

# PEDIATRIC EMERGENCY MEDICINE PRACTICE

AN EVIDENCE-BASED APPROACH TO PEDIATRIC EMERGENCY MEDICINE ▲ EB MEDICINE.NET

## Push Hard And Push Fast: The Who, How, And Why Of Pediatric Advanced Life Support (PALS)

*It's 11:00, and you are called to pick up an 11-year-old girl from an outside hospital. Her problem is described simply as "respiratory distress." Upon arrival, you find a hypoxic, hypotensive patient who is being intubated. Blood is spewing out of the endotracheal (ET) tube. You have no intravenous (IV) or intraosseous (IO) access yet. Is there a medication that can be delivered via the ET tube that will help reverse pulmonary hemorrhage and hypotension?*

*At 18:00 that same day you are in an ambulance going to pick up a 9-year-old boy with "congenital heart disease" who suddenly collapsed at home. The 9-1-1 response team found a pulseless and apneic patient. Bag-valve-mask ventilations and chest compressions were initiated. One round of epinephrine was administered, and one shock was delivered at 2 J/kg for pulseless ventricular tachycardia (VT). When you arrive, you find an intubated patient with mottled, cool skin and 1+ pulses. Later you are in the back of the ambulance, en route to your pediatric intensive care unit. You note 4- to 8-beat runs of VT on your monitor. Are these real or are they an artifact caused by the bumpy road? At this point you plug in the pediatric defibrillator pads and palpate for pulses. Before you can hit the "Manual" button, the display on the defibrillator reads "shock advised." Should you blindly follow the machine's instructions or verify the findings clinically? How many joules should you deliver? Should you start cardiopulmonary resuscitation (CPR)? If so, what is the appropriate ratio of breaths-to-chest compressions?*

*At 14:55 on your next shift, you get a call to pick up a 3-week-old baby from a community ER who is in unstable supraventricular tachycardia (SVT). As you make your way over there, you advise the staff to skip vagal*

November 2009

Volume 6, Number 11

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### CME Objectives

Upon completion of this article, you should be able to:

1. Recognize the most recent (2005) PALS guidelines and identify their strengths and weaknesses.
2. Identify the most common causes of pediatric cardiopulmonary arrest.
3. Identify the unique developmental, anatomic, and functional aspects of pediatric arrest.

*Date of original release: November 1, 2009*

*Date of most recent review: October 10, 2009*

*Termination date: November 1, 2012*

*Medium: Print and Online*

*Method of participation: Print or online answer form and evaluation  
Prior to beginning this activity, see "Physician CME Information."*

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maneuvers (because he is in unstable SVT) and recommend giving adenosine and, ultimately, performing synchronized cardioversion. Although both these maneuvers have correctly been attempted several times by staff at the community ER, and again by your team upon arrival, the baby continues to be in unstable SVT. What is the next step?

**N**early all pediatricians avail themselves to pediatric advanced life support (PALS) training and certification. Most of us blindly accept the PALS guidelines as being true and unquestioningly commit them to memory. But is there evidence that PALS works? Who comes up with these guidelines and how do they do it? How do these guidelines work and what happens after the initial resuscitation steps have been completed?

The goal of PALS, which was developed by the American Heart Association, is to present a systematic approach to recognizing, treating, and improving the outcomes of seriously ill and injured children. The program is intended to guide healthcare providers through the stabilization or transport phases of a pediatric emergency, either in or out of the hospital.<sup>1</sup> The authors of the PALS guidelines promote an “assess-categorize-decide-act” approach and present an organized pedagogical approach to pediatric resuscitation.<sup>2</sup>

The PALS program has been successful. One study demonstrated an improvement of pediatric survival from respiratory failure and shock from 10% to 85%.<sup>3</sup> We, as medical professionals, should have a deeper understanding of how and why PALS works and of its strengths and weaknesses. It is with this mindset that we will be able to respond intelligently and physiologically to life-threatening situations and to ask questions that will further our body of knowledge regarding the resuscitation of the pediatric patient.

While the last 25 years have undeniably seen advances in the understanding and management of pediatric cardiopulmonary failure, many questions remain unanswered and progress must continue to be made.

## Critical Appraisal Of The Literature

In order to appreciate the impact of PALS we must examine survival rates from cardiopulmonary arrest for time periods both before and after PALS was instituted. It is impossible to measure the definite impact of PALS due to a paucity of high quality data. A 2008 article in *Pediatrics* reported an improvement in survival to discharge from 14% to 34%.<sup>4</sup> A 2002 report in *Critical Care Medicine* cited a reduction in deaths from neonatal and pediatric septic shock from 97% in the 1960's to 9% in 1999.<sup>6</sup> A 1999 review article from UCLA stated that overall survival after cardiac arrest was poor at 13% and

that children who had suffered out-of-hospital arrest fared worse than did inpatients (8.4% versus 24% survival).<sup>7</sup>

The truth is, as of the writing of this article, there is no reliable data on the incidence and outcomes of pediatric resuscitations performed in the United States each year. Numerous articles review PALS guidelines and introduce updates, yet there is a lack of clear evidence to demonstrate the utility or futility of certain maneuvers. As a result, data is extrapolated from childhood mortality rates and clinical practice is then based on physiologic experiments, case series, cohort studies and expert opinion.<sup>8,9</sup>

Nonetheless, an undeniable trend is emerging from the data: survival is improving. The American Heart Association is currently spearheading a National Registry of Cardiopulmonary Resuscitation (NRCPR) which will attempt to centralize data regarding pediatric arrest. Not only will the registry confirm improved survival since the inception of PALS guidelines; it will potentially identify ways in which we can achieve better results. By pooling our collective experience with pediatric cardiopulmonary arrest, we can create a platform from which the next advances in PALS guidelines can be made and step closer towards evidence-based medicine.

## Leading Causes Of Death In Children And Young Adults

The National Center for Health Statistics maintains a database to monitor the 10 leading causes of death by age group in the United States.<sup>9</sup> (See Table 1.)

## Children Are Not Simply “Little Adults”

Why are more children surviving cardiopulmonary arrest? One very important concept is prominent in nearly all literature regarding PALS: children have unique biomechanical and physiologic features that greatly differ from those of adults. (See Table 2, page 4) Recognizing this and adapting our assessment and management accordingly improves survival.

## Body Size And Weight

One obvious difference between adult and pediatric patients is size. Children require specialized equipment such as smaller bag valve masks, smaller endotracheal tubes, smaller laryngoscopes (see Figure 1, page 5), and defibrillators that can deliver appropriate amounts of energy based on the child's weight.

In addition, stabilization equipment, such as cervical collars and backboards, must be tailored to smaller body sizes. (See Figures 2 and 3, page 5.)

## Differences In Heart Size, Physiology, And Vulnerability

Children have different causes for cardiac failure, different cardiac physiology, and a different absolute cardiac size than adults. (See Table 2, page 4.) The etiology of adult cardiac arrest is typically a sudden dysrhythmia, most commonly ventricular fibrillation (VF), or the end result of coronary artery disease or hypertension. Cardiac failure itself is seen more commonly in adults than in children. Pediatric cardiac arrest typically results from unrecognized respiratory failure, trauma, or shock.<sup>10</sup>

The cardiac physiologies of adults and children differ significantly. In general, neonates with congenital heart disease have normal coronary arteries and myocardium. This is not necessarily true for

adults with coronary artery disease, hypertension, or who smoke. As the myocardium matures, physiologic changes influence the ability of the heart to withstand ischemia and reperfusion injury. It is believed that the normal neonatal myocardium is more resistant to ischemia and reperfusion injury than the adult myocardium. This difference is based on myocardial energy production and substrates: the adult heart mainly uses long-chain fatty acids for energy, whereas the pediatric heart prefers glucose.<sup>11</sup> Moreover, the neonatal myocardium has diminished sensitivity to insulin and a greater ability to store glycogen.<sup>12</sup>

The literature reveals that mechanical rather than electrical dyssynchrony contributes to ventricular dysfunction in the adult population. One study

**Table 1. Ten Leading Causes Of Death By Age Group**

Infants (<1 Year Of Age)	
Cause Of Death	No Of Deaths (%)
All causes	28,609 (100)
Congenital malformations	5827 (20.3)
Short gestation	4841 (16.9)
Sudden infant death syndrome	2145 (7.4)
Maternal complications	1694 (5.9)
Complications of placenta	1123 (3.9)
Unintentional injuries	1119 (3.9)
Respiratory distress of newborn	801 (2.8)
Sepsis	786 (2.7)
Neonatal hemorrhage	598 (2.1)
Circulatory system	539 (1.8)
All other causes	9136 (32)

Children 1 to 4 Years Of Age	
Cause Of Death	No Of Deaths (%)
All causes	4636 (100)
Unintentional injuries	1591 (34.3)
Congenital malformations	501 (11)
Malignant neoplasms	372 (8)
Assault	350 (7.5)
Heart disease	160 (3.5)
Influenza and pneumonia	114 (2.5)
Septicemia	88 (1.9)
Perinatal conditions	67 (1.4)
Other neoplasms	63 (1.3)
Cerebrovascular disease	53 (1.1)
All other causes	1277 (28)

Children 5 to 14 Years Of Age	
Cause Of Death	No Of Deaths (%)
All causes	6136 (100)
Unintentional injuries	2228 (36.3)
Malignant neoplasms	916 (14.9)
Assault	387 (6.3)
Congenital malformations	330 (5.4)
Heart disease	242 (3.9)
Suicide	213 (3.5)
Chronic lower respiratory tract diseases	113 (1.8)
Cerebrovascular disease	93 (1.5)
Septicemia	78 (1.3)
Other neoplasms	76 (1.2)
All other causes	1460 (24)

Young Adults 15 to 24 Years Of Age	
Cause Of Death	No Of Deaths (%)
All causes	34,632 (100)
Unintentional injuries	15,859 (46)
Assault	5596 (16)
Suicide	4097 (12)
Malignant neoplasms	1643 (4.7)
Heart disease	1021 (2.9)
Congenital malformations	456 (1.3)
Cerebrovascular diseases	206 (1)
HIV	198 (0.57)
Influenza and pneumonia	180 (0.52)
Pregnancy, childbirth, the puerperium	172 (0.5)
All other causes	5204 (15)

Data from National Vital Statistics System, National Center for Health Statistics, Centers for Disease Control and Prevention (CDC), Preliminary Data from 2006. Available at [http://www.cdc.gov/nchs/data/nvsr/nvsr57/nvsr57\\_14.pdf](http://www.cdc.gov/nchs/data/nvsr/nvsr57/nvsr57_14.pdf)<sup>9</sup>

posits that the differences in the degree of dyssynchrony between children and adults is a result of the smaller dimensions of a child's heart.<sup>13</sup> Smaller cardiac dimensions affect the duration of the QRS complex and possibly myocardial conduction. Infants have higher heart rates than adults. The higher rate is needed to meet the high metabolic demand of the infant, whose small ventricle size cannot compensate by increasing stroke volume. The infant heart tends to be right ventricular dominant, reflecting fetal circulation. Growth from infancy to adulthood sees a shift from right dominance to left dominance. As the heart grows, it can accommodate higher volumes of blood, so a higher rate is no longer necessary.<sup>14</sup>

The most common dysrhythmias seen in children are supraventricular tachycardia (SVT),<sup>15</sup> bradycardia, and sinus arrhythmia.<sup>16</sup> Atrial fibrillation, atrial flutter, and VF are seen more frequently in adults. Children with congenital heart disease may present with dysrhythmia related to their heart disease or to the complications resulting from surgical repair.

### Differences In Lung Maturity And Function

Important differences also exist between pediatric and adult lung physiology. (See Table 2.) An infant's thoracic cage is more compliant than that of an older child or an adult. This contributes to more effective CPR as compared to CPR on older children whose chest walls are less compliant.<sup>17</sup> In children, the intercostal muscles are relatively poorly developed and cannot achieve the motion characteristic of adult breathing. Furthermore, the pediatric diaphragm is shorter and flatter, has fewer type I muscle fibers, and fatigues more easily than the adult diaphragm.<sup>18</sup> An infant's airways are smaller in caliber, resulting in increased resistance to inspiratory and expiratory airflow and greater susceptibility to occlusion (eg, by mucus plugging or airway edema). The smaller alveoli in children provide less surface area for gas exchange and have a greater tendency to collapse

or develop atelectasis.<sup>19</sup> It is suspected that younger infants may have a more reactive pulmonary vascular bed than adults. Infants may also be obligate nose-breathers, have an anterior larynx, and/or have relatively large tongues. The cricoid cartilage tends to be the narrowest part of the airway in a child, whereas in adults the narrowest portion is at the glottic opening.<sup>20</sup> Thus, a younger respiratory tract is more highly susceptible to compromise than an adult respiratory tract.

### Differences In Response To Trauma

A child's anatomic and pathophysiologic responses to trauma differ from those seen in adult patients. Between 30% and 70% of pediatric trauma deaths are due to head injuries.<sup>21</sup> Compared with adults, the head of a child is larger in proportion to his or her body. Children have relatively weak neck muscles and lax ligaments,<sup>22</sup> their skulls are thinner, and their scalps are more vascular than those of adults.

The infant spine has facet joints that are more shallow than those of an adult and more underdeveloped spinous processes, resulting in an immature spine that is less stiff and has a greater range of motion than the adult spine.<sup>23</sup> Because of this anatomic difference, children may sustain spinal cord injury without radiographic abnormalities (SCIWORA). Children are at increased risk for intra-abdominal injuries because of the relatively larger size of their liver and spleen and the greater flexibility of their ribs. Furthermore, a child's bones are more porous, have less volumetric bone mineral density, and have less compressive strength than adult bones.<sup>24</sup> So, it is well established that children have unique developmental and anatomic features that impact cardiopulmonary compromise.

In 2002, after an extensive review of literature and dedicated scientific symposia, the American College of Critical Care Medicine recognized these physiologic differences between adults and children and concluded that adult guidelines have little ap-

**Table 2. Key Differences In Cardiopulmonary Features And Effects Of Trauma Between Children And Adults**

	Heart	Lung	Trauma
Children	Normal coronary arteries Glucose for energy source Diminished sensitivity to insulin Greater ability to store glycogen Smaller cardiac dimensions Right ventricular dominance Typical dysrhythmia: supraventricular tachycardia	Compliant thoracic cage Weaker intercostal muscles Shorter, flatter diaphragm Smaller airways	Larger head in proportion to body Proportionally larger occiput Relatively weak neck muscles and lax ligaments Less volumetric bone mineral density Compliant chest walls Proportionally larger abdominal Organs
Adults	Coronary artery disease Hypertension Long-chain fatty acids as energy source Left ventricular dominance Typical dysrhythmia: ventricular fibrillation	Larger alveoli Less reactive pulmonary bed	Deeper vertebral facets and better developed spinous processes Bones have greater compressive strength

plication to the management of pediatric or neonatal shock.<sup>25</sup> Management algorithms used for adults cannot simply be applied to children.

For useful algorithms that do apply to pediatric patients visit [http://circ.ahajournals.org/cgi/content/full/112/24\\_suppl/IV-167](http://circ.ahajournals.org/cgi/content/full/112/24_suppl/IV-167). This online version of *Circulation* details the 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care.

## Etiology

There are 3 perspectives to consider in regard to the etiology of cardiopulmonary failure: respiratory arrest, cardiac arrest, and the 2 combined — cardiopulmonary arrest. The most common causes of respiratory arrest in the pediatric population can be divided into lower airway processes (eg, pneumonia, asthma, bronchiolitis, aspiration) and upper airway processes (eg, croup, foreign body, epiglottitis, an intrinsic mass, laryngospasm). Respiratory failure typically occurs when the patient can no longer maintain adequate ventilation and oxygenation. This can be the result of muscle fatigue, mechanical obstruction, intrinsic pulmonary disease, and central nervous system compromise. As hypoxia and hypercarbia progress, the body changes over to anaerobic energy metabolism. The resulting metabolic acidosis and hypoxemia lead to depressed brain and cardiac functions. Hypotension, worsening cardiac output, and poor tissue perfusion ensue because prolonged hypoxemia and metabolic acidosis cause myocardial dysfunction, decreased contractility, and bradycardia. Cardiac arrest then follows.<sup>26</sup>

## Figure 1. Advanced Airway Equipment Designed For Pediatric Patients



(Left to right): laryngeal mask airway, oral airway, nasal trumpet, mask (without bag attached), and cuffed endotracheal tube. (Photo by Marisa K. Bell, MD, © 2009.)

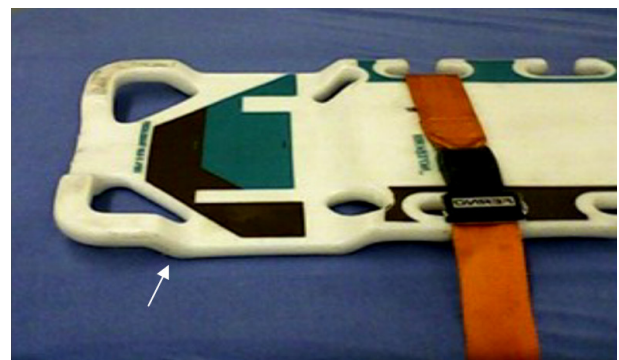
The most common causes of cardiac arrest, as noted in a 2002 *Pediatrics* article, were respiratory failure and circulatory shock.<sup>5</sup> A 2004 study by Young et al prospectively studied 601 out-of-hospital cardiac arrest events.<sup>27</sup> The 3 most common causes were sudden infant death syndrome (SIDS) (23%), trauma (20%), and respiratory compromise (16%). Other researchers report that the most common presenting rhythms in pediatric cardiac arrest were asystole (78%), pulseless electrical activity (PEA) (12.5%), bradycardia (1%),<sup>34</sup> and VF/ pulseless ventricular tachycardia (8% to 18%).<sup>28</sup> The most common causes of prehospital combined cardiopulmonary

## Figure 2. Pediatric-Size Collar For Cervical Spine Stabilization



Please note that this backboard has a pad for the occiput. The pad is for adult patients. Children have proportionally larger occiputs than adults. So, the pad should be removed for pediatric use, since it could force the chin down and the neck out of neutral spinal alignment. Additionally, this position might thereby cause airway obstruction. Jacob Parres-Gold demonstrating. (Photo by Marisa K. Bell, MD, © 2009.)

## Figure 3. Backboard Designed For Pediatric Patients



This backboard features a recess to accommodate the larger occiput of the pediatric patient. (Photo by Marisa K. Bell, MD, © 2009.)

arrest were found to be SIDS, trauma, poisoning, submersion, choking, asthma, and pneumonia.<sup>29</sup>

## Epidemiology

In the United States it is estimated that 16,000 children die each year of unexpected cardiopulmonary arrest.<sup>30</sup> Because information about pediatric cardiopulmonary arrest is poorly reported and not centralized, it is difficult to report accurate epidemiologic information on a national or worldwide scale. However, a number of small- and medium-scale studies and reviews have been conducted. (See Table 3.)

In a 1999 study, a team from Baylor College of Medicine prospectively examined all children (n=300) who were treated for apneic and pulseless conditions over 3½ years in Houston.<sup>31</sup> They found that 60% were male, 54% were 12 months of age or younger, and that a disproportionate number of arrests occurred in African-American children (51.6%) as compared to Hispanic (36.6%) and Caucasian (17%) children. Although over 60% of the arrests occurred in the home, CPR was initiated in only 17% of those cases. The authors found that intubation was the only factor that correlated positively with return of spontaneous circulation (ROSC) (P=0.032). A major limitation of this study was that the patient population consisted only of children with both apnea and absent pulses; it did not include cases of isolated respiratory arrest. As previously stated, many pediatric arrest events begin as airway or respiratory problems.

A 2002 prospective investigation into in-hospital arrest events using the Utstein reporting style

(a Norwegian guide for reporting arrest events) followed 6024 children admitted to a university children's hospital in Sao Paulo, Brazil and found that 2% had an arrest event.<sup>5</sup> The main precipitating causes were respiratory failure and shock; 64% of the children attained ROSC within 20 minutes, and 15% were still alive at 1 year.

A *Pediatrics* review article in 2004 studied 601 out-of-hospital pediatric arrest events in 2 Southern California hospitals.<sup>27</sup> There was no seasonal variation, 58% of the children were male, and 25% were African-American. The latter statistic is of interest because African-American children comprised only 12% of the population in the area studied. Moreover, the risk for cardiopulmonary arrest among African-American children in Los Angeles County is reportedly twice that of the rest of the population. Over half the patients were under 1 year of age (54%), and newborns were the most likely to survive (36%), as were those with PEA. In terms of the origin of these events, 16% were respiratory and 8% were cardiac. Survival rates were highest among newborns, those with a respiratory etiology, and submersion victims. No child who received more than 3 doses of epinephrine or was treated with CPR for more than 30 minutes survived with good neurologic outcomes. This study establishes data for building an evidence-base for our practice. For example, increased outreach about SIDS and bystander CPR might reduce the incidence of arrest events or improve survival in the African-American population.

In 2005, a group in Galicia, Spain reviewed out-of-hospital pediatric cardiac arrests over a period of

**Table 3. Summary Of Causes Of Arrest And Presenting Rhythm Disorders**

Study Site (Reference)	Causes Of Arrest	Presenting Rhythm Disorder	ROSC
<b>Baylor College, Texas</b> (Sirbaugh et al, 1999) <sup>31</sup>	SIDS (26%) Trauma (15%) Unknown (10%) Pulmonary in origin (8%) Submersion (8%)	Asystole (83%) PEA (12%) VF (4%)	11% (Survival to discharge = 2%)
<b>Sao Paulo, Brazil</b> (Reis et al, 2002) <sup>5</sup>	Respiratory failure (61%) Shock (29%) Cardiopulmonary failure (4%)	Asystole (55%) Bradycardia (33%) PEA (9%)	64% (1-year survival = 15%)
<b>UCLA, California</b> (Young et al, 2004) <sup>27</sup>	SIDS (23%) Trauma (20%) Respiratory distress (16%)	Asystole (67%) PEA (24%) VF (9%)	27.4% (Overall survival = 8.6%)
<b>Galicia, Spain</b> (Iglesias-Vasquez et al, 2005) <sup>32</sup>	Cardiac in origin (83.9%) Respiratory in origin (16.1%) Trauma (16.1%)	Asystole (67%)	16%
<b>Ontario, Canada</b> (Gerein et al, 2006) <sup>33</sup>	Trauma (37.2%) SIDS (20.3%) Respiratory disease (11.6%) Drowning (8.4%)	Asystole (77.2%) PEA (16.4%) VF/VT (4%)	5.0%

PEA = pulseless electrical activity, ROSC = return of spontaneous circulation, SIDS = sudden infant death syndrome, VF = ventricular fibrillation, VT = ventricular tachycardia.

5 years. They reported an incidence of 3.4 annual arrests per 100,000 children.<sup>32</sup> The etiology was respiratory in 16.1% of cases and cardiac in 83.9% of cases. CPR was unsuccessful in 32.2% of cases, and 35.5% of the children were dead on arrival at the emergency department. This study is of interest because it conflicts with the majority of similar studies, in that it shows a larger percentage of cardiac arrest events.

In 2008, a Canadian group retrospectively studied out-of-hospital pediatric cardiac arrests in Ontario over an 11-year period.<sup>33</sup> They found 503 cases; 58.4% were male, and 37% were under 1 year of age. The study revealed an annual incidence of 9.1 per 100,000 children. The top 3 causes of out-of-hospital arrest events were trauma (37.6%), SIDS (20.3%), and respiratory disease (11/6%).

These studies help us to understand the etiology and epidemiology of pediatric cardiopulmonary arrest. For example, neonates and infants have better survival rates than other groups studied.<sup>35</sup> However, the studies are limited by retrospective data collection, small sample size, mixed cohorts (in-hospital vs. out-of-hospital arrests), and varying inclusion/exclusion criteria. Hopefully, the NRCPR data<sup>36</sup> will further us on our quest to better understand pediatric arrest.

## Differential Diagnosis

Identifying a child in cardiac or pulmonary arrest sounds straightforward: the patient is either breathing or not, and the pulses are either present or absent. By observing the chest rise or listening for breath sounds, we can typically assess respiratory effort. By palpating the carotid, brachial, radial, and femoral arteries, we can assess pulses. Hypoxia and poor perfusion are recognized by the presence of cyanosis and poor capillary refill.

One possible differential diagnosis involves error in the clinical assessment of both pulses and respiratory effort. The evaluation of these vital signs can be more complicated in out-of-hospital settings, such as in moving transport vehicles. Another possible source of error is the reliance on monitors or equipment rather than clinically assessing the patient. For example, pulse oximetry can be affected by the presence of nail polish or poor peripheral perfusion.<sup>37</sup>

The best way to improve survival is to prevent the arrest event in the first place. Beyond that, early recognition and appropriate intervention are our best tools for improving survival. See **Table 4** for reversible causes of cardiopulmonary arrest.

## Prehospital Care

The subject of cardiopulmonary arrest in children lends itself to a discussion on prehospital care, since many such events occur outside the hospital setting.

Family members, bystanders, and EMS personnel are often the ones who initially attend to the stricken child. The provision of adequate ventilations, chest compressions, and defibrillation/cardioversion are prehospital interventions that can save a life.

An article by Hickey et al<sup>40</sup> in the *Annals of Emergency Medicine* reviewed out-of-hospital arrests in Houston, Texas. (n=300) The mean interval between the 9-1-1 call and the response was 4.5 minutes for first responders (who provide Basic Life Support) and 9.4 minutes for paramedics. Most of the 9-1-1 calls were made between 7 am and 10 pm. Bystanders performed basic CPR only 26% of the time. The study points out that although 60% of the arrest events occurred in the home with family members present, only 17% of the victims received CPR from those family members. Only 22% of children whose arrest event occurred at home received bystander CPR compared with 36% of those with arrest events at other locations. These results indicate a need for more widespread education about CPR amongst families. Clearly, the EMS response, bystander capability, and willingness to perform CPR are important (but understudied) prehospital factors that could improve outcomes for children with cardiopulmonary arrest.

It has been established that placement of Automated External Defibrillators (AEDs) in public places like stadiums, airports, and casinos improves adult survival from ventricular fibrillation (VF). For the purposes of AED use, "adult" is defined as "being greater than 8 years old or weighing more than 55 pounds." Prior to 2001, all available AEDs delivered shocks with energies ranging from 150 to 360 joules. These energy levels can potentially cause myocardial damage and burns in patients who are younger than 8 years old or less than 55 lbs. Another concern was that children with sinus tachycardia or SVT could have high heart rates that might be misinterpreted as a "shockable" rhythm by an AED program designed to analyze adult arrhythmias. The results of a 1999 study suggested that the survival

**Table 4. Reversible Causes Of Cardiopulmonary Arrest**

H's	T's
Hypoxia	Tamponade
Hypovolemia	Trauma
Hypothermia	Toxidromes
Hypoglycemia	Thrombosis
Hypokalemia (and hyperkalemia)	Tension pneumothorax
Hydrogen ion (metabolic acidosis)	

Data from the AHA, 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, *Circulation*. 2005;112:IV-156-IV-166.<sup>38</sup>

rate of children in VF might have been compromised because those who were younger than 8 years of age had to wait for manual defibrillation.<sup>41</sup> These very issues were highlighted at ILCOR's 2000 conference as being some of the most pressing concerns regarding the management of pediatric cardiac arrest victims.<sup>42</sup>

Why is public-access to AEDs so important? The main determinant of survival from VF cardiac arrest is the time between the patient's collapse and the first defibrillation attempt. For every 1-minute delay in defibrillation, the survival rate may decrease by as much as 10% (depending on the presence and quality of bystander CPR).<sup>43</sup> A 2006 article in *Critical Care* reviewed pediatric defibrillation after cardiac arrest in Spain.<sup>28</sup> They found that those undergoing a defibrillation attempt in the first 4 minutes had better return of spontaneous circulation (68.9% versus 37.5%), better initial survival (55.1% versus 12.5%), and better final survival (10.3% versus 0%) than those who received shocks after 4 minutes. Appropriate AED use and availability is an important and understudied prehospital intervention that can improve outcomes for children in cardiac arrest.<sup>40</sup>

## ED Evaluation

The evaluation generally begins when a critically ill child or a child in cardiopulmonary arrest is brought to the ED by parents, a transport team, or EMS. Some form of treatment (CPR, bag-valve-mask ventilation, defibrillation) has typically been initiated prior to the child's arrival. It is absolutely essential to obtain as much detailed information as possible about the child's past medical history, circumstances surrounding the current condition and any interventions made prior to arrival in the ED. This information can typically be obtained by talking to the parents, EMS, or transport team.

According to the text *Pediatric Emergency Medicine*, "Lay people and Emergency Medical Services providers have been shown [to be] inaccurate at detecting breathlessness and the presence of a pulse in patients with cardiac arrest."<sup>16</sup> Thus, a complete reassessment of the ABCs and physical examination are essential upon ED arrival.<sup>44</sup> Since respiratory failure is the most common cause of pediatric arrest, the airway should be properly opened and 2 rescue breaths should be given to the apneic patient. In the ED, advanced airway techniques may subsequently be employed (eg, endotracheal intubation, nasal trumpet, oral airway, laryngeal mask airways [LMAs], cricothyrotomy).

In a 1995 study in *Annals of Emergency Medicine* entitled "Death and Resuscitation in the Pediatric Emergency Department," Teach et al<sup>45</sup> described patients who suffered complete cardiopulmonary arrest or respiratory arrest while in a pediatric ED. The authors identified 2 factors associated with

the arrest events (1) 1 or more abnormal vital signs (87.5%) and (2) the presence of a pre-existing condition (75%). Interestingly, 43% of the patients had an abnormal temperature at triage (26% with hyperthermia, 17% with hypothermia). Loss of vital signs occurred in 1 out of every 8163 visits. Outcomes were better for those whose arrest occurred in the pediatric ED than for those who suffered prehospital arrest and were worse than those with inpatient arrest. Close monitoring and early establishment of IV access in pediatric ED patients with at least 1 abnormal vital sign and a pre-existing condition merits further study.

One way EDs can minimize the time to drug delivery and the incidence of dosage error is to base dosages on the patient's actual weight rather than on body length, as measured by using the Broselow<sup>TM</sup> Pediatric Emergency Tape (Armstrong Medical). While a 2008 study by Fineberg et al has its flaws, it did show that weight-based dosing is better than the Broselow method in terms of speed and accuracy of medication delivery in an emergency situation.<sup>46</sup> Using the Broselow tape can also potentially result in the *under resuscitation* of children. One study showed that the Broselow tape inaccurately predicted actual weight in one-third of the children studied.<sup>47</sup> In light of increased childhood obesity, this consideration should be taken into account.

## Diagnostic Assessment And Tests

The evaluation begins with observation. The PALS *general assessment* is a very quick visual and auditory assessment of the child's appearance, work of breathing, and color. The PALS *primary assessment* is a more detailed evaluation of the child's airway, breathing, circulation, and level of disability. Vital signs should be obtained. Laboratory values such as a complete blood count, blood gas, serum lactate, and electrolytes can provide further insight into the child's cardiopulmonary status.

To date, there is no evidence-based data about the diagnosis of "breathlessness" and "pulselessness." One study examined the "effectiveness of checking for breathing in an emergency situation" and attempted "to determine the necessary amount of time until diagnosis."<sup>44</sup> When these researchers tested physicians, medical students, laypersons, and EMS personnel, they found that the median time to obtain a diagnosis was 12 seconds, and the correct diagnosis was achieved 81% of the time. EMS personnel were the strongest performers in assigning the correct diagnosis (in 89.7% of cases), and the physicians were second best (in 84%). Another study by Albarran et al showed that the correct diagnosis of cardiopulmonary arrest was made more often when rescuers used sequential checks for breathing and pulses as compared with a simultaneous check of these signs.<sup>48</sup> Rescuers tended



to need 10 to 20 seconds to make an accurate diagnosis. Healthcare professionals consistently experienced difficulty assessing pulses when using a time frame of only 10 seconds.<sup>48</sup>

It is important to note that attempting CPR on a patient who appears lifeless but does have a pulse has not been shown to be harmful. Conversely, not starting CPR on a patient with cardiopulmonary arrest would definitely result in a poor outcome. It has been suggested that an “if in doubt, summon help and start CPR” rule might compensate for the inability to correctly diagnose cardiopulmonary arrest.<sup>48</sup> Perhaps the very act of starting CPR on a patient who is not in arrest would elicit a response, indicating the presence of circulation. Moreover, if the patient is in a low cardiac output state, CPR may even be beneficial.

Two additional tools have been suggested to aid in the diagnosis and management of patients in cardiac arrest: monitoring of end-tidal CO<sub>2</sub> (ETCO<sub>2</sub>) and ultrasonography. During CPR, a rise in ETCO<sub>2</sub> to above 15 mm Hg suggests a higher probability of ROSC,<sup>50</sup> whereas ETCO<sub>2</sub> levels persistently below 10 mm Hg suggest a near-zero probability of ROSC.<sup>51</sup> Bedside ultrasound can be used in the ED to identify pneumothorax, cardiac activity, and cardiac tamponade.<sup>52</sup> In an adult study, “adults with any cardiac activity on [ultrasound] during resuscitation had a 26% chance of survival to hospital admission compared to 3% for those with no cardiac activity.”<sup>51</sup> Ultrasound has also been used to detect VF in patients thought to have asystole<sup>53</sup> and to evaluate trauma patients (ie, the Focused Assessment with Sonography in Trauma [FAST] exam). Both ultrasound and capnography have been used to differentiate between patients with true PEA from those with low blood pressure.

What all these studies reveal is that detecting pulses and respirations is not as easy as it sounds and may take longer than the recommended 10 seconds.<sup>54</sup> In addition, new technologies such as the measurement of regional tissue oxygenation are emerging. Cerebral/Somatic oximetry continuously and noninvasively measures regional tissue oxygenation (rSO<sub>2</sub>) by means of *in vivo* cerebral and somatic optical spectroscopy.<sup>55</sup> Site-specific oxygen levels can be measured by placing sensors over the exact brain and body areas of interest.<sup>56</sup> This technology can be used for the early detection of hypoxia that can be associated with low cardiac output states, renal dysfunction, neurologic damage, shock, ECMO cannulation, and seizures.

## Treatment According To PALS Guidelines

### How Was PALS Developed?

In 1983, the American Heart Association (AHA) recognized the need for resuscitation training and

guidelines designed specifically for children in cardiopulmonary arrest. The first PALS manual was published in 1988 by the AHA and the first course was introduced that same year. Since then, the AHA convenes an international conference every 5 years to review the resuscitation literature and to publish an evidence-based evaluation of resuscitation science. The assembled group, called the International Liaison Committee on Resuscitation (ILCOR), represents a scientific consensus of experts from a variety of countries, cultures, and disciplines.<sup>39</sup>

The mission of ILCOR is to “identify and review international science” and “to offer consensus on treatment recommendations.”<sup>57</sup> The most recent gathering of the ILCOR Pediatric Task Force took place in 2005. Over the course of 6 days, 380 experts reviewed the literature, evaluated recent data, and developed treatment recommendations. This “evidence evaluation process” represents the most comprehensive, systematic review of the resuscitation literature to date. The results of the international conference were published in the November 2005 issue of *Circulation*<sup>58</sup> and were the basis for the latest revisions to the PALS guidelines, which were published in the December 2005 issue of *Circulation*.<sup>59</sup> (The next international collaborative conference is scheduled to be convened in 2010.)

Although the AHA and ILCOR strive to provide the best possible evidence-based recommendations and guidelines, it is important to be critical. The body of evidence on pediatric resuscitation is often inconsistent and contradictory, and a sufficient amount of high-quality evidence — ideally in the form of prospective, randomized, controlled studies — is simply not available in the field of pediatric resuscitation. Thus, expert opinion and inference from the adult literature must play a significant role in the creation of these guidelines.

### Guideline Changes From 2000 To 2005

Three main changes have been made to the Basic Life Support recommendations:<sup>58</sup>

1. A greater emphasis has been placed on high-quality CPR, with one universal compression-to-ventilation ratio (30:2) recommended for all lone rescuers.
2. Rescue breaths should be delivered over 1 second.
3. Defibrillation recommendations have been revised.

### Increased Emphasis On CPR

The AHA is now recommending the “**push hard and push fast**” approach.<sup>2</sup> Researchers have found that half the chest compressions performed by professional rescuers were too shallow and that “no compressions were provided during 24% to 29% of CPR time.”<sup>60</sup> Chest compressions that are not deep enough or fast enough will fail to generate adequate

blood flow to vital organs.

The correct *chest-compression rate* for all victims of cardiac arrest (except neonates) is 100 compressions per minute. This rate can be achieved by compressing to the beat of the song "Stayin' Alive" by the Bee Gees (a teaching tool validated by a group of researchers from Illinois).<sup>61</sup>

According to the 2005 guidelines, the definition of "child" (with regard to chest compressions) is no longer based on age but on evidence that the child has reached puberty.<sup>58</sup> The signs of puberty are breast development in girls and axillary hair in boys. For infants and children without these signs, the chest should be compressed to one-third to one-half the depth of the chest, using either the 1-hand or the 2-hand technique.<sup>62</sup> (See Figures 4 and 5.) For adults and for children with signs of puberty, the chest should be compressed to a depth of 2 inches with the heels of 2 hands, one over the other, placed at the center of the nipple line. In all cases, the chest should be allowed to recoil completely for adequate refilling of the heart.

Interruptions in compressions should be minimized to prevent the cessation of blood flow. Recent literature shows that when compressions are interrupted, blood flow stops and coronary artery perfusions falls.<sup>30</sup> The initial compressions just prime the pump; the later compressions actually generate blood flow. Reports indicate that when compressions are interrupted, coronary artery perfusion drops.<sup>63</sup> Therefore, decreasing the number of interruptions in compressions will improve the victim's chances of survival. In the spirit of minimizing interruptions

**Figure 4. Single-hand technique for chest compression in CPR**



The heel of one hand is placed on the lower half of the sternum at the nipple line. For the prepubertal child, the chest is compressed to one-third to one-half the depth of the chest. **NOTE: In this photo, the presence of the occipital pad pushes the chin down toward the chest, which can not only occlude the airway, but it can also shift the spine out of neutral alignment. Ideally, a pediatric spine board without the pad should be used.** Jill Parres-Gold, RRT, demonstrating on Jacob Parres-Gold. (Photo by Marisa K. Bell, MD, © 2009.)

in compressions, the AHA now recommends one universal compression-to-ventilation ratio of 30:2 for infants, children, and adults.

The only exception to this universal ratio of 30:2 is when 2 rescuers are performing CPR on infants and on children without signs of puberty, when the ratio becomes 15:2. Children with signs of puberty and adults should continue to receive the universal 30:2 compression to ventilation ratio even when 2-rescuer CPR is being performed.

### Rescue Breaths

During CPR, blood flow to the lungs is only one-third to one-half the normal amount, so less ventilation is required.<sup>60</sup> The delivery of rapid rescue breaths will provide sufficient ventilation and will interrupt compressions only briefly. Each rescue breath should be given over a period of 1 second. The rescuer should avoid overventilation of the lungs or ventilation with high pressures, since such measures can potentially reduce venous return to the heart and the cardiac output that can be generated by the next chest compression.

Ventilation recommendations depend on whether or not the patient requires chest compressions and if an advanced airway has been established. (See Ta-

**Figure 5. Two-Hand Technique For CPR Using The Heels Of The Hands Superimposed On Each Other**



For both single- and 2-hand techniques, the compression-to-ventilation ratio is 30:2 for patients of all ages (except neonates) in lone-rescuer CPR and 15:2 for 2-rescuer CPR in infants and in children without signs of puberty. The goal rate is 100 compressions per minute ("push hard and push fast"). Allow full chest recoil between compressions. When performing chest compressions in children, 1 or 2 hands may be used depending on the size of the child and the size of the rescuer's hands; a rescuer with small hands may have to use the 2-hand technique in order to achieve adequate compression.

**NOTE: In this photo, the presence of the occipital pad pushes the chin down toward the chest, which can not only occlude the airway, but it can also shift the spine out of neutral alignment. Ideally, a pediatric spine board without the pad should be used.**

Jill Parres-Gold, RRT, demonstrating on Jacob Parres-Gold. (Photo by Marisa K. Bell, MD, © 2009.)

**ble 5.)** If an advanced airway has been established, then chest compressions need not be interrupted for the delivery of breaths.

**Defibrillation (See Table 6)**

The most current recommendation is to deliver 1 shock, immediately followed by CPR for 2 minutes (starting with chest compressions). Pulses and rhythm should be reassessed after 2 minutes of CPR. These recommendations are based on the findings that (1) rhythm analysis by an AED can take up to 37 seconds and (2) the first shock eliminates ventricular fibrillation 85% of the time.<sup>64</sup> If the first shock is not successful, performing CPR for 2 minutes will “prime” the heart for the next shock. If the first shock succeeds, it still takes the heart several minutes to achieve effective cardiac contractility/output, so a 2-minute period of CPR is helpful.

In scenarios in which manual defibrillation is not available, AEDs may be used for children who are at least 1 year of age with no signs of circulation. There is insufficient evidence to rule for or against the use of AEDs in infants (under 1 year of age). Manual defibrillation is still probably ideal in this age group. When AEDs are used in children, pediatric attenuator devices are recommended. If an attenuator is not available, a standard AED may still be used.<sup>59</sup>

Regarding the activation of EMS in an unwitnessed or nonsudden collapse, the rescuer should first perform CPR for 2 minutes and then request EMS backup and retrieve an AED. In a witnessed sudden collapse, which is likely to be related to a pulseless arrhythmia, the lone rescuer should first activate EMS and retrieve an AED before initiating CPR. When a rescuer is reluctant to perform rescue breaths, it is preferable to perform CPR without rescue breaths rather than to forgo CPR. It should be noted, that the reference to “compression-only” CPR is from the adult literature.<sup>31</sup> Compression-only CPR was discussed as a recommendation for adult out-of-hospital, sudden/witnessed cardiac arrest

where the rescuer is unwilling or unable to perform conventional CPR. This recommendation may not be as applicable to pediatric victims because the majority of pediatric cardiopulmonary arrests are the end result of respiratory arrest. It follows that ventilations would be an essential component of pediatric resuscitation efforts.<sup>65</sup>

**Specific Changes To The PALS Algorithm**

The AHA now offers specific recommendations regarding the use of advanced airways, drug administration, and defibrillation.

**Advanced Airways**

For neonates (up to 28 days of age) uncuffed endotracheal (ET) tubes are still recommended since the cricoid narrowing of the neonatal airway functions as a physiologic cuff. For infants (28 days old to 1 year old) and older patients, cuffed ET tubes have been deemed just as safe as uncuffed ET tubes when used correctly.<sup>66,67</sup> In situations where there is poor lung compliance or large air leak, a cuffed tube may even be preferable. See Table 7 for instructions on how to determine the appropriate size<sup>66</sup> and depth of insertion<sup>67</sup> for ET tubes.

**Table 5. Ventilation Recommendations Based On Status Of Pulses And Advanced Airway**

Clinical Scenario	Ventilation Recommendations
Pulses Present No Advanced Airway	12-20 breaths per minute or 1 breath every 3 seconds
Pulses Absent No Advanced Airway	Ratio of 30:2 or 15:2
Pulses Absent Advance Airway Present	8-10 breaths per minute or 1 breath every 6 seconds. Chest compressions no longer interrupted for the delivery of breaths.

Data from 2007 PALS Provider Manual.<sup>2</sup>

**Table 6. Summary of the AHA 2005 CPR Recommendations<sup>38</sup>**

Age Group	Technique	Compression- to-ventilation Ratio	Depth Of Chest Compression	Site Of Compression	Rate Of Compressions
Neonate (0-28 days)	Two thumbs with hands encircling chest, or 2-finger compression	3:1	One-third to one-half anterior-posterior or chest diameter	Lower third of sternum	120 events/min
Infant (1 month – 1 year)	Two thumbs and fingers encircling chest, or 2-finger compression	30:2 (or 15:2 if 2 rescuers)	One-third to one-half anterior-posterior or chest diameter	Lower half of sternum, just below nipple line	100/min
Child (1 year – signs of puberty)	Heel of one or 2 hands	30:2 (or 15:2 if 2 rescuers)	One-third to one-half anterior-posterior or chest diameter	Center of chest at nipple line	100/min
Adult (signs of puberty and older)	Heel of 2 hands	30:2	2 inches	Center of chest at nipple line	100/min

The cuff inflation pressure should be kept below 20 cm H<sub>2</sub>O to avoid damage to the mucosal lining the trachea and to lower the risk of subsequent subglottic stenosis. Along with clinical examination to confirm proper tube placement, the use of colorimetric devices is a new PALS priority. ET tube placement and successful ventilation should be confirmed by clinical examination (symmetric chest and breath sounds) and the use of confirmatory devices (CO<sub>2</sub> capnometric devices and end-tidal CO<sub>2</sub> measurements).

Laryngeal mask airways (LMAs) are now an officially acceptable airway adjunct if endotracheal intubation cannot be achieved. Advantages of the LMA include its ease of placement and range of sizes. Disadvantages include the fact that it cannot prevent aspiration, it cannot be used to deliver resuscitation medications, and its correct placement depends to a large extent on the user.

#### Administration Of Drugs (See Table 8)

IV or IO drug administration is preferred, but lipid-soluble drugs can be administered via the ET tube. The disadvantages of ET tube delivery are (1) optimal endotracheal doses are not known and (2) absorption is unpredictable. The typical endotracheal dose of medications is 2 to 3 times the IV dose. Four medications can be given via the ET tube: lidocaine, epinephrine, atropine, and naloxone (LEAN). Vasopressin can also be given via the endotracheal route, but this is not recommended by the AHA because the optimal dose is unknown. Endotracheal medications should be flushed with 5 mL of normal saline, followed by 5 ventilations.

High-dose epinephrine (1:1000) is no longer recommended for IV or IO use because studies have not demonstrated any survival benefit from its use,<sup>69</sup> and it may even be harmful in patients with asphyxia. High-dose IV epinephrine should be considered only in exceptional circumstances, such as  $\beta$ -blocker overdose. However, high-dose epinephrine (0.1 mg/kg of body weight administered as 0.1 mL/kg of 1:1000) is recommended by the endotracheal route, and this dose is 10 times the IV dose. Animal studies and anecdotal reports suggest that even larger doses are actually needed.

According to the 2005 AHA recommendations, CPR should never be interrupted for medication administration.

#### Table 7. Formulas For Endotracheal (ET) Tube Sizing And Depth Of Insertion<sup>67,68</sup>

Sizing for cuffed ET tube: (Age in years  $\div$  4) + 3 (eg, 8 years  $\div$  4 = 2 + 3 = 5)

Sizing for uncuffed ET tube: (Age in years  $\div$  4) + 4

Suggested lip-to-tip distance: ETT tube size  $\times$  3

#### Treating Rhythm Disturbances And Defibrillation

CPR should be performed for 2 minutes after each defibrillation attempt instead of delivering 3 stacked shocks. Pulses and heart rhythm should be reassessed only after 2 minutes of CPR have been completed. Amiodarone is now preferred over lidocaine as the medication of choice for treating ventricular arrhythmias. For short-term survival, amiodarone has shown benefits over lidocaine and is now considered the antiarrhythmic of choice. Tachycardia with adequate perfusion no longer requires immediate resuscitation interventions, and biphasic defibrillators are now recommended over monophasic defibrillators because of their proven superiority and greater safety.

There are 2 different defibrillator waveforms: monophasic and biphasic. The monophasic waveform is an older technology that delivers current in one polarity. The newer biphasic waveform delivers positive current, followed by an abrupt reversal to negative current. Biphasic defibrillators are now thought to be superior to monophasic defibrillators<sup>70</sup> since they minimize myocardial damage and burns, require lower energies (160-200 J), and deliver a more effective shock. It has been shown that biphasic defibrillators have an initial shock success of 90%.<sup>71</sup> In contrast, monophasic defibrillators have a lower first-shock efficacy (54%-77%). Although VF in adults can be terminated with lower energies using biphasic defibrillators, the current defibrillation/cardioversion recommendations for children remain unchanged even when biphasic defibrillators are used.

#### Specific Changes To The Neonatal Resuscitation Program Algorithm

##### Oxygen

It has been deemed reasonable to begin resuscitation with less than 100% oxygen. For infants with meconium staining, the formerly routine intrapartum use of oropharyngeal/nasopharyngeal suctioning is no longer advised.

#### Table 8. Dosage Of Endotracheal Medications<sup>38</sup>

Medications*	Dose
Lidocaine	2-3 mg/kg
Epinephrine	0.1 mg/kg (0.1 mL/kg at 1:1000)
Atropine	0.03 mg/kg
Naloxone	< 5 y or < 20 kg: 0.1 mg/kg $\geq$ 5 y or $\geq$ 20 kg: 2.0 mg/kg

\*Flush endotracheal medications with 5 mL of normal saline and follow with 5 ventilations.

### Advanced Airways

LMAs, self-inflating bags, flow-inflating bags, and T-pieces have been officially approved for use in neonates. Exhaled CO<sub>2</sub> detection is recommended to confirm proper placement of the ET tube. Small, neonatal-sized CO<sub>2</sub> capnometer devices should be used to detect the small volumes of exhaled CO<sub>2</sub>. Remember that most CO<sub>2</sub> devices require a perfusing rhythm to function correctly. The endotracheal delivery of high-dose epinephrine has been approved, but endotracheal naloxone is not recommended in neonates.

### Temperature Control

Hyperthermia is to be avoided in the neonate, and there is insufficient evidence to recommend the routine use of cerebral hypothermia in this population.

### Chest Compressions

Studies have shown that for infants the use of 2-thumbs with trunk-encircling hands technique for chest compression generates higher systolic, diastolic, and coronary blood pressures. Therefore it is the technique of choice in 2-rescuer CPR for infants. The 2-finger technique is still recommended for lone rescuer CPR so that ventilations can be performed with minimal interruption of chest compressions. The ideal depth is one-third to one-half of the anterior-posterior chest diameter. Full chest recoil should be allowed between compressions.

## PALS: A General Review

### Ensuring An Airway

The airway must be clear and patent for successful ventilation. Head-tilt, chin-lift, and jaw-thrust can be performed to open and maintain the airway. (See Figure 6.) Performing the jaw-thrust (without head-tilt or chin-lift) is recommended for any situation in which cervical spine stabilization is needed. (See Figure 7.)

Nasal airways (such as a nasal trumpet), oral airways, and suctioning can be employed for this purpose. Oral airways are intended for unconscious patients who do not have an intact gag reflex. Nasal airways will be better tolerated by patients who are not deeply unconscious. All children are to receive oxygen in the highest concentration available, along with cardiac monitoring and pulse oximetry. Neonates may not necessarily need 100% FiO<sub>2</sub>. Remember that pulse oximetry may be unreliable in patients with poor perfusion.

### Removing Airway Obstruction (Choking)

Obstruction of the airway by a foreign body is an immediate life-threatening emergency. Any child who has choked on a foreign body but who is coughing, crying, or speaking should initially be observed. Normal airway reflexes will likely fully

clear the obstruction. If respirations worsen or if the airway becomes fully obstructed, the rescuer must intervene.

For infants under 1 year of age, the head-down, 5 back-blows (between the shoulder blades), and 5 chest-thrusts (over the sternum) maneuver is recommended. Ideally, this will generate sufficient

**Figure 6. Isolated Jaw-Thrust Technique Demonstrated Without The Cervical Spine Collar**



Jill Parres-Gold, RRT, demonstrating on Jacob Parres-Gold. (Photo by Marisa K. Bell, MD, ©2009)

**Figure 7. Isolated Jaw-Thrust Technique Demonstrated With The Cervical Spine Collar**



When spine stabilization must be maintained, perform an isolated jaw-thrust to open the airway. For neutral spinal position, the external auditory meatus should be in alignment with the anterior shoulder.

**NOTE:** In this photo, the presence of the occipital pad pushes the chin down toward the chest, which can not only occlude the airway, but it can also shift the spine out of neutral alignment. Ideally a pediatric spine board without the pad should be used.

Jill Parres-Gold, RRT, demonstrating on Jacob Parres-Gold. (Photo by Marisa K. Bell, MD ©2009)

intrathoracic pressure to expel the foreign body. The abdominal thrust is not appropriate for this age group owing to concern over possible damage to underlying organs and the typically compliant chest wall in this age group.

For children over 1 year of age, the abdominal thrust or Heimlich maneuver is recommended. The recommendations vary slightly, depending on whether or not the patient is conscious. In a conscious patient who is sitting or standing, the rescuer should stand behind the patient with his or her arms positioned under the patient's axilla and encircling the chest. (See Figure 8.) The thumb side of one fist should be placed on the abdomen above the navel (and below the xiphoid process). The other hand should be placed over the fist, and 5 upward-inward thrusts should be performed. This maneuver should be repeated if the airway remains obstructed.

In an unconscious choking victim, first open the airway to attempt to visualize the foreign body. If the foreign body is not visible, CPR is in order. If the airway continues to be obstructed in a patient who is unconscious or lying down, the patient should be placed supine and the rescuer should straddle the patient's hips. The airway should be opened by means of a chin-lift or jaw-thrust and, with the heels of 2 hands on the abdomen (positioned above the navel and below the xiphoid process), 5 quick upward thrusts should be performed. Rescue breathing should then be attempted. This maneuver actually becomes more effective if the patient loses consciousness (and muscle tone). If the airway continues to be obstructed, one should attempt to visualize and remove the foreign body manually. A blind finger-sweep should never be performed. If visualization and removal of the foreign body are unsuccessful, the preceding sequence of steps should be repeated.

In the ED, visualization of the airway by direct laryngoscopy, followed by removal of the foreign body with Magill forceps or intubation may be attempted in the unconscious patient while preparing for a surgical airway. Intubation may force the foreign body into 1 of the mainstem bronchi, and the patient may temporarily be supported by ventilating the unobstructed lung.<sup>72</sup>

### Assessing And Restoring Oxygenation (Breathing)

Respiratory effort, breath sounds, skin color, and oxygen saturation should all be assessed to determine the child's oxygenation status. Respiratory rates below 10 or greater than 60 breaths per minute suggest impending respiratory failure. True apnea involves no inspiratory airflow for at least 20 seconds, or for a shorter period of time if accompanied by bradycardia or cyanosis. Bag-valve-mask ventilation, intubation, and place-

ment of an LMA are accepted advanced airway techniques. (See Figure 9.) Formulas can be used to determine the appropriate size of an ET tube, or the tube can be matched to the size of the child's nostril or fifth finger.

Needle cricothyroidotomy and tracheostomy are other advanced airway adjuncts. Emergency cricothyroidotomy and tracheostomy are procedures of last resort when all other attempts at achieving an airway have failed and the child has upper airway obstruction.

To interject a point of historical interest, in 1620 Nicholas Habicot is credited with performing the first successful pediatric tracheostomy on a 14-year-old boy who, in order to prevent theft, had swallowed a bag of gold that subsequently lodged in his esophagus and obstructed his trachea.<sup>49</sup>

### Assessing And Restoring Circulation

Adequacy of perfusion is assessed based on heart rate, blood pressure, pulse quality, capillary refill, ex-

**Figure 8. Standing Abdominal Thrust In A Conscious Patient**



*The rescuer stands behind the patient with arms under the axilla and encircling the chest. The thumb side of one fist is placed on the abdomen (above the navel and below the xiphoid process), while the other hand encloses the fist, allowing the rescuer to perform 5 upward-inward thrusts. (Jill Parres-Gold, RRT, demonstrating on Jacob Parres-Gold. Photo by Marisa K. Bell, MD ©2009.)*

tremity temperature, and urine output. In children, heart rate is the most sensitive reflection of perfusion and oxygenation. Tachycardia is the first compensatory physiologic response to shock. Blood pressure is a measure of the patient's ability to compensate during shock. An increase in systemic vascular resistance, as indicated by a narrowing of the pulse pressure (secondary to an elevation in diastolic blood pressure), is the second compensatory response to a decrease in cardiac output. Hypotension indicates decompensated shock.

Chest compressions should be instituted for a heart rate of less than 60 beats per minute if there is clinical evidence of cardiorespiratory compromise. A firm surface that extends from the shoulders to the waist and across the full width of the bed provides optimal support for effective chest compressions. In ambulances and mobile units, a spine board or backboard can provide adequate support for chest compressions.

As the chest is compressed, aortic and right atrial pressures rise. During chest recoil, right atrial pressure falls faster than aortic pressure, thus generating a pressure gradient that perfuses the heart during diastole. Full chest recoil is important since it creates the negative intrathoracic pressure required to generate coronary perfusion and myocardial blood flow.<sup>73</sup>

- **For the infant up to 1 year of age**, a lone rescuer should compress the chest to one-third the depth of the chest with 2 fingers placed one finger-breadth below the nipple line. Two-rescuers should use the 2-thumbs hands-encircling method.
- **For children without signs of puberty**, use the heel of 1 or 2 hands to compress the middle of the chest at the nipple line. **For children with signs of puberty**, use the adult method of compressing the center of the chest with the heel of 2 hands to a depth of 1.5 to 2 inches.
- **For all infants, children, and adults**, single rescuers should use a ratio of 30:2. Two-rescuers should use the 15:2 ratio in infants and children (with no signs of puberty). Children with signs of puberty should continue to receive the adult compression-to-ventilation ratio 30:2 even when 2 or more healthcare providers are present.

Once an advanced airway is in place, chest compressions should never be interrupted during the rescue breaths. Compressions are continued at a rate of 100 compressions per minute and rescue breaths are delivered at a rate of 8 to 10 breaths per minute (or 1 breath every 6 seconds) via the advanced airway. For neonates, the ratio of chest compressions to rescue breaths is 3:1, with a compression rate of 120 events per minute (90 compressions interspersed with 30 ventilations).

## Intravascular Access (Intraosseous Cannulation)

For administering medication, vascular access is preferred over the endotracheal route. However, a delay of 90 seconds to place an IV line, or failing to do so after 3 attempts, can prove fatal in a critically ill child. So this approach is no longer recommended. Instead, IO cannulation should be attempted in any child for whom vascular access is critically necessary. The bone marrow functions as a giant, noncollapsible vein. Although defined age restrictions no longer apply, placement of an IO cannula may become more difficult as children age and their bones become more calcified. IO needles can be placed in the proximal tibia or distal femur. Alternative sites include the distal tibia (proximal to the medial malleolus), the superior iliac crest, and the sternum. Although an IO needle with a stylet is preferred, butterfly needles, hypodermic needles, and spinal needles can be inserted into the marrow successfully and used effectively. One absolute contraindication of IO placement is pre-existing fracture of the intended bone. Another contraindication is suspected disruption of vascular return to the intended leg. Complications of IO cannulation include extravasation, compartment syndrome, and infection. For fluid resuscitation, normal saline, lactated Ringer's, or blood can be delivered through an IO needle.

## Providing Pressor Support

Dopamine, dobutamine, and epinephrine are the recommended agents to restore and maintain

## Figure 9. Correct "E" And "C" Hand Technique



Correct "E" and "C" hand technique for achieving a tight seal between the patient and the mask. Select a mask size that will cover both the mouth and the nose and create a tight seal. Try to place the 3 fingers on the child's mandible, not on the submental soft tissues, which could potentially obstruct the airway. (Jill Parres-Gold, RRT, demonstrating on Jacob Parres-Gold. Photo by Marisa K. Bell, MD ©2009.)

arterial pressure. The use of norepinephrine in the pediatric population is a contentious topic. Norepinephrine's potent alpha-receptor activity causes intense vasoconstriction that can impair perfusion to vital organs and extremities. Use of norepinephrine in scenarios where there is low contractility and low stroke volume may actually be counterproductive. It is contraindicated in right ventricular dysfunction and pulmonary hypertension because of the resulting pulmonary vasoconstriction. The only true indication for norepinephrine seems to be warm shock.

Phosphodiesterase inhibitors such as milrinone and inamrinone are highly effective but underutilized positive inotropic drugs. They exhibit positive inotropic properties as well as peripheral and pulmonary vasodilation (a property known as lusitropy). These agents are most effective in situations where there is low contractility as in heart failure or high pulmonary pressures. Vasopressin is not recommended in the PALS guidelines, mostly because of a study that revealed vasopressin to be less effective than epinephrine in pediatric porcine models.

## Dysrhythmia Management (See Table 9)

### Bradycardia

Epinephrine is the drug of choice for bradycardia that is causing cardiorespiratory compromise. The recommended dose, 0.1 mL/kg of 1:10,000 solution (equivalent to 0.01 mg/kg), can be given via IV or IO and can be repeated every 3 to 5 minutes during CPR. Remember that high-dose epinephrine (1:1000) is no longer recommended except via the endotracheal route. The endotracheal dose of epinephrine is 0.1 mL/kg of 1:1000 solution (equivalent to 0.1 mg/kg). Atropine is the second-line drug for bradycardia and will treat increased vagal tone or primary atrioventricular block (0.02 mg/kg, minimum 0.1 mg, maximum 1 mg). Transcutaneous pacing should always be ready on standby in case the bradycardia persists despite adequate oxygenation/ventilation, epinephrine, and atropine.

### Asystole Or Pulseless Electrical Activity (PEA)

Epinephrine is still the drug of choice for asystole and PEA and is given in the same dose as for bradycardia (0.1 mL/kg of body weight of 1:10,000 solution) every 3 to 5 minutes during CPR. If possible, treat the underlying cause of PEA. Since the most common cause in children is hypovolemia, a rapid IV fluid bolus should be considered.

### Shockable Rhythms: Ventricular Fibrillation And Ventricular Tachycardia

Shockable rhythms are ventricular fibrillation (VF) and pulseless ventricular tachycardia (VT). Pulseless VT is grouped with VF because it will eventually degenerate into VF.<sup>74</sup> Defibrillation works by depolarizing all the myocardial cells at once. This allows

the natural pacemaker cells of the heart to resume an organized rhythm. The 2005 PALS guidelines have only 1 major algorithm change regarding treatment of these shockable rhythms. Previously, VF and pulseless VT were treated with 3 stacked shocks. Current guidelines recommend immediate resumption of CPR for 2 minutes after each shock. The pulses should not be rechecked until CPR has been performed for 2 minutes.

The initial defibrillation dose is 2 J/kg, and each subsequent defibrillation dose should be 4 J/kg. If the second rhythm check still reveals VF or pulseless VT, epinephrine should be administered with the second shock and may be repeated every 3 to 5 minutes. If these dysrhythmias still persist after the second shock, an antidysrhythmic drug should be given with the third shock. The preferred drug for this purpose is amiodarone (or lidocaine if amiodarone is contraindicated or not available). After the third shock, other antiarrhythmic agents should be considered. The dose of amiodarone is 5 mg/kg (maximum 300 mg) and is typically given over 20 minutes.<sup>75</sup> However, for VF or pulseless VT, amiodarone is given as a rapid IV push. Magnesium (50 mg/kg, max 2 g) should also be considered if the arrhythmia appears to be torsades des pointes.

Recently, several manufacturers have designed pediatric attenuator devices for use with adult AEDs. By increasing the impedance of the system, these devices reduce the current actually delivered to the patient to 50 to 75 J.<sup>76</sup> Typically the device is built into the cables/cords or pediatric pads or is attached separately to the AED. Some devices use a one-size pad system and a pediatric attenuator key. In a 2003 Grand Rounds session of the American Association of Pediatricians, the algorithms for an adult AED were evaluated by a panel of 3 experts. The AED had a sensitivity of 99% and a specificity of 99.5%, demonstrating that AED algorithms for adults also have a high specificity and sensitivity in children. However, each manufacturer's algorithm is different and should be tested against pediatric rhythms to verify its efficacy in this population.

There is insufficient data to allow recommendations about the best placement of AED pads (anterior/posterior vs. sternal/apical). However, the pads should not be touching. In smaller children, if the pads are close to touching each other when placed in the anterior chest positions, then the pads should be placed in the anterior/posterior positions. (See Figure 10.) Hand-held paddles or self-adhesive pads have been shown to be equally effective for defibrillation or cardioversion as long as they are not in contact with each other. However, the self-adhesive pads are generally preferred because the electrode gel is contained within the pad and they allow for hands-free shock delivery.

In order for defibrillation to be successful, there



must be sufficient current flow (amperes) for a critical amount of time to depolarize a critical mass of myocardium. Insufficient current leads to ineffective defibrillation; excessive current leads to myocardial damage. Increasing the energy of the shock (joules), using electrical conducting gel, and increasing paddle pressure are maneuvers that increase current flow.<sup>77</sup> Smaller electrode pads, large lung volumes, and lack of conducting gel increase impedance (ohms), which leads to a reduction of current flow. One case report describes the successful defibrillation of a 3-year-old by using a biphasic AED designed for adults. The child received 150 J (9 J/kg), and the post resuscitation serum creatine kinase and troponin levels were normal. The post resuscitation echocardiogram showed no change in ventricular function when compared with previous examinations.<sup>77</sup>

Despite years of clinical success, no research to date has confirmed that 2 to 4 J/kg is the most effective defibrillation dose. In the 1970s, Gutgesell and colleagues evaluated the efficacy of defibrillation attempts at energy doses of 2 J/kg.<sup>78</sup> They reviewed 71 attempts in 27 children and reported that 91% of

**Table 9. Summary Of PALS Dysrhythmia Management**

Dysrhythmia	Management
<b>Bradycardia</b> (unstable)	Ventilate Oxygenate CPR Epinephrine Atropine Pacing
<b>Asystole / Pulseless Electrical Activity (PEA)</b>	CPR Epinephrine q3-5min Treat underlying cause
<b>VF or Pulseless VT</b>	Defibrillate (2 J/kg) + CPR 2min Defibrillate (4 J/kg) + CPR 2min + Epi q3-5min Defibrillate (4 J/kg) + CPR 2min + Amiodarone or lidocaine
<b>VT – with pulse and stable</b>	Amiodarone or lidocaine
<b>VT – with pulse but unstable</b>	Synchronized cardioversion (0.5-1 J/kg then 2 J/kg)
<b>SVT – stable</b>	Vagal maneuvers (Valsalva, ice to face, blow through occluded straw) Adenosine
<b>SVT – unstable</b>	Adenosine Synchronized cardioversion (0.5-1 J/kg, then 2 J/kg) Amiodarone

SVT = supraventricular tachycardia, VF = ventricular fibrillation, VT = ventricular tachycardia. Data from Inaba AS. Cardiopulmonary Resuscitation. In: Strange GR, Ahrens WR, Schafermeyer RW, Wiebe R, eds. *Pediatric Emergency Medicine*. 3rd ed. New York:McGraw Hill Medical; 2009:202-210. (Textbook chapter)<sup>81</sup>

shocks within 10 J of the standard 2 J/kg dose successfully terminated VF. Notably, the PALS recommendation of a 2 J/kg shock is based entirely on this study, which had a small sample size and defined success without reference to post-shock clinical outcomes, such as a sustained perfusing rhythm. So, the optimal defibrillation dose in children is actually unknown. Some studies suggest that higher doses could be safe and more effective. Various publications describe cases in which children were successfully defibrillated with the standard adult doses of electricity using AEDs and sustained no myocardial damage. Thus, in the absence of pediatric-specific or manual defibrillators, the use of the adult system is preferable to no defibrillation at all in children over 1 year of age.

### Synchronized Cardioversion For Unstable Tachycardias

Children with hemodynamically unstable tachycardias (ie, unstable SVT or ventricular tachycardia with a pulse) should be treated immediately with synchronized cardioversion (starting dose 0.5-1 J/kg). In synchronized cardioversion, the shock is synchronized to the R peak of the QRS complex.<sup>75</sup> The shock is delivered a few milliseconds after the R wave to avoid the vulnerable period of the cardiac cycle and should be repeated if needed at 2 J/kg. Unsynchronized shocks can actually induce ventricular fibrillation. The clinician should also consider sedating the child, since the shocks can be quite painful.<sup>15</sup>

**Figure 10. Inappropriately Sized Pads**



Pads must be selected according to the size of the child. In this case, the apical pad is improperly covering the patient's entire right clavicle and right nipple. The sternal pad is in an acceptable position. Anterior/posterior placement of the pads would be preferred in this scenario, since the child's chest wall is too small to accommodate sternal/apical pad placement. Jacob Parres-Gold demonstrating. (Photo by Marisa K. Bell, MD, ©2009.)

## Management Of Stable SVT

Vagal maneuvers can be attempted in children with stable SVT. These include performing the Valsalva maneuver (having the child blow against an occluded straw or blowing on the tip of a syringe) and/or applying ice to the patient's face. If vagal maneuvers fail to convert the SVT and the child remains hemodynamically stable, the rapid administration of adenosine is indicated (initial dose 0.1 mg/kg, subsequent doses 0.2 mg/kg, maximum single dose 12 mg).<sup>79</sup> Amiodarone is now recommended for cases of SVT refractory to vagal maneuvers, adenosine, and synchronized cardioversion. Amiodarone prolongs the AV node refractory period and slows ventricular conduction. Verapamil should never be used in children. A pediatric cardiologist should be consulted prior to considering the use of verapamil, since profound and possibly lethal ventricular dysfunction, shock, and cardiac arrest have been reported after its use in patients under 1 year of age.<sup>80</sup> Specific doses of commonly used resuscitation medications can be found in **Table 10**.

## Additional PALS Recommendations

The PALS guidelines also provide algorithms and medication recommendations for shock, fluid resuscitation, toxidromes, and trauma. Reducing oxygen consumption and correcting metabolic derange-

ments are discussed. Norepinephrine, nitroprusside (a vasodilator), and hydrocortisone are also discussed. The importance of identifying and treating the underlying cause of the disability cannot be overemphasized.

## Special Circumstances

There are specific scenarios in which ventricular fibrillation (VF) should be suspected. For example, VF may be the result of tricyclic antidepressant overdose and prolonged QT syndrome. A phenomenon reported predominantly in children 4 to 6 years old is *commotio cordis*, in which a low-energy impact to the chest wall during a narrow window of repolarization mechanically initiates VF. A high level of suspicion of VF will allow providers to hasten defibrillation attempts. If a patient has an implanted pacemaker or defibrillator, the pads should be placed at least 1 inch to the side of the implanted device. Defibrillator pads should not be placed over the device, since the device may block the current.

Although clinical experience with cardiac pacing is limited in children, this technique may be attempted if drug therapy has failed. In 1987, a Canadian cardiology group reported the first study of transcutaneous pacing in children.<sup>82</sup> External pacing was carried out in 22 children with no ensuing complications. They concluded that pediatric noninvasive transcutaneous pacing could be safe and effective. Pacing is indicated in children with bradycardic dysrhythmias. Most commonly, pacing is used as a temporizing measure in heart block (ie, second-degree type II and third-degree blocks). Three electrocardiographic leads and 2 defibrillator pads should be applied to the patient during pacing. A pacing rate of 60 beats per minute and an energy level of 0 mA are typically used as starting points, and these values can be titrated up until capture is achieved. Electrical capture should also be confirmed clinically by the presence of pulses. Meanwhile, any reversible causes should be addressed and a more permanent solution (such as a pacemaker) established. Although transcutaneous pacing can be extremely successful when the underlying problem involves electrical conduction, it is much less effective in situations such as hypoxia and hypovolemic shock.

The AHA also addresses the social and ethical issues surrounding resuscitation and now recommends that healthcare providers offer family members the opportunity to be present during the resuscitation of their child. Studies have shown that if they can witness the resuscitation attempts, family members experience less anxiety and depression and more constructive grief behaviors.<sup>39</sup> Ideally, a social worker or team member should remain with the family during the resuscitation efforts.

**Table 10. Doses Of Commonly Used Resuscitation Medications**

Medication	Intravenous/Intraosseous Dose
Epinephrine	0.1 mL/kg, 1:10,000 solution —equals 0.01 mg/kg
Atropine	0.02 mg/kg —minimum dose 0.1 mg; maximum single dose 0.5 mg for child and 1 mg for adolescent —can repeat to total maximum dose of 1 mg for child and 2 mg for adolescent
Adenosine	First dose: 0.1 mg/kg, maximum 6 mg/dose Repeat doses: 0.2 mg/kg, maximum 12 mg/dose —push rapidly —follow with 10 to 20 mL normal saline flush —proximal vein preferred
Amiodarone	5 mg/kg over 20 to 60 minutes; maximum 300 mg/dose —rapid push for unstable rhythms —do not use with drugs that prolong the QT interval (eg, procainamide)
Lidocaine	1 mg/kg —does not prolong the QT interval
Magnesium sulfate	50 mg/kg, maximum 2 g/dose —rapid push for pulseless VT from torsades —over 10 to 20 min for VT with pulse from torsades

## Controversies/Cutting Edge Topics

The most appropriate medication for a hemodynamically unstable patient can evolve during resuscitation. For example, during a low-flow phase of cardiac arrest, intense vasoconstriction can improve coronary perfusion pressure and the likelihood of return of spontaneous circulation. That same intense vasoconstriction might also increase afterload and myocardial strain in the post resuscitation period. Phenylephrine, angiotensin II, and isoproterenol are medications worth being aware of, even if they are not recommended by the PALS guidelines. As our understanding of the physiology of cardiopulmonary arrest improves, more target-specific therapies can be devised. For example, deficiencies of protein C have been seen in patients with severe sepsis. Activated protein C is now being explored as an anti-inflammatory agent for the treatment of severe sepsis. Biomarkers such as lactate, neuron-specific enolase (NSE), plasma B-type natriuretic peptide, and s100b protein (an early marker of cerebral damage) are now also being explored as possible prognostic markers.

Modifications to conventional external CPR that would enhance perfusion are also being explored. During the chest recoil phase, negative intrathoracic pressure can be enhanced by briefly blocking airflow to the lungs, which promotes increased venous return, cardiac output, and mean aortic pressure. This application has been studied in animal and adult human trials but has not yet been explored in the pediatric setting. Another proposed CPR modification is interposed abdominal compressions (IAC).<sup>83</sup> IAC are deployed during diastole and are intended to augment venous return to the heart.<sup>84</sup> In IAC-CPR, a third rescuer compresses the abdomen midway between the umbilicus and the xiphoid process, over the abdominal aorta. Remarkably, the increase in blood flow during CPR appears to translate into a rough doubling of resuscitation success in the clinical studies of Sack et al.<sup>85</sup> Because of insufficient data and concern for damage to underlying organs, IAC-CPR cannot be recommended for children at this time.

A recent radiologic study of chest compressions in infants and children found that chest compressions performed either at the lower-half of the sternum or at the inter nipple line resulted in direct compressions of the heart structures. This likely stems from the relatively larger cardiac silhouette of pediatric patients as compared to adults. These results suggest that in the future, 2 different recommendations for pediatric CPR guidelines may not be necessary. This same study also suggested that the recommended depth of chest compressions for pediatric CPR (one-half to one-third the anterior-posterior distance) is too deep.<sup>86</sup> Most likely the

findings in this study will be discussed at the 2010 ILCOR conference.

It has been reported that high-quality, standard CPR generates 10% to 25% of baseline myocardial blood flow and 50% of normal cerebral blood flow.<sup>73</sup> Although surgical thoracotomy is often impractical, open-chest massage has been shown to generate near normal cerebral blood flow, improve coronary perfusion pressure, and increase the chance of successful defibrillation in animals and humans.<sup>87</sup> Typical indications for massage include open-heart surgery, penetrating trauma, and cardiac tamponade.

Although calcium is frequently given during CPR, its value remains controversial. Calcium ions play a major role in myocardial contractility and impulse propagation; however, limited prospective and retrospective studies have not shown that calcium administration during CPR provides any benefit. To the contrary, high serum calcium and cytoplasmic calcium accumulation may be involved in cell death. The AHA recommends that the administration of calcium be limited to patients with documented hypocalcemia, hyperkalemia, hypermagnesemia, and calcium-channel blocker overdose. In a recent study, Srinivasan et al reviewed 1477 pediatric cardiac arrests and concluded that patients who received calcium during CPR have lower survival rates and poorer neurologic outcomes than did those who did not receive calcium.<sup>88</sup> However, causality was not proven in this study.

In light of new data, the approach to temperature management is now being reconsidered. A growing body of literature demonstrates a neuroprotective effect of hypothermia. The benefit of hypothermia was first noted from the favorable outcomes seen after resuscitations from cold-water drownings. Cerebral oxygen consumption has been shown to decrease by 50% for each 10-degree Celsius drop; hence, there is increased tolerance to decreased perfusion. Multi-center clinical trials are currently under way to study hypothermia, particularly in asphyxiated neonates. The target temperature for this neuroprotective effect is around 33° C (91.4° F). Hypothermia can also have unwanted effects including myocardial depression and coagulopathy. It is important to remember that the recommended therapeutic goal for patients with hemodynamic instability is rewarming the core to greater than 29° C (84.2° F) (below which defibrillation and antiarrhythmic therapy are often ineffective) and that death cannot be declared until the patient has been rewarmed to greater than 29° C (84.2° F).<sup>89</sup>

It is current practice to actively warm critically ill, moderately hypothermic patients, but this approach may need to be reconsidered. A 2000 study by Hickey et al found that "children resuscitated from cardiac arrest frequently present with hypothermia and that this is often followed by the development of fever."<sup>90</sup> It was postulated that the

hypothermia is secondary to a reduction in metabolic rate, CNS depression, or equilibration with the ambient temperature. The cause of the subsequent fever was unknown. A high frequency of abnormal chest x-rays suggested the possibility of a pulmonary etiology, but in reality the cause is probably multifactorial. Although the topic needs further study, one study concluded that "it appears prudent to avoid aggressive attempts to rewarm hemodynamically stable patients with spontaneously developed mild-moderate hypothermia after cardiac arrest....Temperature should be closely monitored after cardiac arrest and fever should be managed expectantly."<sup>90</sup>

## Disposition

Post resuscitation care must be ongoing. Ideally, the child should be transferred to a pediatric intensive care unit (PICU) for ongoing medical care. For now, the recommendation is to maintain normal body temperature and to avoid hyperthermia. Inamrinone and milrinone are becoming recognized for their role in treating post resuscitation myocardial depression. Hyperventilation should be avoided because it reduces venous return to the heart as well as cerebral blood flow. Normocapnia should be maintained and normoglycemia is recommended. Hyperglycemia and hypoglycemia in critically ill children have been associated with lower chances of survival and poorer neurologic outcomes. The post-arrest phase may provide opportunities to increase our understanding of cell injury, reperfusion

injury, and cell death.

There are no hard and fast rules about when to terminate resuscitative efforts. Such decisions are optimal when there is parental agreement. In neonates, it may be reasonable in situations such as extremely low birth weight (< 400 g), extreme prematurity (< 23 wks), or multiple congenital anomalies (eg, anencephaly). Furthermore, if respirations or heart rate do not return after 10 minutes of proper, continuous resuscitation, it may be reasonable to discontinue attempts, since after this time there is evidence to indicate greater rates of death and neurodevelopmental disability.<sup>8</sup> There are no clear indicators that suggest at what point continued CPR efforts are futile. According to the AHA 2005 guidelines, "the rescuer should consider whether to discontinue resuscitation efforts after 15 to 20 minutes of CPR." Considerations include reversible contributing factors, availability of resources, and the site of the resuscitation. The AHA recommends "prolonged resuscitative efforts" for infants and children who have recurring VF/VT, drug toxicity, or primary hypothermia. Extracorporeal membrane oxygenation (ECMO) is also mentioned as a consideration for children with acute, reversible conditions.<sup>91</sup> One large-scale study on children showed good outcomes when ECMO is established with CPR within 30 to 90 minutes of in-hospital arrest. The deployment of all available technologies must be tempered by common sense and the likelihood of a good outcome.

## Cost- And Time- Effective Strategies

1. **The MOST cost-and-time-effective strategy is to recognize a patient in distress or in danger and to prevent the arrest event from happening in the first place.**
2. **EDUCATE patient families.** Encourage parents and family members to become CPR certified. According to one study, 60% of arrests occurred in the presence of family members but only 17% of those patients received bystander CPR.<sup>40</sup>
3. **ALWAYS prioritize Airway, Breathing, and Circulation when assessing a patient.** Accurate assessment of the ABCs will maximize the patient's opportunity for a good outcome. This is considered the standard of care. Failure to do so can result in costly legal complications as well as a poor patient outcome.
4. **When in doubt about the presence of respirations or pulses, initiate CPR.** If indeed the patient is in cardiopulmonary arrest or in a low flow state, CPR will help. If the patient does

have adequate circulation and oxygenation, CPR may provoke a response from the patient. If a lay rescuer does not want to perform mouth-to-mouth, chest-compression-only CPR is better than nothing.

5. **Placement of AEDs in public settings is a time-effective strategy for maximizing good outcomes from ventricular fibrillation.** For every 1-minute delay in defibrillation, the survival rate may decrease by as much as 10%. (This number is influenced by the presence and quality of bystander CPR.)
6. **Do NOT treat children like little adults.** This can result in harm to the patient and escalate the patient's healthcare needs. Examples of the importance of pediatric-specific care include poor patient outcomes caused by the lack of pediatric sized equipment and lethal ventricular dysfunction resulting from the use of IV verapamil in patients younger than 1 year with SVT.

## Transport

Transport is another important aspect of post-resuscitation management. A 2009 article by Orr et al compared interfacility transports of critically ill children performed by pediatric critical care specialized teams versus nonspecialized teams.<sup>92</sup> Unplanned events occurred in 61% of patients transported by nonspecialized teams versus 1.5% of patients transported by specialized teams. In addition, death was more common during transport by nonspecialized compared with specialized teams (23% vs. 9%).

Coordination and communication between facilities, the family, and healthcare providers is essential. Ideally, the patient should be taken to a tertiary care center with a pediatric intensive care unit. All clinics and hospitals should maintain a list of local pediatric tertiary care facilities, pediatric transport teams, and their telephone numbers. If time is of the essence, the needs of the transport team must be anticipated. For example, preparing IV medications and drips into syringes and having copies of the chart and x-rays ready can greatly facilitate a transport.

The mode of transport and composition of the transport team is typically based on the condition of the patient and the logistics of the transfer. Ground

transports have the advantage of being the most spacious, and the ambulance can stop easily if a procedure needs to be performed. The main disadvantages are traffic and delays over long distances. Helicopter transport is fast (see **Figure 11**), but performing procedures in a helicopter is difficult and the cabins are not pressurized. Moreover, many facilities lack a helipad or a safe place to land a helicopter. Fixed-wing aircraft are ideal for long-distance transports and have the advantage of pressurized cabins but require ambulance transfers to and from the airport.

Whether local EMS personnel, a specialized pediatric critical care team, or medical personnel from the referring hospital are performing the transport, it is important to have pediatric equipment available. Specialized pediatric critical care transport teams provide “optimum” transport for critically ill children according to the AHA. The PALS manual recommends using “the most qualified team that is available within an acceptable time interval based on the child’s condition.”<sup>59</sup>

## Spreading The Word

Pediatric cardiopulmonary arrest is a relatively infrequent event. The PALS guidelines are typically

## Risk Management Pitfalls For Pediatric CPR

1. **“No one in the patient’s family knew CPR.”** Encourage patient families to take a CPR course – it could save their own child’s life.
2. **“I couldn’t tell whether or not pulses were present or if the patient was breathing.”** When in doubt, initiate CPR until 9-1-1 arrives.
3. **“I didn’t want to do mouth-to-mouth.”** Be aware that chest-compression only CPR is better than no CPR at all. For healthcare professionals – utilize a bag and mask or carry a key-chain face shield.
4. **“We didn’t think that he needed a cervical collar.”** If there is any suspicion of spine injury based on physical examination, history, or mechanism of injury – it is safer to utilize a collar and a backboard until the child is in a place where the proper examination and radiographs can be performed.
5. **“We don’t have pediatric sized equipment.”** Clinics of all types should try to stock adult and pediatric-sized basic equipment so that they can provide basic life support until 9-1-1 can arrive. Emergency rooms should try to stock all emergency equipment in all sizes and defibrillators that can provide appropriate levels of energy for patients of all sizes.
6. **“We use verapamil for adults; I assumed that we could use it in children too.”** Verapamil is not safe to use in young children, especially children younger than one year of age. In this age group, IV administration of verapamil can cause hypotension and asystole. Adenosine is the first-line medication for children with SVT. Amiodarone can be considered in cases of refractory, unstable SVT.
7. **“We couldn’t get IV access.”** Emergently, intraosseous cannulation can be performed and lidocaine, epinephrine, atropine, and naloxone can be delivered endotracheally.
8. **“I don’t feel comfortable intubating the patient.”** Bag-mask-ventilate the patient until the patient is in a place where experienced medical personnel can intubate the patient. Make sure that there is a good seal between the mask and the face of the patient.
9. **“The child has a pacemaker; I don’t know where to put the defibrillator pads.”** Do not place the defibrillator pads over the pacemaker. Give the pacemaker a one-inch clearance. The pacemaker can block or interfere with the electrical current.
10. **“The child has so many injuries, I don’t know where to start.”** ALWAYS start with the ABCs: Airway, Breathing, and Circulation.

taught in a 2-day course, with a 1-day recertification course required every 2 years. Do healthcare providers learn and maintain a sufficient skill level to accurately employ the PALS guidelines? A 2007 study by Grant et al published in *Pediatric Critical Care Medicine* addresses these questions.<sup>93</sup> The study evaluated the effectiveness of the PALS curriculum in providing pediatric residents with the skills, knowledge, and confidence to resuscitate a patient. They found that the PALS curriculum was successful in providing basic resuscitation information to residents, but the knowledge gained was not retained. This suggests that the PALS course alone does not provide sustained competency in managing a pediatric patient in cardiopulmonary arrest.

Another interesting study published in *Pediatrics* in 2006 found that increased 24-hour survival from pediatric in-hospital arrest was associated with the presence of physicians trained in pediatrics. The presence of pediatric residents was associated with the greatest improvement in 24-hour survival.<sup>94</sup> This study reinforces the importance of pediatric-specific resuscitation guidelines. It also suggests that in a teaching-hospital environment, where PALS guidelines are more likely to be reinforced, competency is less likely to deteriorate. A group from Washington State explored video conferencing as a means of providing PALS retraining to physicians in geographically isolated locations.<sup>95</sup> They found no difference in effectiveness between video conferencing and instruction provided in the traditional format. Thus, video conferencing may be a viable alternative for providers in remote locations. Nevertheless, both groups showed a decline in knowledge and skill at 1 year. This does not necessarily suggest that the AHA

**Figure 11. Emergency Department Transport Vehicles**



(Photo by Geri Greogorczyk ©2009.)

should increase the frequency of PALS recertification, since this would place an even greater burden on already overburdened providers. What it does suggest is that on a personal and perhaps institutional level, efforts should be made to reinforce the most current PALS guidelines. For example, video recording actual resuscitations and reviewing them may reinforce the PALS guidelines and help medical personnel identify and rectify management errors.<sup>96</sup>

## Summary

PALS guidelines provide a cohesive, standardized pedagogical approach to the resuscitation of the pediatric patient. While survival remains poor, it is improving. An essential part of improving pediatric survival is recognizing that children have unique biomechanical and physiologic features that differ from adults in important ways. Trauma, SIDS, and respiratory compromise are the most common causes of pediatric cardiopulmonary arrest. Epidemiologic studies revealed a preponderance of arrest events in children who are male, African-American, and younger than 12 months old. Because family members tend to not provide CPR, increased CPR education for parents should be provided. Recent updates to the PALS guidelines focus on high-quality CPR, new defibrillation recommendations, and the use of advanced airways. The future of PALS seems to reside in continued study of the pathophysiology of pediatric cardiopulmonary arrest, in increasing the successful deployment of lay rescuer CPR and AED programs in the community, and in improving skills retention for PALS providers.

## Case Conclusions

*The first patient, with pulmonary hemorrhage, was stabilized with endotracheal epinephrine, endotracheal cold normal saline, and manual ventilation with relatively high peak inspiratory pressure (PIP) and positive end-expiratory pressure (PEEP). The endotracheal epinephrine dose was 0.1 mL/kg at a concentration of 1:1000, although multiple doses were needed. Intravenous access was established, and she was safely transported to a pediatric tertiary care center.*

*The second patient, the little boy with the history of congenital heart disease, did indeed have ventricular fibrillation. The defibrillator was switched to the manual mode, and VF was verified clinically. The patient was given one shock of 2 J/kg, and successful defibrillation was confirmed after 2 minutes of CPR. Since this patient was already intubated, chest compressions were performed at a rate of 100 per minute without stopping compressions for ventilations. Ventilations were delivered at a rate of 8 to 10 breaths per minute.*

*The third patient, the baby with refractory, unstable SVT, was given amiodarone (5 mg/kg of body weight by*

rapid IV push) and, after an initial attempt at synchronized cardioversion (0.5-1.0 J/kg), was finally successfully converted to sinus rhythm with the delivery of a 2 J/kg shock.

## References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study, will be included in bold type following the reference, where available. In addition, the most informative references cited in this paper, as determined by the authors, will be noted by an asterisk (\*) next to the number of the reference.

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## CME Questions

1. **Survival rates from pediatric cardiopulmonary arrest have \_\_\_\_\_ since the institution of the PALS program.**
  - a. Remained the same
  - b. Decreased
  - c. Improved to 100%
  - d. Can't accurately say due to lack of reliable centralized data
2. **Children:**
  - a. Have the same causes for cardiac failure as adults
  - b. Have lower heart rates than adults
  - c. Have more compliant thoracic cages than adults
  - d. Have smaller heads in proportion to their bodies than adults.

3. **Which of the following statements is true:**
  - a. Children can be treated like little adults
  - b. Management algorithms for adults cannot simply be applied to children
  - c. Children suffer trauma in the same way as adults
  - d. The adult spine is more flexible than the pediatric spine
  
4. **It is estimated that \_\_\_\_\_ children die each year of unexpected cardiopulmonary arrest in the United States.**
  - a. 1000
  - b. 123,000
  - c. 16,000
  - d. 987
  
5. **Information about pediatric cardiopulmonary arrest is:**
  - a. Poorly reported and not centralized
  - b. Totally organized
  - c. Well described
  - d. Easily accessible
  
6. **According to a 1999 study out of Baylor College, most children who suffered apneic and pulseless events were:**
  - a. Female
  - b. Caucasian
  - c. Adolescent
  - d. Male
  
7. **The most common cause of pediatric out-of-hospital arrest, according to a 2004 Pediatrics article, is:**
  - a. SIDS
  - b. Dehydration
  - c. Trauma
  - d. Negligence
  
8. **All of the following are pre-hospital interventions that can save a life EXCEPT:**
  - a. CPR
  - b. Public AED placement
  - c. Feeding the patient
  - d. Activation of EMS
  
9. **Which of the following can be used in an ED to facilitate the diagnosis and management of patients in cardiac arrest:**
  - a. Blood smear
  - b. Ultrasound
  - c. Urine analysis
  - d. Breath test
  
10. **In an unwitnessed or nonsudden collapse:**
  - a. Activate EMS, retrieve an AED, and then start CPR
  - b. Immediately perform CPR for 2 minutes and then activate EMS and retrieve an AED
  - c. Panic
  - d. The cause has a high probability of being related to a pulseless arrhythmia
  
11. **All of the following are changes that have been made to the PALS recommendations since 2005 EXCEPT:**
  - a. Increased emphasis on chest compressions
  - b. Minimizing interruptions in chest compressions
  - c. When defibrillating, deliver 3 stacked shocks
  - d. Perform 2 minutes of CPR after each shock
  
12. **For children 1 year or older and in cardiopulmonary arrest, the recommended CPR ratio for lone-rescuer CPR is:**
  - a. 15:2
  - b. 30:1
  - c. 30:2
  - d. 90:30



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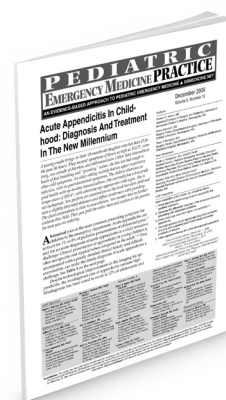
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**Needs Assessment:** The need for this educational activity was determined by a survey of medical staff, including the editorial board of this publication; review of morbidity and mortality data from the CDC, AHA, NCHS, and ACEP; and evaluation of prior activities for emergency physicians.

**Target Audience:** This enduring material is designed for emergency medicine physicians, physician assistants, nurse practitioners, and residents.

**Goals & Objectives:** Upon reading *Pediatric Emergency Medicine Practice*, you should be able to: (1) demonstrate medical decision-making based on the strongest clinical evidence; (2) cost-effectively diagnose and treat the most critical ED presentations; and (3) describe the most common medicolegal pitfalls for each topic covered.

**Discussion of Investigational Information:** As part of the newsletter, faculty may be presenting investigational information about pharmaceutical products that is outside Food and Drug Administration approved labeling. Information presented as part of this activity is intended solely as continuing medical education and is not intended to promote off-label use of any pharmaceutical product. Disclosure of Off-Label Usage: Though the authors of this issue of *Pediatric Emergency Medicine Practice* have not recommended any off-label drug use, very few individual metabolic conditions have medicines that are approved for their use.

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### EVIDENCE-BASED PRACTICE RECOMMENDATIONS

#### Push Hard And Push Fast: The Who, How, And Why Of Pediatric Advanced Life Support (PALS)

Bell M, Lowe C. November 2009; Volume 6, Number 11

*While the last 25 years have undeniably seen advances in the understanding and management of pediatric cardiopulmonary failure, many questions remain unanswered and progress must continue to be made. This issue of Pediatric Emergency Medicine Practice strives to answer the questions: Is there evidence that PALS works? Who comes up with these guidelines and how do they do it? How do these guidelines work and what happens after the initial resuscitation steps have been completed? For a more detailed and systematic look at the PALS guidelines, see the full text article at [www.ebmedicine.net](http://www.ebmedicine.net).*

Key Points	Comments
<p><b>Children are not simply little adults.</b> Children differ not only in body size and weight, but also heart size, physiology, and vulnerability, lung maturity, and function and response to trauma.<sup>10,12,13-25</sup></p>	<p>Whenever possible, use pediatric-specialized equipment such as smaller bag valve masks, smaller endotracheal tubes, smaller laryngoscopes, and defibrillators that can deliver appropriate amounts of energy based on the child's weight. In addition, stabilization equipment, such as cervical collars and backboards, must be tailored to smaller body sizes.</p>
<p>The best way to improve survival is to prevent the arrest event in the first place. Beyond that, early recognition and appropriate intervention are our best tools for improving survival.</p>	<ul style="list-style-type: none"> <li>Educate patient families on proper CPR procedures.<sup>40</sup></li> <li>ALWAYS prioritize Airway, Breathing, and Circulation when assessing a patient.<sup>44</sup></li> <li>When in doubt about the presence of respirations or pulses, initiate CPR.<sup>48</sup></li> <li>Placement of AEDs in public settings is a time-effective strategy for maximizing good outcomes from ventricular fibrillation.<sup>28,41,43</sup></li> </ul>
<p>The AHA is now recommending the "push hard and push fast" approach to CPR.<sup>2</sup></p>	<ul style="list-style-type: none"> <li>For infants and children without signs of puberty, the chest should be compressed to one-third to one-half the depth of the chest, using either the 1-hand or the 2-hand technique.<sup>62</sup></li> <li>For adults and for children with signs of puberty, the chest should be compressed to a depth of 2 inches with the heels of 2 hands, one over the other, placed at the center of the nipple line. In all cases, the chest should be allowed to recoil completely for adequate refilling of the heart.</li> <li>Minimize any interruptions in compressions to prevent the cessation of blood flow. The AHA now recommends one universal compression-to-ventilation ratio of 30:2 for infants, children, and adults.</li> </ul>
<p>During CPR, blood flow to the lungs is only one-third to one-half the normal amount, so less ventilation is required.<sup>60</sup></p>	<p>In pediatric patients with a known metabolic condition who present with an acute illness, the administration of dextrose and fluids is a priority. A good rule of thumb is to initiate IV fluids with dextrose 10% in 1/2 normal saline at 1.5 times maintenance until laboratory results are available.</p>
<p>In scenarios in which manual defibrillation is not available, AEDs may be used for children who are at least 1 year of age with no signs of circulation.</p>	<p>The most current recommendation is to deliver 1 shock, immediately followed by CPR for 2 minutes (starting with chest compressions). Pulses and rhythm should be reassessed after 2 minutes of CPR. These recommendations are based on the findings that (1) rhythm analysis by an AED can take up to 37 seconds and (2) the first shock eliminates ventricular fibrillation 85% of the time.<sup>64</sup></p>

See reverse side for reference citations.

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