# An Algorithm to Discriminate SVT from VT in Pediatric AED Based on Spectral Parameters

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## Abstract

*Supraventricular tachycardia (SVT) often has very high heart rates in children. Automated external defibrillators (AED), whose use for children is recommended since 2003, could misinterpret high rate SVT as ventricular tachycardia (VT) producing an incorrect shock diagnosis. The objective of this study is to develop an algorithm to accurately discriminate SVT from VT in children.*

*The algorithm was designed using a database of surface ECG, 322 SVT and 70 VT, collected from 259 patients in five Spanish hospitals. The mean age of the patients was 7.4 years and the mean duration of the ECG samples is 14.1 s. For each 3.2 s window two spectral parameters were calculated: the percent power content around the dominant frequency and the percent power content above 12.5 Hz. These two parameters were use to build a logistic regression model. The discrimination method was validated using a 10 fold cross validation scheme: 96.6% for SVT windows and 98.8% of the VT windows where correctly identified. The diagnosis of each window was used to compute a diagnosis for each ECG sample using a majority criterion: 96.0% of the SVT samples and 100% of the VT samples were correctly classified.*

*Heart rate oriented AED shock advice algorithms are prone to classify high rate pediatric SVT as VT. We have developed an algorithm based on two spectral parameters that effectively discriminates SVT from VT in pediatric patients. This algorithm could be used in heart rate oriented AED shock advice algorithms to accurately diagnose high rate rhythms.*

## 1. Introduction

In the year 2003 the International Liaison Committee on Resuscitation (ILCOR) approved the use of Automated External Defibrillators (AED) in children under 8 years of age [1]. There are, however, differences in pediatric and adult arrhythmias relevant in the design of AED shock advice algorithms. Supraventricular tachycardia (SVT) in children can have very high heart rates, consequently heart rate oriented AED shock advice algorithms designed for adult patients might identify high rate pediatric SVT as fast Ventricular Tachycardia (VT).

Atkins et al. [2] showed in a recent study how an AED algorithm designed for adult patients failed to accurately identify pediatric supraventricular arrythmias as nonshockable. Two other studies [3, 4] tested adult AED algorithms on children, although the algorithms were not heart rate oriented. The specificity for SVT was high, on the contrary sensitivity for VT was either low or not conclusive due to the small amount of samples.

We propose a simple method to adapt heart rate oriented AED shock advice algorithms for pediatric use. First, the thresholds for fast VT must be adapted to the pediatric case, shockable VT has higher rates in children [3, 4]. Second, rhythms exceeding the fast VT rate threshold will be further processed using a SVT/VT discrimination algorithm. In this study we describe a simple algorithm based on two spectral parameters to discriminate SVT from VT in pediatric AED.

## 2. Materials and methods

ECG were collected from archived eletrophysiology studies of patients under 20 years of age conducted in five Spanish hospitals: Cruces Hospital in Barakaldo, Donostia Hospital in San Sebastian, La Paz Hospital and Gregorio Marañón Hospital in Madrid and San Joan de Deu Hospital in Barcelona.

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 for the design of AED shock advice algorithms [5] the samples contained a single rhythm and were free of artifact. All the samples were resampled to a common sampling frequency of $f_s = 250\ Hz$ and preprocessed using an order four butterworth passband filter ($0.7 - 35\ Hz$) to eliminate base line wander and high frequency noise.

Three cardiologists independently classified the samples into two categories: SVT and VT. The samples with

Table 1. Summary of the samples collected, grouped by age. The rhythm type reflect the final consensus decision of the cardiologists.

| Age group [a] | | SVT samples | SVT patients | VT samples | VT patients |
|---|---|---|---|---|---|
| <1y | (32) | 38 | 29 | 10 | 4 |
| 1y-8y | (113) | 143 | 100 | 40 | 18 |
| >8y | (115) | 141 | 107 | 20 | 14 |
| **Total** | (260) | 322 | 236 | 70 | 36 |

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

differences in the classification were further discussed and a consensus decision was reached.

We initially collected a total of 413 samples, 21 were discarded because no consensus decision could be reached. The remaining 392 samples came from 259 patients aged 4 days to 20 years, mean age $7.4 \pm 4.8$ years. The samples had a mean duration of $14.1 \pm 11.7$ $s$, the shortest sample had a duration of $4.0$ $s$. The cardiologists classified 322 samples from 235 patients, aged $7.8 \pm 4.7$ years, as SVT and 70 samples from 36 patients, aged $5.6 \pm 4.7$ years, as VT.

The ILCOR recommendations on the use of AEDs in children apply to children 1 to 8 years of age, the patients were therefore classified in three age groups: under 1 year of age, 1-8 years of age and above 8 years of age. Table 1 provides a summary of the collected samples.

## 2.1. The SVT/VT discrimination method

We analyzed the ECG samples in non-overlapping windows of $3.2$ $s$, using two parameters extracted in the frequency domain to classify each window. For a sample consisting of several windows a majority criterion was adopted for the SVT/TV diagnosis of the sample. In an AED implementation this means that two or three windows will be need for the diagnosis, that is less than $9.6$ $s$. In those AED algorithms that use the frequency domain [6,7], this SVT/VT discrimination stage does not add much computational cost to the algorithm.

### 2.1.1. The spectral parameters

Each $3.2$ $s$ window, 800 samples, was passed through a hamming window and zero padded to 1024 points. The normalized power spectral density ($P_{xx}(f)$) was then estimated as the square of the modulus of the 1024 point FFT ($X(f)$) divided by the total power in the $0 - 35$ $Hz$ band:

$$P_{xx}(f) = \frac{|X(f)|^2}{\sum_{f=0}^{35} |X(f)|^2}$$

The classification was based on the differences in shape of the normalized power spectral density of SVT and VT rhythms. Figure 1 shows two typical windows in the time and frequency domain: a pediatric SVT and a pediatric VT. Both rhythms are fast (above 200 bpm) and almost periodic. There are however important differences in the harmonic content. In VT most of the power is concentrated in the fundamental harmonic and the number of significant harmonics is low (typically one or two), there is therefore little power in the high frequencies. In contrast SVT rhythms have more harmonic components, the power around the fundamental harmonic is smaller and there is more power in the higher frequencies.

To quantify how the power is concentrated around the fundamental component we calculated the percent power content around the dominant frequency ($\%P_{f_0}$). The dominant frequency ($f_0$) is the frequency in the $1 - 10$ $Hz$ range where $P_{xx}(f)$ is maximum:

$$f_0 = \underset{f}{\mathrm{argmax}} \{P_{xx}(f)\}$$

The parameter $\%P_{f_0}$ was calculated using a $1.2$ $Hz$ bandwidth, sufficient to include the power of the harmonic while preventing the spill over into adjacent harmonics.

$$\%P_{f_0} = 100 \cdot \sum_{f_0-0.6}^{f_0+0.6} P_{xx}(f)$$

The percent power content of the high frequencies ($\%P_{HF}$) measures the contribution to the total power of the higher harmonics. For very fast rhythms (heart rate above 360 bpm) a cut off frequency of $f_{lim} = 12.5$ $Hz$ is sufficient to consider harmonics above the second, $\%P_{HF}$ is therefore calculated as:

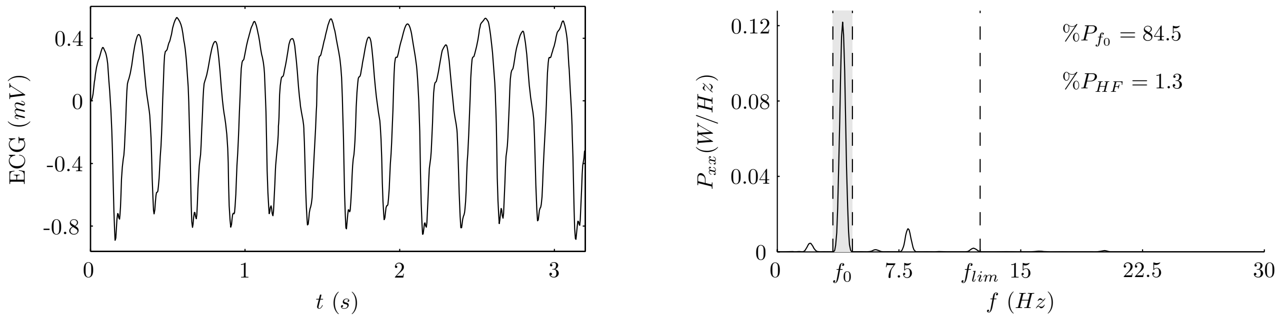
$$\%P_{HF} = 100 \cdot \sum_{f=12.5}^{35} P_{xx}(f)$$

### 2.1.2. The classification algorithm

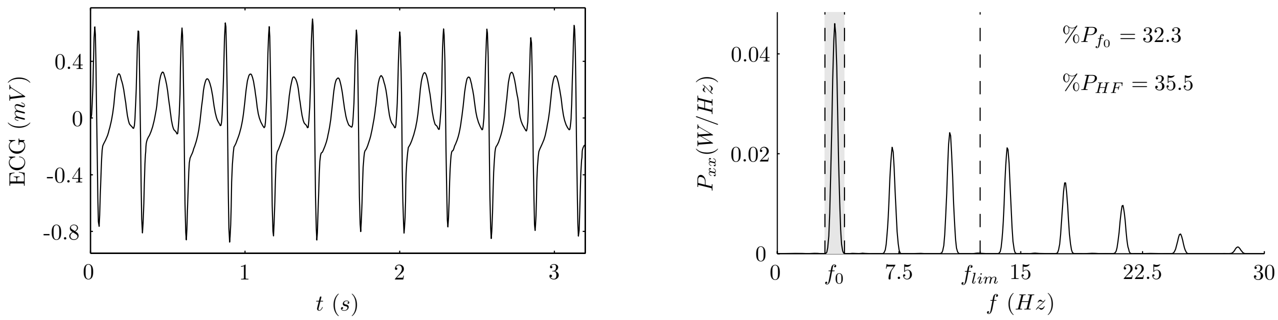
The two spectral parameters ($\%P_{HF}$ and $\%P_{f_0}$) were used to fit a logistic regression model to predict the type of rhythm:

$$P = \frac{e^Y}{1 + e^Y} \qquad Y = \beta_0 + \beta_1 \%P_{HF} + \beta_2 \%P_{f_0}$$

and the decision threshold was set to $P = 0.5$, i.e when $P \geq 0.5$ the rhythm was classified as VT and when $P < 0.5$ as SVT.




(a) VT window in the time and frequency domains




(b) SVT window in the time and frequency domains

Figure 1. VT and SVT windows in the time and frequency domains. The power is concentrated around the dominant frequency ($f_0$) in VT consequently $\%P_{f0}$ is high and $\%P_{HF}$ is low. SVT rhythms have higher harmonic content, therefore $\%P_{f0}$ is lower and $\%P_{HF}$ higher.

The unbalance in number of samples per rhythm type, 322 SVT and 70 VT, introduces a bias toward SVT in the estimation of the logistic regression coefficients ($\beta_i$). Furthermore longer samples have more windows (the longest sample has 51 windows while the shortest samples have one) and this adds a second bias. We assigned a weight to each window in the estimation of $\beta_i$ so each sample had the same weight in its rhythm type and the total weight of SVT and VT samples was the same.

## 3. Results

We calculated the spectral parameters for all the windows (1302 SVT and 221 VT windows), the histograms for each parameter are shown in figure 2. These values where then weighted to avoid bias and used in the maximum likelihood estimation of the coefficients $\beta_i$, which produced the following result:

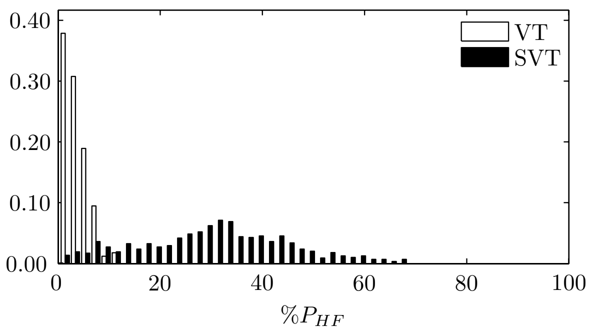
$$\beta_0 = -8.605, \quad \beta_1 = -0.432, \quad \beta_2 = 0.191$$

We computed the sensitivity (VT) and specificity (SVT) using a 10 fold cross validation on the weighted windows. The sensitivity was 98.8% and the specificity was 96.6%. When the testing results were restricted to the patients in the 1-8 years of age group we obtained a sensitivity of 97.9% and a specificity of 96.8%.

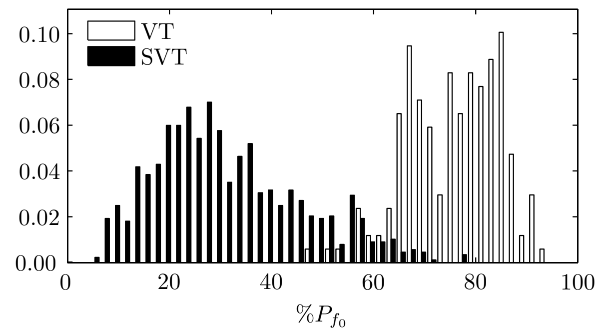
In an AED implementation the algorithm gives a shock decision for a rhythm based on the diagnosis of consecutive windows. We used the predominant diagnosis of the windows of the sample as the diagnosis for the sample, which in practice means that a maximum of three windows will be analyzed before the sample is diagnosed (two windows with the same diagnosis are enough to diagnose the sample). Table 2 shows the results per sample compared to the AHA performance goals [5].

Table 2. Per sample Sensitivity and Specificity for the complete database and the 1-8 years of age subset of patients. The 95% confidence interval (CI) was calculated using the adjusted Wald interval.

| Group | | $n$ | sens/spec | 95% CI | AHA goal |
|---|---|---|---|---|---|
| **1y-8y** | VT | 40 | 100% | 89.6% | $>$ 75% |
| | SVT | 143 | 97.2% | 92.8% | $>$ 95% |
| **Total** | VT | 70 | 100% | 93.8% | $>$ 75% |
| | SVT | 322 | 96.6% | 93.9% | $>$ 95% |




(a) Percent power content above 12.5 Hz.




(b) Percent power content around the dominant frequency.

Figure 2. Normalized histograms of the two spectral parameters used to discriminate SVT from TV. For each ECG sample a maximum of three windows were taken to compute the histograms.

## 4. Discussion and conclusions

Heart rate oriented AED algorithms designed for adult patients might produce the miss-diagnosis of high rate SVT in children. Those algorithms can be adapted for pediatric patients if a SVT/VT discrimination stage is added for the rhythms exceeding the threshold for fast VT in children. We have developed a simple SVT/VT discrimination algorithm for pediatric rhythms that meets the AHA performance goals on SVT specificity and VT sensitivity. Furthermore, the algorithm is based on two parameters computed in the frequency domain, a domain used in several AED algorithms, the modifications are therefore computationally very cheap.

Using a 10 fold cross validation method we obtained a 96.8% specificity for SVT and a 97.9% sensitivity for VT, above the 95% specificity and 75% sensitivity goals set by the AHA. The results are also representative of the per sample performance due to the weighting applied to the SVT and VT windows. The AHA performance goals are not equally restrictive, however if higher SVT specificity is desired more importance can be assigned to the SVT windows in the weighting process. Once the $\beta_i$ are known it is possible to modify the decision threshold in the logistic regression model, for instance to increase SVT specificity at the expense of lower VT sensitivity.

Non heart rate oriented adult AED algorithms have shown good SVT specificity [3,4]. However VT sensitivity was either inconclusive (Atkinson et al. [4] had only 3 VT samples) or below AHA goals (Cecchin et al. [3] reported a 71% sensitivity). These algorithms could be modified in the same way.

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