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The effect of ischemia on ventricular fibrillation as measured by fractal dimension and frequency measures☆,☆☆

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Summary
Introduction: Most animal studies of ventricular fibrillation (VF) waveform characteristics involve healthy animals with VF initiated by electric shock. However, clinical VF is usually the result of ischemia. The waveform characteristics in these two types of VF may differ. The angular velocity (AV), frequency ratio (FR) and median frequency (MF) are three frequency-based measures of VF. The scaling exponent (ScE), the logarithm of the absolute correlations (LAC) and the Hurst exponent (HE) are three measures of the fractal dimension of VF.
Hypothesis: We hypothesized that these quantitative measures would differ between ischemic and electrically initiated VF.
Methods: VF was induced in 14 swine by electric shock and in 12 swine by ischemia. For ischemia induced VF animals, an angioplasty catheter was positioned in the mid-LAD and the balloon inflated. A mean of 891 ± 608 (S.D.) s later, VF occurred. For electrically induced animals, an AC current was passed through a catheter in the RV. Following initiation by either method, VF was recorded for 7 min. Sequential 5 s epochs were analyzed for AV, FR, MF and fractal dimension measures.
Results: Ischemic VF demonstrated a significantly higher fractal dimension as estimated by the ScE for the first 0—90 s ($p = 0.021$) and for 90—180 s ($p = 0.016$). The

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Hurst exponent was significantly higher for ischemic VF for both 0—90 s ($p < 0.0001$) and 90—180 s ($p < 0.0001$). The fractal dimension as estimated by the LAC method was not significantly different for 0—90 s ($p = 0.056$) but was highly significant for 90—180 s ($p = 0.001$). During the initial 90 s the groups did differ in all measures of frequency as follows: AV ($p < 0.001$), FR ($p < 0.001$), MF ($p < 0.001$). These differences did not persist beyond 90 s except for a mild elevation of the FR after 270 s ($p < 0.02$).
Conclusion: Fractal based measures indicate an increase in the fractal dimension of ischemia induced VF for the first 180 s when compared to electrically induced VF. Frequency-based measures uniformly demonstrate a pattern of higher frequencies for electrically induced VF for the first 90 s. The increased fractal dimension and decreased frequencies associated with ischemia induced VF may reflect changes in the underlying myocardial physiology that can be used to guide therapies.

Introduction

Ventricular fibrillation (VF) is the first recorded electrocardiographic rhythm in approximately 30% of sudden cardiac death events in the out-of-hospital setting.[1,2] Three large studies of cardiac arrest have demonstrated that when cardiopulmonary resuscitation (CPR) is performed for one and one half to three minutes prior to defibrillation there is an associated increase in survival of over 10%.[1—3] The increased survival is due almost exclusively to greater survival (approximately 15%) in the group of patients with VF duration of over 4—5 min. In these studies, patients with shorter VF durations did not show an increase in survival when CPR was performed prior to defibrillation.

The findings of these clinical trials, as well as laboratory investigations, have led to the search for a method which would discriminate VF of over 5 min duration (prolonged VF) from VF of under 5 min duration (early VF). Such a method would allow the application of CPR prior to defibrillation for those patients with prolonged VF and potentially increase the likelihood of survival. It would also identify those patients with early VF who would benefit from immediate defibrillation.

Earlier laboratory studies have demonstrated that VF waveform analysis methods can provide an estimate of the duration of VF from the recorded electrocardiogram for use in treatment algorithms.[4—10] These methods exploit the two main features of the VF waveform, namely, frequency and roughness. Frequency is most often measured by Fourier analysis techniques and roughness is estimated by the use of the fractal dimension. The fractal dimension is based on chaos theory and is a quantitative measure of the roughness of a line.[11] A straight line has a dimension of 1. Early VF which has large smooth contours has a dimension near 1.1 and this gradually increases with VF duration to a dimension of 1.5 or greater as the waveform becomes more irregular.[7,9]

The three frequency-based measures have been studied extensively and include median frequency, angular velocity, and frequency ratio.[4—8,12,16] Measures of the fractal dimension have also been developed to analyze VF and include the scaling exponent (ScE)[9,13—15] and the logarithm of the absolute correlations (LAC).[17] Another measure of fractal dimension is the Hurst exponent.[7,18—20] The Hurst exponent indicates the degree to which the values in a waveform deviate from being random. In random Brownian motion the Hurst exponent is 0.5. Hurst exponents less than this indicate a waveform that is significantly more 'rough' than a Brownian path. All three fractal measures therefore estimate the roughness of the VF waveform.

Methods to estimate the duration of VF have been derived from VF waveform recordings from healthy swine in which VF was induced by brief AC current electrical stimulation of the myocardium. However, VF in the clinical arena is often preceded by ischemia. It is likely that measures of VF frequency and roughness result from alterations in the underlying myocardial physiology and that these measures would demonstrate differences between electrically induced VF and that produced by ischemia. In other words, ischemically induced VF may appear to be more prolonged in duration compared to electrically induced VF. We sought to determine whether VF produced by electrical shock differed from that produced by ischemia in terms of measures based on frequency and fractal dimension. Differences would have implications regarding estimation of VF duration and could affect decisions regarding initial therapy, namely, CPR versus immediate countershock. Specifically, if ischemically induced VF deteriorates more quickly than electrical VF, it would indicate that patients with ischemic VF should receive CPR earlier than those with other types of VF. Patients with other types of VF would be responsive to electric shock for a longer period of time. The difference between the two would be determined directly by these