Current perspectives

Automated external defibrillators for children: what is new?

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Although automated external defibrillators (AEDs) have been available for adults for more than 20 years, their use in children under 8 years of age has been approved by the International Liaison Committee on Resuscitation (ILCOR) as recently as June 2003. The following concerns about AEDs limited their use in children: amount of delivered energy, effect of biphasic waveforms in children, pad size, and capacity of detecting pediatric shockable and non-shockable rhythms. Lately, a new generation of AEDs addressed these issues and new encouraging data are available. New AEDs safely identify pediatric shockable and non-shockable rhythms and deliver fixed lower energy shocks through pads of appropriate size.

This perspective briefly describes the main advances which heralded the new recommendations of ILCOR. Randomized clinical trials are now needed to identify whether these new pediatric devices can improve the outcome of pediatric cardiac arrest.

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Sudden cardiac death (SCD) occurs in 1 per 1000 adults annually, while it occurs in less than 2 per 100 000 children[1]. One of the reasons for such a low incidence is that ventricular fibrillation (VF), the leading rhythm in SCD, is uncommon before 8 years of age. Children's hearts are smaller than those of adults and we know that a critical mass of myocardial tissue is always required to maintain VF. This may be one of the reasons why VF is less prevalent in children than in adults[2,3]. However, even though rather uncommon, the occurrence of SCD increases with age. If we consider the absolute numbers, 16 000 children die of SCD in the United States every year[3,4]. Because the Italian population is about one fifth the American one, we may estimate that in Italy approximately 3000 children die of SCD per year. Moreover, pediatric SCD has always been a high burden on parents and operators, and the number of years of life lost rivals that of adult SCD[3]. Thus, pediatric SCD is rare but not negligible.

Causes of pediatric cardiac arrest

In 90% of cases, pediatric cardiac arrest (PCA) is heralded by bradycardia due either to respiratory failure (e.g. trauma, seizures, lung disease or toxic ingestion) or to shock (e.g. septic, or hypovolemic caused by vomiting, diarrhea or trauma). In 10% of cases, the etiology of cardiac arrest is VF or ventricular tachycardia (VT) without a pulse, which must always be defibrillated. The main causes of VF/VT are as follows: congenital rhythm anomalies (long QT syndrome), cardiomyopathies, trauma, tricyclic antidepressant ingestion, congenital heart disease (already treated or waiting for surgery), electrolyte disorders, acidosis and hypothermia (Fig. 1). The causes of VF in out-of-hospital PCA are very different from those in adults. Adult VF is caused mostly by ischemic events, whereas pediatric VF is usually caused by trauma[5]. If we consider VF only, its incidence in PCA varies between 6%[5,6] and 19 to 24% if sudden infant deaths are excluded[5]. The incidence of VF also varies according to the arrival time of advanced support: from 19% for a 4 min arrival to 5% for a 9 min arrival[7]. The variation among studies is also due to the fact that data on the initial rhythm of PCA are few. According to the international guidelines, the PCA protocol starts with basic cardiopulmonary resuscitation (ventilation and chest compressions) for 1 min after which the emergency team is called. Basic cardiopulmonary resuscitation is then continued until

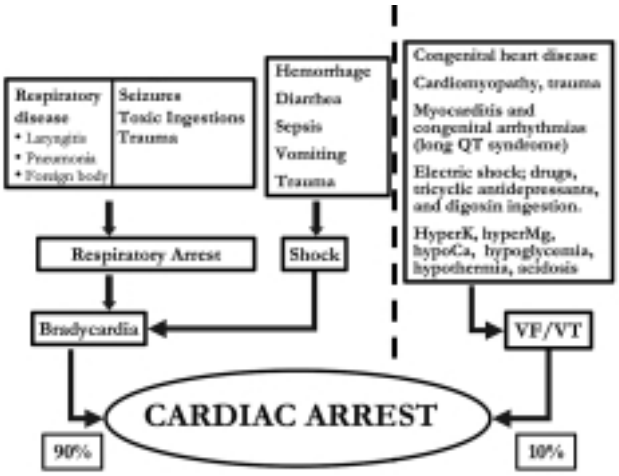

Figure 1. *Schematic representation of pediatric cardiac arrest. VF = ventricular fibrillation; VT = ventricular tachycardia.*

the arrival of the advanced life support team, when a monitor is applied to the patient and the running rhythm is identified. Because the advanced team usually arrives several minutes later (≥ 8 min), we do not know much about the initial rhythm in an out-of-hospital setting. Even though VF may start PCA, subsequently it might become asystole when a monitor is applied. Conversely, according to resuscitation guidelines, early defibrillation in adults is pivotal, automated external defibrillators (AEDs) are widely applied to patients, and much more information is available on the initial rhythm in out-of-hospital cardiac arrests.

Pediatric defibrillation protocol, traditional defibrillators and automated external defibrillators according to the international guidelines on pediatric resuscitation

The first successful pediatric defibrillation was performed in 1947 by Dr. Charles Beck, a thoracic surgeon[8]. In 2000, the international guidelines stated that pediatric defibrillation must be performed with conventional monophasic defibrillators and shocks must be in triplets with the first triplet of 2-2-4 J/kg, the second and the following of 4 J/kg[9,10]. Because of the paucity of clinical data, only one small paragraph was dedicated to AEDs in children. Their ability to identify VF was acknowledged; however, their ability to identify tachyarrhythmias (class IIb) was not[10]. Two other issues were addressed by the international guidelines: 1) AED shocks are usually delivered at a fixed energy (150-200 J) which exceeds the current recommendations of 2-2-4 J/kg; 2) biphasic truncated exponential waveforms, which are incorporated into new AEDs, have not yet been studied in children < 8 years. Therefore, the international guidelines concluded that AEDs can only be safely applied to children > 8 years (25 kg)[10].

Can early defibrillation be helpful in children too?

PCA has a mortality rate as high as 90-95% and, just as in adults, the time between cardiac arrest and the beginning of resuscitation is extremely important. Survival from adult cardiac arrest has improved from < 20% to > 40% with the use of early defibrillation[6]. The Mogayzel study on PCA has suggested that even pediatric survival may benefit from an earlier detection and treatment of VF[5]. However, whether "phone first" or "phone fast" is the best approach in children is still under discussion and particular situations in which one or the other approach is applied have been identified.

In a large-scale study of 3094 PCA cases, more than 30% of the patients with VF were discharged alive from the hospital, whereas only 5% of those with a pulseless electrical activity or asystole survived[11]. Therefore, according to this study, PCA has a better outcome when the initial rhythm is VF or VT rather than asystole or pulseless electrical activity. Even though VF is an uncommon pediatric rhythm, it is not rare, and maybe, just as in adults, thousands of children may benefit from early defibrillation.

Pediatric automated external defibrillators

In May 2000, a new AED (Heartstart/Heartstream ForeRunner 2) was introduced by Agilent Technologies Inc. (Palo Alto, CA, USA) (Fig. 2). Its main features are described in table I and its protocol of use does not differ from that of normal adult AEDs (Table II). Since the

Figure 2. *The first adult automated external defibrillator with pediatric attenuating electrodes, Heartstream ForeRunner 2, published by courtesy of Philips, distributed by Laerdal. Other manufacturers, such as Schiller (FRED® easy), LIFEPAK CR® Plus (Medtronic PHYSIO-Control), Cardiac Science Inc. (Powerheart®) and others recently got the license from Philips and are currently making this automated external defibrillator-connecting cable and pad system.*

Table I. Main features of the first pediatric automated external defibrillator.

Pad placement	anterior/posterior
Weight	2.1 kg
Dimensions	218 × 218 × 66 mm
Battery capacity	300 shocks
Shelf life	2 years
Energy delivered	50 J/shock
Type of electric wave	Biphasic truncated exponential
Adhesive pad surface area	44 cm^2
Conductor pad surface area	32 cm^2

Table II. Protocol of use for a pediatric automated external defibrillator.

1. Apply pediatric pads to the chest (anterior/posterior) and insert the connector into the device.
2. Turn on the automated external defibrillator.
3. Keep bystanders away, nobody can touch the victim while the rhythm analysis is on.
4. If the device says that the rhythm is shockable, check security around the operator within a 360° visual range, warn everyone near the victim, and push the button to deliver shock.
5. Listen to the device to know if more shocks are needed.

time it was introduced, it seemed that a new device could make early defibrillation possible for children < 8 years, and that extensive testing should be performed to approve its use.

Are pediatric automated external defibrillators efficacious in identifying the pediatric rhythm?

In May 2001 *Circulation*, the official journal of the American Heart Association (AHA), published a paper which answered this question[12]. The new AED, Heartstart/Heartstream ForeRunner 2, was modified to avoid delivering shocks and was tested. A total of 191 children (110 males and 81 females) aged 1 day to 12 years were enrolled in the study. Heart diseases were present in 73% of the children, among whom 63% had congenital heart disease and 10% had a cardiomyopathy. A total of 696 rhythm patterns were analyzed by the modified AED and by three pediatric electrophysiologists. During the study, conventional defibrillators were available whenever needed. A 100% specificity was achieved for non-shockable rhythms and a 96% sensitivity for VF. Thus AHA adult requirements were achieved in all types of rhythms but not in high rate VT for which the sensitivity was lower (70.7 vs 75%). However, high rate VT is rather rare in an out-of-hospital setting, and must be defibrillated when there is no pulse. These conclusions were extremely favorable for this new AED. This new device was appropriate for all ages, and its high specificity and sensitivity for shockable and non-shockable rhythms showed that the risk of delivering an unneeded shock was extremely low.

On the basis of this study, in May 2001, the American Food and Drug Administration (FDA) cleared the way for the marketing of Heartstart/Heartstream ForeRunner 2 for use in children < 8 years. Always in May 2001, the AHA released a position statement where it stated that: "... The development of this new pad and cable system for this AED is a very encouraging development that helps address the AHA's safety concerns about electrical 'overdosing' of infants and children ... The results of this recent study are highly encouraging and suggest that the rhythm detection of the AED tested may perform well when used to actually assess cardiac rhythm of children ..."[13].

In July 2001, the British Resuscitation Council also released a position statement: "... At present time, accordingly, employing a standard fixed energy level AED in children under the age of 8 cannot be recommended as a policy by the Resuscitation Council (UK). Any decision on such use must be the responsibility of the operator who will be in a position to consider specific circumstances of giving, or not giving the shock. One manufacturer has FDA approval for use of its defibrillator with special pediatric pads which deliver a fixed energy level of 50 J. This machine would be preferable to a defibrillator delivering only 'adult' fixed doses in situations where children may require defibrillation and a fully adjustable defibrillator is unavailable or unsuitable"[14].

The results of Cecchin's study were recently confirmed in a prospective study by Atkinson et al.[15]. The latter examined the accuracy of the rhythm analysis of the LIFEPAK 500 AED, and its performance with anterior-posterior vs sternal-apex pad placement. The sensitivity for VF was 94%, which satisfied the AHA recommendation of > 90%. The sensitivity for rapid VT was 60% (AHA recommendation is to be > 75%). The specificity for shockable rhythms was > 99%. Moreover, there was no significant difference in specificity between pads placed in the sternal-apical position and those placed in the anterior-posterior position.

Is the pediatric attenuator appropriate to deliver 50 J through an adult automated external defibrillator?

The main feature of the model approved by the FDA is that an attenuator is plugged into an adult AED. This modification allows the same AED to be used for both adults and children. Consequently, the costs are lower and less space is occupied in the emergency vehicles or wherever an AED is needed. Nevertheless, the use of this device is extremely safe because only a connector is needed and there is not a button to push, a knob to turn, or calculations to be made in order to defibrillate a child, and this connector can be plugged only into its own model not in others. Training is also easier and

rhythm analysis is excellent. In April 2002 a laboratory study showed that, though changing the impedance through animal bodies, the connector was always able to deliver 50 J without losing its ability to identify the rhythm correctly[16].

Can biphasic waveform technology be applied to children?

Biphasic truncated exponential waveforms require less energy than conventional monophasic waveforms for defibrillation[17]. Unfortunately, evidence-based medicine in children is not yet available. In November 2002, *Resuscitation* published a paper on the safety of these waveforms in pediatric-sized piglets[18]. In this study, the external defibrillation threshold was always 2-3 J/kg in piglets weighing 3.8-20.1 kg with biphasic waveform technology, both with adult and pediatric pads. Moreover, the authors observed that the hemodynamic, rhythm and ST-segment changes were always temporary for shocks with energy levels up to 360 J. Myocardial function was always preserved even with a high level of delivered energy. They concluded: 1) if the adult biphasic AED is the only one available, it can be appropriate for all but the smallest pediatric patients, 2) it may be reasonable to lower the recommended age for use of the current adult AED, 3) 50-100 J may be appropriate for children weighing approximately 25 kg.

Is it safe to deliver 50 J through an automated external defibrillator to a child?

This decisive issue was addressed in December 2002[19]. In this study, VF was induced in mechanically ventilated piglets weighing 3.8-25 kg. Subsequently, they were treated with cardiopulmonary resuscitation and defibrillation through 1) a conventional manual defibrillator, 2) an adult AED modified to deliver 50 J only, and 3) an adult AED with pediatric attenuating electrodes. The outcomes were significant: the post-resuscitation hemodynamic and myocardial functions quickly returned to baseline values in animals resuscitated both with conventional defibrillators and with AEDs delivering 50 J. These 50 J shocks delivered through the adapter were both safe and efficacious.

A nursing perspective

In December 2002, a nursing editorial was published in *Pediatric Emergency Care*[20]. Because of the available new evidence on this new technology, it stated that it was time to review the current policy on the use of AEDs in children. Appropriate pediatric pads were available, pediatric shockable and non-shockable rhythms were correctly identified, and the delivered energy (50 J) was safe and efficacious. Their practical consideration was also the following: if we apply an AED to a 25 kg child (which is permitted) we would deliver 10-14 J/kg, much more than the recommended 2-4 J/kg, and if we apply a new AED delivering 50 J we would deliver a maximum of 12 J/kg with an infant of 4 kg, which is an extremely rare event.

June 2003: the Advisory Statement of the International Liaison Committee on Resuscitation on the use of automated external defibrillators for children

In June 2003, the Pediatric Advanced Life Support Task Force of the International Liaison Committee on Resuscitation (ILCOR) expanded and clarified the previous 2000 ILCOR recommendations on the potential use of AEDs in children[21]. After having examined the available literature in October 2002, the Pediatric Advanced Life Support Task Force of ILCOR released the following consensus: 1) AEDs can be used for children 1 to 8 years of age without signs of circulation. These devices can deliver lower energy shocks and can have a high specificity for non-shockable rhythms and a high sensitivity for shockable rhythms; 2) at present, the published evidence is not sufficient for recommending their use in infants; 3) 1 min cardiopulmonary resuscitation is always required in a child without signs of circulation before advanced life support teams are activated or an AED is attached; 4) defibrillation is always recommended for VF or VT without any pulse.

Conclusions

The current published evidence on pediatric defibrillation through new AEDs is encouraging. ILCOR has allowed their use in children aged 1 to 8 years without signs of circulation. AEDs for children make early pediatric defibrillation possible both for out-of-hospital and for in-hospital cardiac arrests. When AEDs will become widely available, we will know more about the initial rhythms of out-of-hospital PCA and we will be able to discuss about the changes of the pediatric life chain, the beginning of new teaching courses such as pediatric basic life support-D, and their distribution throughout the emergency services and wherever there are large groups of children. However, new randomized clinical trials are needed in order to evaluate their impact on PCA outcome. Hopefully, in a near future, AEDs will be just as pivotal in early pediatric defibrillation as they are in adults.

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