POSITION PAPER
NATIONAL ASSOCIATION OF EMS PHYSICIANS

THE USE OF AUTOMATED EXTERNAL DEFIBRILLATORS IN CHILDREN

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POSITION STATEMENT

1. Although the incidence of ventricular fibrillation (VF) in children is far less than that of adults, the outcome for VF is better than for other nonperfusing rhythms and is improved with early defibrillation.
2. Strategies for the treatment of pediatric arrest should focus on shortening the intervals from collapse to recognition of VF and to defibrillation.
3. Data on the correct energy for defibrillation of children are limited. Animal studies suggest that the immature heart is less susceptible to energy-related damage than the adult heart and that there is a wide therapeutic range of defibrillation energy dose.
4. Although using a fixed-energy automated external defibrillator (AED) in some children may have the potential for harm, not treating VF has the potential for even greater harm, death of the child. As such, defibrillation should not be withheld based on weight and size criteria alone.
5. Systems should attempt to provide defibrillation to children suffering VF in the timeliest fashion possible. Strategies may include:
   - Manual defibrillation.
   - AEDs designed for defibrillation of young children.
   - Standard AEDs used in children with appropriate protocols and medical oversight.

INTRODUCTION

Early defibrillation has been shown to be the most effective treatment for out-of-hospital cardiac arrest due to VF.[1,2] The likelihood of survival decreases by about 10% with each minute of delay to defibrillation after cardiac arrest. Strategies to decrease the time to defibrillation that have been shown to be effective include the use of automated external defibrillators (AEDs) by emergency medical technicians (EMTs) and nonmedical personnel.[3–5] Automated external defibrillators represent a significant breakthrough for adult out-of-hospital cardiac arrest. The availability and proper use of a defibrillator within minutes of an adult cardiac arrest can greatly improve the chance for survival.[3] In adults, the use of early defibrillation when combined with effective cardiopulmonary resuscitation (CPR) has been shown to produce the highest rates of survival.[2] The 2000 National Association of EMS Physicians position paper on early defibrillation advocates AEDs in strategies to shorten the time from arrest to defibrillation.[6]

In children, the use of defibrillation has been downplayed, with a focus on early airway and ventilatory assistance as a result of the belief that asystole was the predominant rhythm and that VF rarely occurred.[7] While not the most common rhythm, VF does occur in children. In addition, the chances for survival from VF are greater than for other nonperfusing rhythms making treatment of VF a priority in pediatric resuscitation.[8]

In the latest American Heart Association (AHA) pediatric guidelines, AEDs are not recommended for children who are younger than 8 years old or who weigh less than 25 kg (55 pounds).[9] There are limited data on effective energy for defibrillation or safety of different energy levels and waveforms in children. The only data were from a single retrospective study from 1976, which showed that on average 2 J/kg treated VF in many children and, if it failed, usually 4 J/kg was effective.[10]

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In order to be effective and safe in children, an AED must achieve several goals. First, it must capture the patient's rhythm from surface electrodes and then use a computer algorithm to determine whether a shock is indicated. For an AED to be used in children, it must have the capability to determine shockable rhythms, but even more importantly, it must accurately determine when not to deliver a shock. When the correct rhythm is identified, the AED must be capable of delivering a shock with sufficient energy to convert the rhythm to a perfusing rhythm without causing damage to the myocardium.

CARDIAC ARREST PHYSIOLOGY

There are anatomical and physiological differences between children and adults, some of which may be significant to pediatric defibrillation. Anatomically, children's hearts are smaller than those of adults. A critical mass of myocardial tissue is required to sustain fibrillation.[11] This could be one of the reasons why VF is less prevalent in the pediatric population than it is in adults.[12]

There are also some important physiological differences between pediatric and adult patients. Children have higher cardiac output per kilogram than adults, but because oxygen demand is high in children, oxygen reserves are limited. Cardiopulmonary deterioration can occur whenever oxygen delivery is compromised or oxygen demand is increased above oxygen supply. Pediatric patients have higher heart rates and lower stroke volumes than adult patients.

In children, sinus tachycardia is the normal response to stress, because infants and children increase their cardiac output by increasing their heart rate rather than stroke volume. Normal heart rates for neonates have been reported to range from 100 to 180 beats per minute. Further, detecting a pulse in infants may be more difficult than it is in adults, due to their shorter, chubbier necks.

There are also biochemical differences between adults and children, which may be relevant to differences in the toxicity of defibrillation shocks. Newborns have substantially less myocardial catecholamine than adults.[13] It is believed that the biochemical effects of catecholamines on oxygen consumption and utilization may have a role in causing myocardial damage.[14] Thus, it may be expected that newborns would have a higher tolerance for high-energy defibrillation shock doses as compared with adults.

CARDIAC ARREST EPIDEMIOLOGY

Children suffer fewer cardiac emergencies than adults. One estimate indicates that sudden cardiac death is one tenth as common in children as it is in adults, and that it occurs in only 1 to 2 per 100,000 children annually.[15] However, the death of a child is an enormous emotional and social loss with a community-wide impact. Because of their life expectancy, the number of years of life lost as a result of pediatric arrests may rival that for all adult arrests.[12] Survival as well as neurological outcomes are better for pediatric patients whose initial recorded rhythm is VF, compared with other causes of pediatric cardiac arrest.[16]

In a six-year retrospective population-based review of pulseless, nonbreathing patients less than 20 years old, Mogayzel et al.[8] compared the causes and outcomes for patients whose initial rhythms were VF with those whose initial rhythms were asystole or pulseless electrical activity (PEA). Of the 157 patients included in the study, VF was the initial rhythm in 19%, excluding patients less than 6 months old who died from sudden infant death syndrome (SIDS). This study reported that in the witnessed arrests, a significant percentage of the patients were in VF as the initial rhythm upon emergency medical services (EMS) arrival. In addition, it was reported that the age of the patient did not alter the percentage of patients with VF. The percentage of patients in VF as a percentage in cardiac arrest is approximately the same for 0–4-year-olds as it is for 15–19-year-olds (17% vs. 19%). The first responders identified the initial rhythm in only 44% of patients. The majority of patients in this study (16 of 29 children) who were initially in VF did not receive defibrillation by the first responder, because protocol and available equipment required the procedure to be performed by a paramedic. These 16 children might have benefited from AED usage.

Young and Seidel's comprehensive review of pediatric CPR included articles published over a 27-year period from 1970 through February 1997, representing 44 studies and involving a total of 3,094 patients.[16] Of the 1,407 patients in cardiac arrest, approximately half were less than 1 year old. Of the patients for whom an initial electrocardiogram (ECG) was recorded, 10% were in VF or pulseless ventricular tachycardia (VT), and 73% had asystole or PEA. Only 5% of the cardiac arrest patients whose initial recorded rhythm was asystole survived to discharge, compared with 30% of the patients in VF/VT. Because of the lack of consistency in definitions, inclusion criteria, and outcome measures, the authors of this review urged the use of pediatric Utstein-style definitions to minimize variations in definitions and outcome measures in future reports of pediatric resuscitation studies.[17] They also noted that the survival rate for pediatric victims of sudden cardiac arrest had not improved in the last decade. Despite the low incidence of VF in this population, there was a dramatic difference in survival for patients in VF compared with other causes of cardiac arrest. Patients in asystole rarely respond to treatment. Because VF may precede asystole, resulting in a short "window of opportunity' for defibrillation, the authors suggested a dramatic change in pediatric resuscitation protocols, emphasizing early defibrillation. Furthermore the studies included in this review may have underestimated the true existence of VF in the pediatric patient. Since AEDs were not authorized for use in children, rhythms were determined only upon arrival of ALS providers. This may have allowed undetected VF at the time of arrival of the first responder to degenerate to asystole by the time an ALS provider had arrived to perform rhythm analysis.

ACCURACY OF RHYTHM DETERMINATION

It is an overall safety goal for AED algorithms to be highly specific in the presence of nonshockable rhythms. Because of the higher normal heart rates in infants and young children, AEDs that advise shocks based primarily on heart rate would not be appropriate for use on pediatric patients. This is of even greater importance for a public-access defibrillation program in that most laypersons are taught not to check the patient's pulse before application of an AED, but to rely on the device's recognition of a shockable rhythm. The anatomic and physiological differences between adults and children summarized above underscore the importance of this requirement. Because many high-rate rhythms in children may be associated with a pulse, it is important that an AED for use on children be designed so that shocks are not advised for such rhythms. In rhythms where there is not general agreement regarding whether a shock is warranted, and there may be an associated pulse (intermediate rhythms), the AED should be designed such that shocks are not advised. The AHA defines intermediate rhythms as ". . . rhythms for which the benefits of defibrillation are limited or uncertain."[18] For these rhythms, the therapeutic benefit of a shock is uncertain and, in addition, the victim may potentially be exposed to some risk if a shock is delivered.

Studies of AED rhythm detection accuracy in children have reported generally good success.[19–21] In one study of patients whose ages ranged from 5 days to 7.5 years old, rhythms from pediatric intensive care unit (ICU) patients were recorded.[19] Rhythms were digitized and annotated by three reviewers and then read into several AEDs. The AED analysis results were then compared with those of the reviewers. The study found that the specificity of the AEDs for pediatric tachycardias was not 100%, and the abstract suggested that modifications to AED algorithms might be needed to address pediatric patients. This 1997 abstract did not indicate which devices were used.

In the only study of out-of-hospital AED use in children less than 16 years, the AEDs were highly accurate, with 100% specificity and 88% sensitivity.[22] The AEDs used include multiple parameters in their analysis algorithms (the criteria upon which these AEDs will advise a shock include more than just heart rate and amplitude). While the sensitivity was 88%, which is excellent, it does represent some missed opportunities and room for improvement. More important was the 100% specificity, which indicates that under no circumstances was a patient incorrectly defibrillated. An AED manufacturer's study of its patient analysis system collected 233 rhythm strips from 71 pediatric patients under 12 years of age, and showed similar results, with 100% specificity and 100% sensitivity for VF and 81.8% for VT.[20] The study supported the feasibility of using a single AED algorithm for both adults and children.

In a case report of the use of an AED on a patient less than 8 years old, the AED correctly detected VF and advised a shock, which defibrillated the VF successfully, and then the device correctly detected the resulting nonshockable rhythm and advised that no shock was required. Importantly, there was no detectable cardiac damage from the defibrillation.[23]

AED ENERGY AND WAVEFORM SAFETY AND EFFICACY

In addition to recognizing a shockable rhythm, an AED must deliver the electrical energy that will have the greatest potential for conversion to a perfusing rhythm while minimizing the potential for harm. The currently accepted prehospital approach for manual defibrillation is 2 J/kg initially, followed by 4 J/kg. The energy range for current AEDs is 150–360 J, depending on type of waveform and model, and may be used for children older than 8 years.[9]

In 1976, Gutgesell et al. reported the results of a retrospective chart review of pediatric cardiac arrests, which was performed to determine whether their institution's guidelines for defibrillation energy dose in pediatric patients were effective. Twenty-seven children were included, with weights ranging from 2.1 to 50 kg and ages ranging from 3 days to 15 years. In these children, 71 defibrillation attempts were made using monophasic wave technology. This study found that 91% of the shocks within 10 J above or below an energy dose of 2 J/kg were effective, while the two shocks below this level were ineffective, and all but one of the 12 shocks above this level was effective. The single higher-energy shock that was ineffective was only 13 J over the 2-J/kg dosage guideline, and the child had previously received an unsuccessful initial shock at a lower level (1.9 J/kg). A third shock at 60 J (3.8 J/kg) was successful in this patient. All shocks above 2 J/kg were at least as effective as shocks in the 2 J/kg ± 10 J band, and the study included one shock that was over 7 J/kg.[10]

Before the study reported by Gutgesell et al. in 1976, the recommendations for initial defibrillation energies in children ranged from 60 to 200 J.[24,25] Afterward, this study was the basis for the pediatric defibrillation recommendations of 2 J/kg followed by 4 J/kg in children. It is important to note that the study by Gutgesell et al. was not designed to establish a defibrillation-threshold based dose in children; rather, it confirmed the guidelines for effective defibrillation that the group had already established based on their previous animal studies. Furthermore, this study established neither dose safety ranges nor the risk benefit of this or any other dosing strategy. Although Gutgesell et al. acknowledged that the damage threshold is much higher, they decided to keep the 2-J/kg initial and 4-J/kg subsequent shocks protocol because it was easy to remember, and it appeared to be successful in most cases. This one retrospective case series using a monophasic waveform has served as the basis for the current AHA guidelines for pediatric defibrillation including extrapolation without evidence to biphasic waveform energy settings.[9]

Mogayzel et al. found similar results, reporting that 93% of the 29 patients in their study whose initial rhythm was VF were defibrillated with 2 to 4 J/kg as the initial dose and 4 J/kg for subsequent shocks.[8] Seventeen percent of the VF patients were discharged with no or mild disability, compared with only 2% of patients whose initial rhythm was asystole or PEA. This study found that VF was the only variable associated with a good outcome in this population, and that patients whose initial rhythms were VF had a survival rate approaching that of adults.

Atkins et al. recently studied out-of-hospital AED use in patients less than 16 years.[22] In total, the AEDs performed 67 analyses, and there were 25 episodes of VF. Three of the seven patients who received shocks survived and were discharged from the hospital, with AEDs delivering either 200 J or 360 J. Two of the VF patients did not receive shocks because the patients were less than 12 years old and/or weighed less than 90 kg, and the dose would have exceeded the 4-J/kg recommendation. Both patients died.

The successful use of an AED in a younger child has been reported.[23] In this case, the a 3-year-old child received a 9-J/kg dose delivered by his mother using a 150-J biphasic AED. The child was awake and crying with a heart rate of 120 beats per minute when the emergency medical team arrived 10 minutes after his defibrillation.[23] The child was successfully defibrillated with one shock. The child's creatine kinase and troponin levels were within normal limits following his resuscitation, indicating no clinically significant damage.

The harmful effects of defibrillation cannot ethically be deliberately induced in human subjects; therefore, it is not possible to determine the dose–response curves for toxic and lethal energies in humans. As a result, appropriate energy dosing for defibrillation and energy dosing that might cause injury must be extrapolated from animal models.

Determination of the defibrillation threshold for a waveform typically requires multiple shocks to be delivered to each subject in a controlled setting, making the study in a human population extremely difficult; the difficulty of studying the effectiveness of external defibrillation shocks in human pediatric subjects is compounded by the lower incidence of pediatric cardiac arrest. One study across a wide variety of animal species showed that the energy dose required for defibrillation is somewhat weight-dependent and ranges from 0.5 to 10 J/kg.[26] Although the external defibrillation effectiveness data are too limited to draw any definitive conclusions, this study suggests that the defibrillation threshold for most patients weighing up to 50 kg is likely close to 2 J/kg. Other studies in animals and humans have shown that repeated high-energy shocks with a 360-J monophasic damped sine waveform might cause significant damage.[27,28] One study found that animals receiving a single high-energy shock sustained little damage, but animals that received multiple shocks had significant cardiac injury and acute pump failure.[29] The authors emphasized the need to optimize first-shock effectiveness.

A clinical study has also shown that initial shocks that were too low (below the defibrillation threshold) caused an increase in the energy requirement for subsequent shocks to defibrillate.[30] This report emphasizes the importance of first-shock effectiveness and casts doubt on the philosophy of starting with a low or moderate energy level with the intent to increase it if needed for subsequent shocks. These reports also provide a possible explanation for the single unsuccessful shock that was over 2 J/kg in the pediatric patient in the Gutgesell study.[10] This patient initially received a shock that was below the 2-J/kg level. In addition, these data suggest that an initial dose somewhat higher than the current recommendations may be warranted for pediatric patients.

In 1980, Babbs et al. published therapeutic indices for effective, damaging, and lethal doses of defibrillation energy using monophasic wave technology, based on studies involving more than 100 dogs.[31] The delivered energies ranged from 1 to 512 J/kg. They found that it took five times more energy to produce detectable histologic damage than was required for effective defibrillation. The ED5O (defined as the energy at which 50% of the animals were successfully defibrillated) was 1.5 J/kg. The TD5O (defined as the energy at which 50% of the animals had detectable myocardial damage) was 30 J/kg. The LD5O (the 50% lethal dose for the population) was 470 J/kg. The ED5O curve was significantly steeper than the TD5O and LD5O curves, showing that the toxic and lethal effects were more variable in the study population. The authors concluded that the ". . . fear of inducing damage should not be a dominant factor in determining defibrillation dose. Instead, effectiveness should be the major criterion."

Gaba and Talner studied monophasic wave defibrillation safety in 21 newborn pigs, ranging from 2 to 18 days old and 0.95 to 4.7 kg.[32] Some animals that were shocked with doses greater than 150 J/kg had substantial myocardial damage, but this effect was not seen in animals shocked at lower energy levels. The dose–response curves established by this study are nonlinear and exponential, as seen in other studies. However, the authors noted that substantially more energy was needed to cause myocardial damage in newborn piglets when compared with results reported in previous investigations of adult dogs. These results suggest that newborns are more tolerant of high-energy doses than adults, and Gaba and Talner hypothesized that the intrinsic structural and physiological differences between newborn and adult myocardia could account for the differences observed.

Several studies have shown that biphasic waveforms cause less damage than monophasic waveforms, and these effects seem to be independent of energy.[33–35] One study found that the use of biphasic waveforms was associated with significantly better postresuscitation myocardial function than monophasic waveforms, even with the same high energies and capacitance typically used for monophasic defibrillation.[36] These studies demonstrate the safety of pediatric defibrillation shocks, even at energy doses significantly higher than the current 4-J/kg recommendations, and especially when the number of shocks delivered is minimized.

The animal data indicate that there is a wide margin between effective and toxic doses,[31] especially in neonates.[32] Due to the prohibition of energy doses higher than 4 J/kg, many children have not received timely shocks for VF (8) even when shocks were advised by AEDs.[22] It is unknown how many children may have died while awaiting defibrillation at lower, recommended energies. All available data indicate that traditional and even very high defibrillation doses from AEDs designed for adults are effective and safe in this population and fall below the TD50 and LD50 levels.

NATIONAL GUIDELINES

The current AHA guidelines include the use of adult AED for patients greater or equal to 8 years of age or greater that 25 kg. At the 200-J level, this corresponds to an energy level up to 10 J/kg for most children. The recommended energy dose for manual defibrillation remains at 2 to 4 J/kg for children less than 8 years of age. At present, no AED will provide an energy dose of 2 to 4 J/kg to children of all sizes and weights.[9] Due to the lack of information as to safety of adult defibrillation energies in patients younger than 8 years, the AHA does not recommend the use of AEDs in this age group. As a result, many emergency care providers delay defibrillation in young patients due to a lack of recommendations or specific local. Under the current recommendations, young victims of cardiac arrest are not receiving the benefits of defibrillation in as timely a manor as could be achieved with the use of adult AEDs for this age group.

AED DESIGN CONSIDERATIONS

One of the reasons for recommending AED use for children more than 8 years old is to simplify resuscitation training of the lay public.[37] In order to be recommended for use in children, this would necessitate a device designed to accurately detect the rhythms in children while not requiring adjustments of the energy based on the weight of the patient. Some have felt that any age-specific cutoff, while arbitrary but allowing simplicity, outweighs the need for strict adherence to the dose recommendations. Studies have shown that keeping resuscitation instructions simple provides for improved skill mastery and retention.[38–40] The more complex the teaching sequence or message, the less likely it is that the rescuer will remember what to do and do it.

Because lay responders or first responders with limited training in arrhythmia recognition use AEDs, it is important to keep the user interface simple. This principle must be applied to pediatric AEDs as well as adult AEDs. Adding complexity to the AED user interface to accommodate pediatric defibrillation could result in opportunities for error in both adult and pediatric defibrillations. Any enhancement to allow treatment of pediatric patients with the AED must be as simple as possible and while not compromising adult care. It may be more appropriate to allow existing adult AEDs to be used on children.

This may require a single pediatric energy dose or the use of existing adult single dose biphasic or monophasic settings. Defibrillation, independent of the energy level provided by the AED, may be preferable to not treating VF in pediatric patients. Currently there is an AED that is designed to provide a 50-J shock for patients under 8 using specialized attenuated pediatric defibrillation pads.[41,42]

Further research is needed to determine the effectiveness in both cost and treatment success of these machines. The cost–effectiveness of maintaining a pediatric AED capability for an EMS system is unclear. Further research may be able to determine the safety of the use of adult energy levels on younger patients.

Conclusions

Although the incidence of VF in the pediatric population is low, there exist a need for developing strategies to provide early defibrillation to patients less than 8 years old. This may include the need for an AED suitable for use in pediatric patients. Because of the limited nature of the effective energy dose data, AED manufacturers should make efforts to gather information regarding pediatric uses of their devices and report it using the pediatric Utstein style. Further, because the literature suggests that some emergency responders may have fears of using AEDs in children, EMS and physician leaders should work with professional organizations, community organizations, and researchers to educate the community regarding the benefits of early pediatric defibrillation and the use of available varieties of AED.

Current pediatric protocols and guidelines recommend energy doses of 2 to 4 J/kg for defibrillation of children. These recommendations evolved from limited data that focused on the likelihood of effectiveness without consideration for therapeutic window determination or analysis of potential toxicity. In addition, these dose recommendations were based on data from defibrillation with monophasic damped sine waveforms and without impedance compensation, making their extrapolation to current monophasic and biphasic technology unreliable. The existing data on the relationship between size or weight and impedance in children are poor, indicating that weight-based dosing may be of limited value in pediatric defibrillation.

The most important safety feature on a AED is specificity. So long as there is a very high level of assurance that shocks will be advised only for appropriate rhythms in the pediatric population, then the risk of myocardial damage from defibrillation shocks is less than the risk of not delivering a shock (probable death). However, the potentially toxic effects of delivering too much energy must be minimized wherever possible. The data extrapolated from animal models support the use of adult energy AEDs even in smaller pediatric patients.

In children aged 8 years or more or above 25 kg body weight, it is acceptable to use a standard fixed-energy AED if a manual defibrillator is unavailable. Although employing a standard fixed-energy level AED in children under the age of 8 years may theoretically cause harm, the potential for harm is unknown. This theoretical risk is far less than the proven risk of failure to use a standard fixed-energy AED if no other defibrillator is available.

The message for the public and EMS systems is that we need to recognize the existence of ventricular fibrillation in children and employ methods to treat it as early as possible in order to improve the survival of children and infants from sudden cardiac arrest. Furthermore, we should not withhold this possible lifesaving therapy purely based on absolute weight and size issues. The key is to fulfill a long-term goal of providing devices that will allow rapid pediatric and adult defibrillation. Minimizing training issues, minimizing the use of limited financial and personnel resources, and treating children without compromising adult care are important.

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