Resuscitation (2007) **72**, 115—123

RESUSCITATION

www.elsevier.com/locate/resuscitation

COMPUTATIONAL AND MATHEMATICAL PAPER

Detection of ventricular fibrillation in the presence of cardiopulmonary resuscitation artefacts☆

Elisabete Aramendi[a,*], Sofia Ruiz de Gauna[a], Unai Irusta[a], Jesus Ruiz[a], Mª Fe Arcocha[b], Jose Miguel Ormaetxe[b]

[a] *Department of Electronics and Telecommunications, University of the Basque Country, Alameda de Urquijo s/n, 48013-Bilbao, Spain*
[b] *Arrhythmias Unit, Electrophysiology Department, Basurto Hospital, 48013-Bilbao, Spain*

Received 7 December 2005; received in revised form 22 May 2006; accepted 30 May 2006

KEYWORDS
Out-of-hospital CPR;
Automated external defibrillator (AED);
Witnessed cardiac arrest;
Ventricular fibrillation

Summary Providing cardiopulmonary resuscitation (CPR) to a patient in cardiac arrest introduces artefacts into the electrocardiogram (ECG), corrupting the diagnosis of the underlying heart rhythm. CPR must therefore be discontinued for reliable shock advice analysis by an automated external defibrillator (AED). Detection of ventricular fibrillation (VF) during CPR would enable CPR to continue during AED rhythm analysis, thereby increasing the likelihood of resuscitation success.

This study presents a new adaptive filtering method to clean the ECG. The approach consists of a filter that adapts its characteristics to the spectral content of the signal exclusively using the surface ECG that commercial AEDs capture through standard patches. A set of 200 VF and 25 CPR artefact samples collected from real out-of-hospital interventions were used to test the method. The performance of a shock advice algorithm was evaluated before and after artefact removal. CPR artefacts were added to the ECG signals and four degrees of corruption were tested. Mean sensitivities of 97.83%, 98.27%, 98.32% and 98.02% were achieved, producing sensitivity increases of 28.44%, 49.75%, 59.10% and 64.25%, respectively, sufficient for ECG analysis during CPR.

Although satisfactory and encouraging sensitivity values have been obtained, further clinical and experimental investigation is required in order to integrate this type of artefact suppressing algorithm in current AEDs.

Introduction

The European Resuscitation Council (ERC) guidelines for resuscitation 2005[1] state that early defibrillation is critical to survival from sudden cardiac

☆ A Spanish translated version of the summary of this article appears as Appendix in the final online version at doi:10.1016/j.resuscitation.2006.05.017.

* Corresponding author. Tel.: +34 94 601 4126.
E-mail address: jtparece@bi.ehu.es (E. Aramendi).

0300-9572/$ — see front matter © 2006 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.resuscitation.2006.05.017

arrest (SCA) for several reasons: (1) at the time of the first cardiac rhythm analysis, about 40% of SCA victims have ventricular fibrillation (VF); (2) the optimum treatment for VF cardiac arrest is immediate bystander CPR (combined chest compression and rescue breathing) plus electrical defibrillation; (3) each minute delay in defibrillation reduces the probability of survival to discharge by 10–15%[2,3] and (4) successful resuscitation is unlikely once the rhythm has deteriorated to asystole.[4] Early defibrillation is thus central to the success of resuscitative attempts during VF cardiac arrest,[5] and is advocated in the above-mentioned guidelines.

The application of CPR, although unlikely to convert VF to a normal rhythm, does maintain VF until defibrillation is available. Moreover, increasing evidence supports a critical interaction between CPR and defibrillation, as delaying defibrillation to provide CPR may improve the outcome of resuscitation,[6,7] while longer compression periods during CPR may increase the survival rate.[8] In fact, the most significant changes in the new guidelines are made to simplify CPR instruction, increase the number of chest compressions per minute and reduce interruptions in chest compressions during CPR.[1]

The mechanical activity from thoracic compressions and ventilation during CPR introduces artefact components into the ECG signal. These artefacts can condition the shock/no-shock decision of an automated external defibrillator (AED). The current application procedure requires chest compressions and ventilations to be interrupted during automatic rhythm analysis. The duration of these hands-off intervals affects the rate of restoration of spontaneous circulation (ROSC).[9,10] AEDs are thus likely to be most effective if they are programmed to secure minimal hands-off periods before the delivery of the electric shock.

The feasibility of VF detection during CPR is a highly challenging issue that, if solved, would enable CPR to continue during AED rhythm analysis, thereby increasing the likelihood of resuscitation success. Furthermore, it would permit time-selective shock therapy in which predictors of defibrillation success are used to maximise the ROSC.[11–13]

CPR artefacts have been successfully removed from a porcine ECG by means of fixed coefficient high-pass digital filters.[13,14] This is possible due to the clear spectral separation of the artefact and the ECG signal. The human VF signal and the CPR artefact show an important spectral overlap which makes a simple approach based on a fixed coefficient filter inadequate.[15,16] The rhythm assessment that some commercial AEDs offer during CPR is not even recommended by the manufacturers.[17]

Recent studies have proposed the use of adaptive filters to remove the CPR artefact from VF signals in humans.[15,18] These methods require several additional signals strongly correlated to the artefact (e.g., compression acceleration and compression depth) besides the surface ECG. These signals are not available from current commercial AEDs, and are not easy to obtain, as they require profound AED hardware alterations. In this study, we investigated an adaptive method that uses only the surface ECG signal to provide a reliable VF signal. This technique would require minimal software modifications of the current AED algorithms.

Materials and methods

Data collection

The VF database used in this research was collected during the 2001–2003 period in a study involving the Basurto Hospital in Bilbao (Spain) and the emergency services of the Community of the Basque Country (Spain). The aim was to collect a VF database adequate to test the sensitivity of an AED. The VF samples correspond to 200 patients having in-hospital (35.5%) and out-of-hospital cardiac arrests (64.5%). There were two sources of in-hospital samples: the Cardiolab system (Prucka Engineering) and the digitalisation of printed ECGs extracted from portable ECG recording systems. Out-of-hospital samples were obtained during emergency interventions, using either manual or automated external defibrillators. Table 1 details the source and number of the ECG records collected.

A total of 200 segments of coarse VF were obtained with an average duration of 15 s. The ECG database fulfils the American Heart Association (AHA) requirements for the evaluation of the arrhythmia analysis algorithm of an AED.[19] Following the criteria defined to test VF sensitivity, the

Table 1 Description of the ECG database

VF database		
Source		No.
Basurto Hospital	Cardiolab	27
	Paper	44
Emergency services		
AED	Digital	83
MED*	Paper	46
Total		200

* Manual external defibrillator.