Part 7.2: Management of Cardiac Arrest

Four rhythms produce pulseless cardiac arrest: ventricular fibrillation (VF), rapid ventricular tachycardia (VT), pulseless electrical activity (PEA), and asystole. Survival from these arrest rhythms requires both basic life support (BLS) and advanced cardiovascular life support (ACLS).

The foundation of ACLS care is good BLS care, beginning with prompt high-quality bystander CPR and, for VF/pulseless VT, attempted defibrillation within minutes of collapse. For victims of witnessed VF arrest, prompt bystander CPR and early defibrillation can significantly increase the chance for survival to hospital discharge. In comparison, typical ACLS therapies, such as insertion of advanced airways and pharmacologic support of the circulation, have not been shown to increase rate of survival to hospital discharge. This section details the general care of a patient in cardiac arrest and provides an overview of the ACLS Pulseless Arrest Algorithm.

Access for Medications: Correct Priorities

During cardiac arrest, basic CPR and early defibrillation are of primary importance, and drug administration is of secondary importance. Few drugs used in the treatment of cardiac arrest are supported by strong evidence. After beginning CPR and attempting defibrillation, rescuers can establish intravenous (IV) access, consider drug therapy, and insert an advanced airway.

Central Versus Peripheral Infusions

Central line access is not needed in most resuscitation attempts. If IV access has not been established, the provider should insert a large peripheral venous catheter. Although in adults peak drug concentrations are lower and circulation times longer when drugs are administered via peripheral sites rather than central sites, the establishment of peripheral access does not require interruption of CPR.[1,2] Drugs typically require 1 to 2 minutes to reach the central circulation when given via a peripheral vein but require less time when given via central venous access.

If a resuscitation drug is administered by a peripheral venous route, administer the drug by bolus injection and follow with a 20-mL bolus of IV fluid. Elevate the extremity for 10 to 20 seconds to facilitate drug delivery to the central circulation.[3]

Intraosseous (IO) cannulation provides access to a noncollapsible venous plexus, enabling drug delivery similar to that achieved by central venous access. Two prospective (LOE 3) trials, in children[4] and adults,[5] and 6 other studies (LOE 4[6]; LOE 5[7–9]; LOE 7[10,11]) documented that IO access is safe and effective for fluid resuscitation, drug delivery, and blood sampling for laboratory evaluation, and is attainable in all age groups. Providers may establish IO access if IV access is unavailable (Class IIa). Commercially available kits can facilitate IO access in adults.

If spontaneous circulation does not return after defibrillation and peripheral venous or IO drug administration, the provider may consider placement of a central line (unless there are contraindications). Note that central venous catheterization is a relative (not absolute) contraindication for fibrinolytic therapy in patients with stroke or acute coronary syndromes.

If IV and IO access cannot be established, some resuscitation drugs may be administered by the endotracheal route. One study in children (LOE 2),[12] 5 studies in adults (LOE 2[13–15]; LOE 3[16,17]), as well as multiple animal studies (LOE 6),[18–20] showed that lidocaine,[14,21] epinephrine,[22] atropine,[23] naloxone, and vasopressin[20] are absorbed via the trachea. Administration of resuscitation drugs into the trachea, however, results in lower blood concentrations than the same dose given intravascularly. Furthermore, recent animal studies[24–27] suggest that the lower epinephrine concentrations achieved when the drug is delivered by the endotracheal route may produce transient β-adrenergic effects. These effects can be detrimental, causing hypotension, lower coronary artery perfusion pressure and flow, and reduced potential for return of spontaneous circulation (ROSC). Thus, although endotracheal administration of some resuscitation drugs is possible, IV or IO drug administration is preferred because it will provide more predictable drug delivery and pharmacologic effect.

In one nonrandomized cohort study of out-of-hospital cardiac arrest in adults (LOE 4)[28] using a randomized control, administration of atropine and epinephrine by the IV route was associated with a higher rate of ROSC and survival to hospital admission than administration of the drugs by the endotracheal route. Five percent of those who received IV drugs survived to hospital discharge, but no patient survived in the group receiving drugs by the endotracheal route.

The optimal endotracheal dose of most drugs is unknown, but typically the dose given by the endotracheal route is 2 to 2½ times the recommended IV dose. In 2 CPR studies the equipotent epinephrine dose given endotracheally was approximately 3 to 10 times higher than the IV dose (LOE 5[29]; LOE 6[30]). Providers should dilute the recommended dose in 5 to 10 mL of water or normal saline and inject the drug directly into the endotracheal tube.[22] Studies with epinephrine[31] and lidocaine[17] showed that dilution with water instead of 0.9% saline may achieve better drug absorption.

Arrest Rhythms

The management of pulseless arrest is highlighted in the ACLS Pulseless Arrest Algorithm (Figure). Box numbers in the text refer to the numbered boxes in the algorithm.

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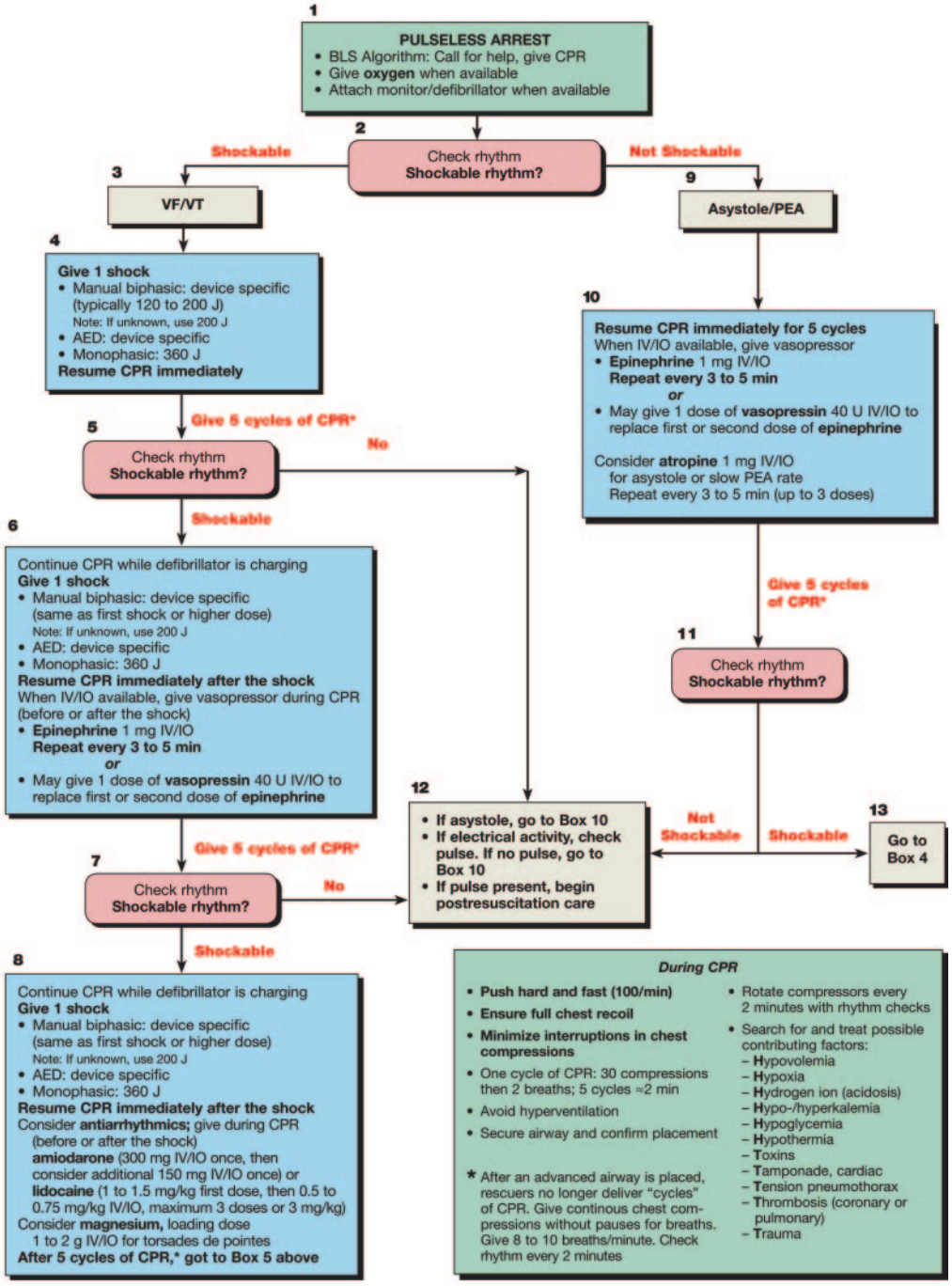

ACLS Pulseless Arrest Algorithm.

Ventricular Fibrillation/Pulseless Ventricular Tachycardia

The most critical interventions during the first minutes of VF or pulseless VT are immediate bystander CPR (Box 1) with minimal interruption in chest compressions and defibrillation as soon as it can be accomplished (Class I). In cases of witnessed arrest with a defibrillator on-site, after delivery of 2 rescue breaths the healthcare provider should check for a pulse. If the provider definitely does not feel a pulse within 10 seconds, the provider should turn on the defibrillator, place adhesive pads or paddles, and check the rhythm (Box 2).

If the healthcare provider does not witness the arrest in the out-of-hospital setting (eg, the emergency medical services [EMS] provider arrives at the scene of an arrest), the provider may give 5 cycles of CPR before attempting defibrillation. In adults with a prolonged arrest, shock delivery may be more successful after a period of effective chest compressions.[32–34] For further information about the sequence of CPR first

versus shock first, see Part 5: "Electrical Therapies: Automated External Defibrillators, Defibrillation, Cardioversion, and Pacing."

If VF/pulseless VT is present (Box 3), providers should deliver 1 shock (Box 4) and then resume CPR immediately, beginning with chest compressions. If a biphasic defibrillator is available, providers should use the dose at which that defibrillator has been shown to be effective for terminating VF (typically a selected energy of 120 J to 200 J). If the provider is unaware of the effective dose range of the device, the rescuer may use a dose of 200 J for the first shock and an equal or higher shock dose for the second and subsequent shocks. If a monophasic defibrillator is used, providers should deliver an initial shock of 360 J and use that dose for subsequent shocks. If VF is initially terminated by a shock but then recurs later in the arrest, deliver subsequent shocks at the previously successful energy level.

Biphasic defibrillators use a variety of waveforms, and each waveform has been shown to be effective in terminating VF over a specific dose range. Manufacturers should display this effective waveform dose range on the face of the biphasic device, and providers should use that dose range to attempt defibrillation with that device. The 200-J "default" energy level was selected because it falls within the reported range of selected doses that are effective for first and subsequent biphasic shocks and can be provided by every biphasic manual defibrillator available in 2005. This is a consensus default dose and not a recommended ideal dose. If biphasic devices are clearly labeled and providers are familiar with the devices they use in clinical care, there will be no need for the default 200-J dose. Ongoing research is necessary to firmly establish the most appropriate initial settings for both monophasic and biphasic defibrillators.

Providers should give 1 shock rather than the 3 successive ("stacked") shocks recommended in previous versions of the ECC guidelines[35] for the treatment of VF/pulseless VT because the first-shock success rate for biphasic defibrillators is high[36] and it is important to minimize interruptions in chest compressions. Although the 1-shock strategy has not been directly studied against a 3-shock strategy, the evidence is compelling that interruption of chest compressions reduces coronary perfusion pressure. The time required to charge a defibrillator, deliver a shock, and check a pulse can interrupt compressions for 37 seconds or longer[37] (for further information see Part 5: "Electrical Therapies: Automated External Defibrillators, Defibrillation, Cardioversion, and Pacing").

When a rhythm check reveals VF/VT, rescuers should provide CPR while the defibrillator charges (when possible), until it is time to "clear" the victim for shock delivery. Give the shock as quickly as possible. Immediately after shock delivery, resume CPR (beginning with chest compressions) without delay and continue for 5 cycles (or about 2 minutes if an advanced airway is in place), and then check the rhythm (Box 5). In in-hospital units with continuous monitoring (eg, electrocardiography, hemodynamics), this sequence may be modified at the physician's discretion (see Part 5).

The management strategy depicted in the ACLS Pulseless Arrest Algorithm is designed to minimize the number of times that chest compressions are interrupted and to enable rescuers to deliver shocks as efficiently as possible. Pulse and rhythm checks are limited and are not recommended immediately after shock delivery; instead healthcare providers give 5 cycles (about 2 minutes of CPR) immediately after the shock and then check the rhythm. Ideally, compression should be interrupted only for ventilation (until an advanced airway is placed), rhythm check, or shock delivery.

Once an advanced airway (eg, endotracheal tube, esophageal-tracheal combitube [Combitube], laryngeal mask airway [LMA]) is placed, 2 rescuers no longer deliver cycles of compressions interrupted with pauses for ventilation. Instead, the compressing rescuer should deliver 100 compressions per minute continuously, without pauses for ventilation. The rescuer delivering the ventilations should give 8 to 10 breaths per minute and should be careful to avoid delivering an excessive number of ventilations. Two or more rescuers should rotate the compressor role approximately every 2 minutes (when the victim's rhythm is checked). This change should prevent compressor fatigue and deterioration in quality and rate of chest compressions.

Establishing IV access is important (see below), but it should not interfere with CPR and delivery of shocks. As always, the provider should recall the H's and T's to identify a factor that may have caused the arrest or may be complicating the resuscitative effort (see the green box, "During CPR," at the bottom of the algorithm).

There is inadequate evidence to identify an optimal number of CPR cycles and defibrillation shocks that should be given before pharmacologic therapy is initiated. The recommended sequence depicted in the algorithm is based on expert consensus. If VF/VT persists after delivery of 1 or 2 shocks plus CPR, give a vasopressor (epinephrine every 3 to 5 minutes during cardiac arrest; one dose of vasopressin may replace either the first or second dose of epinephrine—see Box 6). Do not interrupt CPR to give medications.

The drug should be administered during CPR and as soon as possible after the rhythm is checked. It can be administered before or after shock delivery, in a CPR–RHYTHM CHECK–CPR (while drug administered and defibrillator charged)–SHOCK sequence (repeated as needed). This sequence differs from the one recommended in 2000[35]: it is designed to minimize interruptions in chest compressions. The 2000 recommendations resulted in too many interruptions in chest compressions.

In these 2005 recommendations, during treatment of cardiac arrest the drug doses should be prepared *before* the rhythm check so they can be administered as soon as possible after the rhythm check, but the timing of drug delivery is less important than the need to minimize interruptions in chest compressions. Rhythm checks should be very brief (see below). If a drug is administered immediately after the rhythm check (before or after the shock) it will be circulated by the CPR given before and after the shock. After 5 cycles (or about 2 minutes) of CPR, analyze the rhythm again (Box 7) and be prepared to deliver another shock immediately if indicated.

When VF/pulseless VT persists after 2 to 3 shocks plus CPR and administration of a vasopressor, consider administering an antiarrhythmic such as amiodarone (Box 8). If

amiodarone is unavailable, lidocaine may be considered. Consider magnesium for torsades de pointes associated with a long QT interval (see below). You should administer the drug during CPR, as soon as possible after rhythm analysis. If a nonshockable rhythm is present and the rhythm is organized (complexes appear regular or narrow), try to palpate a pulse (see Box 12).

Rhythm checks should be brief, and pulse checks should generally be performed only if an organized rhythm is observed. If there is any doubt about the presence of a pulse, resume CPR. If the patient has ROSC, begin postresuscitation care. If the patient's rhythm changes to asystole or PEA, see "Asystole and Pulseless Electrical Activity" below (Boxes 9 and 10).

If a perfusing rhythm is transiently restored but not successfully maintained between repeated shocks (recurrent VF/VT), the patient may be a candidate for early treatment with antiarrhythmic medications (see Part 7.3: "Management of Symptomatic Bradycardia and Tachycardia").

During treatment of VF/pulseless VT, healthcare providers must practice efficient coordination between CPR and shock delivery. When VF is present for more than a few minutes, the myocardium is depleted of oxygen and metabolic substrates. A brief period of chest compressions can deliver oxygen and energy substrates, increasing the likelihood that a perfusing rhythm will return after shock delivery.[38] Analyses of VF waveform characteristics predictive of shock success have documented that the shorter the time between chest compression and shock delivery, the more likely the shock will be successful.[38,39] Reduction in the interval from compression to shock delivery by even a few seconds can increase the probability of shock success.[40]

Asystole and Pulseless Electrical Activity (Box 9)

PEA encompasses a heterogeneous group of pulseless rhythms that includes pseudo-electromechanical dissociation (pseudo-EMD), idioventricular rhythms, ventricular escape rhythms, postdefibrillation idioventricular rhythms, and bradyasystolic rhythms. Research with cardiac ultrasonography and indwelling pressure catheters has confirmed that pulseless patients with electrical activity have associated mechanical contractions, but these contractions are too weak to produce a blood pressure detectable by palpation or noninvasive blood pressure monitoring. PEA is often caused by reversible conditions and can be treated if those conditions are identified and corrected.

The survival rate from cardiac arrest with asystole is dismal. During a resuscitation attempt, brief periods of an organized complex may appear on the monitor screen, but spontaneous circulation rarely emerges. As with PEA, the hope for resuscitation is to identify and treat a reversible cause.

Because of the similarity in causes and management of these two arrest rhythms, their treatment has been combined in the second part of the ACLS Pulseless Arrest Algorithm.

Patients who have either asystole or PEA will not benefit from defibrillation attempts. The focus of resuscitation is to perform high-quality CPR with minimal interruptions and to identify reversible causes or complicating factors. Providers should insert an advanced airway (eg, endotracheal tube, Combitube, LMA). Once the airway is in place, 2 rescuers should no longer deliver cycles of CPR (ie, compressions interrupted by pauses when breaths are delivered). Instead the compressing rescuer should give continuous chest compressions at a rate of 100 per minute without pauses for ventilation. The rescuer delivering ventilation provides 8 to 10 breaths per minute. The 2 rescuers should change compressor and ventilator roles approximately every 2 minutes (when the rhythm is checked) to prevent compressor fatigue and deterioration in quality and rate of chest compressions. When multiple rescuers are present, they should rotate the compressor role about every 2 minutes. Rescuers should minimize interruptions in chest compressions while inserting the airway and should not interrupt CPR while establishing IV or IO access.

If the rhythm check confirms asystole or PEA, resume CPR immediately. A vasopressor (epinephrine or vasopressin) may be administered at this time. Epinephrine can be administered approximately every 3 to 5 minutes during cardiac arrest; one dose of vasopressin may be substituted for either the first or second epinephrine dose (Box 10). For a patient in asystole or slow PEA, consider atropine (see below). Do not interrupt CPR to deliver any medication. Give the drug as soon as possible after the rhythm check.

After drug delivery and approximately 5 cycles (or about 2 minutes) of CPR, recheck the rhythm (Box 11). If a shockable rhythm is present, deliver a shock (go to Box 4). If no rhythm is present or if there is no change in the appearance of the electrocardiogram, immediately resume CPR (Box 10). If an organized rhythm is present (Box 12), try to palpate a pulse. If no pulse is present (or if there is any doubt about the presence of a pulse), continue CPR (Box 10). If a pulse is present the provider should identify the rhythm and treat appropriately (see Part 7.3: "Management of Symptomatic Bradycardia and Tachycardia"). If the patient appears to have an organized rhythm with a good pulse, begin postresuscitative care.

When Should Resuscitative Efforts Stop?

The resuscitation team must make a conscientious and competent effort to give patients a trial of CPR and ACLS, provided that the patient has not expressed a decision to forego resuscitative efforts. The final decision to stop efforts can never be as simple as an isolated time interval. Clinical judgment and respect for human dignity must enter into decision making. There is little data to guide this decision.

Emergency medical response systems should not require field personnel to transport every victim of cardiac arrest to a hospital or emergency department (ED). Transportation with continuing CPR is justified if interventions are available in the ED that cannot be performed in the field, such as cardiopulmonary bypass or extracorporeal circulation for victims of severe hypothermia (Class IIb).

Unless special situations are present (eg, hypothermia), for nontraumatic and blunt traumatic out-of-hospital cardiac arrest, evidence confirms that ACLS care in the ED offers no advantage over ACLS care in the field. Stated succinctly, if ACLS care in the field cannot resuscitate the victim, ED care

will not resuscitate the victim. Civil rules, administrative concerns, medical insurance requirements, and even reimbursement enhancement have frequently led to requirements to transport all cardiac arrest victims to a hospital or ED. If these requirements are nonselective, they are inappropriate, futile, and ethically unacceptable. Cessation of efforts in the out-of-hospital setting, following system-specific criteria and under direct medical control, should be standard practice in all EMS systems.

Medications for Arrest Rhythms

Vasopressors

To date no placebo-controlled trials have shown that administration of any vasopressor agent at any stage during management of pulseless VT, VF, PEA, or asystole increases the rate of neurologically intact survival to hospital discharge. There is evidence, however, that the use of vasopressor agents favors initial ROSC.

Epinephrine and Vasopressin

VF and Pulseless VT

Epinephrine

Epinephrine hydrochloride produces beneficial effects in patients during cardiac arrest, primarily because of its α-adrenergic receptor-stimulating (ie, vasoconstrictor) properties.[41] The α-adrenergic effects of epinephrine can increase coronary and cerebral perfusion pressure during CPR.[42] The value and safety of the β-adrenergic effects of epinephrine are controversial because they may increase myocardial work and reduce subendocardial perfusion.[43]

Although epinephrine has been used universally in resuscitation, there is a paucity of evidence to show that it improves survival in humans. Both beneficial and toxic physiologic effects of epinephrine administration during CPR have been shown in animal and human studies.[44–50] Initial or escalating high-dose epinephrine has occasionally improved initial ROSC and early survival rates. But in 8 randomized clinical studies involving >9000 cardiac arrest patients, high-dose epinephrine produced no improvement in survival to hospital discharge rates or neurologic outcomes when compared with standard doses, even in subgroups given initial high-dose epinephrine.[50–57]

It is appropriate to administer a 1-mg dose of epinephrine IV/IO every 3 to 5 minutes during adult cardiac arrest (Class IIb). Higher doses may be indicated to treat specific problems, such as β-blocker or calcium channel blocker overdose. If IV/IO access is delayed or cannot be established, epinephrine may be given by the endotracheal route at a dose of 2 to 2.5 mg.

Vasopressin

Vasopressin is a nonadrenergic peripheral vasoconstrictor that also causes coronary and renal vasoconstriction.[58,59] Despite 1 promising randomized study (LOE 2),[60] additional lower-level studies (LOE 5),[61–63] and multiple well-performed animal studies, 2 large randomized controlled human trials (LOE 1)[64,65] failed to show an increase in rates of ROSC or survival when vasopressin (40 U, with the dose repeated in 1 study) was compared with epinephrine (1 mg, repeated) as the initial vasopressor for treatment of cardiac arrest. In the large multicenter trial involving 1186 out-of-hospital cardiac arrests with all rhythms (LOE 1),[65] a post-hoc analysis of the subset of patients with asystole showed significant improvement in survival to hospital discharge but not neurologically intact survival when 40 U (repeated once if necessary) of vasopressin was used as the initial vasopressor compared with epinephrine (1 mg, repeated if necessary).

A meta-analysis of 5 randomized trials (LOE 1)[66] showed no statistically significant differences between vasopressin and epinephrine for ROSC, 24-hour survival, or survival to hospital discharge. The subgroup analysis based on initial cardiac rhythm did not show any statistically significant difference in survival to hospital discharge (LOE 1).[66]

In a large in-hospital study of cardiac arrest, 200 patients were randomly assigned to receive either 1 mg of epinephrine (initial rhythm: 16% VF, 3% VT, 54% PEA, 27% asystole) or 40 U of vasopressin (initial rhythm: 20% VF, 3% VT, 41% PEA, 34% asystole). There was no difference in survival to 1 hour (epinephrine: 35%, vasopressin: 39%) or to hospital discharge (epinephrine: 14%, vasopressin: 12%) between groups or subgroups.[64]

A retrospective analysis documented the effects of epinephrine alone (231 patients) compared with a combination of vasopressin and epinephrine (37 patients) in out-of-hospital cardiac arrest with VF/VT, PEA, or asystole. There was no difference in survival or ROSC when VF or PEA was the presenting rhythm, but ROSC was increased in the epinephrine plus vasopressin group among patients presenting with asystole.[67]

Because vasopressin effects have not been shown to differ from those of epinephrine in cardiac arrest, one dose of vasopressin 40 U IV/IO may replace either the first or second dose of epinephrine in the treatment of pulseless arrest (Class Indeterminate).

Asystole and Pulseless Electrical Activity

Vasopressors

The studies described above enrolled patients with PEA and asystole and failed to show that either vasopressin or epinephrine is superior for treatment of PEA regardless of the order of administration. In the case of asystole, a single post-hoc analysis of a larger study found a survival benefit of vasopressin over epinephrine but did not find an increase in intact neurologic survival.

On the basis of these findings, providers may consider vasopressin for treatment of asystole, but there is insufficient evidence to recommend for or against its use in PEA. Further studies are required. Epinephrine may be administered every 3 to 5 minutes during the attempted resuscitation; vasopressin may be substituted for the first or second epinephrine dose.

Atropine

Atropine sulfate reverses cholinergic-mediated decreases in heart rate, systemic vascular resistance, and blood pressure. No prospective controlled studies support the use of atropine in asystole or slow PEA arrest. Administration of atropine for asystole is supported by a retrospective review (LOE 4)[68] of

intubated patients with refractory asystole who showed improved survival to hospital admission with atropine. A case series (LOE 5)[69] of adults in cardiac arrest documented conversion from asystole to sinus rhythm in 7 of 8 patients.

Literature to refute the use of atropine is equally sparse and of limited quality. A small prospective controlled nonrandomized study (LOE 3)[70] of patients with out-of-hospital cardiac arrest found no difference versus control when atropine 1 to 2 mg was given as the initial resuscitation medication, but subtherapeutic dosing and delay to epinephrine administration may have had an impact on survival in the study. In an animal model of PEA (LOE 6),[71] no difference was noted in resuscitation outcome between standard-dose atropine and placebo groups.

Asystole can be precipitated or exacerbated by excessive vagal tone, and administration of a vagolytic medication is consistent with a physiologic approach. Atropine is inexpensive, easy to administer, and has few side effects and therefore can be considered for asystole or PEA. The recommended dose of atropine for cardiac arrest is 1 mg IV, which can be repeated every 3 to 5 minutes (maximum total of 3 doses or 3 mg) if asystole persists (Class Indeterminate).

Antiarrhythmics

There is no evidence that any antiarrhythmic drug given routinely during human cardiac arrest increases survival to hospital discharge. Amiodarone, however, has been shown to increase short-term survival to hospital admission when compared with placebo or lidocaine.

VF and Pulseless VT

Amiodarone

IV amiodarone affects sodium, potassium, and calcium channels as well as α- and β-adrenergic blocking properties. It can be considered for the treatment of VF or pulseless VT unresponsive to shock delivery, CPR, and a vasopressor.

In blinded randomized controlled clinical trials in adults with refractory VF/pulseless VT in the out-of-hospital setting (LOE 1),[72,73] paramedic administration of amiodarone (300 mg[72] or 5 mg/kg[73]) improved survival to hospital admission rates when compared with administration of placebo[72] or 1.5 mg/kg of lidocaine.[73] Additional studies (LOE 7)[74–78] documented consistent improvement in defibrillation response when amiodarone was given to humans or animals with VF or hemodynamically unstable VT.

Amiodarone produced vasodilation and hypotension in 1 of the out-of-hospital studies.[72] A canine study (LOE 6)[79] noted that administration of a vasoconstrictor before amiodarone prevented hypotension. A new aqueous formulation of amiodarone does not contain the vasoactive solvents (polysorbate 80 and benzyl alcohol) of the standard formulation. In an analysis of the combined data of 4 prospective clinical trials of patients with VT (some included hemodynamically unstable patients), aqueous amiodarone produced no more hypotension than lidocaine.[77]

In summary, amiodarone may be administered for VF or pulseless VT unresponsive to CPR, shock, and a vasopressor (Class IIb). An initial dose of 300 mg IV/IO can be followed by one dose of 150 mg IV/IO.

Lidocaine

The use of lidocaine for ventricular arrhythmias was supported by initial studies in animals (LOE 6)[80,81] and extrapolation from the historic use of the drug to suppress premature ventricular contractions and prevent VF after acute myocardial infarction.[82] Although lidocaine improved short-term survival in 1 prehospital study (LOE 4),[83] 3 randomized trials comparing amiodarone and lidocaine found lower rates of ROSC[73,84] and a higher incidence of asystole[85] with use of lidocaine. The out-of-hospital double-blind randomized controlled trial (LOE 1)[73] that compared amiodarone with lidocaine found that amiodarone improved rate of survival to hospital admission and that lidocaine was associated with more asystole after defibrillation.

In summary, lidocaine is an alternative antiarrhythmic of long standing and widespread familiarity with fewer immediate side effects than may be encountered with other antiarrhythmics. Lidocaine, however, has no proven short-term or long-term efficacy in cardiac arrest. Lidocaine should be considered an alternative treatment to amiodarone (Class Indeterminate). The initial dose is 1 to 1.5 mg/kg IV. If VF/pulseless VT persists, additional doses of 0.5 to 0.75 mg/kg IV push may be administered at 5- to 10-minute intervals, to a maximum dose of 3 mg/kg. This is the same dose that was recommended in the *ECC Guidelines 2000*.

Magnesium

Two observational studies (LOE 5)[86,87] showed that IV magnesium can effectively terminate torsades de pointes (irregular/polymorphic VT associated with prolonged QT interval). One small adult case series in adults (LOE 5)[88] showed that isoproterenol or ventricular pacing can be effective in terminating torsades de pointes associated with bradycardia and drug-induced QT prolongation. Magnesium is not likely to be effective in terminating irregular/polymorphic VT in patients with a normal QT interval.[87]

When VF/pulseless VT cardiac arrest is associated with torsades de pointes, providers may administer magnesium sulfate at a dose of 1 to 2 g diluted in 10 mL D_5W IV/IO push, typically over 5 to 20 minutes (Class IIa for torsades). When torsades is present in the patient *with pulses*, the same 1 to 2 g is mixed in 50 to 100 mL of D_5W and given as a loading dose. It can be given more slowly (eg, over 5 to 60 minutes IV) under these conditions. See Part 7.3: "Management of Symptomatic Bradycardia and Tachycardia" for additional information about management of torsades de pointes not associated with cardiac arrest.

Potentially Beneficial Therapies

Fibrinolysis

Adults have been successfully resuscitated following administration of fibrinolytics (tPA) after initial failure of standard CPR techniques, particularly when the condition leading to the arrest was acute pulmonary embolism or other presumed cardiac cause (LOE 3[89]; LOE 4[90–92]; LOE 5[93–97]). Evidence from 1 large clinical trial (LOE 2),[98] however, failed to show any significant treatment effect when a fibrinolytic (tPA) was given to out-of-hospital patients with undifferentiated PEA cardiac arrest unresponsive to initial interventions.

There is insufficient evidence to recommend for or against the routine use of fibrinolysis for cardiac arrest. It may be considered on a case-by-case basis when pulmonary embolus is suspected (Class IIa). Ongoing CPR is not a contraindication to fibrinolysis.

Interventions Not Supported by Outcome Evidence

Pacing in Arrest

Several randomized controlled trials (LOE 2)[99–101] failed to show benefit from attempted pacing for asystole. At this time use of pacing for patients with asystolic cardiac arrest is not recommended.

Procainamide in VF and Pulseless VT

Use of procainamide in cardiac arrest is supported by 1 retrospective comparison study of 20 patients.[102] Administration of procainamide in cardiac arrest is limited by the need for slow infusion and by uncertain efficacy in emergent circumstances.

Norepinephrine

Norepinephrine has been studied in only a limited fashion for treatment of cardiac arrest. Human data is limited, but it suggests that norepinephrine produces effects equivalent to epinephrine in the initial resuscitation of cardiac arrest.[53,103] In the only prospective human trial comparing standard-dose epinephrine, high-dose epinephrine, and high-dose norepinephrine, the norepinephrine was associated with no benefit and a trend toward worse neurologic outcome (LOE 1).[53]

Precordial Thump for VF or Pulseless VT

There are no prospective studies that evaluated the use of precordial (chest) thump. In 3 case series (LOE 5),[104–106] VF or pulseless VT was converted to a perfusing rhythm by a precordial thump. In contrast, other case series documented deterioration in cardiac rhythm, such as rate acceleration of VT, conversion of VT to VF, or development of complete heart block or asystole following the use of the thump (LOE 5[105,107–111]; LOE 6[112]).

The precordial thump is not recommended for BLS providers. In light of the limited evidence in support of its efficacy and reports of potential harm, no recommendation can be made for or against its use by ACLS providers (Class Indeterminate).

Electrolyte Therapies in Arrest Rhythms

Magnesium

In-hospital and out-of-hospital studies in adult cardiac arrest (LOE 2[113–116]; LOE 3[117]; LOE 7[118]) and animal studies (LOE 6)[119–122] showed no increase in the rate of ROSC when magnesium was routinely given during CPR. Administration of magnesium can be considered for treatment of torsades de pointes (Class IIa—see above), but it is not effective for treatment of cardiac arrest from other causes.

Routine Administration of IV Fluids During Cardiac Arrest

There were no published human studies evaluating the effect of routine fluid administration during normovolemic cardiac arrest, and the results of 4 animal studies (LOE 6)[123–126] were neutral. There is insufficient evidence to recommend routine administration of fluids to treat cardiac arrest (Class Indeterminate). Fluids should be infused if hypovolemia is suspected.

Summary

Ideally ACLS providers will prevent pulseless arrest if they are able to intervene in the prearrest period. If arrest occurs, good ACLS begins with high-quality BLS. During resuscitation rescuers must provide good chest compressions (adequate rate and depth), allow complete recoil of the chest between compressions, and minimize interruptions in chest compressions. Rescuers should be careful to avoid provision of excessive ventilation, particularly once an advanced airway is in place. Resuscitation drugs have not been shown to increase rate of survival to hospital discharge, and none has the impact of early and effective CPR and prompt defibrillation.

References

1. Barsan WG, Levy RC, Weir H. Lidocaine levels during CPR: differences after peripheral venous, central venous, and intracardiac injections. *Ann Emerg Med*. 1981;10:73–78.
2. Kuhn GJ, White BC, Swetnam RE, Mumey JF, Rydesky MF, Tintinalli JE, Krome RL, Hoehner PJ. Peripheral vs central circulation times during CPR: a pilot study. *Ann Emerg Med*. 1981;10:417–419.
3. Emerman CL, Pinchak AC, Hancock D, Hagen JF. Effect of injection site on circulation times during cardiac arrest. *Crit Care Med*. 1988;16:1138–1141.
4. Banerjee S, Singhi SC, Singh S, Singh M. The intraosseous route is a suitable alternative to intravenous route for fluid resuscitation in severely dehydrated children. *Indian Pediatr*. 1994;31:1511–1520.
5. Brickman KR, Krupp K, Rega P, Alexander J, Guinness M. Typing and screening of blood from intraosseous access. *Ann Emerg Med*. 1992;21:414–417.
6. Fiser RT, Walker WM, Seibert JJ, McCarthy R, Fiser DH. Tibial length following intraosseous infusion: a prospective, radiographic analysis. *Pediatr Emerg Care*. 1997;13:186–188.
7. Ummenhofer W, Frei FJ, Urwyler A, Drewe J. Are laboratory values in bone marrow aspirate predictable for venous blood in paediatric patients? *Resuscitation*. 1994;27:123–128.
8. Glaeser PW, Hellmich TR, Szewczuga D, Losek JD, Smith DS. Five-year experience in prehospital intraosseous infusions in children and adults. *Ann Emerg Med*. 1993;22:1119–1124.
9. Guy J, Haley K, Zuspan SJ. Use of intraosseous infusion in the pediatric trauma patient. *J Pediatr Surg*. 1993;28:158–161.
10. Macnab A, Christenson J, Findlay J, Horwood B, Johnson D, Jones L, Phillips K, Pollack C Jr, Robinson DJ, Rumball C, Stair T, Tiffany B, Whelan M. A new system for sternal intraosseous infusion in adults. *Prehosp Emerg Care*. 2000;4:173–177.
11. Ellemunter H, Simma B, Trawoger R, Maurer H. Intraosseous lines in preterm and full term neonates. *Arch Dis Child Fetal Neonatal Ed*. 1999;80:F74–F75.
12. Howard RF, Bingham RM. Endotracheal compared with intravenous administration of atropine. *Arch Dis Child*. 1990;65:449–450.
13. Lee PL, Chung YT, Lee BY, Yeh CY, Lin SY, Chao CC. The optimal dose of atropine via the endotracheal route. *Ma Zui Xue Za Zhi*. 1989;27:35–38.
14. Prengel AW, Lindner KH, Hahnel J, Ahnefeld FW. Endotracheal and endobronchial lidocaine administration: effects on plasma lidocaine concentration and blood gases. *Crit Care Med*. 1991;19:911–915.
15. Schmidbauer S, Kneifel HA, Hallfeldt KK. Endobronchial application of high dose epinephrine in out of hospital cardiopulmonary resuscitation. *Resuscitation*. 2000;47:89.
16. Raymondos K, Panning B, Leuwer M, Brechelt G, Korte T, Niehaus M, Tebbenjohanns J, Piepenbrock S. Absorption and hemodynamic effects of airway administration of adrenaline in patients with severe cardiac disease. *Ann Intern Med*. 2000;132:800–803.
17. Hahnel JH, Lindner KH, Schurmann C, Prengel A, Ahnefeld FW. Plasma lidocaine levels and PaO2 with endobronchial administration: dilution with normal saline or distilled water? *Ann Emerg Med*. 1990;19:1314–1317.
18. Brown LK, Diamond J. The efficacy of lidocaine in ventricular fibrillation due to coronary artery ligation: endotracheal vs intravenous use. *Proc West Pharmacol Soc*. 1982;25:43–45.
19. Jasani MS, Nadkarni VM, Finkelstein MS, Hofmann WT, Salzman SK. Inspiratory-cycle instillation of endotracheal epinephrine in porcine arrest. *Acad Emerg Med*. 1994;1:340–345.
20. Wenzel V, Lindner KH, Prengel AW, Lurie KG, Strohmenger HU. Endobronchial vasopressin improves survival during cardiopulmonary resuscitation in pigs. *Anesthesiology*. 1997;86:1375–1381.

21. Prengel AW, Rembecki M, Wenzel V, Steinbach G. A comparison of the endotracheal tube and the laryngeal mask airway as a route for endobronchial lidocaine administration. *Anesth Analg*. 2001;92:1505–1509.
22. Jasani MS, Nadkarni VM, Finkelstein MS, Mandell GA, Salzman SK, Norman ME. Effects of different techniques of endotracheal epinephrine administration in pediatric porcine hypoxic-hypercarbic cardiopulmonary arrest. *Crit Care Med*. 1994;22:1174–1180.
23. Johnston C. Endotracheal drug delivery. *Pediatr Emerg Care*. 1992;8: 94–97.
24. Vaknin Z, Manisterski Y, Ben-Abraham R, Efrati O, Lotan D, Barzilay Z, Paret G. Is endotracheal adrenaline deleterious because of the beta adrenergic effect? *Anesth Analg*. 2001;92:1408–1412.
25. Manisterski Y, Vaknin Z, Ben-Abraham R, Efrati O, Lotan D, Berkovitch M, Barak A, Barzilay Z, Paret G. Endotracheal epinephrine: a call for larger doses. *Anesth Analg*. 2002;95:1037–1041.
26. Efrati O, Ben-Abraham R, Barak A, Modan-Moses D, Augarten A, Manisterski Y, Barzilay Z, Paret G. Endobronchial adrenaline: should it be reconsidered? Dose response and haemodynamic effect in dogs. *Resuscitation*. 2003;59:117–122.
27. Elizur A, Ben-Abraham R, Manisterski Y, Barak A, Efrati O, Lotan D, Barzilay Z, Paret G. Tracheal epinephrine or norepinephrine preceded by beta blockade in a dog model: can beta blockade bestow any benefits? *Resuscitation*. 2003;59:271–276.
28. Niemann JT, Stratton SJ, Cruz B, Lewis RJ. Endotracheal drug administration during out-of-hospital resuscitation: where are the survivors? *Resuscitation*. 2002;53:153–157.
29. Schuttler J, Bartsch A, Ebeling BJ, Hornchen U, Kulka P, Suhling B, Stoeckel H. [Endobronchial administration of adrenaline in preclinical cardiopulmonary resuscitation.] *Anasth Intensivther Notfallmed*. 1987;22: 63–68.
30. Hornchen U, Schuttler J, Stoeckel H, Eichelkraut W, Hahn N. Endobronchial instillation of epinephrine during cardiopulmonary resuscitation. *Crit Care Med*. 1987;15:1037–1039.
31. Naganobu K, Hasebe Y, Uchiyama Y, Hagio M, Ogawa H. A comparison of distilled water and normal saline as diluents for endobronchial administration of epinephrine in the dog. *Anesth Analg*. 2000;91:317–321.
32. Cobb LA, Fahrenbruch CE, Walsh TR, Copass MK, Olsufka M, Breskin M, Hallstrom AP. Influence of cardiopulmonary resuscitation prior to defibrillation in patients with out-of-hospital ventricular fibrillation. *JAMA*. 1999;281:1182–1188.
33. Yakaitis RW, Ewy GA, Otto CW, Taren DL, Moon TE. Influence of time and therapy on ventricular defibrillation in dogs. *Crit Care Med*. 1980;8: 157–163.
34. Wik L, Hansen TB, Fylling F, Steen T, Vaagenes P, Auestad BH, Steen PA. Delaying defibrillation to give basic cardiopulmonary resuscitation to patients with out-of-hospital ventricular fibrillation: a randomized trial. *JAMA*. 2003;289:1389–1395.
35. American Heart Association in collaboration with the International Liaison Committee on Resuscitation. Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care: International Consensus on Science. *Circulation.* 2000;102:I1–I384.
36. Martens PR, Russell JK, Wolcke B, Paschen H, Kuisma M, Gliner BE, Weaver WD, Bossaert L, Chamberlain D, Schneider T. Optimal Response to Cardiac Arrest study: defibrillation waveform effects. *Resuscitation.* 2001;49:233–243.
37. Yu T, Weil MH, Tang W, Sun S, Klouche K, Povoas H, Bisera J. Adverse outcomes of interrupted precordial compression during automated defibrillation. *Circulation*. 2002;106:368–372.
38. Eftestol T, Wik L, Sunde K, Steen PA. Effects of cardiopulmonary resuscitation on predictors of ventricular fibrillation defibrillation success during out-of-hospital cardiac arrest. *Circulation.* 2004;110:10–15.
39. Eftestol T, Sunde K, Aase SO, Husoy JH, Steen PA. Predicting outcome of defibrillation by spectral characterization and nonparametric classification of ventricular fibrillation in patients with out-of-hospital cardiac arrest. *Circulation*. 2000;102:1523–1529.
40. 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.
41. Yakaitis RW, Otto CW, Blitt CD. Relative importance of α and β adrenergic receptors during resuscitation. *Crit Care Med*. 1979;7:293–296.
42. Michael JR, Guerci AD, Koehler RC, Shi AY, Tsitlik J, Chandra N, Niedermeyer E, Rogers MC, Traystman RJ, Weisfeldt ML. Mechanisms by which epinephrine augments cerebral and myocardial perfusion during cardiopulmonary resuscitation in dogs. *Circulation*. 1984;69:822–835.
43. Ditchey RV, Lindenfeld J. Failure of epinephrine to improve the balance between myocardial oxygen supply and demand during closed-chest resuscitation in dogs. *Circulation*. 1988;78:382–389.
44. Berg RA, Otto CW, Kern KB, Hilwig RW, Sanders AB, Henry CP, Ewy GA. A randomized, blinded trial of high-dose epinephrine versus standard-dose epinephrine in a swine model of pediatric asphyxial cardiac arrest. *Crit Care Med*. 1996;24:1695–1700.
45. Hoekstra JW, Griffith R, Kelley R, Cody RJ, Lewis D, Scheatzle M, Brown CG. Effect of standard-dose versus high-dose epinephrine on myocardial high-energy phosphates during ventricular fibrillation and closed-chest CPR. *Ann Emerg Med*. 1993;22:1385–1391.
46. Hornchen U, Lussi C, Schuttler J. Potential risks of high-dose epinephrine for resuscitation from ventricular fibrillation in a porcine model. *J Cardiothorac Vasc Anesth*. 1993;7:184–187.
47. Niemann JT, Cairns CB, Sharma J, Lewis RJ. Treatment of prolonged ventricular fibrillation: immediate countershock versus high-dose epinephrine and CPR preceding countershock. *Circulation*. 1992;85:281–287.
48. Tang W, Weil MH, Sun S, Noc M, Yang L, Gazmuri RJ. Epinephrine increases the severity of postresuscitation myocardial dysfunction. *Circulation*. 1995;92:3089–3093.
49. Rivers EP, Wortsman J, Rady MY, Blake HC, McGeorge FT, Buderer NM. The effect of the total cumulative epinephrine dose administered during human CPR on hemodynamic, oxygen transport, and utilization variables in the postresuscitation period. *Chest*. 1994;106:1499–1507.
50. Lindner KH, Ahnefeld FW, Prengel AW. Comparison of standard and high-dose adrenaline in the resuscitation of asystole and electromechanical dissociation. *Acta Anaesthesiol Scand*. 1991;35:253–256.
51. Brown CG, Martin DR, Pepe PE, Stueven H, Cummins RO, Gonzalez E, Jastremski M. A comparison of standard-dose and high-dose epinephrine in cardiac arrest outside the hospital: the Multicenter High-Dose Epinephrine Study Group. *N Engl J Med*. 1992;327:1051–1055.
52. Stiell IG, Hebert PC, Weitzman BN, Wells GA, Raman S, Stark RM, Higginson LA, Ahuja J, Dickinson GE. High-dose epinephrine in adult cardiac arrest. *N Engl J Med*. 1992;327:1045–1050.
53. Callaham M, Madsen CD, Barton CW, Saunders CE, Pointer J. A randomized clinical trial of high-dose epinephrine and norepinephrine vs standard-dose epinephrine in prehospital cardiac arrest. *JAMA*. 1992;268: 2667–2672.
54. Lipman J, Wilson W, Kobilski S, Scribante J, Lee C, Kraus P, Cooper J, Barr J, Moyes D. High-dose adrenaline in adult in-hospital asystolic cardiopulmonary resuscitation: a double-blind randomised trial. *Anaesth Intensive Care*. 1993;21:192–196.
55. Choux C, Gueugniaud PY, Barbieux A, Pham E, Lae C, Dubien PY, Petit P. Standard doses versus repeated high doses of epinephrine in cardiac arrest outside the hospital. *Resuscitation*. 1995;29:3–9.
56. Sherman BW, Munger MA, Foulke GE, Rutherford WF, Panacek EA. High-dose versus standard-dose epinephrine treatment of cardiac arrest after failure of standard therapy. *Pharmacotherapy*. 1997;17:242–247.
57. Gueugniaud PY, Mols P, Goldstein P, Pham E, Dubien PY, Deweerdt C, Vergnion M, Petit P, Carli P. A comparison of repeated high doses and repeated standard doses of epinephrine for cardiac arrest outside the hospital. European Epinephrine Study Group. *N Engl J Med*. 1998;339: 1595–1601.
58. Oyama H, Suzuki Y, Satoh S, Kajita Y, Takayasu M, Shibuya M, Sugita K. Role of nitric oxide in the cerebral vasodilatory responses to vasopressin and oxytocin in dogs. *J Cereb Blood Flow Metab*. 1993;13:285–290.
59. Lindner KH, Strohmenger HU, Ensinger H, Hetzel WD, Ahnefeld FW, Georgieff M. Stress hormone response during and after cardiopulmonary resuscitation. *Anesthesiology*. 1992;77:662–668.
60. Lindner KH, Dirks B, Strohmenger HU, Prengel AW, Lindner IM, Lurie KG. Randomised comparison of epinephrine and vasopressin in patients with out-of-hospital ventricular fibrillation. *Lancet*. 1997;349:535–537.
61. Lindner KH, Prengel AW, Brinkmann A, Strohmenger HU, Lindner IM, Lurie KG. Vasopressin administration in refractory cardiac arrest. *Ann Intern Med*. 1996;124:1061–1064.
62. Mann K, Berg RA, Nadkarni V. Beneficial effects of vasopressin in prolonged pediatric cardiac arrest: a case series. *Resuscitation*. 2002;52: 149–156.
63. Morris DC, Dereczyk BE, Grzybowski M, Martin GB, Rivers EP, Wortsman J, Amico JA. Vasopressin can increase coronary perfusion pressure during human cardiopulmonary resuscitation. *Acad Emerg Med*. 1997;4:878–883.
64. Stiell IG, Hebert PC, Wells GA, Vandemheen KL, Tang AS, Higginson LA, Dreyer JF, Clement C, Battram E, Watpool I, Mason S, Klassen T, Weitzman BN. Vasopressin versus epinephrine for inhospital cardiac arrest: a randomised controlled trial. *Lancet*. 2001;358:105–109.
65. Wenzel V, Krismer AC, Arntz HR, Sitter H, Stadlbauer KH, Lindner KH. A comparison of vasopressin and epinephrine for out-of-hospital cardiopulmonary resuscitation. *N Engl J Med*. 2004;350:105–113.
66. Aung K, Htay T. Vasopressin for cardiac arrest: a systematic review and meta-analysis. *Arch Intern Med*. 2005;165:17–24.
67. Guyette FX, Guimond GE, Hostler D, Callaway CW. Vasopressin administered with epinephrine is associated with a return of a pulse in out-of-hospital cardiac arrest. *Resuscitation*. 2004;63:277–282.
68. Stueven HA, Tonsfeldt DJ, Thompson BM, Whitcomb J, Kastenson E, Aprahamian C. Atropine in asystole: human studies. *Ann Emerg Med*. 1984;13:815–817.
69. Brown DC, Lewis AJ, Criley JM. Asystole and its treatment: the possible role of the parasympathetic nervous system in cardiac arrest. *JACEP*. 1979;8:448–452.
70. Coon GA, Clinton JE, Ruiz E. Use of atropine for bradyasystolic prehospital cardiac arrest. *Ann Emerg Med*. 1981;10:462–467.
71. DeBehnke DJ, Swart GL, Spreng D, Aufderheide TP. Standard and higher doses of atropine in a canine model of pulseless electrical activity. *Acad Emerg Med*. 1995;2:1034–1041.
72. Kudenchuk PJ, Cobb LA, Copass MK, Cummins RO, Doherty AM, Fahrenbruch CE, Hallstrom AP, Murray WA, Olsufka M, Walsh T. Amiodarone for resuscitation after out-of-hospital cardiac arrest due to ventricular fibrillation. *N Engl J Med*. 1999;341:871–878.
73. Dorian P, Cass D, Schwartz B, Cooper R, Gelaznikas R, Barr A. Amiodarone as compared with lidocaine for shock-resistant ventricular fibrillation. *N Engl J Med*. 2002;346:884–890.
74. Skrifvars MB, Kuisma M, Boyd J, Maatta T, Repo J, Rosenberg PH, Castren M. The use of undiluted amiodarone in the management of out-of-hospital cardiac arrest. *Acta Anaesthesiol Scand*. 2004;48:582–587.
75. Petrovic T, Adnet F, Lapandry C. Successful resuscitation of ventricular fibrillation after low-dose amiodarone. *Ann Emerg Med*. 1998;32:518–519.
76. Levine JH, Massumi A, Scheinman MM, Winkle RA, Platia EV, Chilson DA, Gomes A, Woosley RL. Intravenous amiodarone for recurrent sus-

tained hypotensive ventricular tachyarrhythmias. Intravenous Amiodarone Multicenter Trial Group. *J Am Coll Cardiol*. 1996;27:67–75.
77. Somberg JC, Bailin SJ, Haffajee CI, Paladino WP, Kerin NZ, Bridges D, Timar S, Molnar J. Intravenous lidocaine versus intravenous amiodarone (in a new aqueous formulation) for incessant ventricular tachycardia. *Am J Cardiol*. 2002;90:853–859.
78. Somberg JC, Timar S, Bailin SJ, Lakatos F, Haffajee CI, Tarjan J, Paladino WP, Sarosi I, Kerin NZ, Borbola J, Bridges DE, Molnar J. Lack of a hypotensive effect with rapid administration of a new aqueous formulation of intravenous amiodarone. *Am J Cardiol*. 2004;93:576–581.
79. Paiva EF, Perondi MB, Kern KB, Berg RA, Timerman S, Cardoso LF, Ramirez JA. Effect of amiodarone on haemodynamics during cardiopulmonary resuscitation in a canine model of resistant ventricular fibrillation. *Resuscitation*. 2003;58:203–208.
80. Borer JS, Harrison LA, Kent KM, Levy R, Goldstein RE, Epstein SE. Beneficial effect of lidocaine on ventricular electrical stability and spontaneous ventricular fibrillation during experimental myocardial infarction. *Am J Cardiol*. 1976;37:860–863.
81. Spear JF, Moore EN, Gerstenblith G. Effect of lidocaine on the ventricular fibrillation threshold in the dog during acute ischemia and premature ventricular contractions. *Circulation*. 1972;46:65–73.
82. Lie KI, Wellens HJ, van Capelle FJ, Durrer D. Lidocaine in the prevention of primary ventricular fibrillation: a double-blind, randomized study of 212 consecutive patients. *N Engl J Med*. 1974;291:1324–1326.
83. Herlitz J, Bang A, Holmberg M, Axelsson A, Lindkvist J, Holmberg S. Rhythm changes during resuscitation from ventricular fibrillation in relation to delay until defibrillation, number of shocks delivered and survival. *Resuscitation*. 1997;34:17–22.
84. Kentsch M, Berkel H, Bleifeld W. Intravenose Amiodaron-Applikation bei therapierefraktarem Kammerflimmern. *Intensivmedizin.* 1988;25:70–74.
85. Weaver WD, Fahrenbruch CE, Johnson DD, Hallstrom AP, Cobb LA, Copass MK. Effect of epinephrine and lidocaine therapy on outcome after cardiac arrest due to ventricular fibrillation. *Circulation*. 1990;82: 2027–2034.
86. Manz M, Pfeiffer D, Jung W, Lueritz B. Intravenous treatment with magnesium in recurrent persistent ventricular tachycardia. *New Trends in Arrhythmias*. 1991;7:437–442.
87. Tzivoni D, Banai S, Schuger C, Benhorin J, Keren A, Gottlieb S, Stern S. Treatment of torsade de pointes with magnesium sulfate. *Circulation*. 1988;77:392–397.
88. Keren A, Tzivoni D, Gavish D, Levi J, Gottlieb S, Benhorin J, Stern S. Etiology, warning signs and therapy of torsade de pointes: a study of 10 patients. *Circulation*. 1981;64:1167–1174.
89. Bottiger BW, Bode C, Kern S, Gries A, Gust R, Glatzer R, Bauer H, Motsch J, Martin E. Efficacy and safety of thrombolytic therapy after initially unsuccessful cardiopulmonary resuscitation: a prospective clinical trial. *Lancet*. 2001;357:1583–1585.
90. Lederer W, Lichtenberger C, Pechlaner C, Kroesen G, Baubin M. Recombinant tissue plasminogen activator during cardiopulmonary resuscitation in 108 patients with out-of-hospital cardiac arrest. *Resuscitation*. 2001;50: 71–76.
91. Lederer W, Lichtenberger C, Pechlaner C, Kinzl J, Kroesen G, Baubin M. Long-term survival and neurological outcome of patients who received recombinant tissue plasminogen activator during out-of-hospital cardiac arrest. *Resuscitation*. 2004;61:123–129.
92. Janata K, Holzer M, Kurkciyan I, Losert H, Riedmuller E, Pikula B, Laggner AN, Laczika K. Major bleeding complications in cardiopulmonary resuscitation: the place of thrombolytic therapy in cardiac arrest due to massive pulmonary embolism. *Resuscitation*. 2003;57:49–55.
93. Scholz KH, Hilmer T, Schuster S, Wojcik J, Kreuzer H, Tebbe U. Thrombolysis in resuscitated patients with pulmonary embolism. *Dtsch Med Wochenschr*. 1990;115:930–935.
94. Klefisch F, et al. Praklinische ultima-ratio thrombolyse bei therapierefraktarer kardiopulmonaler reanimation. *Intensivmedizin*. 1995;32: 155–162.
95. Tiffany PA, Schultz M, Stueven H. Bolus thrombolytic infusions during CPR for patients with refractory arrest rhythms: outcome of a case series. *Ann Emerg Med*. 1998;31:124–126.
96. Gramann J, Lange-Braun P, Bodemann T, Hochrein H. Der Einsatz von Thrombolytika in der Reanimation als Ultima ratio zur Überwindung des Herztodes. *Intensiv-und Notfallbehandlung*. 1991;16:134–137.
97. Ruiz-Bailen M, Aguayo de Hoyos E, Serrano-Corcoles MC, Diaz-Castellanos MA, Ramos-Cuadra JA, Reina-Toral A. Efficacy of thrombolysis in patients with acute myocardial infarction requiring cardiopulmonary resuscitation. *Intensive Care Med*. 2001;27:1050–1057.
98. Abu-Laban RB, Christenson JM, Innes GD, van Beek CA, Wanger KP, McKnight RD, MacPhail IA, Puskaric J, Sadowski RP, Singer J, Schechter MT, Wood VM. Tissue plasminogen activator in cardiac arrest with pulseless electrical activity. *N Engl J Med*. 2002;346:1522–1528.
99. Hedges JR, Syverud SA, Dalsey WC, Feero S, Easter R, Shultz B. Prehospital trial of emergency transcutaneous cardiac pacing. *Circulation*. 1987;76:1337–1343.
100. Barthell E, Troiano P, Olson D, Stueven HA, Hendley G. Prehospital external cardiac pacing: a prospective, controlled clinical trial. *Ann Emerg Med*. 1988;17:1221–1226.
101. Cummins RO, Graves JR, Larsen MP, Hallstrom AP, Hearne TR, Ciliberti J, Nicola RM, Horan S. Out-of-hospital transcutaneous pacing by emergency medical technicians in patients with asystolic cardiac arrest. *N Engl J Med*. 1993;328:1377–1382.
102. Stiell IG, Wells GA, Hebert PC, Laupacis A, Weitzman BN. Association of drug therapy with survival in cardiac arrest: limited role of advanced cardiac life support drugs. *Acad Emerg Med*. 1995;2:264–273.
103. Lindner KH, Ahnefeld FW, Bowdler IM. Comparison of different doses of epinephrine on myocardial perfusion and resuscitation success during cardiopulmonary resuscitation in a pig model. *Am J Emerg Med*. 1991;9: 27–31.
104. Befeler B. Mechanical stimulation of the heart; its therapeutic value in tachyarrhythmias. *Chest*. 1978;73:832–838.
105. Volkmann HK, Klumbies A, Kühnert H, Paliege R, Dannberg G, Siegert K. [Terminating ventricular tachycardias by mechanical heart stimulation with precordial thumps.] *Z Kardiol*. 1990;79:717–724.
106. Caldwell G, Millar G, Quinn E. Simple mechanical methods for cardioversion: defence of the precordial thump and cough version. *BMJ*. 1985; 291:627–630.
107. Morgera T, Baldi N, Chersevani D, Medugno G, Camerini F. Chest thump and ventricular tachycardia. *Pacing Clin Electrophysiol*. 1979;2:69–75.
108. Rahner E, Zeh E. Die Regularisierung von Kammertachykardien durch präkordialen Faustschlag [The regularization of ventricular tachycardias by precordial thumping]. *Medizinsche Welt*. 1978;29:1659–1663.
109. Gertsch M, Hottinger S, Hess T. Serial chest thumps for the treatment of ventricular tachycardia in patients with coronary artery disease. *Clin Cardiol*. 1992;15:181–188.
110. Krijne R. Rate acceleration of ventricular tachycardia after a precordial chest thump. *Am J Cardiol*. 1984;53:964–965.
111. Sclarovsky S, Kracoff OH, Agmon J. Acceleration of ventricular tachycardia induced by a chest thump. *Chest*. 1981;80:596–599.
112. Yakaitis RW, Redding JS. Precordial thumping during cardiac resuscitation. *Crit Care Med*. 1973;1:22–26.
113. Thel MC, Armstrong AL, McNulty SE, Califf RM, O'Connor CM. Randomised trial of magnesium in in-hospital cardiac arrest. Duke Internal Medicine Housestaff. *Lancet*. 1997;350:1272–1276.
114. Allegra J, Lavery R, Cody R, Birnbaum G, Brennan J, Hartman A, Horowitz M, Nashed A, Yablonski M. Magnesium sulfate in the treatment of refractory ventricular fibrillation in the prehospital setting. *Resuscitation*. 2001;49:245–249.
115. Fatovich D, Prentice D, Dobb G. Magnesium in in-hospital cardiac arrest. *Lancet*. 1998;351:446.
116. Hassan TB, Jagger C, Barnett DB. A randomised trial to investigate the efficacy of magnesium sulphate for refractory ventricular fibrillation. *Emerg Med J*. 2002;19:57–62.
117. Miller B, Craddock L, Hoffenberg S, Heinz S, Lefkowitz D, Callender ML, Battaglia C, Maines C, Masick D. Pilot study of intravenous magnesium sulfate in refractory cardiac arrest: safety data and recommendations for future studies. *Resuscitation*. 1995;30:3–14.
118. Longstreth WT Jr, Fahrenbruch CE, Olsufka M, Walsh TR, Copass MK, Cobb LA. Randomized clinical trial of magnesium, diazepam, or both after out-of-hospital cardiac arrest. *Neurology*. 2002;59:506–514.
119. Siemkowicz E. Magnesium sulfate solution dramatically improves immediate recovery of rats from hypoxia. *Resuscitation*. 1997;35:53–59.
120. Brown CG, Griffith RF, Neely D, Hobson J, Miller B. The effect of intravenous magnesium administration on aortic, right atrial and coronary perfusion pressures during CPR in swine. *Resuscitation*. 1993;26:3–12.
121. Seaberg DC, Menegazzi JJ, Check B, MacLeod BA, Yealy DM. Use of a cardiocerebral-protective drug cocktail prior to countershock in a porcine model of prolonged ventricular fibrillation. *Resuscitation*. 2001;51: 301–308.
122. Zhang Y, Davies LR, Martin SM, Bawaney IM, Buettner GR, Kerber RE. Magnesium reduces free radical concentration and preserves left ventricular function after direct current shocks. *Resuscitation*. 2003;56:199–206.
123. Ditchey RV, Lindenfeld J. Potential adverse effects of volume loading on perfusion of vital organs during closed-chest resuscitation. *Circulation*. 1984;69:181–189.
124. Gentile NT, Martin GB, Appleton TJ, Moeggenberg J, Paradis NA, Nowak RM. Effects of arterial and venous volume infusion on coronary perfusion pressures during canine CPR. *Resuscitation*. 1991;22:55–63.
125. Jameson SJ, Mateer JR, DeBehnke DJ. Early volume expansion during cardiopulmonary resuscitation. *Resuscitation*. 1993;26:243–250.
126. Voorhees WD, Ralston SH, Kougias C, Schmitz PM. Fluid loading with whole blood or Ringer's lactate solution during CPR in dogs. *Resuscitation.* 1987;15:113–123.

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