Introduction

Cardiac arrest in the pediatric population is an unfortunate and devastating occurrence. It is estimated that 16,000 American children suffer a cardiac arrest each year. Tragically, only 5% to 10% of patients survive out-of-hospital arrests and often with severe neurological sequelae. Survival statistics for pediatric cardiac arrests occurring in the hospital are somewhat better, with 27% of patients surviving to discharge and 65% of them leaving with good neurological outcomes.

Some pediatric cardiac arrests are sudden and unexpected, especially those that occur outside the hospital. Warning signs can be absent or go unrecognized. Pediatric arrests often occur as a complication of, or progression of, respiratory failure, circulatory shock, or both. Although the cause may vary, the goal is the same: immediately reestablish effective cardiac output and deliver oxygen to tissues with high-quality cardiopulmonary resuscitation (CPR).

The difference in outcomes for out-of-hospital arrests compared to those that happen in the hospital can be attributed to the etiology of the arrests, how rapidly the situations are recognized, and the quality of the treatment by caregivers.

In this issue of Code Communications, we will explore current resuscitation research to help answer the following clinical queries:

- Why do children arrest?
- What challenges do clinicians face?
- Why should children not be treated as little adults for defibrillation? and
- What is in the future of pediatric resuscitation?
Why do children arrest?

The potential causes of cardiac arrest in children are numerous. Complications from respiratory conditions, underlying cardiac abnormalities, trauma, and chronic pre-existing conditions can all progress to cardiac arrest.

_Respiratory Causes_

Most often, cardiac arrest in children is the result of a primary respiratory cause. Breathing conditions such as anaphylaxis, apnea, aspiration, asthma, bronchiolitis, epiglottitis, drowning, pneumonia, respiratory syncytial virus, smoke inhalation, and suffocation can quickly deteriorate into respiratory failure. Variable periods of systemic hypoxemia, hypercapnea, and acidosis occur, with progression to bradycardia and hypotension, terminating in cardiac arrest.6

Sudden infant death syndrome (SIDS) continues to be a phenomenon of unknown cause. Since 1992, when the American Academy of Pediatrics released it’s “Back to Sleep,”8 recommendation encouraging parents to place infants on their backs to sleep, the incidence has dropped significantly. The percentage of infants placed on their backs has increased by more than 50 percent since this campaign started.9 Nonetheless, and despite a remarkable reduction in rates over the past decade, SIDS is still responsible for more infant deaths in the United States than any other cause of death during infancy.7

_Cardiac Causes_

Underlying structural abnormalities and electrical conditions can place children at risk of cardiac arrest. Many of these conditions present without symptoms until the arrest. Structural conditions include arrhythmogenic right ventricular dysplasia, coronary artery abnormalities, dilated cardiomyopathy, hypertrophic cardiomyopathy, Kawasaki disease, Marfan syndrome, mitral valve prolapse, and myocarditis.

The epsilon wave (marked by the red triangle) is found in about 50% of those with arrhythmogenic right ventricular dysplasia. This is described as a terminal notch in the QRS complex. It is due to slowed intraventricular conduction. The epsilon wave may be seen on a surface ECG; however, it is more commonly seen on signal averaged ECGs.

Cardiac arrhythmias that can predispose children to cardiac arrest include Brugada syndrome, catecholaminergic polymorphic ventricular tachycardia (CPVT), long QT syndrome, and Wolf-Parkinson-White syndrome.9 *Brugada syndrome* is characterized by ST-segment abnormalities in leads V1-V3 on
ECG and a high risk of ventricular arrhythmias and sudden death.\textsuperscript{10} CPVT is a rare, malignant ventricular tachycardia often occurring with exercise. Most patients with CPVT experience ventricular fibrillation during syncope—in other words, without treatment, patients with CPVT are prone to ventricular fibrillation (VF) and sudden death.\textsuperscript{11} Long QT syndrome ranges from asymptomatic ECG repolarization abnormalities to sudden death, \textsuperscript{12} while Wolf-Parkinson-White Syndrome patients have an accessory pathway and therefore a predisposition to develop supraventricular tachydysrhythmias.\textsuperscript{13} The ECG also features two abnormalities, a short PQ interval and a delta wave. The supraventricular tachycardia patterns can turn into VF, putting patients at risk for sudden death. Most of these arrhythmias remain undetected until a cardiac arrest occurs.

The media frequently highlight unexpected, sudden deaths in adolescent athletes. We know that the best preventive measure is to have all adolescent athletes in high school complete a pre-participation physical that includes a thorough family history, an ECG, and asking questions that might uncover unusual symptoms. These simple steps may identify a possible underlying cardiac abnormality.

Unfortunately for many pediatric patients, a pre-participation physical is not required to play Saturday afternoon soccer with the town team. Unless children complain of shortness of breath, chest tightness or pain, or seizures, for example, the identification, treatment, and ultimately prevention of a catastrophic cardiac arrest may not be possible. Advocacy groups such as Sudden Arrhythmia Death Syndromes and Parent Heart Watch are working diligently in the community to help promote improved preventative screening for children.

\textit{Other Causes}

Commotio cordis is a rare traumatic event caused by a sudden blow to the chest at the moment when the ventricular myocardium is repolarizing, in the ascending phase of the T wave. Other causes of pediatric cardiac arrest include electrical shock, accidents, and impacts with a considerable degree of injury leading to shock and ultimately arrest. Various drugs and toxins can also speed up the heart, causing ventricular fibrillation. In-hospital CPR events have also been documented in children with pre-existing conditions, such as genetic, hematologic, immunologic, metabolic, or oncologic disorders.\textsuperscript{14}

\textbf{CPR and early defibrillation}

Resuscitation efforts that are geared to the pediatric population in the hospital are often aimed at treating possible respiratory failure and/or shock or pre-existing conditions, not sudden cardiac arrhythmias. If a child does not respond to interventions or continues to decompensate, the cardiac rhythm usually progresses through bradyarrhythmias to asystole or pulseless electrical arrest (PEA) rather than to VF.\textsuperscript{3}
A PEA or asystole event requires an organized, skilled pediatric advanced life support (PALS) team to provide possible lifesaving treatment as soon as possible. High-quality CPR is key to survival for these patients. Both PEA and asystole are not shockable cardiac rhythms. If there is no return of a shockable or life-sustaining rhythm, the patient will not survive.

Victims of pediatric cardiac arrest in the community depend on bystanders to provide immediate resuscitation. According to multiple studies referenced in the latest guidelines for pediatric basic life support, only one third to one half of infants and children who suffer cardiac arrest receive bystander CPR.15

Pediatric patients who have a rhythm of pulseless ventricular tachycardia or ventricular fibrillation should be defibrillated as soon as a device is available and ready for use. Most areas of the hospital are equipped with devices that can quickly be placed on a patient. Community access to automated external defibrillators (AEDS) is increasing, improving the chances for early defibrillation.

What challenges do clinicians face?

A pediatric cardiac arrest is one of the most stressful situations a clinician can experience.16 Prevention and treatment of the risk factors or precipitating causes that may lead to a cardiac arrest is always the focus of any medical team. Unfortunately, despite a medical team’s best effort, some pediatric patients will require resuscitation from a cardiac arrest. Utilization of rapid response teams or medical emergency teams in the hospital can help to decrease mortality and morbidity from pediatric cardiac arrests.

Training and Maintaining Skills

Clinicians who provide care for pediatric patients train and prepare for cardiac arrests. Enrollment in lifesaving courses such as pediatric basic life support (BLS) and PALS is required every two years. The American Heart Association (AHA) coordinates the curriculum and includes requirements such as a low student-to-mannequin ratio. The hope is that all students will receive similar training. The traditional BLS or PALS class is held in a classroom environment with lectures and a short skill demonstration. Unless the hospital or unit provides more frequent training, the clinician may only practice these
lifesaving skills every two years. This scenario creates a challenge for clinicians. Although many will never utilize their skills, is it reasonable to maintain an expectation that effective and high-quality CPR will be given when it is required?

The expectation is that clinicians meet the recommended CPR parameters related to rate, depth, and release of chest compressions, and ventilations while avoiding CPR-free intervals.¹⁷ Resuscitation researchers have studied the accuracy of clinicians performing CPR according to the AHA Guidelines. Multiple published papers report that adherence is inconsistent. The issue does not seem to be the understanding of the cognitive aspects of CPR but the psychomotor aspects of delivering a chest compression or delivering a rescue breath.¹⁸,¹⁹,²⁰ Perkins and Mancini described this well: “The frequency with which a healthcare professional is required to use resuscitation skills is also likely to have an impact on the frequency with which refresher training is needed in order to prevent the degradation of knowledge and skills.”²¹

To improve and preserve good CPR skills, the pediatric intensive care unit at the Children’s Hospital of Philadelphia created an approach known as the “Rolling Refresher.”¹⁷ The sessions focused solely on skill performance. Individual clinicians caring for children who were subjectively at highest risk of impending cardiac arrest were chosen to refresh their skills. Over 15 weeks, 420 clinicians (nurses, physicians, and respiratory therapists) were refreshed. Participants found these sessions to be effective when they took part in actual resuscitations. Is this something your department could use to improve CPR skills?

Many studies review the quality of CPR by measuring whether the provider is meeting the Guideline requirements for rate and depth. Another aspect of CPR is allowing the chest to fully recoil between chest compressions. The incomplete release is termed “leaning,” which creates a high intrathoracic pressure that impedes blood returning to the heart.²²,²³ Niles et al. studied this aspect of pediatric CPR and found that leaning was prevalent (in 90% of chest compressions).²⁴ Automated feedback and audiovisual prompts were used to alert the individual to reduce leaning. Think of the last time you provided CPR. Were you concentrating on your rate, depth, and complete release? It is a lot to coordinate appropriately, especially when your hands are pushing down on a young patient.

Following the PALS guidelines accurately and in a time-sensitive manner is imperative to the survival of pediatric patients. Most hospitals use physicians in the team leader role. A study by Hunt et al. exposed the skill set and knowledge gaps within a pediatric residency class using a simulation environment.²⁵ The residents were much more focused on providing ventilations than providing circulation or timely defibrillation. This is a snapshot of one residency, but it shines a light on yet another challenge for clinicians and provides strong evidence that more frequent, intensive training may lead to higher quality resuscitation practices.

The study by Hunt et al. also revealed that residents had notable problems operating the defibrillator.²⁵ Knowing how to use the defibrillator is just as vital as knowing when to use it. There are a number of defibrillators in the hospital environment. Clinicians need to be familiar with their devices and the hospital policy on their use. Many hospitals that provide care for adult patients use the automated external defibrillator (AED) functionality in non–critical care environments so that the patient may
receive treatment in a more timely and efficient manner. When the code team arrives, it may be appropriate to convert from the AED mode to a manual mode. Almost all manual defibrillators that have the AED functionality have treatment algorithms for the adult population only. The exception to this is the ZOLL R Series® defibrillators. These defibrillators can be used in manual mode or AED mode for the pediatric population. When pediatric electrodes are attached to an R Series defibrillator, the it recognizes and adjusts to an algorithm that is specifically designed for pediatric patients. One of the defibrillators in this series, the R Series Plus®, has simple, easy-to-follow controls that allow a clinician to use the defibrillator as an AED. When a PALS code team arrives at the patient’s bedside, this defibrillator can easily be switched to manual mode if desired.

Why should children not be treated as little adults for defibrillation?

Decreased energy levels

When children receive medication to treat their disease processes, they do not receive adult-size doses. The weight of the child is considered in the overall pharmacokinetic profile of the medication. The recommended dosing for pediatric defibrillation is also weight based. This treatment strategy works with a manual defibrillator, but what if the available defibrillator is an AED? Children and adults have different types and characteristics of shockable and non-shockable rhythms. If a child has a cardiac arrest and the only device available is a standard AED with an adult algorithm, it should be used, as some treatment is better than no treatment. AEDs are not currently capable of determining or incorporating the weight of a child in order to provide a weight-based shock.

Many AEDs on the market are now capable of providing defibrillation designed specifically for the pediatric population. Currently, The ZOLL R Series® defibrillators are the only manual defibrillators that offer the pediatric algorithm in AED mode. All other units require that children be shocked manually – the AED algorithm may not be used. The ZOLL pediatric algorithm not only decreases the amount of energy delivered to the patient (via a rectilinear biphasic waveform) but also correctly classifies pediatric high-rate rhythms as non-shockable, whereas an adult algorithm may classify these rhythms as shockable.

Regardless of whether the pediatric patient is defibrillated at a predetermined or weight-based energy level, the hope is that not only will the patient survive, but with a good outcome. In a number of studies, Berg et al. used a piglet model to compare the effect of adult and pediatric doses to terminate VF and found that the pediatric doses resulted in fewer cases of myocardial damage and less post-resuscitation dysfunction.

Impedance

Another concern when comparing an adult patient to a pediatric patient is impedance. The impedance level directly affects the amount of current that is delivered to the heart. Surprisingly, pediatric patients have a high impedance level, given their small thoracic circumference and the small area of the pediatric electrodes. Some current is always lost when a shock is delivered to a patient with a circuit-based
attenuation system. The biphasic defibrillation impedance compensation method by ZOLL measures the actual patient impedance and adjusts the current accordingly.

CPR

With the release of the 2010 AHA Guidelines for CPR, the resuscitation steps for infants, children, and adults have been reordered from the previous sequence of past Guidelines. The new recommended sequence is to provide chest compressions first, followed by airway, and then breathing/ventilations. By providing compressions first, ideally, the victim will have minimal interruptions in oxygenated blood flow as treatment is initiated. At the current time, for infants and children, it is not known whether outcomes will be affected if a rescuer provides compressions or ventilations first.

The new Guidelines also promote compressions-only CPR for untrained lay rescuers who are helping adult victims of cardiac arrest. If an infant or child is the victim, should a bystander just do compressions? The optimal CPR for infants and children is still compressions and ventilations. Since the most common etiology for cardiac arrests in pediatric patients is pulmonary related asphyxia-induced events, ventilations remain an important intervention. However, if the bystander is not aware of this difference in the Guidelines, Compression-Only CPR is certainly preferable to no CPR.

What is in the future of pediatric resuscitation?

Will the new Guidelines help to increase the survival rates of children? Will the increase in AEDs in the community change the outcome of cardiac arrests that occur outside the hospital? Will the rate of bystander CPR improve with the increased awareness of the hands-only option? These are some of the questions that everyone in the pediatric resuscitation community will be following as research is collected and published.

Pediatric resuscitation teams and untrained rescuers alike will be looking forward to the time when defibrillators include CPR coaching, allowing for immediate feedback. This will provide the opportunity to positively affect outcomes for survival.

What is the optimal pediatric defibrillation dose? Current guidelines suggest the first shock of 2 joules/kilogram (J/kg), second shock 4 J/kg, and subsequent shock of ≥ 4 J/kg. A recently published study compared the recommended 2 J/kg for the initial shock to 4 J/kg for the first shock. The higher shock was not associated with higher rates of termination of VF or pulseless VT.

After children suffer cardiac arrest, it is imperative to provide the best post-resuscitation care. Should this include therapeutic hypothermia? Look to the future for results of multicenter studies examining outcomes after therapeutic hypothermia is used.

Prevention and education remain important aspects of pediatric cardiac arrest. Someday no parent will leave the hospital with a new baby without CPR certification. Someday all schools will be required to include CPR as part of the health curriculum.

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References:
