Cardiac rhythm analysis during ongoing cardiopulmonary resuscitation using the Analysis During Compressions with Fast Reconfirmation technology

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BACKGROUND Pauses in chest compressions (CCs) have a negative association with survival from cardiac arrest. Electrocardiographic (ECG) rhythm analysis and defibrillator charging are significant contributors to CC pauses.

OBJECTIVE Accuracy of the Analysis During Compressions with Fast Reconfirmation (ADC-FR) algorithm, which features automated rhythm analysis and charging during CCs to reduce CC pauses, was retrospectively determined in a large database of ECGs from 2701 patients with out-of-hospital cardiac arrest.

METHODS The ADC-FR algorithm generated a total of 7264 advisories, of which 3575 were randomly assigned to a development data set and 3689 to a test data set. With ADC-FR, a high-pass digital filter is used to remove CC artifacts, while the underlying ECG rhythm is automatically interpreted. When CCs are paused at the end of the 2-minute cardiopulmonary resuscitation interval, a 3-second reconfirmation analysis is performed using the artifact-free ECG to confirm the shock/no-shock advisory. The sensitivity and specificity of the ADC-FR algorithm in correctly identifying shockable/nonshockable rhythms during CCs were calculated.

RESULTS In both data sets, the accuracy of the ADC-FR algorithm for each ECG rhythm exceeded the recommended performance goals, which apply to a standard artifact-free ECG analysis. Sensitivity and specificity were 97% and 99%, respectively, for the development data set and 95% and 99% for the test data set.

CONCLUSION The ADC-FR algorithm is highly accurate in discriminating shockable and nonshockable rhythms and can be used to reduce CC pauses.

KEYWORDS Cardiac arrest; Rhythm analysis; Automated external defibrillation; Preshock pauses; Chest compression; Defibrillation

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Introduction

Cardiopulmonary resuscitation (CPR) in conjunction with prompt electrical defibrillation can reestablish spontaneous circulation (ROSC) after cardiac arrest (CA) from ventricular fibrillation (VF) and pulseless ventricular tachycardia (VT).[1] Nevertheless, resuscitative efforts are often unsuccessful and poor outcomes may result from ineffective and/or frequently interrupted chest compressions (CCs).[2–6]

Among the different causes of interrupting CCs during CPR are the preshock pauses mandated by automated external defibrillators (AEDs). CCs create artifacts on the electrocardiographic (ECG) signal, such that interruptions are mandatory for rhythm analysis before a defibrillation attempt.[7–9] Limiting the frequency and the duration of such CC interruptions may improve outcomes of CA.[10–14]

A novel technology was developed to limit CC interruptions required for both rhythm analysis and defibrillator charging. This technology, called Analysis During CPR with Fast Reconfirmation (ADC-FR), features automated ECG analysis and defibrillator charging during ongoing CCs, with a 3-second ECG rhythm reconfirmation analysis.[15] The purpose of the present study was to investigate the sensitivity and specificity of the ADC-FR algorithm in a large data set of ECG traces with CC artifacts obtained from patients with prehospital CA.

Methods

A database of defibrillator records (AED Pro, AED Plus, E Series) collected during prehospital CPR was used to develop and test the ADC-FR algorithm. The database, managed by ZOLL Medical Corporation (Chelmsford, MA), included field case submissions from multiple

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Table 1 Electrocardiographic (ECG) rhythm categories identified by the Analysis During Compressions with Fast Reconfirmation algorithm

ECG rhythm categories
Shockable
Coarse ventricular fibrillation (coarse VF)
Ventricular tachycardia with rate ≥150 beats/min (rapid VT)
Nonshockable
Normal sinus rhythm (NSR)
Asystole
Any other nonshockable rhythms: atrial fibrillation, atrial flutter, supraventricular tachycardia, sinus bradycardia, premature ventricular contractions, second- or third-degree heart block, idioventricular rhythm
Intermediate rhythms
Fine ventricular fibrillation (fine VF)
Ventricular tachycardia with rate <150 beats/min (other VT)

emergency medical services agencies between January 1, 2004 and December 31, 2014. The electronic data did not contain any patient's identifiable information in compliance with the Health Insurance Portability and Accountability Act regulations.

ECG traces were recorded at a sample rate of 250 Hz. CCs were detected using an accelerometer, and acceleration data were sampled at 125 Hz. The acceleration records associated with the ECG traces were manually inspected to identify CC intervals (continuous CCs ≥15 seconds) and subsequent pauses (pauses in CCs ≥11 seconds, regardless of the reason for the pause). All ECG segments matching the above criteria were included. The included ECG traces were blindly and randomly partitioned into a development data set and a test data set and subsequently processed by the ADC-FR algorithm, which generated a shock/no-shock decision for each ECG trace. The sensitivity and specificity of the ADC-FR algorithm were calculated by comparing the automated analysis results with a corresponding rhythm annotation by expert reviewers (Q.T., N.Z., and G.R.). ECG rhythms were evaluated and coded according to the recommendations for specifying and reporting arrhythmia analysis algorithm performance by the American Heart Association (AHA).[16] Since the aim of the ADC-FR algorithm was to discriminate between shockable and nonshockable rhythms, a simplified rhythm categorization was used, as detailed in Table 1. The methods are detailed in the Supplemental Methods.

ADC-FR technology

The ADC-FR technology uses the signal from the accelerometer embedded in the defibrillation pads (CPR-D-padz or CPR Stat-padz) to identify the presence of CCs. When CCs are detected, a high-pass digital filter is used to minimize CC artifacts from the ECG signal. A previously validated algorithm for ECG analysis during ongoing CCs is then applied to the filtered trace in order to determine whether the patient's rhythm is shockable.[17] Subsequently, upon interruption of CCs and settling of the ECG, the ADC-FR algorithm performs a 3-second analysis using the compression-free ECG trace to reconfirm the decision determined during CCs. This reconfirmation analysis is compared against the previous analysis during CCs, and the shock/no-shock decision is immediately made if both match. For the clinical implementation of the feature, the ADC-FR algorithm is applied only at the end of the preconfigured 2-minute CPR interval, as detailed in Figure 1. The capacitor of the defibrillator is automatically charged 4 seconds before the end of the 2-minute CPR interval, allowing for immediate defibrillation after the reconfirmation pause, if a shockable rhythm is confirmed. The same 3-second analysis during CC pause occurs in the instance of a nonshockable rhythm. In this case, the AED issues a "no shock advised" order and CCs can restart promptly (Figure 1).

If a shock/no-shock decision cannot be made using the combination of analysis during CCs and the 3-second reconfirmation analysis, an additional segment of the ECG is analyzed. In the instance that a shock/noshock decision cannot be made after 2 ECG segments, a final ECG segment is analyzed. In summary, the ADC-FR algorithm makes the shock/noshock determination during CCs on the basis of three 3-second segments (9 seconds total); then, when CCs are paused, the algorithm performs the reconfirmation analysis, again on the basis of a 3-second segment (requiring from a minimum of 1 up to 3, ie, 3–9 seconds). Supplemental Figure 1 provides more details on the ADC-FR algorithm, while Supplemental Figure 2 depicts the logical decision algorithm of the ADC-FR technology. Samples of raw ECG traces for different rhythms, correctly interpreted by the ADC-FR algorithm, are reported in Figure 2.

Statistical analysis

The performance of the ADC-FR algorithm was evaluated in terms of accuracy of the shockable/nonshockable decision. *Accuracy* was defined as the number of correct advisories (shockable/nonshockable) divided by the total number of advisories for each ECG rhythm. *Sensitivity* was defined as the number of ECG rhythms correctly classified as shockable divided by the total number of shockable rhythms. *Specificity* was defined as the number of ECG rhythms correctly classified as nonshockable (Table 1) divided by the total number of nonshockable rhythms. Accuracy of the ADC-FR algorithm for each rhythm was compared to the AHA recommendations for arrhythmia algorithm performance.[16] Calculation of confidence intervals is presented in the Supplemental Methods.

Results

A total of 7264 CC intervals with one of the ECG rhythms listed in Table 1 from 2701 patients with CA were included in the analysis (3.8 ± 2.9 segments per patient). Of these, 3575 were randomly assigned to the development data set while the remaining 3689 to the test data set. The different ECG rhythms included in the development and test data sets are reported in Table 2. For both data sets, the number of intervals analyzed for each ECG rhythm exceeded the minimum required sample size from the AHA recommendations.[16]