Comparative Analysis of the Parameters Affecting AED Rhythm Analysis Algorithm Applied to Pediatric and Adult Ventricular Tachycardia

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Abstract

In this study pediatric and adult Ventricular Tachycardia (VT) are used to test the efficiency of an AED analysis algorithm. Statistical assessment of the four significant parameters that define the shock-noshock classification algorithm has been performed. The following parameters are considered: Pulse Rate (PR), Waveform Power Ratio (WPR), and two morphological parameters, Baseline Content (BC) and Probability Distribution Width (PDW).

A set of 76 adult and 55 pediatric shockable VT episodes is considered to measure the sensitivity of the classification algorithm originally developed for adult patients (100% for rapid adult VT). The sensitivity for the whole pediatric set is 96.36 %, but increases to 100% for the 1-8 years of age subgroup..

1. Introduction

In 2003 the International Liaison Committee on Resuscitation (ILCOR) updated and clarified the previous recommendations on the potential use of Automated External Defibrillators (AED) in children. This update has become critical due to the growth in the number of AEDs placed in public access settings, the increase of the use of AEDs by non traditional responders, and the likelihood of AED usage with patients younger than 8 years of age.

The ILCOR recommendation [1] expands the use of AEDs to children 1 to 8 years of age who have no signs of circulation. There is insufficient evidence to support a recommendation for or against the use of AEDs in the case of children <1 year of age.

Two important points must be addresses to evaluate whether AEDs designed for the adult patients are effective and safe for children. First, the delivered energy has to be adapted to children, who require a much lower defibrillation dose. This can be accomplished using pediatric pad/cable systems that reduce the delivered energy. Second, the rhythm analysis algorithm must be evaluated to determine its capability to safely differentiate between shockable and nonshockable rhythms in children.

The rhythm analysis program of one AED system generally satisfies the sensitivity and specificity criteria recommended by AHA for the performance of an AED [2]. But having been developed and tested with adult databases, the algorithm should be assessed using pediatric arrhythmia databases in order to demonstrate its efficacy in this patient population.

Two studies have been recently published dealing with that issue [3, 4]. Both of them showed that the AED algorithms developed to detect adult arrhythmias can provide high specificity and reasonable sensitivity for the arrhythmia detection in infants and children. The performance with ventricular tachycardia in the first study was not deeply analyzed as it only considered 3 episodes. The second one reported a sensitivity of 71% with 58 samples of rapid VT.

In this paper the algorithm of a commercial AED is evaluated using a pediatric database obtained from two Spanish hospitals. The algorithm has been tested using pediatric database of shockable VT and the resulting sensitivity is compared to that obtained with the adult database. This algorithm had been previously evaluated with non-shockable rhythms and the specificity was compared for adult and pediatric sets [5]. The Parameters used by the decision algorithm are computed and statistically compared to those obtained with the adult database. The capability of an AED to appropriately detect life-threatening ventricular tachycardias is thus evaluated.

2. Materials and methods

The adult database used in this study consists of records extracted from commercial databases (AHA and MIT databases), and from Spanish hospital and emergency services. The samples of the pediatric database were obtained exclusively from Spanish hospitals.

The adult database fulfills the requirements set by the AHA recommendation [2] to report the performance of an AED algorithm, and it has been used for the development and testing of the algorithm implemented in the Reanibex 200 AED, currently being commercialized by Osatu S. Coop. (Ermua, Spain). The database contains 76 samples with a mean duration of 11.56 s, corresponding to a unique rhythm each (rapid VT), with no artifacts. Only one record per patient has been considered.

The pediatric rhythm database was created from archived ECG studies of patients under 14 years of age. They were collected in Cruces Hospital in Barakaldo and La Paz Hospital in Madrid during the last two years. The rhythm collection criteria are similar to those applied for the adult database but more than one record per patient and type of rhythm were permitted. The database contains a total of 55 VT episodes from 20 patients with a mean duration of 12.27 s. Most of the episodes from the same patient have were in different circumstances. There are a total of 23 VT episodes in the 1-8 years of age subgroup.

The AHA recommendation [2] divides the VT into two categories, the lethal shockable rhythms corresponding to rapid VT and the intermediate VT for which the benefits of defibrillation are uncertain. The minimum heart rate to define a rapid VT in adult patients was set to 150 beats per minute (bpm), which is widespread among AED manufactures. In this first approach this threshold is kept to define rapid, thus shockable, VT for the pediatric group. Every episode was classified as shockable by three cardiologists.

Table 1. Sensitivity for each database. (n indicates the number of samples)

	Shockable VT
Adult (n=76)	100 %
Pediatric (0-14) (n=55)	96.36 %
Pediatric (1<&<8) (n=23)	100 %
AHA Goal (n>50)	**>75%**

The analysis algorithm tested is a Matlab PC version of the detection algorithm of the Reanibex 200 AED, which is detailed in [6]. It consist of a decision tree built on the values of 4 significant parameters, which are computed every non overlapping 4.8s signal window, and compared to empirically set thresholds to decide if the analyzed ECG is shockable or not. This algorithm satisfies the sensitivity and specificity criteria of the AHA recommendation [2].

The four parameters used in the decision algorithm measure different characteristics of the rhythm samples. The first parameter is the Pulse Rate (PR), which corresponds to the rate of the ECG complex in normal sinus rhythms and with the dominant frequency of the waveform in general. The PR is computed using the autocorrelation of the signal, and given in beats per minute (bpm). The higher the PR value, the higher the probability of being a shockable rhythm.

The second parameter, the Waveform Power Ratio (WPR), measures the percentage of the power that the ECG signal concentrates in a frequency bandwidth around the PR. It is computed in the frequency domain as the ratio of the power concentrated in a 90% bandwidth of the PR around the PR. The higher the WPR, the higher the probability of being a shockable rhythm.

The third and fourth parameters are morphological. These parameters are linked to the probability distribution of the amplitude of the ECG waveform samples. In non-shockable rhythms most of the samples of the signal are close to the baseline, while in shockable rhythms such as VT or VF, the samples show higher dispersion. From the histogram, the Baseline Content (BC) and the Probability Distribution Width (PDW) are computed. BC is the percentage of the samples concentrated in an amplitude range around the baseline. The lower the BC, the higher the probability of being a shockable rhythm. The PDW is the range of amplitude values, in which 50% of the samples accumulate. The higher the PDW, the higher the probability of being a shockable rhythm.

3. Results

The sensitivity of the AED analysis algorithm for adult and pediatric databases has been computed. Three age groups have been considered: the adult database (n=76, n indicates the number of samples), the whole pediatric set (0 to 14 years of age, n=55), and the 1-8 years of age pediatric subse (n=23). The results obtained for sensitivity results are summarized in Table 1.

In the adult group all the 76 VTs are correctly detected as shockable, which means a measured sensitivity of 100%. For the pediatric group 2 out of 55 VTs where classified as non-shockable (both correspond to patients under 1 year), that is a sensitivity of 96.36 % for the whole set and a sensitivity of 100% for the 1-8 years of age subgroup. The two misclassified samples are polymorphic VT.

The results of the statistical analysis of the rhythm characteristics are shown in Figure 1. The probability distributions of the four parameters for adult and pediatric patients are compared by means of the histograms shown in Figure 1. The values were normalized using the number of rhythms in each age group because the two databases were different in size.

The mean and standard deviation of the parameters have been computed. The Pulse Rate is significantly higher ($p<0.001$) in pediatric patients, (mean PR of 253±40 bpm, mean±std), than in adult patients (mean PR

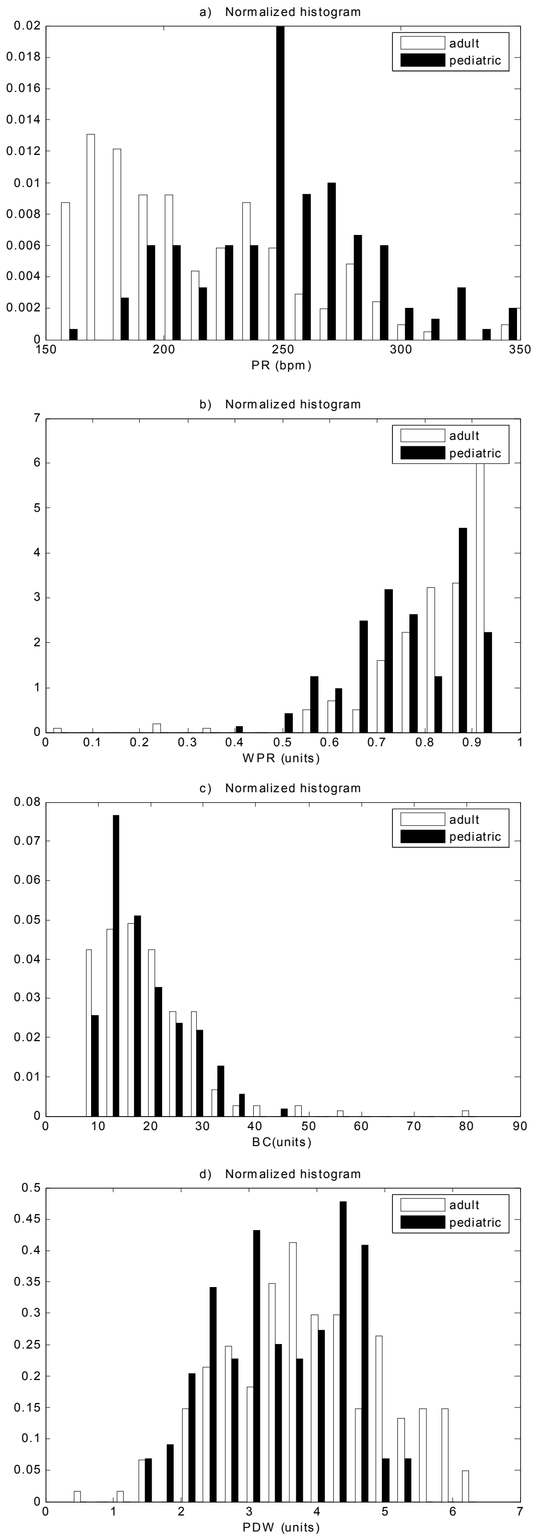

Figure 1. Histograms of the characteristic parameters of the AED algorithm for adult and pediatric patients.

of 209±41 bmp). That difference can be observed in Figure 1a) where rates corresponding to pediatric subjects are shifted in mean towards higher values. That difference is also evident in Figure 2 where the adult group is compared to the two pediatric subgroups.

The distributions of the WPR and the morphology parameters (BC and PDW) obtained for the adult samples do not differ significantly ($p>0.001$) from pediatric values. Their distributions are plotted in Figures 1b), 1c) and 1d). The adult mean values for WPR (0.81±0.13), BC (18.48±9.32) and PDW (3.81±1.15), measured in their corresponding units, do not significantly differ from the pediatric values, WPR (0.77±0.12), BC (19.18±7.55) and PDW (3.53±0.96). There is no significant difference between the adult and the 1-8 years of age subgroup in the values of WPR (0.82±0.1) and PDW (4.07±0.78); however the difference is statistically significant ($p<0.001$) for PR (256±36) and BC (15.06±4.92). A summary of these results is plotted in bars in Figure 2, where the mean and standard deviation of each parameter for the three population groups are shown.

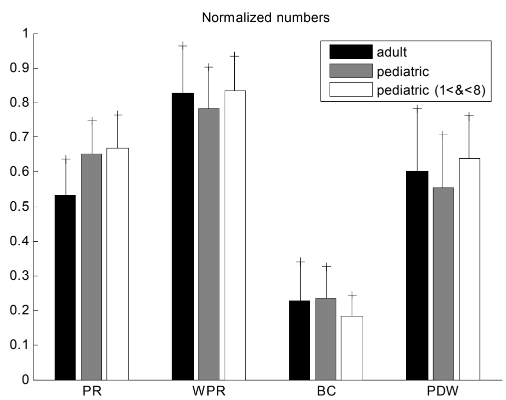

Figure 2. Comparison of the characteristic parameters of the AED rhythm analysis algorithm for the three age groups..

4. Discussion and conclusions

This study assesses the parameters that define the sensitivity of an AED classification algorithm when applied to rapid VT. A comparative analysis has been performed considering adult and pediatric databases. The adult database comes from previous studies, while the pediatric samples have been exclusively supplied by Spanish hospitals. This work complements the previous one described in [5] where specificity was analyzed.

The analysis algorithm of a commercial AED has been tested. This algorithm was validated with the adult database, exceeding the AHA goals. When tested with shockable pediatric rhythms the results satisfy the AHA requirements, as a sensitivity of 96.36% has been measured for the complete pediatric set, and 100% for the 1-8 years of age subgroup.

There is only one study where an AED algorithm is tested against a considerable amount of pediatric VT samples [4]. The reported sensitivity, 71%, did not satisfy the 75% threshold established by AHA. The Reanibex 200 algorithm shows a much higher sensitivity: 96.36 %. However it has a lower specificity than those tested in previous studies [3, 4], as it was evidenced in [5]. This shows that it is necessary to test each classification algorithm originally developed for adult rhythm detection with a pediatric database for the secure use in childern.

The statistical analysis of the four characteristic parameters that determine the AED algorithm shows significant differences between the pulse rate distributions of adult and pediatric databases; the differences are not significant for the other three parameters used by the AED algorithm. The classification algorithm consists of a decision tree based on the comparison of the 4 parameters with experimentally set thresholds. The first parameter considered in the tree is the pulse rate, which determines the comparative thresholds for the other three. But it is the combination of all the features extracted which decide the shock/no shock decision. Looking at the results it seems that the relevance of the other parameters, those that reflect the influence of the morphology in the algorithm, are correctly considered to accurately detect shockable VT.

Finally, despite the limited pediatric database available, the classification algorithm originally developed and validated with adult shockable VT can be safely applied to pediatric patients.

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