Evaluation of the Reduction in Time-to-Defibrillation Due to CPR Artefact Suppression in Long Duration Out-of-Hospital Cardiac Arrest

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Abstract

Diagnosis during cardiopulmonary resuscitation (CPR) is highly desirable because it has been reported to be determinant for a successful outcome from sudden cardiac arrest. This study evaluates the accuracy and the time-effect of applying CPR artefact suppression prior to rhythm classification with long out-of-hospital cardiac arrest episodes.

A total of 191 episodes were considered corresponding to intervals between two consecutive defibrillation attempts. 127 maintained ventricular fibrillation as the underlying rhythm and 64 began in asystole but converted to a final ventricular fibrillation rhythm. The records comprised subintervals with and without chest compressions.

A dual-channel adaptive filter is used to suppress the CPR artefact prior to applying the shock advice algorithm. The accuracy of the diagnosis during CPR is evaluated and the reduction in time-to-defibrillation and no-flow-time were computed.

1. Introduction

Out-of-hospital cardiac arrest (OHCA) is a major health problem in the industrialized world. Ventricular Fibrillation (VF) is the most common cause of cardiac arrest. The only effective treatment for VF is a defibrillating electrical shock to restore an effective cardiac rhythm, which out-of-hospital is delivered using an automated external defibrillator (AED).

Several factors affect the chance of survival of a patient in cardiac arrest. Time is crucial, and early defibrillation has high priority. It is well known that during VF the condition of the heart deteriorates rapidly when no artificial or natural circulation is present. The probability of defibrillation success decreases by 10% every minute defibrillation is delayed [1].

Cardiopulmonary resuscitation consists of chest compressions and ventilations that maintain a minimum circulation until a defibrillator is available. Pauses in chest compressions introduce intervals without blood flow known as no-flow-time (NFT) intervals. NFT intervals of only a few tens of seconds significantly reduce the chance of a successful resuscitation [2-4]. Consequently much attention has been given to methods that reduce the NFT and advance defibrillation.

The mechanical activity of chest compressions during cardiopulmonary resuscitation (CPR) corrupts the ECG signal, and the rhythm analysis by the AED is no longer reliable. Compressions must therefore be discontinued to safely use the shock advice algorithm (SAA) of the AED on a clean ECG. Unfortunately these pauses, increase the NFT.

Many adaptive filters have been proposed to suppress the CPR artefact. They are traditionally tested for short episodes of corrupted ECG signals, and their performance is evaluated in terms of the classification of the filtered ECG by a SAA. After filtering the sensitivity for shockable rhythms is above 90% but the specificity for nonshockable rhythms is below 90%. So far, the accuracy of these methods has not been evaluated for long OHCA episodes.

This study evaluates the diagnosis during CPR for long OHCA episodes focusing on accuracy and time analysis. An accurate diagnosis during CPR would eliminate pauses in chest compressions for rhythm analysis reducing NFT, and it would also advance the shock when a shockable rhythm is detected during compressions. These two factors are key to improve resuscitation outcome.

2. Materials

The dataset used in this study is a subset of a large database acquired in a prospective study of OHCA patients [10]. The episodes were recorded in three geographical locations between 2002 and 2004 in a study coordinated from the Ulleval University Hospital in Oslo. The surface ECG and several additional reference channels were acquired using a modified version of Laerdal's Heartstart 4000 defibrillator. The sampling rate was 500 Hz with a resolution of 1.031 μV per least significant bit. Expert reviewers annotated the rhythm types within the episodes.

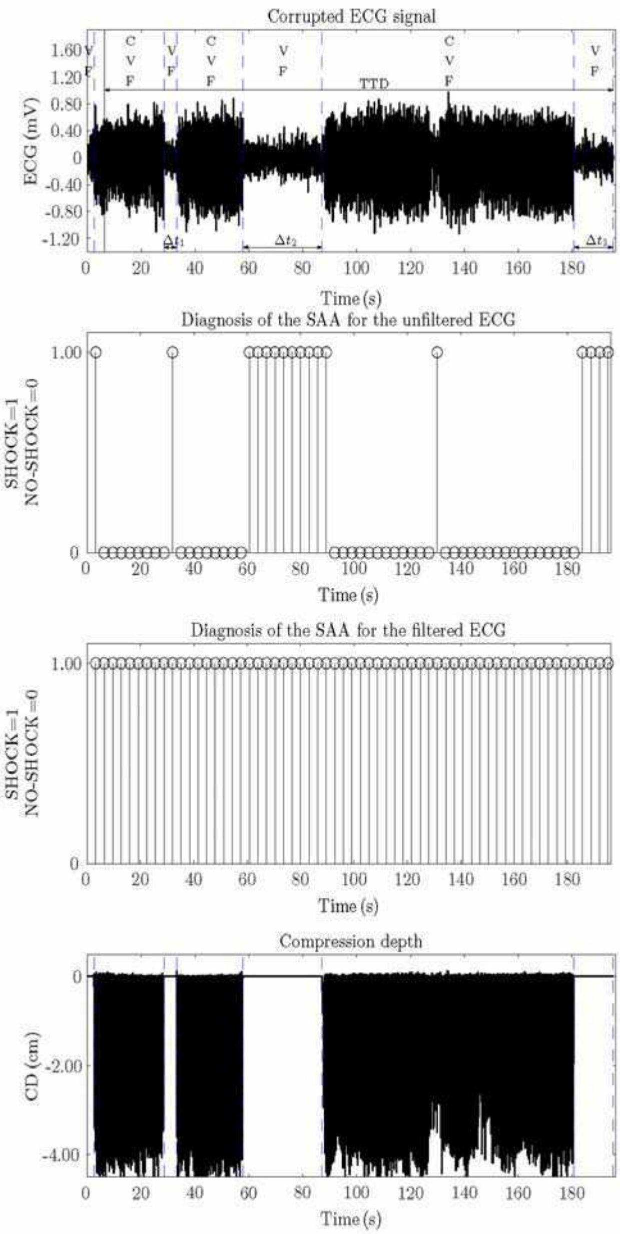

Figure 1. Record of the S-S pattern group.

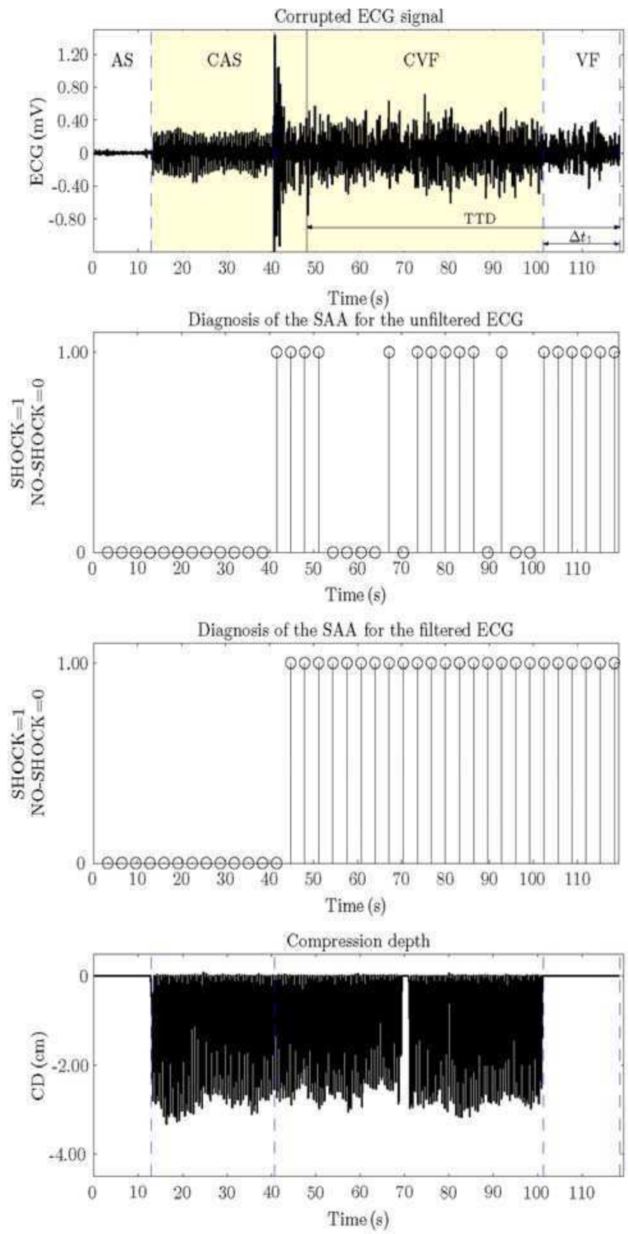

Figure 2. Record of the NS-S pattern group.

We extracted a dataset of records corresponding to the interval between two consecutive defibrillation attempts. Each record consists of the surface ECG signal acquired through the AED pads, and the compression depth computed from the acceleration signals recorded by the CPR pad.

The records were further divided in two groups. The first group presented a shock to shock (S-S) rhythm pattern. It consisted of 127 records of sustained VF, including clean subintervals (VF) and subintervals corrupted by CPR artefact (CVF) as shown in Fig. 1. The mean duration of the records in this group was 152±111s. The second group presented a noshock to shock (NS-S) rhythm pattern. It consisted of 64 records with three intervals: a non-shockable interval (asystole rhythm), a transition interval and a shockable interval (VF rhythm). Each interval contained clean subintervals (AS/VF) and subintervals corrupted by CPR artefact (CAS/CVF) as shown in Fig. 2. The mean duration of the records in this group was 212±211s.

3. Methods

The ECG in each record was first filtered to suppress the CPR artefact and then it was continuously diagnosed by a SAA. For every analysis window the SAA classified the filtered ECG as Shock ('1') or NoShock ('0') as shown in Fig.1 and Fig.2. The accuracy and time analysis of the diagnosis during CPR were then evaluated.

The CPR artefact suppression method is an adaptive dual-channel filter based on the chest compression depth and the least mean square (LMS) algorithm [9]. The sensitivity and specificity of the LMS filter reported for short OHCA records were 95.6% and 86.4% respectively; a performance similar to that of other adaptive methods [5-8].

The filtered ECG was diagnosed using an off-line version of the SAA found in a commercial AED manufactured by Osatu S. Coop. (Ermua, Spain). This algorithm analyses three 3.2s non-overlapping windows and recommends shock when two out of three consecutive windows are classified as shockable.

We assessed the accuracy of the diagnosis during CPR by evaluating three factors: sustained shock diagnosis during VF for the S-S pattern, accurate shock diagnosis in the transition interval for the NS-S pattern and accuracy of the first shock advised for the NS-S pattern.

The time analysis of the records comprised the evaluation of the reduction in time-to-defibrillation (TTD) and the reduction of NFT that resulted from diagnosing the filtered ECG. As shown in Fig.1 and Fig. 2, TTD was evaluated as the time between the first time shock was advised during chest compressions and the end of the record, the instant when defibrillation was really provided. The reduction in NFT was computed by adding the duration of all the no-flow intervals that would be avoided if shock was advanced (i.e. contained in the TTD interval), those no-flow intervals denoted as Δt_i in Fig.1 and Fig. 2.

4. Results

The sensitivity of the SAA for the last window of clean ECG preceding defibrillation was 97.6% (S-S and NS-S groups), and the specificity for the initial clean AS interval was 98.4% (NS-S group). Both values are well above the goals set by the AHA for AED rhythm classification algorithms [11].

For the S-S group continuous shock was diagnosed in 93/127 records (73%), although shock was diagnosed during 95.8% of the time of all records. For the NS-S group the change of diagnosis from nonshockable to continuous shockable occurred in the transition interval in 53/64 records (83%), Fig. 2 shows an example. The first shock was correctly advised within the transition interval in 46/64 records (72%) and wrongly advised during the nonshockable interval in 18 records. However, evaluating the correctness of this advise is not always easy because the transition interval is composed of corrupted asystole (CASY) followed by corrupted VF (CVF), and the annotation of the underlying rhythm during chest compressions is hampered by the CPR artefact. A correct advice was assumed when the first shock was identified during any moment of the transition interval except the initial windows where the classification change might be caused by the start of the chest compressions (CPR artefact).

The time analysis was applied to the complete S-S pattern group and to the records in the NS-S pattern group for which the first shock was correctly advised in the transition interval. The reduction in TTD and NFT for those records are given in Table 1. Shock is advised in the very initial windows for most of the records in the S-S pattern group, which advances defibrillation a mean 81.73% of the total duration of the record. The mean reduction in TTD was 141±112 s. For the NS-S group the reduction in TTD was 108±71 s, (a mean of 62.18% of the total duration). The NFT reductions for the S-S and the NS-S groups were 52±60 s and 19±8 s, with a mean reduction of 33.51% and 14.48% respectively.

Table 1. Time parameters for the S-S and NS-S groups. The mean±std and the percentage of time of the complete record are reported for both TTD and NFT.

	S-S pattern	*NS-S pattern*
Duration (s)	152±111	212±211
TTD reduction	141±112 s (81.73%)	108±71 s (62.18%)
NFT reduction	52±60 s (33.51%)	19±8 s (14.48%)

5. Discussion and conclusions

In this study we assessed rhythm analysis during chest compressions after filtering the CPR artefact for long OHCA episodes. We evaluated both the accuracy of the methods and their benefits in terms of the reduction of NFT and TTD. We used a state of the art CPR suppression method that had reported sensitivity and specificity scores similar to other adaptive methods for short OHCA episodes. When applied to long OHCA episodes the first shock was correctly advised in 72% of records in the NS-S pattern group, well bellow the performance reported for short episodes. The results reported for short episodes were quite optimistic compared to the real performance during transition intervals in long episodes.

We measured mean NFT reductions of 52 s and 19 s, slightly above the 21.4 s given by Eilevstjonn et al. [12]. However, this is because we counted preshock pauses and all pauses in chest compressions during the episode, and we did not consider human NFT.

This is the first time that reduction in TTD is evaluated. We measured mean reductions in TTD of 141 s and 108 s when the diagnosis of the SAA was accurate for the filtered ECG. An earlier defibrillation for a shockable rhythm is always desirable because the probability of restoration of spontaneous circulation decreases with time [1]. We measured a substantial reduction in TTD in this study, although this reduction does not guarantee a successful defibrillation.

Diagnosis during CPR is not reliable enough yet [13]. Our results show that diagnosis during CPR is even less reliable for long OHCA episodes than what has been reported for short OHCA episodes. However we demonstrate that when the analysis is accurate there are important reductions in NFT and TTD, both key factors to improve resuscitation outcome.

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