A New Algorithm to Diagnose during Chest Compressions: Effect on Cardiopulmonary Resuscitation Delivery

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Abstract

Rhythm analysis methods for shock advice during CPR are evaluated in terms of sensitivity and specificity. However, these figures do not convey the real impact that using these methods would have on the delivery of CPR. This study evaluates the impact on CPR delivery of a new rhythm analysis method.

First, the original method was modified to increase the reliability of a shock diagnosis by the addition of high and low confidence diagnoses and the combination of several diagnoses before deciding a shock. Compared to the current CPR guidelines, the modified rhythm analysis method showed a 94.4% probability of delivering the shock earlier to patients in shockable rhythms and a 94.1% probability of reducing CPR interruptions for rhythm reassessment in nonshockable rhythms.

Although the results are promising further testing is needed on complete resuscitation episodes.

1. Introduction

During cardiopulmonary resuscitation (CPR), chest compressions cause an artifact in the ECG, making rhythm analysis for shock advice unreliable in automated external defibrillators (AED). Current CPR guidelines recommend two minutes of uninterrupted CPR followed by a pause in chest compressions to allow a reliable rhythm analysis by the AED [1]. If the AED detects a shockable rhythm a shock is delivered, otherwise CPR is resumed. However, interruptions in chest compressions adversely affect the probability of survival of patients in out-of-hospital cardiac arrest (OHCA) [2]. A reliable method to analyze the rhythm during CPR would eliminate the need to stop CPR every two minutes. Consequently, CPR would not be interrupted in patients with nonshockable rhythms and the shock would be delivered earlier to patients with shockable rhythms.

Several methods have been proposed to diagnose the rhythm during CPR [3–5]. These methods are generally evaluated in terms of their sensitivity (Se) and specificity (Sp), i.e. their capacity to detect shockable and nonshockable rhythms, respectively. In most studies Se was above 90%, the performance goal recommended by the American Heart Association (AHA) when AEDs analyze artifact-free ECGs [6]. However, Sp rarely exceeded 85%, far from the 95% recommended by the AHA.

The Se/Sp pair measures the accuracy of a method. However, the key question is how using a rhythm analysis method affects the delivery of CPR, particularly when compared to CPR delivered according to the guidelines, i.e 2-minutes of uninterrupted CPR followed by a pause for rhythm reassessment. In this line, a recently developed methodology [7] established a framework to evaluate the effect of rhythm analysis on uninterrupted CPR time. The goal was to evaluate how rhythm analysis helps to: (1) deliver the shock before two minutes to patients with shockable rhythms, and (2) prolong uninterrupted CPR beyond two minutes for patients with nonshockable rhythms.

The aim of this study was to apply this new methodology to a new rhythm analysis method specially designed to analyze the rhythm during CPR.

2. Methods

2.1. ECG database

The database used in this study was originally compiled to develop the new methodology to evaluate the effect of rhythm analysis on uninterrupted CPR time [7]. The database is a set of records extracted from a large prospective study of OHCA episodes [8], with rhythm type and CPR/no-CPR annotations done by expert reviewers. The records correspond to intervals from the original episodes with a large proportion of time during CPR, a single underlying rhythm, and a duration of at least 30 s to allow several consecutive rhythm analyses. In this study the shockable category only includes coarse ventricular fibrillation (VF), i.e. with peak-to-peak amplitude $>$ 200 μV.

The database is composed of 214 shockable records from 86 patients and 634 nonshockable records from 219 patients. The median durations of the shockable and the nonshockable records were 120 s (25–75 percentiles, 65–180) and 162.5 s (90–260), respectively.

2.2. Rhythm analysis method

The rhythm analysis method was previously designed (manuscript in preparation). The method is based on the analysis of the ECG after filtering the CPR artifact and it was designed to obtain a high Sp. The block diagram of the method is shown in Fig. 1. An LMS filter [4] removes the CPR artifact from s_{in}, the input ECG, to obtain s_{filt}, the filtered ECG, and $\hat{s}_{\text{cpr}}$, an estimate of the artifact. Then, nonoverlaping 3 s windows are classified as follows. First, windows with large CPR artifacts are detected. In those cases the diagnosis is considered unreliable. Otherwise, the SAA analyzes s_{filt} in two steps. First, windows with little electrical activity (LEA), asystole for example, are identified and classified as nonshockable. The rest of the windows are classified as shockable or nonshockable by a support vector machine (SVM) classifier based on features obtained from the spectral and slope analysis of s_{filt}. When evaluated on a test database the method identified 2% of windows in the test database as unreliable and showed Se and Sp of 90.5% and 95.1%, respectively.

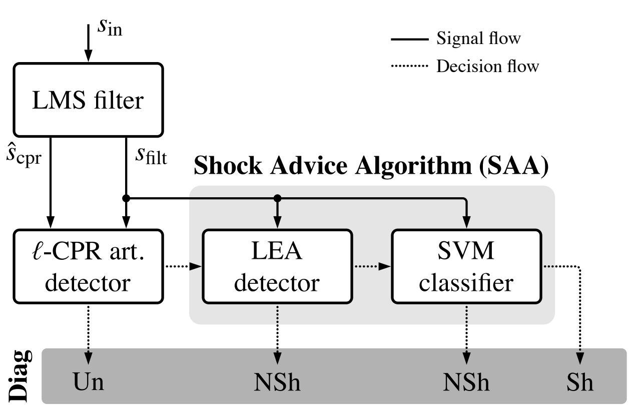


Figure 1. Block diagram of the rhythm analysis method. After filtering the CPR artifact every 3 s window is classified as unreliable diagnosis (Un), nonshockable (NSh) or shockable (Sh).

2.2.1. Criteria for shock diagnosis

In order to increase the confidence in a shock diagnosis two changes were done to the rhythm analysis method:

- At the output of the SAA, four intermediate classes were defined based on the output of the SVM discriminant function, $f(\boldsymbol{x})$. As shown in Fig. 2, the regions with a clear separation between the Sh/NSh classes were labeled as high-confidence shockable (hSh) and nonshockable (hNSh) categories. The region with a strong overlap between the Sh/NSh classes was divided into the low-confidence shockable (lSh) and nonshockable (lNSh) categories. Since the LEA detector had a large negative predictive value, its NSh output was considered a hNSh diagnosis.
- A shock decision was only taken if the method produced three consecutive hSh decisions or after four consecutive shock decisions of which at least two were hSh. In all cases only one intermediate Un decision was allowed.

2.3. Uninterrupted CPR time

In this study we followed a recently developed methodology [7] to evaluate the duration of the uninterrupted CPR time: t_{uCPR}. In this framework the rhythm analysis method is used as follows. CPR starts after a defibrillation attempt or pause in CPR for rhythm assessment. The rhythm analysis method starts one minute after the beginning of CPR and continuously analyzes the rhythm during CPR. In this way, at least one minute of CPR is secured, which enables a minimum period of blood flow. Finally, CPR continues uninterrupted until the method gives a shock diagnosis. At this point CPR would be stopped for a confirmatory diagnosis without CPR artifacts or to deliver a shock. Consequently, the time

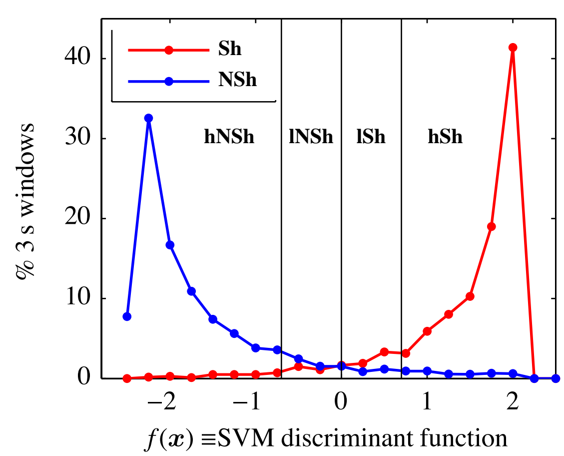


Figure 2. Distribution of the Sh and NSh diagnoses at the SVM output for the method's test database, and definition of the intermediate classes: hNSh, lNSh, lSh, hSh.

to the first shock diagnosis (t_{FSD}) determines the duration of uninterrupted CPR:

$$t_{\mathrm{uCPR}}(\mathrm{min}) = 1 + t_{\mathrm{FSD}}(\mathrm{min}). \quad (1)$$

Then, t_{uCPR} can be compared to the 2 minutes stated by the guidelines. For shockable rhythms t_{uCPR} under 2 minutes means the shock would be delivered earlier. For nonshockable rhythms t_{uCPR} above 2 minutes means uninterrupted CPR would be prolonged beyond the 2 minutes stated in the guidelines.

First, t_{FSD} was determined for all the records, then we used Kaplan-Meier curves to estimate the probability of interrupting CPR as a function of time (t_{FSD}, or equivalently t_{uCPR}) for both shockable and non-shockable rhythms. Records without a shock diagnosis were considered censored observations. The 95% confidence intervals (CI) for these curves were obtained using Greenwod's variance. In these curves cutoff points can be defined at $t_{\mathrm{uCPR}} = 2\,\mathrm{min}$ to evaluate the probability of improving therapy compared to the guidelines.

3. Results

The rhythm analysis method was used to classify all the nonoverlapping 3 s windows of the 848 records in our database. The per window classification results (before applying the criteria for a shock diagnosis) are summarized in Table 1. Only 1.6% of windows, mostly nonshockable, had large CPR artifacts that made the diagnosis unreliable. For the rest of windows, Sp and Se were, respectively, 1.2 and 2.3 points below the values recommended by AHA. The positive predictive value obtained for a single Sh/NSh diagnosis was 74.9%, far from the values necessary to reliably stop CPR if the method gives a shock diagnosis.

Table 1. Classification of the rhythm analysis method for the 3 s windows, n is the number of windows.

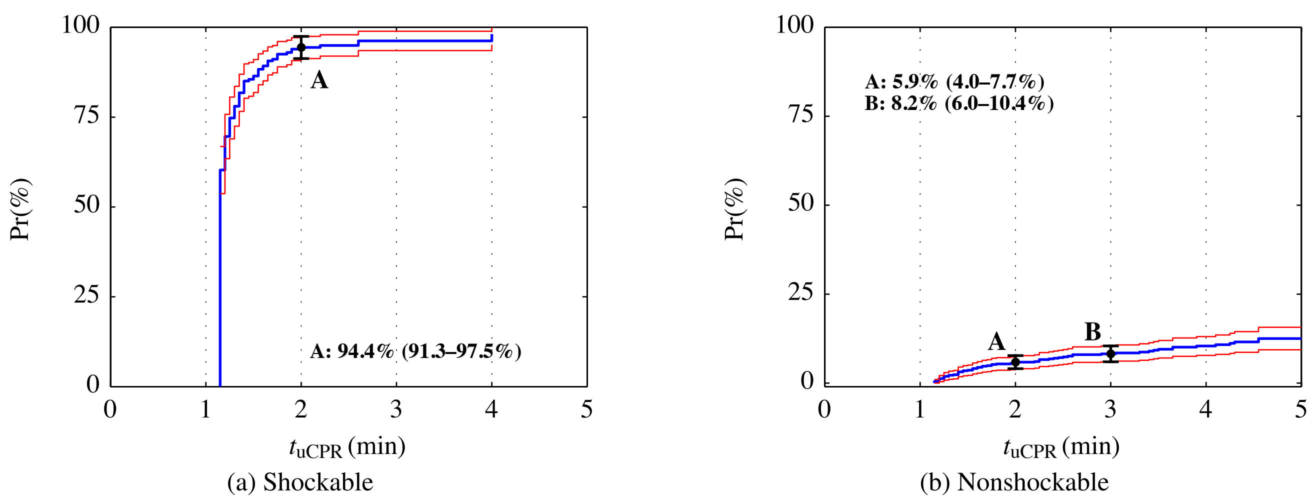
		Diagnosis (% windows)					
Rhythm	n	Un	hNSh	lNSh	lSh	hSh	Se/Sp
Nonshock	44937	1.9	89.9	3.9	2.5	3.7	93.8
Shock	9327	0.5	8.3	4.0	6.0	81.7	87.7

Fig. 3 shows the Kaplan-Meier curves, i.e. the probability of interrupting CPR before a given time (t_{uCPR}). Combining several diagnoses to decide a shock substantially increases the confidence in a shock diagnosis, as shown by Fig. 3. For shockable rhythms, the probability of delivering the shock before 2 minutes was 94.4% (95% CI, 91.3–97-5%). For nonshockable rhythms, the probability of prolonging CPR beyond 2 and 3 minutes were 94.1% (92.3–96.0%) and 91.8% (89.6–94.3%) respectively. These are the complementary percentages of the cutoff points A and B in Fig. 3 (b).

4. Discussion and conclusions

In this study we evaluated the performance of a new rhythm analysis method specially designed to work during CPR. A large database of long duration OHCA records was used. The method was evaluated in a classical way, in terms of Se/Sp, but also in terms of how using the method would compare to delivering CPR according to guidelines.

The Se and Sp of the method for the 3 s windows were slightly below both AHA recommendations [6] and



(a) Shockable (b) Nonshockable

Figure 3. Kaplan-Meier curves and their 95% confidence intervals for Pr(%), the probability of interrupting CPR, as a function of t_{uCPR}. During the first minute there is no rhythm analysis so Pr=0. Cutoff points are highlighted at $t_{\mathrm{uCPR}} = 2\,\mathrm{min}$ (CPR guidelines) for all rhythms, and at $t_{\mathrm{uCPR}} = 3\,\mathrm{min}$ (substantial increase in t_{uCPR}) for nonshockable rhythms.

the results obtained to develop/test the method. The method preserved a high specificity even when tested with a comprehensive database of nonshockable rhythms (624 records and 44937 analyses). This confirms the robustness of the method's design approach, aimed at obtaining a high Sp and based on the analysis of the rhythm after filtering the CPR artifact.

Using the method would have a positive impact on CPR delivery compared to CPR delivered according to guidelines. For patients in shockable rhythms, the shock would be delivered earlier in 94.4% of cases. This could be beneficial given that the oxygen demand is high during recurrent VF [9]. For patients in nonshockable rhythms, uninterrupted CPR would be prolonged or substantially prolonged in 94.1% and 91.8% of cases, respectively. Interruptions in CPR for rhythm reassessment would substantially decrease, which would improve coronary perfusion pressure [10] and the likelihood of return of spontaneous circulation [11].

The positive impact on CPR delivery is explained by two factors. First, the high Sp of the method. Second, the increased reliability of a shock diagnosis achieved by the addition of high/low confidence diagnoses and their efficient combination before deciding a shock. When compared to the classical "CPR filter+AED analysis" approach [7] on the same data, our new approach resulted in a 36 point increase in the probability of prolonging CPR for a 5 point decrease of the probability of advancing the shock. However, unlike in [7], we excluded fine VF because its optimal treatment (advance the shock or continue CPR) is unclear [6].

Finally, although the results of this study are promising, they should be confirmed on a comprehensive database of complete resuscitation episodes with CPR delivered according to the latest CPR guidelines.

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