PEDIATRIC DEFIBRILLATION:

Because Children Are Not Just Little Adults

THE IMPORTANCE OF A PEDIATRIC ANALYSIS ALGORITHM

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When the American Heart Association's (AHA) "Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care" were published, Automatic External Defibrillator (AED) use in children under the age of 8 was not recommended. At that time, study results had demonstrated an AED's ability to accurately detect ventricular fibrillation (VF) for all ages under 8, however, there was limited data regarding an AED's ability to distinguish shockable versus non-shockable tachyarrhythmia in the infant and young child age groups. The latter concern relates to the possibility that sinus tachycardia (ST) or supraventricular tachycardia (SVT) in pediatric patients may be mistaken for shockable rhythms by an AED with an arrhythmia analysis program originally developed for evaluating adult arrhythmias.

Since that time, AED use in children under age 8 has been shown to be safe and effective. Most recently, in July 2003, the American Heart Association provided an update that included the results of two studies demonstrating high sensitivity for VF and high specificity for non-shockable rhythms, primarily for children ages 1 to 8 using the adult algorithms[1]. The update provided the evidence for the following recommendations:

- AED use in children (ages 1 to 8) is a Class I recommendation for VF and pulseless VT.
- AED use in the infant age group (under age 1) is not recommended because of insufficient data on safety and efficacy. This will be clarified as future studies are completed.
- CPR is recommended for the first minute, followed by AED application.

It is a common notion among clinicians to "treat the patient, not the device being used to treat the patient." This simple notion is particularly applicable to pediatric emergencies, since cardiac arrest represents only a small subset of all pediatric arrest cases. ZOLL Medical Corporation has taken just such a "treat the patient" approach to pediatric defibrillation by providing the only ACLS platform that:

- Is able to automatically detect whether the patient is a child by the type of electrode used;
- Automatically decreases the energy to a safer level (50J first shock);
- Is cleared for use in infants < 1 year of age;
- Defaults to an AED analysis algorithm specifically designed for children's ECG; and
- Uses an optimized biphasic defibrillation waveform, unfiltered by attenuation resistors.

An ECG Analysis Algorithm Designed Specifically for the Pediatric Population

Children differ from adults as to the types and characteristics of shockable and non-shockable ECG rhythms. The lower incidence of VF in children indicates that they are more likely to have non-shockable rhythms than are adults[2]. It is important to correctly classify non-shockable high-rate pediatric rhythms such as sinus tachycardia (ST), supraventricular tachycardia (SVT), and accelerated ventricular rhythms when presented to an AED used on a child. Adult-based AED arrhythmia analysis algorithms may have difficulty correctly classifying these high-rate pediatric rhythms as non-shockable since the characteristics of the non-shockable pediatric rhythms overlap the shockable criteria used in the adult-based algorithms.

ZOLL Medical Corporation has developed a dedicated pediatric AED arrhythmia analysis algorithm that accurately distinguishes shockable versus non-shockable pediatric rhythms – even the most difficult high-rate, non-shockable rhythms. The analysis algorithm detects the use of either pediatric or adult therapy electrodes and automatically adjusts the arrhythmia analysis processing for the appropriate patient type. This algorithm is available in all ZOLL Public Access AEDs as well as in the ZOLL R Series® platform. In the presence of pediatric pads, the units automatically switch to pediatric mode and perform a complex rhythm analysis of the ECG morphology and rate.

Since SVT is a prominent pediatric arrhythmia, special efforts were made to gather a significant number of SVT rhythms during development of the ZOLL pediatric ECG algorithm. Adult-based algorithms typically consider high-rate SVT as a shockable rhythm. However, small children can have perfusing rhythms at these same rates and should not be shocked. These non-shockable rhythms in the database included abnormal ventricular and supraventricular rhythms with rates up to 300 bpm, which are often found in infants and young children. Performance of the ZOLL pediatric arrhythmia algorithm on this database exceeded the performance recommendations of the AHA[3] published for adult AED arrhythmia processing algorithms. The use of separate processing algorithms provides the means to retain a high-rate SVT in adults as a shockable rhythm while providing for pediatric SVT to be classified as non-shockable.

Although it is subject to the specifics of a given database, the ZOLL analysis algorithm demonstrated superior performance as compared to the performance reported in other pediatric AED studies that were based on the evaluation of adult-based algorithms on pediatric ECG signals.[4,5] (Figure 1).

Contrary to the previous pediatric AED studies[4,5], shockable and non-shockable VT rhythms were more prominent than VF in our data collection. The database contained 122 records of shockable and non-shockable VT as compared to 42 records of VF. The ability of the dedicated pediatric algorithm to detect these rhythms and recommend the appropriate therapy is a significant improvement over adult-based algorithms. The increased sensitivity in the detection of shockable ventricular tachyarrhythmia will reduce the time to cardioversion and return to spontaneous circulation. The increased specificity in the detection of non-shockable VTs will avoid unnecessarily shocking a pediatric patient not needing defibrillation therapy.

Biphasic Defibrillation Optimized for Children

Contrary to what one might expect based on common sense alone, pediatric patients, while having a smaller thoracic circumference, actually have high defibrillation impedances. Published work by Atkins has shown that average impedances of pediatric patients are 90 ohms[2],. This is primarily because of the smaller area of pediatric electrodes. As a result, impedance compensation methods are very important in the pediatric population.

AEDs that use circuits to attenuate the energy delivered to pediatric patients (the bulge you see on the wires of pediatric electrodes) put resistors in between the defibrillator and the patient. This process has two negative effects:

1. The unit has no ability to distinguish between the resistors in the wire and the impedance of the patient. As a result, the ability to compensate for patient impedance, an important part of a waveform's efficacy, is significantly compromised.
2. In some pediatric systems, a resistor that shunts current away from the child is used to attenuate the energy. This method has the negative effect that as patient impedance increases, proportionally more and more current is steered away from the patient – exactly the opposite of what biphasic defibrillation impedance compensation methods are attempting to accomplish.

Figure 1: Comparative Reported Sensitivity of Pediatric Advisory Algorithms

	AHA GOAL	ZOLL	AED A	AED B
Shockable				
Coarse VF	> 90% sensitivity	100% (42/42)	94.3% (50/53)	98.6% (71/72)
Rapid VT	> 75% sensitivity	93.9% (77/82)	70% (21/30)	Insufficient Data
Non-shockable				
NSR	> 99% specificity	100% (208/208)	100% (374/374)	99.2% (792/798)
SVT (heart rates 152-302 BPM	> 95% specificity	99.4% (160/161)	Insufficient Data	Insufficient Data

Figure 2: Percent of Current Delivered to 50 ohm Patient vs. Impedance with Circuit-based Energy Attenuation

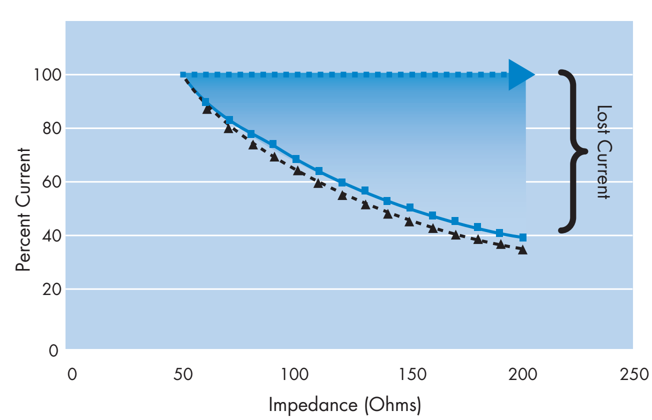

Figure 2 shows the amount of current delivered to a pediatric arrest patient as a function of the patient's impedance, compared to how much would have been delivered to a patient with 50 ohms. The two curves are for commercially available AED pediatric defibrillation systems. As can be seen in the figure, 40% of the current is lost to the patient, for an impedance of 100 ohms – typical in the pediatric population – and nearly half of the current is not delivered to the patient, for an impedance of 150 ohms for both AEDs.

The ZOLL Biphasic waveform, when used with ZOLL OneStep™ Pediatric electrodes, automatically decreases the initial energy to a starting dose of 50 J but allows the device to measure the actual patient impedance and adjust accordingly, delivering sufficient current for effective conversion while not overdosing the patient.

Superior Biphasic Defibrillation Waveform for Pediatrics

ZOLL received FDA approval for the use of the Rectilinear Biphasic waveform on children ages 1 to 8 as well as infants under the age of 1. Additionally, a clinical study by Wang et al states "The ZOLL RLB waveform provided a superior ability to defibrillate a porcine pediatric model in terms of energy dose per body weight (J/Kg) and per heart weight (g) when compared to Physio-Medtronic BTE waveform." The results of this trial were published in 2007 in the Journal of Critical Care Medicine. The abstract is below.

Comparison of rectilinear biphasic waveform with biphasic truncated exponential waveform in a pediatric defibrillation model

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Objective: To compare the rectilinear biphasic waveform with a biphasic truncated exponential waveform for pediatric defibrillation.

Design: Prospective, randomized study.

Setting: Experimental laboratory of a university-affiliated research institute.

Subjects: Male domestic piglets (4–24 kg).

Interventions: Eleven piglets (4–8 kg), which represented a patient <1 yr old, and ten piglets (16–24 kg), which represented a pediatric patient between the ages of 2 and 8 yrs, were anesthetized, intubated, and mechanically ventilated. Ventricular fibrillation was induced and maintained for 30 secs, and a predetermined shock was then delivered to defibrillate. Following defibrillation, the animal was permitted to stabilize hemodynamically for 4 mins. Fifty shocks were applied to each animal using a randomization schedule based on a predetermined permutation of 50. The 50 shocks were 25 shocks for each rectilinear biphasic and biphasic truncated exponential waveforms, comprising five shocks at five energy settings. Each group of five shocks was fixed at a predetermined energy value, depending on the body weight of the animal. Dose-response curves were constructed using logistic regression. Aortic pressure, electrocardiogram, left ventricular pressure, and left ventricular pressure value of 40 mm Hg were continually measured.

Measurements and Main Results: Dose-response curves determined defibrillation thresholds at 50% (D50) and 90% (D90) probability of success. The rectilinear biphasic waveform defibrillated with <90% of the D50 and D90 energies required for a biphasic truncated exponential waveform. The rectilinear biphasic waveform also successfully defibrillated with significantly less energy per body weight and per heart weight compared with a biphasic truncated exponential waveform.

Conclusions: The rectilinear biphasic waveform has superior defibrillation performance compared with a biphasic truncated exponential waveform in a piglet defibrillation model for young children. (Crit Care Med 2007; 35:1961–1965)

KEY WORDS: rectilinear biphasic defibrillation; pediatric patients; resuscitation

Conclusion

A pediatric AED algorithm in an ALS defibrillator allows first responders to: confidently act, speed the time to first shock, and more efficaciously manage these special patients.

Shockable Rhythm Definitions	
Ventricular Fibrillation (VF) – 1	Uncoordinated ventricular depolarizations. Minimum of 5 complexes with an average > 0.2 mVpp during a 3 second window.
Rapid Ventricular Tachycardia (VT) – 2	Absence of P waves. Rate > 200 beats per minute (R-R interval ≤ 300 milliseconds). QRS Complex width > 160 milliseconds. Includes monomorphic or polymorphic VT, and ventricular flutter. Minimal (or no) isoelectric activity.

Non-shockable Rhythm Definitions	
Normal Sinus Rhythm (NSR) – 3	Complexes show a supraventricular origin. Rate > 180 bpm. QRS duration < 120 milliseconds. R-R interval variability < 20%.
Supraventricular Tachycardia (SVT) – 4	Complexes show a supraventricular origin. Rate > 180 bpm. QRS duration < 120 milliseconds. R-R interval variability < 20%.
Supraventricular Arrhythmias (ABN) - 4	Other supraventricular arrhythmias that do not qualify as NSR or SVT with or without AV block and bundle-branch block (BBB). Includes Atrial Fibrillation (AF), Atrial Flutter (AF), Junctional Rhythms, Sinus Rhythm & Arrhythmia (SA) with or without Premature Atrial (PAC), Premature Junctional (PJC), or Premature Ventricular (PVC) Contractions. Complex width < 160 ms.
Idioventricular Rhythms (ABN) – 4	Ventricular complexes only, no supraventricular complexes. Monomorphic or polymorphic. Rate < 100 beats per minute. At least 1 complex > 0.3 mVpp.
Asystole (ASY) – 5	Absence of consistent electrical activity of at least 0.1 mVpp amplitude.
Fine VF (FVF) – 6	Uncoordinated ventricular depolarizations with a minimum of 5 complexes with an average > 0.1 mVpp and < 0.2 mVpp.
Intermediate VT (OVT) – 7	QRS duration > 160 milliseconds. Absence of P waves, or AV dissociation if P waves present, Ventricular complexes only. Rate < 200 bpm and > 100 bpm (the idioventricular rate). Includes monomorphic and polymorphic VT.

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