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Ventricular Fibrillation Waveform Analysis during Cardiopulmonary Resuscitation

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ABSTRACT

Ventricular fibrillation (VF) is the primary rhythm associated with cardiac arrest characterized as rapid, disorganized contractions of the heart with complex electrocardiogram (ECG) patterns. Recent studies have reported that performing cardiopulmonary resuscitation (CPR) procedure prior to shock increases the survival rate especially especially when VF is untreated for more than 5 minutes. The waveform analysis is objective help in the choice of the right therapy (shock parameters, shock first or CPR first, drug administration). This analysis is a precondition of individually optimized defibrillation and contribute substantially to an increased quality of CPR and reduce delivery of failed rescue shock. Animal and clinical studies confirmed that ventricular fibrillation waveform analysis contains information to reliably predict the countershock success rate and further improved countershock outcome prediction.

Keywords: cardiac arrest, ventricular fibrillation, waveform analysis, prediction defibrillation success, effectiveness of chest compression, uninterrupted cardiopulmonary resuscitation

Introduction

Ventricular fibrillation (VF) is the primary rhythm associated with cardiac arrest characterized as rapid, disorganized contractions of the heart with complex electrocardiogram (ECG) patterns. The only reliable method to treat VF remains electrical defibrillation, which was first used in humans in 1947. (1) It is increasingly clear that not all patients in VF benefit from being treated with the same intervention since the duration of VF is a major determinant of countershock outcome. Patients in VF may be treated differently and with improved outcome depending on the interval after onset of the VF and the consequent myocardial metabolic state. (2)

The purpose of ventricular fibrillation waveform analysis

VF waveform analysis, which was initially developed to accurately identify shockable rhythms and to recommend a shock, has been used to obtain information concerning the state of the fibrillating myocardium in order to guide cardiopulmonary resuscitation (CPR) by estimating the duration of VF, predicting the likelihood of successful defibrillation and evaluating the effectiveness of chest compression. (3) VF waveform analysis has also focused on the removal of CPR artifacts and the analyzing of waveforms during uninterrupted chest compressions because of the recognition that interruption of CPR greatly decreases the likelihood of successful resuscitation.

Identifying a shockable rhythm to guide CPR

Shockable rhythm identification algorithms are important tools that enable online monitoring of cardiac activities. A number of detection and analysis techniques have been evolved to classify VF by extracting some of the ECG signal features that distinguish VF from other rhythms. (4)

In the time domain, direct ECG features such as threshold crossing criteria, correlation waveform analysis, sequential probability ratio test and complexity assessment by the conversion of the ECG signal into a binary signal are used to detect VF. In the frequency domain, a VF filter method is used which relies on the fact that VF frequencies are concentrated in the range 4–7 Hz. Other methods analyze the ECG by means of band-stop filtering of the signal and estimation of the leakage, and spectrum analysis methods. Detection of VF has also been performed in the time-frequency plane and by wavelet-based techniques, including continuous wavelet transform (CWT) and discrete wavelet transform (DWT). Chaotic and nonlinear methods are also promising in detecting VF with high accuracy, such as trajectory analysis, approximation entropy and phase space reconstruction. (5) Additionally, the combination of parameters, which reflects the frequency and morphological ECG characteristics, is found to be an efficient approach for providing shock-advisable decisions. (6,7)

Prediction of the likelihood of a successful shock and optimizing the timing of defibrillation

Emerging data suggested that if defibrillation was undertaken when the myocardial metabolic state was compromised, success rates were poor. Therefore, VF waveform based prediction of defibrillation success may reduce the delivery of failed shocks. The search for defibrillation prediction features gained from VF data goes back 20 years, and recently published review articles (8,9) give an excellent overview of various techniques developed for VF waveform analysis and the resulting information obtained. Approaches for optimizing timing of defibrillation include measures based on VF amplitude and slope, VF frequency measures, including wavelet decomposition, nonlinear dynamics methods, or a combination of these methods. In animals and humans, higher amplitude or power of prolonged VF was associated with significantly increased responsiveness to defibrillation. Frequency domain features resulting from fast Fourier transform (FFT) analysis of the VF signal include peak power (dominant) frequency, median frequency, spectral flatness measure, fibrillation power, instantaneous mean frequency, frequency ratio and amplitude spectrum area (AMSA), all of which have been shown to be capable of predicting countershock success. Joint time-frequency approach, and continuous wavelet technique for VF waveform analysis by providing concomitant spatial and temporal analysis within the VF signal, result in improved performance when compared to FFT based features. (10) Nonlinear measures of randomness, including scaling exponent, detrended fluctuation analysis and entropy, also revealed that an increased degree of organization of the VF waveform was associated with short downtime and an increased countershock success rate. (11)

A clinical study demonstrated that the feature combination employing neural networks does not further improve defibrillation prediction in comparison with the best predictive single features. (12) This result may indicate that an upper limit in outcome prediction using VF waveform analysis in the time and frequency domain has already been reached. Additionally, the presence of acute myocardial infarction alters VF waveform features and compromises the ability for shock outcome prediction. (13,14)

Monitoring the effectiveness of chest compression

The importance of chest compression has been re-emphasized during CPR because existing data showed that if the quality of chest compression was suboptimal or poor during resuscitation efforts, the outcome was likely to be poor. There has been increasing interest in the techniques available to monitor the quality of CPR. (15) Options now available are compression depth and rate, compression force, echocardiography, end-tidal CO_2, respiratory rate and tidal volume, transthoracic impedance and VF waveform analysis. However, some have significant limitations and are only readily available in hospital settings. (16)

VF waveform analyses have proven promising for monitoring the effectiveness of CPR in several simulator studies and clinical trials because no additional equipment is required. Several studies have shown that the quality of chest compressions affects the development of the shock predictor, such as median slope (MS), spectral features and AMSA. (17-19) Therefore, VF waveform analysis can be used to monitor the quality of compression in addition to prompting the timing of defibrillation during CPR.

VF waveform analysis: from interrupted CPR to uninterrupted CPR

Reliable and accurate VF waveform analysis is a difficult task, especially with the presence of CPR artifacts in the ECG signal to be evaluated. Efforts are therefore focused on VF waveform analysis from interrupted CPR to uninterrupted CPR. For VF classification, numerous artifact filtering algorithms have been developed to clean the chest compression corrupted ECG signal for further analysis. (20) Some filtering techniques used a separate reference signal together with ECG recordings to suppress artifacts and reconstruct the fundamental ECG signal, such as Kalman filtering, adaptive filtering and Gabor multipliers. Other algorithms analyzed the ECG waveform for rhythm classification and shock advisory without a reference signal but used the information derived from the ECG waveform itself. (21-23)

Although techniques for VF detection during uninterrupted CPR obtained satisfactory and encouraging results, the performance was still inadequate, especially for nonshockable rhythms. Further clinical and experimental investigation is required in order to integrate this type of artifact suppressing and analysis algorithm into current automatic external defibrillators (AEDs).

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