 patients in Pordenone province, Italy [11••]. Out of 24 patients with ventricular fibrillation or ventricular tachycardia, the precordial thump had no effect in 23 and produced pulseless electric activity (PEA) in one (4%); the precordial thump appeared to be associated with a return of spontaneous circulation (ROSC) in three out of 78 patients with asystole (4%) – all three were EMS-witnessed cardiac arrests, and the thump was given in less than 3 min – two survived to leave hospital; out of 42 patients with PEA, the precordial thump resulted in asystole in one, and there was no change in the remaining patients. In an accompanying editorial, Koster [12•] points out that rhythm strips from two of the three patients with asystole in which ROSC was achieved show P waves, suggesting that atrioventricular block without an escape rhythm was the cause of cardiac arrest. In the absence of an external pacing unit, the appropriate treatment for this rhythm is percussion pacing, that is, repetitive blows over the cardiac apex, rather than a single precordial thump. A precordial thump will not be successful if the asystole follows a prolonged period of cardiac arrest. Data from these three studies should provoke careful consideration of the role, if any, of the precordial thump in the 2010 resuscitation guidelines.

Conclusion

A defibrillation strategy that enables rhythm analysis to recognize ventricular fibrillation, defibrillator charging and optimally timed shock delivery with minimal or no interruptions to chest compressions will improve the chances of shock success. Advances in defibrillator technology will enable rhythm analysis during chest compressions and indicate the optimal timing and energy dose for shock delivery. Feedback and debriefing of rescuers based on their actual skill performance and increasing evidence that the risk to rescuers during defibrillation is far less than previously thought will also help minimize interruptions to chest compressions for shock delivery.

Acknowledgement

Jerry P. Nolan is co-chair of the International Liaison Committee on Resuscitation, Chairman of the Resuscitation Council (UK) and Editor-in-Chief of *Resuscitation*.

Jasmeet Soar is the International Liaison Committee on Resuscitation (ILCOR) task force co-chair for education, implementation and teams, vice chair of the Resuscitation Council (UK) and an editor for *Resuscitation*.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:
- • of special interest
- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 268–269).

1 • Hollenberg J, Herlitz J, Lindqvist J, *et al.* Improved survival after out-of-hospital cardiac arrest is associated with an increase in proportion of emergency crew-witnessed cases and bystander cardiopulmonary resuscitation. Circulation 2008; 118:389–396.

One of several recent studies showing that survival following out-of-hospital cardiac arrest is improving.

2 • Steinmetz J, Barnung S, Nielsen SL, *et al.* Improved survival after an out-of-hospital cardiac arrest using new guidelines. Acta Anaesthesiol Scand 2008; 52:908–913.

In this before and after study from Denmark, the implementation of new resuscitation guidelines was associated with improved 30-day survival following out-of-hospital cardiac arrest.

3 Rea TD, Helbock M, Perry S, *et al.* Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest: survival implications of guideline changes. Circulation 2006; 114:2760–2765.

4 • Becker L, Gold LS, Eisenberg M, *et al.* Ventricular fibrillation in King County, Washington: a 30-year perspective. Resuscitation 2008; 79:22–27.

Survival after out-of-hospital cardiac arrest is improving. In this study, the greatest increase in survival occurred following the CPR–defibrillation protocol change in 2005.

5 Edelson DP, Abella BS, Kramer-Johansen J, *et al.* Effects of compression depth and preshock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006; 71:137–145.

6 •• Perkins GD, Davies RP, Soar J, *et al.* The impact of manual defibrillation technique on no-flow time during simulated cardiopulmonary resuscitation. Resuscitation 2007; 73:109–114.

This manikin study shows how defibrillation technique can significantly affect the duration of the preshock pause.

7 • Perkins GD, Lockey AS. Defibrillation-safety versus efficacy. Resuscitation 2008; 79:1–3.

An important editorial that discusses the importance of minimizing the preshock pause.

8 Eftestol T, Sunde K, Steen PA. Effects of interrupting precordial compressions on the calculated probability of defibrillation success during out-of-hospital cardiac arrest. Circulation 2002; 105:2270–2273.

9 Deakin CD, Nolan JP. European Resuscitation Council guidelines for resuscitation 2005. Section 3. Electrical therapies: automated external defibrillators, defibrillation, cardioversion and pacing. Resuscitation 2005; 67 (Suppl 1): S25–S37.

10 •• Haman L, Parizek P, Vojacek J. Precordial thump efficacy in termination of induced ventricular arrhythmias. Resuscitation 2009; 80:14–16.

One of three studies in this review that questions the role of the precordial thump in resuscitation. In this study from an electrophysiology laboratory, a precordial thump terminated poorly tolerated ventricular tachycardia or ventricular fibrillation in just two (1.3%) (polymorphic ventricular tachycardia) out of 155 patients.

11 •• Pellis T, Kette F, Lovisa D, *et al.* Utility of the precordial thump for treatment of out of hospital cardiac arrest: a prospective study. Resuscitation 2009; 80:17–23.

In this prehospital study, out of 24 patients with ventricular fibrillation or ventricular tachycardia, a single precordial thump had no effect in 23 and produced PEA in one (4%); the precordial thump appeared to be associated with an ROSC in three out of 78 patients with asystole (4%).

12 • Koster RW. Precordial thump: friend or enemy? Resuscitation 2009; 80:2–3.

This editorial questions the value of the precordial thump in the context of the findings from two recent studies.

13 Rea TD, Shah S, Kudenchuk PJ, *et al.* Automated external defibrillators: to what extent does the algorithm delay CPR? Ann Emerg Med 2005; 46:132–141.

14 Proceedings of the 2005 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Resuscitation 2005; 67:157–341.

15 Nolan JP, Deakin CD, Soar J, *et al.* European Resuscitation Council guidelines for resuscitation 2005. Section 4. Adult advanced life support. Resuscitation 2005; 67 (Suppl 1):S39–S86.

16 ECC Committee, Subcommittees and Task Forces of the American Heart Association. 2005 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2005; 112:IV1–IV203.

17 • Berg RA, Hilwig RW, Berg MD, *et al.* Immediate postshock chest compressions improve outcome from prolonged ventricular fibrillation. Resuscitation 2008; 78:71–76.

In this swine study, immediate postshock compressions resulted in better survival rates compared with a 55-s delay before resuming compressions.

18 • Chamberlain D, Frenneaux M, Steen S, *et al.* Why do chest compressions aid delayed defibrillation? Resuscitation 2008; 77:10–15.

A valuable commentary on the potential reasons for the importance of chest compressions before and after attempted defibrillation.

19 •• Edelson DP, Litzinger B, Arora V, *et al.* Improving in-hospital cardiac arrest process and outcomes with performance debriefing. Arch Intern Med 2008; 168:1063–1069.

An important study showing that use of performance-integrated debriefing improves the efficiency of a resuscitation team and reduces the preshock pause.

20 Nolan J, Soar J, Lockey A, *et al.* Advanced life support. 5th ed. London: Resuscitation Council (UK); 2006.

21 •• Lloyd MS, Heeke B, Walter PF, *et al.* Hands-on defibrillation: an analysis of electrical current flow through rescuers in direct contact with patients during biphasic external defibrillation. Circulation 2008; 117:2510–2514.

This study, which was undertaken during elective cardioversion for atrial fibrillation, suggests that the risk of accidental electrocution of rescuers during attempted defibrillation has probably been overstated.

22 • Kerber RE. 'I'm clear, you're clear, everybody's clear': a tradition no longer necessary for defibrillation? Circulation 2008; 117:2435–2436.

In this editorial, on the basis of the study above, the role of the comprehensive and prolonged safety check is challenged.

23 • Wigginton JG, Isaacs SM, Kay JJ. Mechanical devices for cardiopulmonary resuscitation. Curr Opin Crit Care 2007; 13:273–279.

A useful review of mechanical CPR devices that mentions the potential for defibrillation without interrupting chest compressions.

24 • Neurauter A, Eftestol T, Kramer-Johansen J, *et al.* Prediction of countershock success using single features from multiple ventricular fibrillation frequency bands and feature combinations using neural networks. Resuscitation 2007; 73:253–263.

One of several studies during the review period that explores techniques for improving methods for predicting shock success.

25 • Neurauter A, Eftestol T, Kramer-Johansen J, *et al.* Improving countershock success prediction during cardiopulmonary resuscitation using ventricular fibrillation features from higher ECG frequency bands. Resuscitation 2008; 79:453–459.

A second study from this group that reports a technique for improving shock success prediction.

26 •• Price RA. Predicting successful defibrillation: are we there yet? Resuscitation 2008; 79:343–345.

A useful editorial that explains, in simple terms, the current techniques used for analysing the cardiac arrest rhythm during chest compressions and predicting shock success.

27 • Gundersen K, Kvaloy JT, Kramer-Johansen J, *et al.* Using within-patient correlation to improve the accuracy of shock outcome prediction for cardiac arrest. Resuscitation 2008; 78:46–51.

This study shows that it is possible to improve shock prediction by using an updating algorithm that learns from previous shocks within a resuscitation effort.

28 • Li Y, Bisera J, Geheb F, *et al.* Identifying potentially shockable rhythms without interrupting cardiopulmonary resuscitation. Crit Care Med 2008; 36:198–203.

The authors of this study used wavelet-based transformation and shape-based morphology detection to classify underlying cardiac rhythm and filter out compression artefact in 111 recordings from AEDs in which the ECG was corrupted during chest compressions. Positive predictive values of 91% were achieved for identification of both shockable and nonshockable rhythms during uninterrupted chest compression.

29 • Berger RD, Palazzolo J, Halperin H. Rhythm discrimination during uninterrupted CPR using motion artifact reduction system. Resuscitation 2007; 75:145–152.

In this swine study, a technique of adaptive noise cancellation was used to reduce motion artefact during mechanical CPR, enabling recognition of ventricular fibrillation without interrupting CPR.

30 Cobb LA, Fahrenbruch CE, Walsh TR, *et al.* Influence of cardiopulmonary resuscitation prior to defibrillation in patients with out-of-hospital ventricular fibrillation. JAMA 1999; 281:1182–1188.

31 Wik L, Hansen TB, Fylling F, *et al.* Delaying defibrillation to give basic cardiopulmonary resuscitation to patients with out-of-hospital ventricular fibrillation: a randomized trial. JAMA 2003; 289:1389–1395.

32 Bobrow BJ, Clark LL, Ewy GA, *et al.* Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. JAMA 2008; 299:1158–1165.
••
This important before and after study showed dramatically better survival rates after implementation of a new CPR protocol designed to minimize interruptions in chest compressions during resuscitation following out-of-hospital cardiac arrest.

33 Stiell IG, Walker RG, Nesbitt LP, *et al.* BIPHASIC Trial: a randomized comparison of fixed lower versus escalating higher energy levels for defibrillation in out-of-hospital cardiac arrest. Circulation 2007; 115:1511–1517.
••
This study showed that for patients requiring more than one shock, ventricular fibrillation, conversion and termination rates were significantly higher when using escalating (200–300–360 J) stacked higher biphasic energy levels compared with fixed lower biphasic energy levels (150–150–150 J). It is not clear whether the findings from this study apply to defibrillators that use different biphasic waveforms to those used in this study.

34 Cayla G, Macia JC, Pasquie JL. Images in cardiovascular medicine. Precordial thump in the catheterization laboratory experimental evidence for commotio cordis. Circulation 2007; 115:e332.
•
Anecdotal evidence from a catheter laboratory showing that ventricular fibrillation can be precipitated by a precordial thump when given to a patient with a perfusing rhythm.

35 Amir O, Schliamser JE, Nemer S, *et al.* Ineffectiveness of precordial thump for cardioversion of malignant ventricular tachyarrhythmias. Pacing Clin Electrophysiol 2007; 30:153–156.
••
Another study from an electrophysiology laboratory that shows the ineffectiveness of the precordial thump for terminating ventricular arrhythmia; it was effective in just one out of 80 patients.