Development of a Pediatric ECG Rhythm Database for the Assessment of the Rhythm Analysis Algorithms of Automated External Defibrillators

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Abstract

In 2003 the International Liaison Committee on Resuscitation (ILCOR) approved the use of Automatic External Defibrillators (AED) in children under 8 years of age. Two independent studies, conducted with commercial AEDs on proprietary pediatric ECG databases, provided the necessary scientific evidence. We have developed a database of pediatric rhythms for the evaluation of the rhythm analysis algorithms of AEDs.

We collected archived ECG studies from patients under 14 years of age in two Spanish hospitals. The extracted rhythm samples contain a single rhythm, no artefact and have a minimum duration of 5 seconds. Three independent cardiologists classified the rhythm samples according to the American Heart's Association (AHA) guidelines; a consensus decision was reached when divergences arose.

We compiled a total of 674 rhythm samples from 363 patients. The cardiologists classified 112 rhythm samples from 32 patients as shockable and 552 rhythm samples from 337 patients as nonshockable; 10 rhythm samples were classified as intermediate. The database contains enough nonshockable rhythm samples to meet the AHA requirements for the assessment of the specificity of AED rhythm analysis algorithms. We are currently working to complete the database with enough shockable rhythm samples to assess the sensitivity of AED rhythm analysis algorithms.

1. Introduction

Cardiac arrest is less prevalent in children than in adults, particularly because of the lower occurrence of Ventricular Fibrillation (VF) in pediatric patients. Despite the lower incidence, the social and emotional impact is enormous due to the children's larger life expectancy. In fact, estimations on years of life lost due to cardiac arrest are similar in adults and children [1].

As late as the year 2000 there existed no conclusive study on the use of Automatic External Defibrillators (AED) in patients aged under 8 years of age. In 2001 and 2003 two independent studies [2, 3] provided the necessary scientific evidence to recommend the use of AEDs in children. Based on this evidence, the International Liaison Committee on Resuscitation (ILCOR) made the following recommendations [4] in the year 2003:

"Automated external defibrillators (AEDs) may be used for children 1-8 years of age who have no signs of circulation. Ideally, the device should deliver a pediatric dose. The arrhythmia detection algorithm used in the device should demonstrate high specificity for pediatric shockable rhythms, i.e. it will not recommend delivery of a shock for nonshockable rhythms (Class IIb).

Currently the evidence is insufficient to support a recommendation for or against the use of AEDs in children $<$1 year of age."

These recommendations are included in the 2005 European resuscitation guidelines [5], which specifically state that AEDs should be tested against pediatric arrhythmias.

AED arrhythmia detection algorithms must therefore be tested against pediatric rhythm databases before they can be approved for use in children. The studies conducted by Cecchin et al [2] and Atkinson et al [3] are based on proprietary pediatric rhythm databases, and demonstrate the adequacy of using certain commercial AED models on children. We have developed a new database of pediatric rhythms that will serve in the development and testing of AED rhythm analysis algorithms for use children.

2. Materials and Methods

The database creation process comprises two steps: the collection of the rhythm samples and the classification of the rhythm samples by expert reviewers. There is currently not a pediatric equivalent to the adult American Heart's

Association (AHA) 1997 guidelines [6] for the creation of rhythm databases for testing AEDs. Along the lines of the previous studies in this field [2, 3], we followed the adult guidelines, particularly in the classification of the rhythm samples. Pediatric ventricular arrhythmias are scarce, we therefore decided not to impose that all the rhythm samples of each rhythm type belonged to a different patient.

2.1. Pediatric rhythm sources

We created the rhythm database from archived ECG studies of patients under 14 years of age. These studies were done under parental consent during the 1995-2006 period and come from the archives of two Spanish hospitals: Cruces Hospital in Barakaldo and La Paz Hospital in Madrid.

The available data was in the form of 12 lead and 3 lead surface ECG recordings. Lead II, equivalent to the defibrillator pads placed in anterior-anterior position, was used to obtain the rhythm samples. Following the AHA guidelines, the rhythm samples must contain a single rhythm and must be free of artifact. Furthermore, we only included in the database rhythm samples with a duration over 5 s. A 5 s duration is sufficient for an AED rhythm analysis algorithm to reach a diagnosis. The study dates, acquisition characteristics and patient data were annotated, in particular the age of the patients.

The surface ECG data came in two different formats: digital recordings and archived paper recordings. All the rhythm samples were converted to a common digital format (250 samples per second and 5 μV resolution) before their addition to the database.

2.1.1. Digital recordings

The digital ECG recordings were obtained using the Prucka Cardiolab® EP system. The signals were first filtered with a 0.05-100 Hz bandwidth and then digitized at 979 samples per second. The recordings had a 12-bit accuracy over a ± 10 mV dynamic range, that is a 5 μV resolution. Lead II was extracted and downsampled to 250 samples per second.

2.1.2. Paper recordings

The archives contained important instances of less frequently occurring arrhythmias stored in paper format, and recorded at a paper speed of 25 mm/s with a gain setting of 10 mm/mV. The recording bandwidths differed but were typically in the 0.5-40Hz range. The paper ECGs were digitized using custom made Matlab® tools.

First a digital image of lead II was obtained using a flatbed scanner. The scanning resolution was set to 508 dpi. Paper strips with a color grid were scanned in 24-bit color and paper strips with black grids in 8 bit gray scale. The grid was eliminated using thresholding techniques producing a binary image of the ECG trace. The binarized ECG trace was then put through a line detection and noise reduction procedure, and the digitized rhythm sample was obtained. All rhythm samples were then visually inspected by superposing the original image and the digitized rhythm sample. Figure 1 shows an extract of a digitized paper strip containing a pediatric VF rhythm.

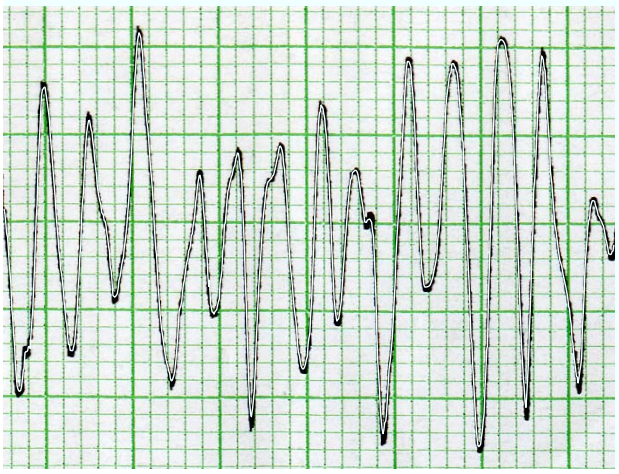


Figure 1. Part of a digitized ECG paper strip. The digitized ECG is superimposed on the original paper strip during the visual validation of the process.

For a paper speed of 25 mm/s and a scanning resolution of 508 dpi, the digitized rhythm samples are recorded at 500 samples per second. The voltage resolution for a gain setting of 10 mm/mV is 5 μV. The digitized rhythm samples were finally downsampled to 250 samples per second.

2.2. Rhythm classification

Three independent cardiologists classified the rhythm samples according to the AHA guidelines [6], which divide cardiac rhythms in three broad categories:

Shockable rhythms
Lethal ventricular arrhythmias, this includes coarse VF (peak-to-peak amplitude > 200 μV) and rapid Ventricular Tachycardia (VT) which includes polymorphic VT.

Nonshockable rhythms
Rhythms that do not benefit from defibrillation: normal sinus rhythm, supraventricular tachycardias (SVT), sinus bradycardia, atrial fibrillation and flutter , second and third degree heart block and ideoventricular rhythms. Asystole is included in this category for safety reasons.

Intermediate rhythms
Rhythms for which the benefits of defibrillation are unclear. This includes fine VF (low amplitude/rate VF) and

Table 1. Summary of the amount of rhythm samples in the pediatric rhythm database, grouped by age and type of recording. The rhythm type and shock/no-shock classification reflect the final consensus decision of the cardiologists.

		Shockable rhythms				**Nonshockable rhythms**						**Intermediate**	
		VF		VT		NSR		SVA		Other		Nonshock VT	
Age group [a]		digit.	paper	digit.	paper	digit.	paper	digit.	paper	digit.	paper	digit.	paper
≤1y	(27)	0	0	22	2	1	9	6	16	0	2	1	1
>1 to <8y	(256)	7	5	3	19	29	249	43	15	7	21	2	1
≥8-14y	(80)	12	29	6	7	44	27	69	0	4	10	5	0
Total	(363)	19	34	31	28	74	285	118	31	11	33	8	2

[a] The number of patients is indicated in parenthesis.

VT that do not meet the criteria for shockable rhythms.

The cardiologists independently classified each rhythm sample in one of the rhythm types specified in the AHA guidelines and then made a shock/no-shock recommendation. The criteria followed to determine the shock/no-shock recommendation were [2]: (1) the patient is unresponsive, (2) the age of the patient is unknown and (3) the patient has no palpable pulse.

Two types of differences among the cardiologists occurred during the classification process: differences in the classification of the rhythm type and differences in the shock/no-shock decision. The latter are the most important ones from an AED rhythm analysis point of view. All the rhythm samples producing differences in the classification process were further discussed. The final consensus shock/no-shock decision was reached after the assessment of the risks of each potential recommendation.

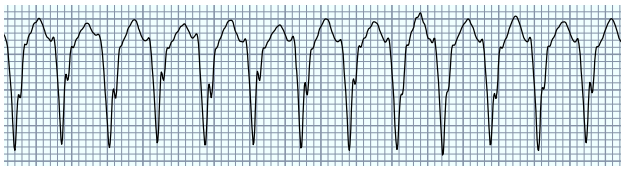
3. Results

We initially collected a total of 713 rhythm samples, but 39 were discarded because they either presented more than one rhythm or were artefacted. The remaining 674 rhythm samples came from 363 patients aged 4 days to 14 years, mean age 4.9±3.2 years. After the initial classification the cardiologists agreed on the rhythm type of 585/674 rhythm samples and on the shock/no-shock decision of 667/674 rhythm samples. Most of the divergences in the shock/no-shock diagnosis occurred when classifying fast supraventricular tachycardias with conduction blocks, showing wide QRS morphology and not easily discernible P waves. Some of these rhythm samples were classified as fast VT by at least one cardiologist. Figure 2 shows two examples.

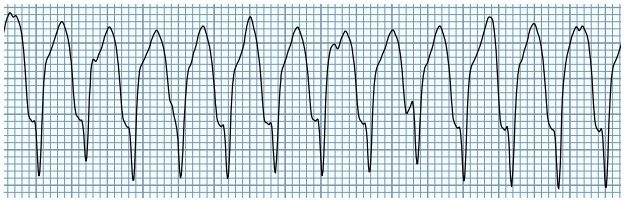
Since the ILCOR recommendations apply to children >1 to <8 years of age, the patients are further classified in three age groups: under 1 year of age, >1 to <8 years of age and ≥8-14 years of age. Table 1 shows a summary of the collected rhythm samples, grouped according to the final consensus decision of the cardiologists. The amount of paper and digital rhythm samples is also specified. A total of 413 rhythm samples came in paper format and were digitized, 349 were classified as nonshockable, 62 as shockable and 2 as intermediate. The remaining 261 rhythm samples came in digital format, 203 were classified as nonshockable, 50 as shockable and 8 as intermediate. Nonshockable rhythm samples have been grouped in three broad categories: Normal Sinus Rhythm (NSR), SupraVentricular Arrhythmias (SVA) [1] and other (idioventricular rhythms, premature ventricular contractions, bradycardias). We were not able to obtain any asystole rhythms samples because asystole is not likely to appear in an archived ECG recording from a hospital. The intermediate rhythm samples are VT classified as nonshockable by the cardiologists, we did not obtain any fine VF rhythm samples.

Table 2 provides a summary of the rhythm samples and patient information of the database for the most important age group: >1 to <8 years of age. We collected 364 nonshockable, 34 shockable and 3 intermediate rhythm samples from 256 patients, mean age 3.9±1.8

[1] supraventricular tachycardias, atrial flutter and atrial fibrillation



(a) SVT classified as fast VT by one of the cardiologists



(b) Fast VT classified as SVT by one of the cardiologists

Figure 2. Rhythm samples with an initial disagreement among the cardiologists in the shock/no-shock decision.

Table 2. Characteristics of the patients and rhythm samples grouped by rhythm type, age group: >1 to <8 years.

	Patients		Rhythm Samples	
Type	num.	age [a]	num.	duration [a]
Shockable				
VF	7	3.9±2.4	12	10.2±4.1
VT	10	3.6±2.1	22	13.9±5.7
Nonshockable				
NSR	204	3.8±1.7	278	16.9±6.3
SVA	36	3.9±2.1	58	16.3±5.1
Other	23	5.22±1.7	28	16.4±10.4
Intermediate				
nonshock VT	2	3.0±1.4	3	19.1±10.0
Total	256	3.9±1.8	401	16.4±6.5

[a] Mean value ± standard deviation.

years. The rhythm samples have a mean duration in seconds of 16.4±6.5, the mean duration was 12.6±5.4 for the shockable and 16.7±6.5 for the nonshockable rhythms.

4. Discussion

We have created a database of pediatric rhythms for the evaluation of rhythm analysis algorithms of AEDs from patients with ages 0-14 years. We will nevertheless only discuss the database composed of rhythms samples from patients >1 to <8 years of age because this is the age group where the ILCOR recommendations apply. Our database contains a sufficient amount of nonshockable rhythms, particularly SNR and SVA, in this age group. We have collected 278 SNR rhythm samples from 204 patients, well above the minimum number stated in the AHA specifications: 100. We have also collected 86 rhythm samples from 56 patients in the SVA/Other group, the AHA specifications require 30 samples. It is therefore possible to test the specificity of AED rhythm analysis algorithms based on this database. We have already indicated the absence of asystole rhythm samples in the database, this limitation should not affect specificity tests. Most algorithms easily detect asystole using signal amplitude thresholds.

The amount of shockable rhythms is not yet sufficient. The database contains only 12 VF samples from 7 patients, well below the minimum required by the AHA: 200. The previous studies in the field have also reported few VF rhythm samples: 15 by Cecchin et al [2] and 34 by Atkinson et al. [3]. The amount of VT rhythm samples (22 from 10 patients) is also below the AHA specifications: 50. The numbers are again low in the studies by Cecchin et al (24 rhythm samples) and Atkinson et al (1 rhythm sample). The amount of shockable rhythm samples in our database is comparable to the figures published in previous studies and reflect the low incidence of shockable rhythms in children. We think that the AHA requirements for shockable rhythms may have to be revised to reflect that VF/VT is much less frequent in children than in adults. We are however in contact with several pediatric hospitals in Spain and we hope to complete the database with more shockable rhythm samples during the coming year.

The divergences in diagnosis among the cardiologists, particularly the discrepancies in the shock/no-shock diagnosis, point to another special feature of pediatric rhythm databases. The divergences occurred mainly between SVT and VT rhythms, particularly for SVT with wide QRS complexes due to heart blocks and non discernible P waves. The AED rhythm analysis algorithm must be able to differentiate these rhythm types and our database provides a useful framework for that test.

Acknowledgements

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