Pediatric Advanced Cardiac Life Support - 2007 Update

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Objectives:
1. Update pediatric basic and advanced cardiac life support treatment protocols.
2. Review causes of anesthesia-related cardiac arrest in the pediatric population.

Introduction:

More than 30 years ago the American Heart Association (AHA), through its emergency cardiovascular care (ECC) committee, published guidelines for cardiopulmonary resuscitation (CPR).[1] Periodic reviews and updates of CPR treatment protocols have been conducted with an ever increasing emphasis on two goals; identification of the scientific basis for recommended clinical care protocols and an international consensus. The most recent CPR update was completed in 2005.[2] This update was significant for its continued commitments to develop International CPR guidelines via the collaborative efforts of the **I**nternational **L**iaison **C**ommittee **o**n **R**esuscitation (**ILCOR**-comprised of representatives from the AHA, European Resuscitation Council (ERC), Heart and Stroke Foundation of Canada (HSFC), Resuscitation Council of Southern Africa (RCSA), Australia and New Zealand Council on Resuscitation (ANZCOR), Inter-American Heart Foundation (IAHF) and the Japan Resuscitation Council (JRC) which is an international observer to ILCOR) and to utilize evidenced-based methodology to evaluate and adopt BLS, ACLS, PALS and Neonatal Resuscitation treatment protocols.[3,4] An international consensus on science and treatment recommendations (**CoSTR**) document for CPR and ECC was published in CIRCULATION in November 2005.[3,4]

Five major changes in the 2005 CPR guidelines apply to all rescuers and all rescue situations: [5]

1. **"Push hard and push fast"** characterizes the emphasis on ***effective chest compressions*** to produce the best cardiac output and oxygen delivery possible during CPR. Under the best circumstances, chest compressions result in a cardiac output that is considerably less than normal. When chest compressions are too slow and too shallow, cardiac output is further compromised. When chest compressions are interrupted, cardiac output ceases.
2. **Employ a 30:2 chest compression-to-ventilation ratio** characterizes the emphasis on a simplified approach to CPR that is easy for all lone rescuers to remember and better assures the delivery of a longer series of uninterrupted chest compressions. **Healthcare providers should employ a 15:2 ratio** for 2-rescuer CPR in pediatric settings.
3. **"Make the chest rise"** focuses on the need for rescuers to give each rescue breath over a one second period visually confirming that the chest rises and alveolar expansion, ie, oxygen delivery, has occurred.
4. **Deliver 1 electrical shock and immediately follow with chest compressions; Check the victim's rhythm after every 5 CPR cycles (about 2 minutes)** acknowledges that 1 defibrillation attempt eliminates ventricular fibrillation (VF) in more than 85% cases, that multiple defibrillation attempts result in long delays in the provision of chest compressions and that defibrillation success is enhanced by the blood flow and oxygen delivery to the heart that results from chest compressions that are ***effective***, ie, fast, hard and interrupted less.
5. **Use AEDs in children 1 year of age and older** reaffirms the 2003 ILCOR statement that AEDs accurately recognize shockable rhythms in pediatric patients and deliver electrical doses appropriate to the size of the pediatric patient when equipped with pediatric pads that attenuate the electrical energy of the shock.

Other important recommendations/changes for the care of infants and children in the 2005 CPR guidelines include: [5]

1. In the pediatric arrest situation, the lone rescuer should perform 5 CPR 30:2 cycles before phoning 911 and retrieving the AED.
2. When performing chest compression on the pediatric patient; use 1 or 2 hands (depending upon how large the child is) positioned on the sternum at the nipple line to compress the chest of the child and use 2 fingers positioned on the sternum just below the nipple line (encircling the thoracic cage when there are 2 rescuers) to compress the chest of the infant.

3. If the heart rate of the infant or child is <60/minute and there are signs of poor perfusion, chest compression is recommended.
4. Once an advanced airway (eg endotracheal tube, LMA or Combitube) is in place, healthcare providers (2-rescuers) will not interrupt chest compressions for ventilation and will continuously deliver 100 compressions per minute. A ventilation rate of 8-10 breaths per minute should avoid hyperventilation.
5. Deliver 90 compressions and 30 ventilations (3:1 ratio) per minute when performing CPR on newborns.

Pediatric Advanced Cardiac Life Support (PALS) Treatment Protocol Updates[6]

A. Airway Adjuncts. Endotracheal intubation remains the "gold standard" approach to securing the airway of a pediatric victim of cardiopulmonary arrest. Only properly trained individuals must attempt endotracheal intubation. When properly trained individuals are not available to perform endotracheal intubation, bag-mask ventilation is strongly recommended. **Bag-mask ventilation** has been shown to be a very effective means of ventilating and oxygenating children especially in situations when transport time to a hospital setting is short. Health care providers other than anesthesiologists who perform endotracheal intubation must be trained in the technique and the use of medications that facilitate successful tube placement. One study documented that 1 of 11 endotracheal tubes placed in children was either in the esophagus or above the glottic opening. **Confirmation of endotracheal placement** of the tube and maintenance of its position in the trachea may be difficult when clinical signs alone are utilized. **Detection of exhaled carbon dioxide** using either a **capnograph or colorimetric device** is strongly recommended to assure endotracheal placement of the tube. **Esophageal detector devices** (self-inflating bulb), may confirm endotracheal placement in children weighing >20 kg but there is insufficient evidence to recommend its use in the pediatric cardiac arrest situation. The **laryngeal mask airway (LMA)**, well known to anesthesiologists as an effective ventilating device used in the operating room, has not been studied sufficiently to allow an evidenced-based recommendation for its use in pediatric CPR. The opinion of resuscitation experts recommends that the LMA be considered as a potentially useful adjunct device for airway control in pediatric patients and newborns when bag-valve-mask ventilation is inadequate or a secured airway cannot be established by tracheal intubation.[7] Individuals electing to use the LMA must be trained in selection of the proper size for pediatric patients, its insertion technique, verification that effective ventilation is present once it is inserted and what complications may occur (eg easy dislodgement of the LMA from a position through which effective ventilation can be assured and sustained).[7] The suggested AHA mnemonic for making the differential diagnosis when an intubated patient deteriorates is to think, "**DOPE**: **D**isplacement of the tube from the trachea, **O**bstruction of the tube, **P**neumothorax, and **E**quipment failure."[7] **Transtracheal Catheter Ventilation via Cricothyroidotomy** may be an effective means of providing ventilation and oxygenation of a child whose airway cannot be easily secured by endotracheal intubation.

B. Vascular Access. Vascular access in pediatric patients may be problematic, especially more so in younger children. A CPR goal is to establish vascular access in as rapid a timeframe as possible. The **intraosseous (IO)** space is a noncollapsible venous plexus within the marrow. Cannulation of the IO space takes 30-60 seconds and permits safe and rapid infusion of fluids and medications (including potent cardiovascular agents and sodium bicarbonate). Recommended IO cannulation sites include the anterior tibia, distal femur, medial malleolus and anterior superior iliac spine. The distal radius, distal ulna and proximal tibia are additional alternative IO cannulation sites in older children. Increasing evidence has been gathered that documents that IO vascular access once recommended for children ≤6 years should be used for all age children when rapid **intravenous (IV)** cannulation cannot be accomplished. **Endotracheal (ET)** administration of some resuscitation drugs (**L**idocaine, **E**pinephrine, **A**tropine and **N**aloxone [**LEAN**]) is possible when IV and IO routes are not available. Lower blood concentrations result when these medications are instilled into the trachea as compared to administration via the IV and IO routes.

C. Pharmacological Agents. Epinephrine and **oxygen** continue to be a mainstay of CPR pharmacology. Epinephrine's α-adrenergic vasoconstrictive effect is key to successful CPR. At the time of the 1992 AHA CPR review and update, use of high-dose epinephrine protocols was recommended based on promising, yet somewhat preliminary data. The use of high-dose epinephrine in pediatric ACLS was de-emphasized in the 2000 PALS protocol. Several studies failed to establish better survival when high-dose epinephrine was used in the pediatric CPR setting. In addition, high-dose epinephrine is associated with clinically significant morbidity including increased myocardial oxygen consumption during the provision of CPR and a post-CPR hyperadrenergic state (tachycardia, hypertension, cardiac rhythm disturbances, myocardial dysfunction/necrosis). The recommended dose for epinephrine for the unconscious, asystolic, pulseless cardiopulmonary arrest patient is shown in Table 1.

Table 1. Epinephrine Administration During CPR for a Pulseless Victim: IV, IO[6]

Initial Dose	0.01 mg/kg (0.1 ml/kg 1:10,000) IV/IO
Initial Dose	0.1 mg/kg (0.1 ml/kg 1:1,000) ET
Subsequent Doses (every 3-5 minutes)	Repeat initial dose
Maximum Dose	1 mg IV/IO; 10 mg ET

There is insufficient evidence to recommend the use of **Vasopressin** during CPR in the pediatric setting. **Amiodarone** may be considered in the treatment algorithms for supraventricular and ventricular arrhythmias (especially refractory ventricular fibrillation). The rationale for including Amiodarone in the 2000 AHA PALS update stemmed from the successful use of this drug in the pediatric cardiac surgery and cardiology settings and the desire to keep the adult and pediatric advanced cardiac life support protocols consistent. **Adenosine** remains the first choice medication for treatment of supraventricular arrhythmias. **Bretylium** has been deleted from the PALS protocols because of its lack of effectiveness in the treatment of ventricular arrhythmias, insufficient data on its effective use in the pediatric setting and clinically significant side effects that include among others, hypotension.

D. Non-pharmacological Treatment of Arrhythmias. **Vagal maneuvers** can be used to the treat children with supraventricular tachycardia who are hemodynamically stable and/or being prepared for cardioversion. Effective termination of supraventricular tachycardia using vagal maneuvers is variable. Utilization of vagal maneuvers must not delay cardioversion or administration of adenosine for children who need these therapies to rapidly treat a poor perfusion state. The most effective vagal stimulant in infants and children is the application of a bag with ice/ice water to the face. Carotid massage (carefully administered) and the Valsalva maneuver are effective treatments in older children. **Automated External Defibrillators (AEDs)** are an integral part of out-of-hospital CPR for adults. AED therapy in the pediatric population includes use of: a) an adult AED for pediatric patients > 8 years of age delivering a truncated exponential biphasic-waveform 150-200 joule shock (6-8 joules/kg for the average weight 8 year old) whose parameters are adjusted as a function of patient impedance and b) an AED with infant/child reduced energy defibrillator pads delivering ~50-75 joules for children < 8 years old.[9] Many AEDs accurately interpret rhythms that will be appropriately defibrillated in the pediatric age group.[9] Currently there is little evidence to justify use of the AED for children < 1 year of age.[9]

E. Preparedness to Implement PALS Guidelines. The success of PALS depends upon knowledgeable and skillful individuals being immediately available to provide resuscitative care based upon the currently accepted guidelines. This standard of care may be precluded by absence of the equipment and medications indicated by the PALS Guidelines. McGillivary et al studied pediatric emergency facilities in Canada and documented that necessary equipment and medications for pediatric resuscitation were often unavailable (site visit unavailability: IO needle 16 %, drug dosing guidelines 7 %, infant blood pressure cuff 15 %, pediatric defibrillation paddles 11%, warming device 59 %, infant bag-valve-mask system 4 %, infant laryngoscope blade 4 %, 3-mm endotracheal tube 3 %, pediatric pulse oximeter 18%).[10] With the United States population being more than 72.3 million people with 26 percent of the population under age 18 (US Bureau of Census 2000) and knowing that more than 21 % of these children will have 1 or more emergency department visits in a year (Centers for Disease Control and Prevention 2003), the potential public health risk for children needing resuscitative care and being cared for in a hospital without the necessary equipment and/or medications is substantial.[11,12] The American College of Emergency Physicians and the American Academy of Pediatrics (AAP) have addressed this deficiency by jointly publishing, "Care of children in the emergency department: guidelines for preparedness".[13] Anesthesiologists should review these guidelines, affirm the appropriateness of the equipment and medication guidelines and query compliance in their practice setting.

F. Post-CPR Neurological Preservation. Rapid return of oxygen delivery to the brain is a goal of CPR. Neurological recovery and preservation depends not only on providing adequate oxygen delivery but also avoiding excessive oxygen requirement. Hyperthermia (core temperature increase) results in approximately a 10% increase in metabolic oxygen demand/degree temperature rise and should be avoided in the post-CPR phase. Insufficient data exists to recommend active cooling of post-CPR patients to produce **mild hypothermia** (temperature > 33^{O} C) to reduce neurological oxygen requirements. Sufficient data does exist to recommend that post-CPR victims that have mild hypothermia should not be actively rewarmed. Maintenance of **normocarbia** is the recommended ventilatory management approach for the post-CPR child. The rationale for this approach is that hyperventilation limits cerebral perfusion by its vasoconstrictive effect and may limit oxygen delivery and result in cerebral ischemia. In addition, hyperventilation may impede venous return, reducing cardiac output and ultimately cerebral perfusion and oxygen delivery. The recommendation, therefore, is to avoid *routine* hyperventilation of the post-CPR patient. Hyperventilation continues to be most appropriately employed in post-CPR children who demonstrate increased intracranial pressure.

G. **Family Presence During CPR.**[14] The first study supporting the presence of family members during CPR for a loved one was published after the 1992 AHA CPR update, hence the lack of mentioning this concept in that PALS review. The 2000 and 2005 AHA CPR updates have incorporated the increasing body of knowledge in the literature that supports family presence during CPR for a loved one. When family members are present during CPR, they report being better able to cope with the loss of their loved one and the required adjustment to their life. Psychological evaluations of family members present during a family member's CPR show they have less anxiety and depression and a more productive grieving process than family members denied that experience or not requesting it. The PALS recommendation is that family members be made aware of the possibility of being present during CPR for their loved one and given the option to elect that. It is important that the hospital staff, including the resuscitation team, be prepared for the presence of family members during resuscitation and have personnel available to answer family member's questions and support them during the acute crisis event and in the immediate post-crisis time period.

Anesthesia-Related Pediatric Cardiopulmonary Arrest

Cardiovascular and respiratory factors are the major causes of cardiopulmonary arrest in the pediatric population during anesthesia. In 1975, Salem et al reported that hypovolemia, preoperative anemia, pharmacological toxicity (succinylcholine, potassium), hypoventilation and airway obstruction were the major cardiovascular and respiratory causes of anesthesia-related cardiac arrest in the pediatric population.[15] In 1993, Morray et al, reported on data collected from the American Society of Anesthesiologists (ASA) Closed Claims Project.[16] Analysis of that data revealed that cardiopulmonary arrest during anesthesia in the pediatric population was different than in the adult population. In the pediatric population, cardiopulmonary arrest during anesthesia was more commonly caused by respiratory events (inadequate ventilation with cyanosis and/or bradycardia preceding the cardiac arrest) and was more likely to result in mortality than in the adult cases.

Anesthesia-related cardiopulmonary arrest is thankfully an uncommon event. It is certainly an uncommon event during anesthesia administered to pediatric patients. In order to expand upon and fully understand data on the uncommon event of anesthesia-related cardiopulmonary arrest in the pediatric population, Morray and colleagues established the **P**ediatric **P**erioperative **C**ardiac **A**rrest (**POCA**) registry.[17] Established in 1994, the POCA registry is co-sponsored by the ASA and AAP and funded by the ASA with facilities provided by the University of Washington Department of Anesthesiology.

The POCA data collection process is characterized by anonymous case reporting (utilizing a report form that combines both structured and unstructured reporting formats) of all pediatric cardiopulmonary arrests in the perioperative period for children 18 years old or younger from institutions enrolled in the registry in the United States and Canada. The initial findings of the first 150 anesthesia-related cardiopulmonary arrests compiled information from 63 institutions during the 1st four years of POCA data collection.[17]

A total of 289 cardiopulmonary arrests were reported with an overall incidence of 1.4 ± 0.45 per 10,000 anesthetics (range 1.1-2.1 per 10,000) and a 26% mortality rate. Medication-related (37%) (eg halothane cardiovascular depression) (cardiovascular depression was the primary cause of 71% of all medication-related cardiopulmonary arrests) and cardiovascular causes (32%) (eg hemorrhage or its therapy) were the most common explanations for anesthesia-related cardiopulmonary arrest in the pediatric population. Respiratory causes accounted for only 20% of the pediatric anesthesia-related cardiopulmonary arrests with laryngospasm and anatomic airway obstruction being the most frequent problems in this category. Of note was the 33% incidence of cardiopulmonary arrest in ASA physical status 1 & 2 patients with 64% of these arrests falling into the medication-related category.

Infants less than 1 year of age accounted for 56% of all anesthesia-related cardiopulmonary arrests. Emergency surgery and ASA physical status 3-5 were predictive of mortality in this study population while patient age and type of surgery were not.

In 2006, the POCA Steering Committee temporarily halted its data collection. Its current goal is analysis of the existing database to direct future data collection. As pointed out in Rothstein's editorial, important questions have been raised by the POCA data which hopefully will provide answers to questions (eg about safe inhalation induction techniques) potentially resulting in a reduction in the incidence of anesthesia-related cardiopulmonary arrest in the pediatric population.[18]

Non-Anesthesia-Related Pediatric Cardiopulmonary Arrest

Non-anesthesia-related pediatric cardiopulmonary arrests result from a heterogeneous set of treatable possible contributing factors (Table 2) [6] unlike adult arrests that are predominately cardiac in origin.

Table 2
Treatable possible contributing factors of Pediatric Cardiopulmonary Arrest[8]

Hypovolemia	Toxins
Hypoxia	Tamponade, cardiac
Hydrogen ion (acidosis)	Tension pneumothorax
Hypo-/hyperkalemia	Thrombosis (coronary or pulmonary)
Hypoglycemia	Trauma
Hypothermia	

Precise data on causes of pediatric cardiopulmonary arrest is lacking as most reports have small numbers of patients. There is also a lack of uniformity of criteria defining pediatric cardiopulmonary arrest and resuscitation. The diverse list of causes of pediatric cardiopulmonary arrest includes among others, trauma, poisoning, choking/asphyxia, sudden infant death syndrome, drowning and sepsis. The common lore has been that the pathway to cardiopulmonary arrest in children is a "… progression from hypoxia and hypercarbia to respiratory arrest and bradycardia and then asystolic cardiac arrest."[7] Cardiac rhythm disturbances (especially ventricular) have been thought uncommon ($\leq$ 15%) in out-of-hospital pediatric cardiopulmonary arrests. Survival from out-of-hospital pediatric cardiopulmonary arrest is poor ranging from 3-17%. The keys to effective CPR and better outcome for children who sustain cardiopulmonary arrest are attention to preventable causes and rapid therapeutic response to minimize the anoxic insult to the brain. In-hospital pediatric cardiac arrest may be very different. The **N**ational **R**egistry of **C**ardio**P**ulmonary **R**esuscitation (**NRCPR**) is an American Heart Association (AHA) sponsored program, whose mission is "To provide an efficient and consistent means for hospitals to effectively collect and analyze resuscitation data, thereby equipping them to evaluate equipment, resources, and training, and improve practice and ultimately save lives!...Initiated in 2000, the NRCPR® is the only national registry of in-hospital resuscitation events, with over 75,000 resuscitation events."[19] The initial findings of this registry reviewed 36,902 adult and 880 pediatric pulseless cardiac arrests reported between January 1, 2000 and March 30, 2004 from 253 hospitals (including 10 pediatric facilities) documenting that in-hospital pulseless arrest was typically asystole and PAE with better outcomes for children; 27% survival for children versus 18% for adults.[20] A surprising result from this database analysis is that VF in pediatric in-hospital cardiopulmonary arrest is more prevalent than always thought; VF or pulseless ventricular tachycardia as the 1st documented cardiac arrest rhythm in children was 14%.[20] Quan's editorial makes it quite clear that data analysis like that accomplished by the NRCPR study provides evidence-based recommendations for change in clinical care; CPR and ventilation alone may be insufficient therapies for resuscitation of hospitalized pediatric patients with more liberally and rapidly applied defibrillation being required as in resuscitation of adults.[21]

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