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Clinical paper

Ventricular fibrillation waveform measures and the etiology of cardiac arrest☆

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ABSTRACT

Background: Early determination of the acute etiology of cardiac arrest could help guide resuscitation or post-resuscitation care. In experimental studies, quantitative measures of the ventricular fibrillation waveform distinguish ischemic from non-ischemic etiology.
Methods: We investigated whether waveform measures distinguished arrest etiology among adults treated by EMS for out-of-hospital ventricular fibrillation between January 1, 2006–December 31, 2014. Etiology was classified using hospital information into three exclusive groups: acute coronary syndrome (ACS) with ST elevation myocardial infarction (STEMI), ACS without ST elevation (non-STEMI), or non-ischemic arrest. Waveform measures included amplitude spectrum area (AMSA), centroid frequency (CF), mean frequency (MF), and median slope (MS) assessed during CPR-free epochs immediately prior to the initial and second shock. Waveform measures prior to the initial shock and the changes between first and second shock were compared by etiology group. We a priori chose a significance level of 0.01 due to multiple comparisons.
Results: Of the 430 patients, 35% (n = 150) were classified as STEMI, 29% (n = 123) as non-STEMI, and 37% (n = 157) with non-ischemic arrest. We did not observe differences by etiology in any of the waveform measures prior to shock 1 (Kruskal–Wallis Test) ($p = 0.28$ for AMSA, $p = 0.07$ for CF, $p = 0.63$ for MF, and $p = 0.39$ for MS). We also did not observe differences for change in waveform between shock 1 and 2, or when the two acute ischemia groups (STEMI and non-STEMI) were combined and compared to the non-ischemic group.
Conclusion: This clinical investigation suggests that waveform measures may not be useful in distinguishing cardiac arrest etiology.

Introduction

Resuscitation following cardiac arrest is challenging and relies on a coordinated set of rescuer actions described by the links in the chain of survival.[1] Typically there is a standard resuscitation protocol. This protocolized approach specifies the selection, dose, and timing of therapies and potentially belies the heterogeneity of arrest etiology and acute time-sensitive physiology.[2–4] In ventricular fibrillation, the etiology of arrest is often attributed to either acute ischemia or non-ischemic arrhythmia.[5–8] Among acute ischemic arrests, some are caused by complete epicardial coronary artery occlusion sometimes manifesting as ST elevation myocardial infarction (STEMI), while others result from other presentations of critical coronary ischemia manifesting as non-STEMI.[6–8] Currently there are no diagnostic tools to distinguish such etiologies of arrest during active resuscitation. Moreover, even after a patient achieves return of spontaneous circulation (ROSC), the 12 lead electrocardiogram (ECG) may not reliably discriminate the underlying etiology of arrest.[6–8] Thus, a real-time appreciation of the cardiac arrest etiology could have implications for resuscitation therapy. Although ventricular fibrillation appears as a chaotic and disorganized rhythm, characteristics of the ventricular fibrillation waveform such as amplitude, frequency, and organization can be systematically quantified in real-time. These measures have correlated with arrest physiology and are strongly related to clinical outcome.[9–11] Evidence from animal studies indicates that ventric-

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ular fibrillation waveform measures are differentially affected by ischemia such that these waveform measures may differ at the outset or over the course of resuscitation.[12–14] We undertook a study of clinical ventricular fibrillation arrest to assess whether quantitative measures of the ventricular fibrillation waveform can distinguish among STEMI, non-STEMI, and non-ischemic etiology of arrest.

Methods

We conducted a retrospective investigation of Emergency Medical Services (EMS)-treated ventricular fibrillation cardiac arrest occurring among persons 18 years or older between January 1st, 2006 and December 31st, 2014 in greater King County, WA. Since the investigation aimed to evaluate the relationship between quantitative waveform measures and the etiology of arrest, we used a convenience sample restricted to cases with an adequate EMS defibrillator recording, defined as a minimum 5-second ventricular fibrillation epoch prior to the first, and if occurring, second shock that was free of CPR-artifact. We excluded cases with insufficient hospital information to classify the etiology of arrest. Cases were also excluded if initial shock was delivered by a public-access defibrillator.

The King County EMS system is a two-tiered system that serves 1.2 million people in urban, suburban, and rural settings. Emergency response is activated by calling 9-1-1. The first tier of EMS response is firefighter emergency-medical-technicians equipped with AEDs. The second tier is paramedics who practice advanced care life support. The EMS generally follows the American Heart Association resuscitation guidelines.[1] Patients who are resuscitated and achieve return of circulation are transported to one of 9 hospitals. Each hospital has an intensive care unit and 24-h coronary intervention services. This study was approved by the Investigational Review Board at the University of Washington Human Subjects Division. The authors have full access to the study data and take responsibility for the results.

The EMS system maintains a registry of every EMS-treated cardiac arrest.[15] The registry is organized according to the Utstein Guidelines and includes information about patient demographics, arrest circumstance, clinical course, and outcome.[16] Information is collected from dispatch reports, EMS forms, defibrillator recordings, hospital records, and vital records.

We used the electronic defibrillator recording from the LIFEPACK 12 and LIFEPACK 15 (Physio-Control, Redmond WA) and the HeartStart MRx (Philips Medical, Bothell WA) to derive the quantitative waveform measures. We identified ECG without CPR using the impedance channel. ECGs were recorded in a single lead (II), corresponding to the usual right infraclavicular and left anterior-apical placement of defibrillator patch electrodes. We sampled 5-second, CPR-free epochs of ventricular fibrillation before each shock. Raw data recordings were stored and processed using MATLAB 2014a (The MathWorks, Inc., Natick, MA).

We derived four quantitative measures: the amplitude spectrum area (AMSA), centroid frequency (CF), mean frequency (MF), and median slope (MS). AMSA was calculated as the sum of each frequency multiplied by its Fourier spectrum power from 4 to 24 Hz.[17] Centroid frequency, also known as median frequency, was calculated as the frequency at the center of mass of the Fourier spectrum up to 25 Hz.[18] Mean frequency was computed as the sum of each frequency multiplied by its power from 4 to 20 Hz, divided by the total power in that range.[19] Median slope was computed as the median value of the slope between adjacent points in the ECG.[20] While other quantitative waveform measures exist, we prospectively selected these 4 specific measures because they have been shown in previous studies to differ according to etiology.[9–11,19–21]

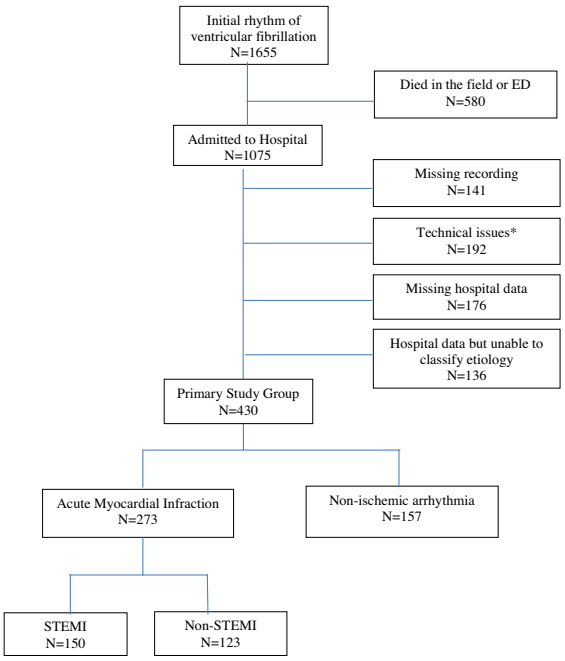
The etiology of arrest was classified into one of 3 exclusive groups: (1) an acute coronary syndrome (ACS) consistent with STEMI, (2) ACS consistent with non-STEMI, or (3) cases without evidence of ACS (non-acute ischemia group). ACS was formally defined as the presence of diagnostic cardiac biomarkers of myocardial injury with one or more additional features: pre-event symptoms or circumstances suggestive of ischemia, acute ECG abnormalities, findings on cardiac catheterization or other cardiac imaging studies, conclusions from cardiology consultation, and/or post-mortem findings.[22] We chose to classify ACS into two ECG groups because interventions for STEMI could differ from non-STEMI given the potential for acute coronary interventions in the STEMI group.[7] In cases where information was not conclusive, the case was classified as indeterminate and not included in the primary study group. Q6

We used descriptive statistics to assess Utstein characteristics according to study inclusion and etiology of arrest. Waveform measures were natural logarithm transformed to achieve a more normal distribution. Analyses used nonparametric and parametric tests depending on the distribution of the measures. Accordingly, we used the nonparametric Kruskal–Wallis Test to compare waveform measures prior to the initial shock. Analysis of covariance (ANCOVA) was used to test the relationship between etiology group and the changes between shocks 1 and 2 in order to account for the initial pre-shock 1 values, as the magnitude of possible change might be related to the initial value before shock 1. In a secondary analysis, we combined the 2 ACS groups of STEMI and non-STEMI for comparison with the non-ischemic etiology group using the nonparametric Mann–Whitney Test to compare the pre-shock 1 values and ANCOVA to compare the change from the pre-shock 1 measure to the pre-shock 2 measure.

All analyses were conducted in SPSS Version 23.0 (SPSS Version 23.0, IBM Corporation, Copyright IBM Corporation 2015). Given the multiple comparisons, we a-priori considered a p value of ≤ 0.01 to be statistically significant.

Results

During the study period, King County EMS agencies treated 1655 cardiac arrest patients who presented with ventricular fib-



* Technical reason for exclusion included lack of an impedance or force signal to assess CPR status, the presence of pacer spikes, severe motion artifact, and high-frequency power noise.

Fig. 1. Flow diagram of study population.