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Clinical Paper

Fully automatic rhythm analysis during chest compression pauses☆

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ABSTRACT

Aim: Chest compression artefacts impede a reliable rhythm analysis during cardiopulmonary resuscitation (CPR). These artefacts are not present during ventilations in 30:2 CPR. The aim of this study is to prove that a fully automatic method for rhythm analysis during ventilation pauses in 30:2 CPR is reliable an accurate.

Methods: For this study 1414 min of 30:2 CPR from 135 out-of-hospital cardiac arrest cases were analysed. The data contained 1942 pauses in compressions longer than 3.5 s. An automatic pause detector identified the pauses using the transthoracic impedance, and a shock advice algorithm (SAA) diagnosed the rhythm during the detected pauses. The SAA analysed 3-s of the ECG during each pause for an accurate shock/no-shock decision.

Results: The sensitivity and PPV of the pause detector were 93.5% and 97.3%, respectively. The sensitivity and specificity of the SAA in the detected pauses were 93.8% (90% low CI, 90.0%) and 95.9% (90% low CI, 94.7%), respectively. Using the method, shocks would have been advanced in 97% of occasions. For patients in nonshockable rhythms, rhythm reassessment pauses would be avoided in 95.2% (95% CI, 91.6–98.8) of occasions, thus increasing the overall chest compression fraction (CCF).

Conclusion: An automatic method could be used to safely analyse the rhythm during ventilation pauses. This would contribute to an early detection of refibrillation, and to increase CCF in patients with nonshockable rhythms.

1. Introduction

Early cardiopulmonary resuscitation (CPR) and early defibrillation are key factors for the survival of out-of-hospital cardiac arrest (OHCA) patients.[1] The use of automated external defibrillators (AED) may shorten time to defibrillation. Current CPR guidelines recommend a 30:2 compression to ventilation (CV) ratio before tracheal intubation, with emphasis on delivering minimally interrupted high-quality chest compressions.[2] Chest compressions should be interrupted only to assess the rhythm, to deliver the shock or to ventilate the patient, taking less than 5 s for the two rescue breaths.[2]

Interruptions in chest compressions are frequent during OHCA.[3] These interruptions have a detrimental effect on shock success and patient survival.[4,5] More importantly, pre-, post- and peri-shock pauses all have a negative effect on shock success.[6–8] For instance, a 5 s increase in pre-shock or peri-shock pause duration may decrease the odds of survival by as much as 18% or 14%, respectively.[8] Post-shock pauses are shortened by immediately resuming compressions after shock delivery. Strategies to shorten pre-shock pauses involve compressions during defibrillator charging,[9,10] simplifying voice prompts,[11] or immediately triggering rhythm analysis at the end of chest compressions.[12] However, interruptions for rhythm analysis are necessary because chest compression artefacts may confound the diagnosis of the shock advice algorithm (SAA) in current AEDs.[13] These interruptions contribute to the pre-shock pause, which lasts between 5.2 and 28.4 s [14] and may compromise the survival of the patient.[6]

Currently chest compressions are interrupted every 2 min to reassess the rhythm.[2] An automatic and reliable method to analyse the rhythm during CPR would shorten or even eliminate the need for these interruptions. For patients with nonshockable rhythms uninterrupted CPR could be prolonged beyond the recommended

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2-min cycles,[2,15] thus increasing the chest compression fraction (CCF). In addition, ventricular fibrillation (VF) could be detected earlier and shocks advanced. All these actions may have a significant positive impact on outcome.[16,17] Over the years, considerable effort has been dedicated to develop methods for rhythm analysis during CPR.[13] Several approaches have been studied such as adaptive artefact filters [18–20] or new SAAs designed to analyse either the artefacted [21,22] or the filtered ECG.[23] When tested on short strips (< 20 s) of OHCA data from defibrillators, only a recently published SAA[23] produced sensitivity and specificity results above 90% and 95%, the performance goals recommended by the American Heart Association (AHA).[24] Nevertheless, the reported sensitivities and specificities were well below those obtained for SAAs on artefact-free ECG.[25] Furthermore, the algorithms were not tested in long strips (minutes) of defibrillator data, i.e. when the method is used to continuously assess the rhythm during CPR. This latter type of testing allows the statistical evaluation of the impact of using the method on the delivery of CPR,[26] as suggested by the 2010 consensus on resuscitation science.[27]

Basic Life Support (BLS) guidelines recommend 30:2 CV-ratio CPR. At the standard rate of 100 compressions per minute, pauses for two ventilations occur approximately every 20 s. Furthermore, in BLS scenarios these pauses normally last longer than 5 s.[28] Recently, Ruiz et al [29] proposed doing rhythm analysis during these pauses because the ECG would not have chest compression artefacts. This would allow an accurate rhythm assessment every 20 s during CPR. The objective of this study is to prove the reliability of a fully automatic method to analyse the rhythm during ventilation pauses, and to evaluate the method's impact on the delivery of CPR.

2. Materials and methods

2.1. Data collection

Data from 370 OHCA cases from adult patients were collected between July 2012 and June 2013 in the city of Oslo (Norway). From the 370 cases 135 qualified for inclusion in this study, as explained at the end of this section. In all cases, CPR was performed by Advanced Life Support (ALS) responders. Lifepak 12/15 defibrillators were used (Physio-Control, Redmond, WA, USA), and ECG and thoracic impedance (TI) acquired from the defibrillation pads were stored.

Within each case, the initial rhythm and each subsequent change in rhythm were annotated by consensus between a clinical researcher (HN) under the supervision of an experienced anaesthesiologist (JKJ), and a biomedical engineer (UI), all specialised in resuscitation. The following rhythm annotations were used: VF and ventricular tachycardia in the shockable category, and asystole (ASY) and organised (ORG) rhythm in the nonshockable category. Intermediate rhythms such as fine VF were annotated as undecided. These are the rhythms for which, according to the AHA statement,[24] the benefits of defibrillation are unclear. Chest compressions were automatically detected by the Code-Stat 9.0 review software (Physio-Control). Periods longer than 1.5 s between consecutive chest compressions were defined as a pause.[30] The chest compression marks in the vicinity of the pauses were visually inspected, and manually corrected when necessary based on the TI and ECG signals. The resulting annotated pauses were used as gold standard for the automatic detection of pauses.

The criterion to include a case in this study was that the case contained at least 4 min of CPR delivered with 30:2 CV-ratio. Frequently the CPR pattern changed within a case, for instance from 30:2 CPR to continuous chest compressions after intubation. Consequently, for each case intervals in which 30:2 CPR was administered were identified. These 30:2 CPR intervals had to have a duration above 1 min and at least two pauses every minute of CPR. The case was included in the study when the aggregate duration of its 30:2 CPR intervals was more than 4 min. In this study only the 30:2 CPR intervals within each case were analysed. The top panels in Fig 1 show a 2-min interval with six pauses for ventilation.

2.2. Fully automatic rhythm analysis method

The reliability of an automatic pause detector based on the TI was evaluated. The detector was used in combination with the automated rhythm analysis of a SAA capable of analysing the rhythm using only a few seconds of the ECG. If a pause was detected and its duration was long enough for a rhythm analysis, the SAA was launched for a shock/no-shock decision.

2.2.1. Shock advice algorithm

The SAA is an AHA compliant algorithm that analyses 3 s of the ECG for an accurate shock/no-shock diagnosis,[29] a detailed description of the algorithm is available.[31] Briefly, the SAA is composed of an asystole detector, a QRS presence detector (nonshockable rhythms) and a final shock/no-shock algorithm based on the regularity, spectral distribution and heart-rate of the rhythm. When tested on an AHA compliant database the SAA presented a sensitivity of 98.5% for shockable rhythms, and a specificity of 99.1% and 100% for ORG and ASY rhythms, respectively.[29] The SAA is a modified Matlab version (MathWorks Inc., Natick, MA) of the one incorporated in the Reanibex R-series defibrillators (Bexen Cardio, Ermua, Spain).

2.2.2. Pause detection and rhythm analysis

The SAA used in this study analyses 3 s of the ECG to make a decision. Consequently, for this study pauses longer than 3.5 s were defined as diagnosable-pauses, i.e. pauses long enough for the SAA to diagnose the rhythm. The initial 0.5 s of the pause were discarded to avoid transients and artefact residuals in the pause. Diagnosable-pauses were automatically detected following these steps (see Fig 1 for a visual description):

1 *Pause identification:* The envelope of the TI signal was obtained by applying standard signal processing techniques [32] (step 1 of Fig 1). The TI-envelope is large during compressions and vanishes during the pauses. Pauses were automatically detected in the TI-envelope using an adaptive threshold. Adaptivity is necessary because the amplitude of the TI-envelope may vary substantially within each case.
2 *Pause onset/offset detection:* A chest compression detector was applied in the vicinity of the detected pause to accurately determine the onset/offset of the pause (step 2 of Fig 1).
3 *Rhythm analysis:* If the pause was longer than 3.5 s, the SAA was automatically launched and the rhythm was analysed 0.5 s after the detected pause onset (step 3 of Fig 1).

2.3. Performance evaluation

The method was evaluated in terms of: (1) accuracy of the pause detector, (2) accuracy of the SAA in the detected pauses and (3) the potential therapeutic benefits of using the method.

2.3.1. Reliability of the pause detector

Detected diagnosable-pauses were compared to the diagnosable-pauses obtained from the gold standard. Pause detection sensitivity was defined as the proportion of correctly detected diagnosable-pauses, and the positive predictive value (PPV) as the proportion of detected diagnosable-pauses that were true diagnosable-pauses. Sensitivity and PPV values were calculated for the whole dataset and for each case. The pause onset