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REVIEW ARTICLE

Improving Outcomes from Out-of-Hospital Cardiac Arrest in Young Children and Adolescents

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Abstract Out-of-hospital cardiac arrest (OHCA) is an unusual but devastating occurrence in a young person. Years of life-lost are substantial and long-term health care costs of survivors can be high. However, there have been noteworthy improvements in cardiopulmonary resuscitation (CPR) standards, out-of hospital care, and postcardiac arrest therapies that have resulted in a several-fold improvement in resuscitation outcomes. Recent interest and research in resuscitation of children has the promise of generating improvements in the outcomes of these patients. Integrated and coordinated care in the out-of-hospital and hospital settings are required. This article will review the epidemiology of OHCA, the 2010 CPR guidelines, and developments in public access defibrillation for children.

Keywords Cardiopulmonary resuscitation · Cardiac arrest · Outcomes

Out of hospital cardiac arrest is an unusual occurrence in a young person. Despite three decades of CPR guidelines directed toward this population, outcomes remain dismal, with typically 3–10% survival, often with poor neurologic outcomes. The economic costs are exceedingly high, related to long-term health care costs and loss of future productivity of the victim. Some have proposed that resuscitation of these patients is futile [82]. However, along with the upsurge in interest in studying and improving outcomes in adults, comparable attention is now directed at OHCA in children and adolescents. These studies indicate that we can improve survival and neurologic outcomes with coordinated out-of-hospital resuscitation and postarrest therapies.

Pediatric cardiologists were the original organizers of the first pediatric CPR guidelines, recognizing that children were not small adults and needed a distinct approach with differing therapies [20]. Over the years, as the specialties of emergency medicine and critical care have evolved, pediatric cardiologists have played a smaller role in CPR research and teaching. However, as awareness of sudden cardiac death has risen in both the lay and medical populations, effective acute and long-term treatments have expanded and pediatric cardiologists, and especially pediatric electrophysiologists, have a renewed interest in all aspects of care of this population.

This article will describe the current understanding of the epidemiology of OHCA and discuss the scientific evidence supporting the updated CPR guidelines. Emphasis will be placed on out-of-hospital response and immediate intensive care.

Epidemiology and Outcomes of OHCA in Children and Adolescents

Recently, several large population-based studies have characterized the epidemiology of cardiac arrest in

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Table 1 Characteristics of Out-of-hospital cardiac arrest in children and adolescents

	Overall	Infants	Children	Adolescents	Adults
Incidence (per 100,000 person-years)	8.03	72	3.73	6.37	50–55
Survival to hospital discharge (%)	1.1–20	3.3	9.1	8.9	1.1–10.6
Favorable neurologic outcome[a] (%)	1–12	2			
Public location (%)	12	4	14	22	16
Bystander CPR (%)	30–47	37	40	28	19
Initial rhythm asystole (%)	82–95	84	83	77	60
Initial rhythm VF (%)	5–10	4	5	15	23

Note: Data abstracted from [6, 24, 25, 46, 55, 56, 64, 70, 87]

[a] Reports vary from 1 to 18 months after event

children and adolescents [6, 25, 46]. Over a broad time interval [25] and diverse populations, [6, 24, 25, 46], the results are strikingly similar. Overall, the population-based incidence of cardiac arrest in patients <18 years of age is 8/100,000 person-years. This contrasts with the adult incidence of 50–55/100,000 person-years [64, 71]. However, there are marked differences when the frequency and incidence are stratified by age group (Table 1). In most studies, infants <1 year of age comprise 30–50% of all patients [6, 25, 46, 82, 86] The population-based incidence in infants <1 year of age is an order of magnitude higher compared to children (1 to <12 years) or adolescents (12–19 years). Undoubtedly, SIDS accounts for this marked discrepancy, a group that is never included in analyses of adult incidence. Incidence in children and adolescents is 4 and 6/100,000 person-years. Survival has ranged from 2 to 12% [6, 24, 25, 46, 55, 82, 86] and infants have by far the greatest mortality (Table 1). Most interesting is that children and adolescents have comparable or higher survival than adults. Indeed, within the Resuscitation Outcomes Consortium (ROC), children and adolescents had an odds ratio (OR) for survival of 2 compared to adults [6]. Additionally, infants are more likely to undergo resuscitation attempts despite definitive evidence of death Thus, studies that group all age groups together artifactually lower survival outcomes. Survival figures for children are not good but do not warrant an attitude of complete futility.

Additional data are available to further stratify the epidemiology of out-of-hospital cardiac arrest (OHCA). The majority of cardiac arrests occur in a nonpublic location, usually defined as residence. In the ROC study, 22% of OHCA in the adolescent population occurred in public, indicating that the majority still occurred in the home (Table 1). Etiologies are more commonly noncardiac or respiratory. First recorded rhythms are typically asystole/pulseless electrical activity. Although ventricular fibrillation (VF) is an uncommon rhythm, it increases with age. Analysis of initial rhythm is potentially compounded in pediatric arrest, as rhythms might not be assessed as quickly. Despite this, VF does occur in all age groups and should no longer be considered "rare."

Predictors of Outcome

Neurologic outcomes are more difficult to assess, but studies indicate that they can be good in long-term survivors at 1 month or 1 year [56]. Many of the epidemiologic studies have demonstrated several factors that predict outcome, often defined as hospital discharge. Witnessed arrest, followed by immediate bystander cardiopulmonary resuscitation (CPR) predicts both return of spontaneous circulation (ROSC) and intact neurologic outcome [25, 36, 37, 46, 49, 54–56, 73]. Unfortunately, only approximately 15–40% of pediatric patients receive bystander CPR [6, 25, 46]. Emergency medical system (EMS) treatment improves survival and outcomes. An initial rhythm of VF might increase outcome several-fold [6, 46]. Traumatic cardiac arrest predicts a very poor survival, whereas submersion injury might predict a slightly better survival.

However, our goal is not hospital discharge but rather intact neurologic survival. These data have been substantially more difficult to collect and quantify. Most pediatric experts would acknowledge that neurologic status at hospital discharge might not predict outcomes at 1 month or 1 year. Indeed, even adults demonstrate significant neurologic improvement 1–12 months after hospital discharge [69]. Thus, many of our studies do not provide an accurate assessment of the results of CPR and postarrest therapies. Studies now being published are reporting later outcomes and demonstrate good neurologic function in a substantial percentage of the patients [46].

New CPR Guidelines

The revised 2010 AHA CPR Guidelines were released November 2010, after a comprehensive and rigorous international evidence evaluation process [28]. The scientific evidence was released simultaneously but separately from individual resuscitation council guidelines [35]. This scientific review is the most comprehensive review of the current resuscitation literature and included 356 scientists from 29 countries, who conducted 411 reviews on 277 topics. The reviews were critically evaluated by online submission and during in-person meetings, webinars, and teleconferences. The end product provides compelling scientific data to support many of our current and new therapies, acknowledges the inaccuracies and uncertainties of other therapies, and provides a framework within which more research can be conducted. The reader is strongly encouraged to read these documents for a full understanding of the breadth of resuscitation science. The original worksheets can be accessed at www.ilcor.org.

As part of the 2010 guidelines, the AHA has modified the "Chain of Survival," an integrated sequence of time-sensitive events, usually represented by links of a chain, which, when implemented, can increase survival of witnessed VF to 50% [3, 38, 72]. The links for adult resuscitation are the following:

Immediate recognition of cardiac arrest and activation of EMS;
Early CPR with an emphasis on compressions;
Rapid defibrillation;
Effective advanced life support;
Integrated postcardiac arrest care [84].

For young children, the first three links are slightly different:

Prevention of cardiopulmonary arrest;
Early, effective CPR;
Activation of EMS;
Advanced pediatric life support;
Integrated postcardiac arrest care [13].

For these guidelines, children are defined as 1 year to onset of puberty, defined as breast development in females and axillary hair in males. Adolescents are those beyond puberty and the adult CPR guidelines apply to that population. For either group, however, CPR is the first therapy. Successful resuscitation declines by 10% for every minute that CPR is delayed, such that by 10 min, death or vegetative state is the only outcome. Unfortunately, bystander CPR is provided at best 30% of the time [77]. Furthermore, CPR is frequently performed poorly [1, 2, 7, 8] even by highly trained rescuers. CPR quality directly correlates with improved survival and neurologic outcomes [78]. We have reviewed the major modifications of the 2010 guidelines to assist providers and pediatric cardiologists, in particular, to encourage families to learn CPR and to deliver the best CPR possible.

CAB Rather than ABC

A fundamental modification is the change from the airway–breathing–chest compressions sequence (ABC) to chest compressions-airway-breathing (CAB) for both adult and pediatric basic life support. This follows the increased emphasis on chest compressions and high-quality CPR that began with the 2005 guidelines [4]. Effective chest compressions are necessary to initiate blood flow to vital organs, especially the brain and heart. By beginning with chest compression, the delay created by giving ventilations first is avoided. Additionally, chest compressions can begin as soon as the patient is supine, avoiding the additional time delay imposed by positioning the head, opening the airway, and creating a seal for mouth-to-mouth or mouth-to-bag-mask ventilations. Most cardiac arrests occur in adults and during VF; compressions are more important than ventilations.

Pediatric cardiopulmonary arrests are more commonly induced by asphyxia than that in adults, and although ventilations are very important, there are no data to indicate that starting with compressions or ventilations is better. Furthermore, the majority of victims do not receive bystander CPR because of fear of infection or fear of performing CPR incorrectly [77]. By performing chest compressions first, it is hoped that more bystanders will be able and willing to administer chest compressions. However, it is acceptable and recommended that health care workers adapt these recommendations based on the most likely cause of arrest. Thus, if the arrest is witnessed and especially if it is sudden, chest compressions alone followed by activation of EMS are most appropriate. However, if the arrest is unwitnessed, downtime is prolonged, or is caused by submersion or other obvious respiratory causes, it is reasonable and acceptable to provide five cycles of conventional CPR, including ventilations, and then activate EMS.

High-Quality CPR

Beginning with the 2005 guidelines [4], there was increased emphasis on high-quality CPR, consisting of more forceful chest compressions, full recoil during decompression, minimizing time without chest compressions, and limiting ventilations to no more than 10 breaths/min. Chest compressions generate blood flow by increasing intrathoracic pressure, forcing blood out of the thorax, and by directly compressing the heart. Blood flow occurs only during chest compressions; thus, they are absolutely critical to success. The mnemonic "push hard, push fast" was coined to encourage rescuers to provide forceful compression at a rate of 100 compressions/min using a compression to ventilation ratio of 30:2 for adults and lay-rescuers for children. Health care providers should use a compression:ventilation (C:V) ratio of 15:2 for children [13]. Equally important is the depth of each compression. Inadequate chest compression depth occurs frequently, even by professional rescuers, and increases with rescuer fatigue. Chest compression depth should be at least

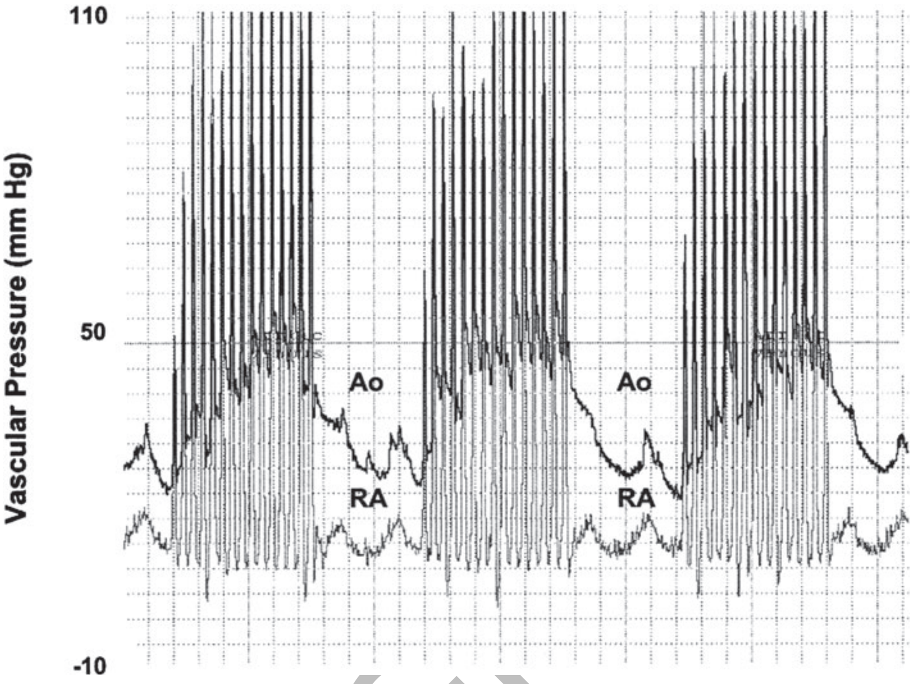

Fig. 1 Simultaneous aortic and right atrial pressure tracings during conventional CPR in a dog. Coronary perfusion pressure drops precipitously as soon as compressions stop for ventilations and requires four to five compressions to reach 15 mm Hg. Used with permission from Berg RA, et al. Adverse Hemodynamic Effects of Interrupting Chest Compressions for Rescue Breathing During Cardiopulmonary Resuscitation for Ventricular Fibrillation Cardiac Arrest. Circulation 2001, 104:2465–2470

one-third the AP diameter of the chest, or 1.5 in. in infants and 2 in. in children.

Equally as important is chest recoil at the end of every compression. Complete recoil is necessary to lower intrathoracic pressure, drawing blood into the thorax, which is necessary to maintain coronary cerebral perfusion. Leaning on the chest, even pressure equivalent to 2–4 kg limits venous return during chest recoil, reduces coronary and cerebral perfusion pressure, and diminishes cardiac output by 25% [85].

"Hands-off time," time without compressions, should be minimized, as there is an immediate drop in coronary perfusion pressure whenever compressions are paused, usually for other cares, such as intubation or vascular access. Effective coronary perfusion pressure is then not restored until several compressions have occurred (Fig. 1). Coronary perfusion pressure is positively related to survival in animals (Fig. 2).

Patients are frequently hyperventilated during CPR by excited and well-meaning professional rescuers. Average ventilation rates have been measured at 30 breaths/min, even with the recommended C:V ratio of 30:2 [7, 8]. Animal studies have demonstrated increasing ventilation rates increased intrathoracic pressure with marked decreased in coronary perfusion pressure and diminished survival.

Hands-Only CPR

In 2008, the AHA released a science advisory statement recommending hands-only (chest compression only) CPR for the *lay bystander in a witnessed adult sudden collapse*

Fig. 2 Survival from prolonged cardiac arrest relates to the coronary perfusion pressures generated during chest compression. Used with permission from Ewy, GA. Cardiocerebral Resuscitation. The New Cardiopulmonary Resuscitation. Circulation 2005;111:2134–2142

[77]. Animal and human clinical data have demonstrated equivalent outcomes between compression-only and conventional CPR as measured by hemodynamics, survival, and neurologic status. However, lack of lung inflation and ventilations induces a progressive decrease in oxygen saturation. It is unclear how long the advantage of continued blood flow with compressions-only will compensate for the decrease in oxygen delivery. Thus, the advisory statement concluded that "the relatively low prevalence of bystander CPR and the potential that further simplification of CPR instructions might encourage more bystanders to take appropriate action." It is important to note that this recommendation does not apply to children, unwitnessed arrest. or arrest of noncardiac origin (e.g., submersion, suffocation, drug overdose, etc.).

Animal studies have consistently demonstrated the value of ventilations in asphyxial arrest [11, 12]. A recent, large pediatric publication supports the need for ventilations in children, especially if the arrest is of noncardiac origin. Kitamura et al. [46] compared 1-month neurologic outcomes from children ≤17 years of age who suffered OHCA, received bystander CPR, and were entered into a nationwide population-based Utstein style database. Children who received bystander CPR had a higher survival rate than those who did not receive bystander CPR. More notable, however, children who had a noncardiac cause of arrest, determined by a physician at the scene, had more favorable outcomes if they received conventional CPR—compressions with ventilations—than if they received just chest compressions (OR: 7.2 vs. 1.6). Survival in children who experienced cardiac arrest of cardiac origin did not differ between chest-compression-only versus conventional CPR. Based on this study, the AHA continued its recommendation for conventional CPR for children, especially for all trained or health care providers. If a rescuer is not trained in CPR or is unwilling or unable to provide ventilations, the chest compression-only is preferred over no attempts at rescue.

Postcardiac Arrest Care

Preservation of neurologic function requires integrated and coordinated care in the postresuscitation period. Significant progress has been made in the recognition of the importance of this to achieve good neurologic outcomes. There are two time periods that are crucial: (1) immediately after the resuscitation during transport and stabilization at a referring facility until transfer to a pediatric tertiary care facility and (2) care within the pediatric intensive care unit. Abrupt deterioration might occur, requiring frequent assessment and modification of therapy.

Elevated PaO_2 levels might increase oxidative injury associated with ischemia–reperfusion states. Care must be taken to maintain oxygen saturations ≥94% by reducing the inspired oxygen concentration. Oxygen saturations of 99–100% can be associated with PaO_2 levels that are well above 100 mm Hg; thus, the recommendation of saturations 94–98%. Exhaled CO_2 (P_{ETCO2}) should be monitored as a tool to quickly assess adequacy of ventilation and continued cardiac output, especially during transport and when arterial blood gases are not readily available [15, 81]. Hyperventilation should be strictly avoided except in situations of impending herniation, as cardiac output and cerebral perfusion are adversely affected and has been shown to impair neurologic outcomes [18].

Metabolic abnormalities especially hyperglycemia might develop in the postarrest period. Both hypoglycemia and hyperglycemia are associated with increased mortality and worse neurologic outcomes [50, 51, 65], but there are no studies demonstrating that treatment improves outcome. Furthermore, intensive therapy to prevent hyperglycemia carries an increased risk of hypoglycemia. Currently, there are no recommendations for children, but for adult patients, the recommended blood sugar target is 144–180 mg/dL [66].

Myocardial dysfunction and derangements of both systemic and pulmonary vascular resistances are common in the postarrest period. Vasoactive support is often necessary to maintain adequate cardiac output and perfusion. Drug therapy must be titrated for each patient depending on the clinical situation, cause of arrest, and response to therapy. Unfortunately, comparison studies to indicate the optimal vasoactive drug or infusion rate are not available. Studies performed in animals [23, 45, 60], pediatric postoperative heart patients [39, 40], or those with septic shock [23] have demonstrated hemodynamic improvement with a variety of drugs.

Neuroprotection is a primary goal of postresuscitation therapy. One of the most exciting developments in postresuscitation care has been the use of therapeutic hypothermia (32–34°C) beginning in the immediate postresuscitation period. Studies in adults [14, 31] and asphyxiated newborns [30, 79, 80] both demonstrate that up to 72 h of therapeutic hypothermia is associated with better outcomes. To date, there are no randomized studies in children outside the neonatal period. Adolescents who are comatose after return of spontaneous circulation from witnessed VF arrest should be treated similarly to adults and cooled to 32–34°C. Therapeutic hypothermia for victims of asphyxial arrest can be considered [47, 48].

Extracorporeal cardiac life support (ECLS) is being used in children who have a treatable or self-limited disease process or are candidates for cardiac transplantation. When ELCS is begun during active resuscitation efforts, it is referred to as ECPR or extracorporeal CPR.

Favorable outcomes have been reported in patients with underlying cardiac disease when the arrest occurred in intensive care units where an ECPR team and protocol were in place prior to the arrest [9, 21, 22, 29, 53, 61, 62, 83]. Poor outcomes have been reported in children with noncardiac disease [9, 62, 83]. Additional factors that might predict a favorable outcome include short duration of CPR and short time interval to initiation of ECPR. Currently, ECPR is recommended only for patients with cardiac disease amenable to future surgery or transplantation in settings in which protocols exist with the expertise to rapidly initiate the therapy.

CPR Training

As indicated above, bystander CPR is only provided in one-third of out-of-hospitals arrest and lack of this predicts bad outcomes. Surveys have demonstrated that a major barrier to bystander CPR is lack of knowledge. Technology and application of educational theory has prompted a shift in CPR course design to increase the number of persons trained in CPR. Instead of multiday instructor-led courses, CPR can now be taught to lay-rescuers using computer and video-directed practice, in as short a time as 30 min [17, 68]. Small kits with inflatable manikins, written instructions, and, most importantly, a 24-min video providing demonstrations of CPR with guided practice can be purchased by groups or individuals to quickly learn CPR. The kits have been provided to middle and high school-aged adolescents [42]. The strength necessary to deliver good CPR might limit the ability of middle school children to perform CPR, but older teenagers are very accepting of learning [41, 43, 57, 58]. Families and parents of high-risk patients can quickly learn CPR and easily refresh their skills with inexpensive self-instruction kits [16, 67]. An additional benefit is that one kit can be used by several people, multiplying the number of persons trained in CPR by a factor of 2 or 3. Training can easily be provided in environments with limited resources, such as public schools, and in underdeveloped countries.

Similar results have been seen with training of automated external defibrillator (AED) use for school-aged children. Students as young as 10 years have comparable performance with pad placement, compliance with AED instructions, and standing clear during shock delivery as emergency medical technicians (EMTs) and paramedics even without prior training [32]. Minimal training, however, improves the ability to use these devices [44, 52, 63, 74, 75].

The AHA strongly encourages broad expansion of CPR training, especially through schools [19], with a recommendation that CPR training become a graduation requirement for high school students. Students should be taught the core principles of the AHA CPR Guidelines, be given the opportunity to practice the psychomotor skills required for high-quality CPR, and be provided instruction on the purpose of an AED, preferable including training and skills practice.

Thirty-six states now have some requirement for CPR training within the schools [19]. The requirements range from a graduation requirement with certification of skills practice, to understanding or recognizing the steps CPR. Unfortunately, several barriers exist to accomplish these requirements, including class time, funding, and equipment. However, multiple school systems have developed models to facilitate this training, such as the use of kits rather than fully trained instructors, inclusion as part of community service for the students, and inclusion in the health class curriculum. Pediatric cardiologists can work with local school systems to accomplish this goal.

Public Access Defibrillation

The adult public access defibrillation (PAD) trial results were published in 2004 [33]. These results demonstrated a significant outcomes benefit for locations that had the availability of CPR plus an AED in comparison to communities that had only CPR available as an interventional modality in OHCA. The survival rate in the CPR + AED group was significantly higher than the CPR-only group (23 vs. 14%). In addition, this and other studies suggested that the cost-effective placement of AEDs should include locations with one arrest every few years, at least 250 adults over 50 years of age during waking hours, high-risk individuals present, or locations with a high frequency of sudden cardiac arrest (SCA) [10].

There are very few data with regard to PAD as it relates to the pediatric population and specifically as it relates to the school environment. Rothmier et al. [76] reviewed the data from high schools in the state of Washington in 2007. A total of 407 high schools were queried, with a 29% response rate: 64% of the 118 schools that responded had at least one AED. Based on this study, the probability of AED use for SCA was 1 in 154 schools per year. This study also assessed the funding sources for school AED programs as well as the people who were trained to use them.

England et al. [27] assessed school AED programs in the Boston area. In this study, it was noted that in 2001, 1 AED was donated to 1 high school in each of 35 school districts. In the follow-up in 2003, 29 of the school districts had functional programs. In 14 schools districts, either some or all of the students were trained; there were 2 successful uses of AEDs in adult cardiac arrests. Finally, a single AED catalyzed 25 of 31 responding school districts to purchase additional AEDs.

In 2007, Lotfi [59] published data on the epidemiology of cardiac arrest in the school setting via review of EMS-treated OHCA in Seattle and King County between 1990 and 2005. This study was designed with special focus on the role of school-based AEDs. During the study period there were 97 cardiac arrests in schools. This represented 0.4% of all cardiac arrests and 2.6% of public location arrests. There were 12 cardiac arrests among students, 33 among faculty and staff employed by the school, and 45 among adults not employed by the school. The school-based arrests occurred on the average of 1 per 111 schools annually with 1 arrest in 8 colleges, 1 arrest per 125 high schools, and 1 arrest per 200 preschools/middle schools. This translated to an annual incidence of 0.18 per 100,000 person-years among students and 4.51 per 100,000 person-years among faculty/staff. Interestingly, in this study it was noted that by 2005, 18% of the schools in Seattle and the King County area had implemented an AED program. Also importantly, the overall survival for OHCA in this study was 39%, significantly better than most current OHCA outcomes data in the literature. Nearly 80% of the SCA patients in this study presented with documented VF/ventricular tachycardia.

Drezner et al. [26] reported on the effectiveness of emergency response planning for SCA in US high schools with AEDs. His study analyzed the adequacy of emergency response planning for SCA in US high schools with an on-site AED program and also determined the effectiveness of AED utilization in those same schools. This study involved a cross-sectional survey involving a school representative who completed a comprehensive survey. One thousand seven hundred ten high schools with an on-site CPR–AED program were further analyzed. Eighty-three percent of the schools had an established emergency action plan for SCA, but only 40% of the schools practiced and reviewed the plan annually. Among the 1710 schools analyzed, 36 (2.1%) schools reported a case of AED use for SCA during the 1-year study period from July 2006 to June 2007. Of the 36 SCA victims, 22 episodes were in older nonstudents (spectators, teachers, staff, coaches, officials; mean age: 57) and 14 were in high school athletes (mean age: 14). Thirty-five of the 36 (97%) SCA cases were witnessed, 34 of the 36 (94%) received bystander CPR, and the AED deployed shocks in 30 of the 36 (83%) of cases, with several victims requiring multiple shocks. Interestingly, survival to hospital discharge after SCA in these high schools was 64% for the students, for the nonstudents, as well as overall for both groups. Although there are clear limitations to this study [5], the outcomes compare favorably to several other PAD studies with encouraging survival, such as those studies in casinos, airports, airlines, and NCAA Division I universities.

Finally, an AHA Consensus statement was published by Hazinski in 2004 [34]. This statement suggested that an AED be placed in all schools with a reasonable probability of cardiac arrest in the next 5 years, those with any student at high risk, or those schools with an emergency to shock time of greater than 5 min. It should also be noted that the school is a community gathering place with multitudes of children and adults present both during school hours as well as after hours. In addition, endeavors to establish school CPR–AED programs, including education of youth, will create a new community of first responders who can "go out into the world" with the potential to save lives.

Project ADAM

Project ADAM is an example a primary and secondary prevention program aimed at children and adolescents. It includes endeavors at establishing school CPR–AED programs. It is based in Wisconsin at Children's Hospital of Wisconsin and includes affiliate sites in several other states in the United States. This program and its implications are described in great detail in a separate chapter within this compendium.

Conclusions

Cardiopulmonary arrest is an infrequent event in pediatrics but devastating. Information is now available to assist lay-rescuers to learn CPR, providing high-quality CPR to increase the probability of rapid ROSC. AEDs can be used even by nontrained lay-rescuers and have increasing prevalence in communities in which cardiac arrest might occur. New therapies are also available for cardiologists and intensivists to preserve neurologic function in children and adolescents who suffer an OHCA. Although published survival rates are low, recent studies have demonstrated survival with good neurologic function as high as 30% with coordinated and integrated prehospital and posthospital care. There is realistic optimism that these efforts will result in improved outcomes for our patients.

References

1. Abella BS, Alvarado JP, Myklebust H, Edelson DP, Barry A, O'Hearn N, Vanden Hoek TL, Becker LB (2005) Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. JAMA 293:305–310
2. Abella BS, Sandbo N, Vassilatos P, Alvarado JP, O'Hearn N, Wigder HN, Hoffman P, Tynus K, Vanden Hoek TL, Becker LB (2005) Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. Circulation 111:428–434
3. Agarwal DA, Hess EP, Atkinson EJ, White RD (2009) Ventricular fibrillation in Rochester, Minnesota: experience over 18 years. Resuscitation 80:1253–1258
4. American Heart Association (2005) 2005 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 112:IV1–IV203
5. Atkins DL (2009) Public access defibrillation: where does it work? Circulation 120:461–463
6. Atkins DL, Everson-Stewart S, Sears GK, Daya M, Osmond MH, Warden CR, Berg RA, Investigators R (2009) Epidemiology and outcomes from out-of-hospital cardiac arrest in children: the Resusctation Outcomes Consortium Epistry-Cardiac Arrest. Circulation 119:1484–1491
7. Aufderheide T (2004) Death by hyperventilation: a common and life-threatening problem during cardiopulmonary resuscitation. Crit Care Med 32:S345–S351
8. Aufderheide T (2004) Hyperventilation-induced hypotension during cardiopulmonary resuscitation. Circulation 109:1960–1965
9. Barrett CS, Bratton SL, Salvin JW, Laussen PC, Rycus PT, Thiagarajan RR (2009) Neurological injury after extracorporeal membrane oxygenation use to aid pediatric cardiopulmonary resuscitation. Pediatr Crit Care Med 10:445–451
10. Becker L, Eisenberg M, Fahrenbruch C, Cobb L (1998) Public locations of cardiac arrest: implications for public access defibrillation. Circulation 97:2106–2109

11. Berg RA, Hilwig RW, Kern KB, Babar I, Ewy GA (1999) Simulated mouth-to-mouth ventilation and chest compressions (bystander cardiopulmonary resuscitation) improves outcome in a swine model of prehospital pediatric asphyxial cardiac arrest. Crit Care Med 27:1893–1899
12. Berg RA, Hilwig RW, Kern KB, Ewy GA (2000) Bystander" chest compressions and assisted ventilation independently improve outcome from piglet asphyxial pulseless "cardiac arrest. Circulation 101:1743–1748
13. Berg MD, Schexnayder SM, Chameides L, Terry M, Donoghue A, Hickey RW, Berg RA, Sutton RM, Hazinski MF (2010) Part 13: Pediatric basic life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 122:S862–S875
14. Bernard SA, Gray TW, Buist MD, Jones BM, Silvester W, Gutteridge G, Smith K (2002) Treatment of comatose survivors of out-of-hospital cardiac arrest with induced hypothermia. N Engl J Med 346:557–563
15. Bhende MS, Allen WD Jr (2002) Evaluation of a Capno-Flo resuscitator during transport of critically ill children. Pediatr Emerg Care 18:414–416
16. Blewer AL, Leary M, Decker CS, Andersen JC, Fredericks AC, Bobrow BJ, Abella BS (2010) Cardiopulmonary resuscitation training of family members before hospital discharge using video self-instruction: a feasibility trial. J Hosp Med (Epub ahead of print)
17. Bobrow BJ, Vadeboncoeur TF, Spaite DW, Potts J, Denninghoff K, Chikani V, Brazil PR, Ramsey B, Abella BS (2011) The effectiveness of ultrabrief and brief educational videos for training lay responders in hands-only cardiopulmonary resuscitation: implications for the future of citizen cardiopulmonary resuscitation training. Circ Cardiovasc Qual Outcomes 4:220–226
18. Buunk G, van der Hoeven JG, Meinders AE (1997) Cerebrovascular reactivity in comatose patients resuscitated from a cardiac arrest. Stroke 28:1569–1573
19. Cave DM, Aufderheide TP, Beeson J, Ellison A, Gregory A, Hazinski MF, Hiratzka LF, Lurie KG, Morrison LJ, Mosesso VN Jr, Nadkarni V, Potts J, Samson RA, Sayre MR, Schexnayder SM (2011) Importance and implementation of training in cardiopulmonary resuscitation and automated external defibrillation in schools: a science advisory from the American Heart Association. Circulation 123:691–706
20. Chameides L (1987) Cardiopulmonary resuscitation: standards, guidelines, and education. Pediatrics 79:446–449
21. Chan T, Thiagarajan RR, Frank D, Bratton SL (2008) Survival after extracorporeal cardiopulmonary resuscitation in infants and children with heart disease. J Thorac Cardiovasc Surg 136:984–992
22. Chow G, Koirala B, Armstrong D, McCrindle B, Bohn D, Edgell D, Coles J, de Veber G (2004) Predictors of mortality and neurological morbidity in children undergoing extracorporeal life support for cardiac disease. Eur J Cardiothorac Surg 26:38–43
23. De Backer D, Biston P, Devriendt J, Madl C, Chochrad D, Aldecoa C, Brasseur A, Defrance P, Gottignies P, Vincent JL (2010) Comparison of dopamine and norepinephrine in the treatment of shock. N Engl J Med 362:779–789
24. Deasy C, Bernard SA, Cameron P, Jaison A, Smith K, Harriss L, Walker T, Masci K, Tibballs J (2010) Epidemiology of paediatric out-of-hospital cardiac arrest in Melbourne, Australia. Resuscitation 81:1095–1100
25. Donoghue AJ, Nadkarni V, Berg RA, Osmond MH, Wells G, Nesbitt L, Stiell IG (2005) Out-of-hospital pediatric cardiac arrest: an epidemiologic review and assessment of current knowledge. Ann Emerg Med 46:512–522
26. Drezner JA, Rao AL, Heistanc J, Bloomingdale MK, Harmon KG (2009) Effectiveness of emergency response planning for sudden cardiac arrest in United States high schools with automated external defibbrillators. Circulation 120:518–525
27. England H, Hoffman C, Hodgman T, Singh S, Homoud M, Weinstock J, Link M, Estes NA 3rd (2005) Effectiveness of automated external defibrillators in high schools in greater Boston. Am J Cardiol 95:1484–1486
28. Field JM, Hazinski MF, Sayre MR, Chameides L, Schexnayder SM, Hemphill R, Samson RA, Kattwinkel J, Berg RA, Bhanji F, Cave DM, Jauch EC, Kudenchuk PJ, Neumar RW, Peberdy MA, Perlman JM, Sinz E, Travers AH, Berg MD, Billi JE, Eigel B, Hickey RW, Kleinman ME, Link MS, Morrison LJ, O'Connor RE, Shuster M, Callaway CW, Cucchiara B, Ferguson JD, Rea TD, Vanden Hoek TL (2010) Part 1: Executive summary: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 122:S640–S656
29. Ghez O, Feier H, Ughetto F, Fraisse A, Kreitmann B, Metras D (2005) Postoperative extracorporeal life support in pediatric cardiac surgery: recent results. ASAIO J 51:513–516
30. Gluckman PD, Wyatt JS, Azzopardi D, Ballard R, Edwards AD, Ferriero DM, Polin RA, Robertson CM, Thoresen M, Whitelaw A, Gunn AJ (2005) Selective head cooling with mild systemic hypothermia after neonatal encephalopathy: multicentre randomised trial. Lancet 365:663–670
31. Group HACaS (2002) Mild therapeutic hypothermia to improve the neurologic outcome after cardiac arrest. N Engl J Med 346:549–556
32. Gundry JW, Comess KA, DeRook FA, Jorgenson D, Bardy GH (1999) Comparison of naive sixth-grade children with trained professionals in the use of an automated external defibrillator. Circulation 100:1703–1707
33. Hallstrom AP, Ornato JP, Weisfeldt M, Travers A, Christenson J, McBurnie MA, Zalenski R, Becker LB, Schron EB, Proschan M, Public Access Defibrillation Trial I (2004) Public-access defibrillation and survival after out-of-hospital cardiac arrest. N Engl J Med 351:637–646
34. Hazinski MF, Markenson DS, Neish SR, Gerardi MJ, Hootman J, Nichol G, Taras H, Hickey RW, O'Connor R, Potts J, van der Jagt E, Berger S, Schexnayder S, Garson A, Doherty A, Smith SA (2004) Response to cardic arrest and selected life-threatening medical emergencies: the medical emergency response plan for schools. A statement of healthcare providers, policymakers, school administrators, and community leaders. Pediatrics 113:155–168
35. Hazinski MF, Nolan JP, Billi JE, Bottiger BW, Bossaert L, de Caen AR, Deakin CD, Drajer S, Eigel B, Hickey RW, Jacobs I, Kleinman ME, Kloeck W, Koster RW, Lim SH, Mancini ME, Montgomery WH, Morley PT, Morrison LJ, Nadkarni VM, O'Connor RE, Okada K, Perlman JM, Sayre MR, Shuster M, Soar J, Sunde K, Travers AH, Wyllie J, Zideman D (2010) Part 1: Executive summary: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Circulation 122:S250–S275
36. Hickey RW (2006) Response to: out-of-hospital pediatric cardiac arrest: an epidemiologic review and assessment of current knowledge. Ann Emerg Med 48:219
37. Hickey RW, Cohen DM, Strausbaugh S, Dietrich AM (1995) Pediatric patients requiring CPR in the prehospital setting. Ann Emerg Med 25:495–501
38. Hinchey PR, Myers JB, Lewis R, De Maio VJ, Reyer E, Licatese D, Zalkin J, Snyder G (2010) Improved out-of-hospital cardiac arrest survival after the sequential implementation of 2005 AHA guidelines for compressions, ventilations, and induced hypothermia: the Wake County experience. Ann Emerg Med 56:348–357

39. Hoffman TM, Wernovsky G, Atz AM, Bailey JM, Akbary A, Kocsis JF, Nelson DP, Chang AC, Kulik TJ, Spray TL, Wessel DL (2002) Prophylactic intravenous use of milrinone after cardiac operation in pediatrics (PRIMACORP) study. Prophylactic intravenous use of milrinone after cardiac operation in pediatrics. Am Heart J 143:15–21
40. Hoffman TM, Wernovsky G, Atz AM, Kulik TJ, Nelson DP, Chang AC, Bailey JM, Akbary A, Kocsis JF, Kaczmarek R, Spray TL, Wessel DL (2003) Efficacy and safety of milrinone in preventing low cardiac output syndrome in infants and children after corrective surgery for congenital heart disease. Circulation 107:996–1002
41. Isbye DL, Rasmussen LS, Lippert FK, Rudolph SF, Ringsted CV (2006) Laypersons may learn basic life support in 24 min using a personal resuscitation manikin. Resuscitation 69:435–442
42. Isbye DL, Rasmussen LS, Ringsted C, Lippert FK (2007) Disseminating cardiopulmonary resuscitation training by distributing 35,000 personal manikins among school children. Circulation 116:1380–1385
43. Jones I, Whitfield R, Colquhoun M, Chamberlain D, Vetter N, Newcombe R (2007) At what age can schoolchildren provide effective chest compressions? An observational study from the Heartstart UK schools training programme. Br Med J 334:1201
44. Kelley JR, Richman PB, Ewy GA, Clark L, Bulloch B, Bobrow BJ (2006) Eighth grade students become proficient at CPR and use of an AED following a condensed training programme. Resuscitation 71:229–236
45. Kern KB, Hilwig RW, Berg RA, Rhee KH, Sanders AB, Otto CW, Ewy GA (1997) Postresuscitation left ventricular systolic and diastolic dysfunction. Treatment with dobutamine. Circulation 95:2610–2613
46. Kitamura T, Iwami T, Kawamura T, Nagao K, Tanaka H, Nadkarni VM, Berg RA, Hiraide A (2010) Conventional and chest-compression-only cardiopulmonary resuscitation by bystanders for children who have out-of-hospital cardiac arrests: a prospective, nationwide, population-based cohort study. Lancet 375:1347–1354
47. Kleinman ME, Chameides L, Schexnayder SM, Samson RA, Hazinski MF, Atkins DL, Berg MD, de Caen AR, Fink EL, Freid EB, Hickey RW, Marino BS, Nadkarni VM, Proctor LT, Qureshi FA, Sartorelli K, Topjian A, van der Jagt EW, Zaritsky AL (2010) Pediatric advanced life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Pediatrics 126:e1361–e1399
48. Kleinman ME, de Caen AR, Chameides L, Atkins DL, Berg RA, Berg MD, Bhanji F, Biarent D, Bingham R, Coovadia AH, Hazinski MF, Hickey RW, Nadkarni VM, Reis AG, Rodriguez-Nunez A, Tibballs J, Zaritsky AL, Zideman D (2010) Part 10: Pediatric basic and advanced life support: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Circulation 122:S466–S515
49. Kuisma M, Alaspää A (1997) Out-of-hospital cardiac arrests of non-cardiac origin: epidemiology and outcome. Eur Heart J 18:1122–1128
50. Langhelle A, Tyvold SS, Lexow K, Hapnes SA, Sunde K, Steen PA (2003) In-hospital factors associated with improved outcome after out-of-hospital cardiac arrest. A comparison between four regions in Norway. Resuscitation 56:247–263
51. Laver SR, Padkin A, Atalla A, Nolan JP (2006) Therapeutic hypothermia after cardiac arrest: a survey of practice in intensive care units in the United Kingdom. Anaesthesia 61:873–877
52. Lawson L, March J (2002) Automated external defibrillation by very young, untrained children. Prehosp Emerg Care 6:295–298
53. Lequier L, Joffe AR, Robertson CM, Dinu IA, Wongswadiwat Y, Anton NR, Ross DB, Rebeyka IM (2008) Two-year survival, mental, and motor outcomes after cardiac extracorporeal life support at less than five years of age. J Thorac Cardiovasc Surg 136:976–983
54. Lopez-Herce J, Garcia C, Dominguez P, Carrillo A, Rodriguez-Nunez A, Calvo C, Delgado MA (2004) Characteristics and outcome of cardiorespiratory arrest in children. Resuscitation 63:311–320
55. Lopez-Herce J, Garcia C, Dominguez P, Rodriguez-Nunez A, Carrillo A, Calvo C, Delgado MA (2005) Outcome of out-of-hospital cardiorespiratory arrest in children. Pediatr Emerg Care 21:807–815
56. Lopez-Herce J, Garcia C, Rodriguez-Nunez A, Dominguez P, Carrillo A, Calvo C, Delgado MA (2005) Long-term outcome of paediatric cardiorespiratory arrest in Spain. Resuscitation 64:79–85
57. Lorem T, Palm A, Wik L (2008) Impact of a self-instruction CPR kit on 7th graders' and adults' skills and CPR performance. Resuscitation 79:103–108
58. Lorem T, Steen PA, Wik L (2010) High school students as ambassadors of CPR: a model for reaching the most appropriate target population? Resuscitation 81:78–81
59. Lotfi K, White L, Rea T, Cobb L, Copass M, Yin L, Becker L, Eisenberg M (2007) Cardiac arrest in schools. Circulation 116:1374–1379
60. Meyer RJ, Kern KB, Berg RA, Hilwig RW, Ewy GA (2002) Post-resuscitation right ventricular dysfunction: delineation and treatment with dobutamine. Resuscitation 55:187–191
61. Morris MC, Ittenbach RF, Godinez RI, Portnoy JD, Tabbutt S, Hanna BD, Hoffman TM, Gaynor JW, Connelly JT, Helfaer MA, Spray TL, Wernovsky G (2004) Risk factors for mortality in 137 pediatric cardiac intensive care unit patients managed with extracorporeal membrane oxygenation. Crit Care Med 32:1061–1069
62. Morris MC, Wernovsky G, Nadkarni VM (2004) Survival outcomes after extracorporeal cardiopulmonary resuscitation instituted during active chest compressions following refractory in-hospital pediatric cardiac arrest. Pediatr Crit Care Med 5:440–446
63. Mosesso VN Jr, Shapiro AH, Stein K, Burkett K, Wang H (2009) Effects of AED device features on performance by untrained laypersons. Resuscitation 80:1285–1289
64. Nichol G, Thomas E, Callaway CW, Hedges J, Powell JL, Aufderheide TP, Rea T, Lowe R, Brown T, Dreyer J, Davis D, Idris A, Stiell I (2008) Regional variation in out-of-hospital cardiac arrest incidence and outcome. JAMA 300:1423–1431
65. Nolan JP, Laver SR, Welch CA, Harrison DA, Gupta V, Rowan K (2007) Outcome following admission to UK intensive care units after cardiac arrest: a secondary analysis of the ICNARC Case Mix Programme Database. Anaesthesia 62:1207–1216
66. Peberdy MA, Callaway CW, Neumar RW, Geocadin RG, Zimmerman JL, Donnino M, Gabrielli A, Silvers SM, Zaritsky AL, Merchant R, Vanden Hoek TL, Kronick SL (2010) Part 9: Post-cardiac arrest care: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 122:S768–S786
67. Pierick TA, Van Waning N, Patel S, Atkins DL (2010) Infant CPRAnytime: self-instructional CPR training for parents of high-risk infants. Circulation 122:A12388
68. Potts J, Lynch B (2006) The American Heart Association CPR Anytime Program: the potential impact of highly accessible training in cardiopulmonary resuscitation. J Cardiopulm Rehabil 26:346–354
69. Rea TD, Eisenberg MS (2003) Long-term survival after resuscitation from cardiac arrest: cause for optimism and continued efforts. Am Heart J 145:749–750
70. Rea TD, Eisenberg MS, Sinibaldi G, White RD (2004) Incidence of EMS-treated out-of-hospital cardiac arrest in the United States. Resuscitation 63:17–24

71. Rea TD, Pearce RM, Raghunathan TE, Lemaitre RN, Sotoodehnia N, Jouven X, Siscovick DS (2004) Incidence of out-of-hospital cardiac arrest. Am J Cardiol 93:1455–1460
72. Rea TD, Helbock M, Perry S, Garcia M, Cloyd D, Becker L, Eisenberg M (2006) Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest: survival implications of guideline changes. Circulation 114: 2760–2765
73. Rodriguez-Nunez A, Lopez-Herce J, Garcia C, Dominguez P, Carrillo A, Bellon JM (2006) Pediatric defibrillation after cardiac arrest: initial response and outcome. Crit Care 10:R113
74. Roppolo LP, Pepe PE, Campbell L, Ohman K, Kulkarni H, Miller RA, Idris A, Bean L, Bettes TN, Idris AH (2007) Prospective, randomized trial of the effectiveness and retention of 30-min layperson training for cardiopulmonary resuscitation and automated external defibrillators: The American Airlines Study. Resuscitation 74:276–285
75. Roppolo LP, Saunders T, Pepe PE, Idris AH (2007) Layperson training for cardiopulmonary resuscitation: when less is better. Curr Opin Crit Care 13:256–260
76. Rothmier JD, Drezner JA, Harmon KG (2007) Automated external defibrillators in Washington State high schools. Br J Sports Med 41:301–305
77. Sayre MR, Berg RA, Cave DM, Page RL, Potts J, White RD (2008) Hands-only (compression-only) cardiopulmonary resuscitation: a call to action for bystander response to adults who experience out-of-hospital sudden cardiac arrest: a science advisory for the public from the American Heart Association Emergency Cardiovascular Care Committee. Circulation 117: 2162–2167
78. Seethala RR, Esposito EC, Abella BS (2010) Approaches to improving cardiac arrest resuscitation performance. Curr Opin Crit Care 16:196–202
79. Shankaran S, Laptook AR, Ehrenkranz RA, Tyson JE, McDonald SA, Donovan EF, Fanaroff AA, Poole WK, Wright LL, Higgins RD, Finer NN, Carlo WA, Duara S, Oh W, Cotten CM, Stevenson DK, Stoll BJ, Lemons JA, Guillet R, Jobe AH (2005) Whole-body hypothermia for neonates with hypoxic-ischemic encephalopathy. N Engl J Med 353:1574–1584
80. Shankaran S, Pappas A, Laptook AR, McDonald SA, Ehrenkranz RA, Tyson JE, Walsh M, Goldberg RN, Higgins RD, Das A (2008) Outcomes of safety and effectiveness in a multicenter randomized, controlled trial of whole-body hypothermia for neonatal hypoxic-ischemic encephalopathy. Pediatrics 122:e791–e798
81. Singh S, Allen WD Jr, Venkataraman ST, Bhende MS (2006) Utility of a novel quantitative handheld microstream capnometer during transport of critically ill children. Am J Emerg Med 24:302–307
82. Sirbaugh PE, Pepe PE, Shook JE, Kimball KT, Goldman MJ, Ward MA, Mann DA (1999) A prospective, population-based study of the demographics, epidemiology, management, and outcome of out-of-hospital pediatric cardiopulmonary arrest. Ann Emerg Med 33:174–184
83. Thiagarajan RR, Laussen PC, Rycus PT, Bartlett RH, Bratton SL (2007) Extracorporeal membrane oxygenation to aid cardiopulmonary resuscitation in infants and children. Circulation 116: 1693–1700
84. Travers AH, Rea TD, Bobrow BJ, Edelson DP, Berg RA, Sayre MR, Berg MD, Chameides L, O'Connor RE, Swor RA (2010) Part 4: CPR overview: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 122:S676–S684
85. Yannopoulos D, McKnite S, Aufderheide TP, Sigurdsson G, Pirrallo RG, Benditt D, Lurie KG (2005) Effects of incomplete chest wall decompression during cardiopulmonary resuscitation on coronary and cerebral perfusion pressures in a porcine model of cardiac arrest. Resuscitation 64:363–372
86. Young KD, Seidel JS (1999) Pediatric cardiopulmonary resuscitation: a collective review. Ann Emerg Med 33:195–205
87. Young KD, Gausche-Hill M, McClung CD, Lewis RJ (2004) A prospective, population-based study of the epidemiology and outcome of out-of-hospital pediatric cardiopulmonary arrest. Pediatrics 114:157–164