Computer Algorithm for Tracking ECG Spectral Dynamics in Ventricular Tachyarrhythmias

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Abstract

ECG spectral dynamics might reveal information about the organization of the underlying reentrant circuits in ventricular arrhythmias. We present a computer algorithm for tracking changes in the spectral dynamics of ventricular tachyarrhythmias applied to 5 recordings each of monomorphic ventricular tachycardia (MVT) and ventricular fibrillation (VF). Peaks in the spectra were continually tracked throughout the recording if the change in frequency at each time step was equal to or less than the spectral resolution (0.12 Hz) and the peak amplitude exceeded the spectral noise. The algorithm was used to quantify the number, frequency, amplitude and durations of the spectral peaks. In all cases MVT was characterised by a single peak lasting for the full duration of the recordings. VF had many more peaks with on average 4.6 peaks. The peaks evolved and diminished with continuous evolution of the longest duration peaks of on average 21.9 s.

1. Introduction

The mechanisms responsible for human ventricular fibrillation are poorly understood. Animal models have been used extensively to elucidate the mechanisms, but important differences between VF in humans and animals are emerging. For example, VF in animals with similar sized hearts to humans appears to be sustained by many more reentrant sources than human VF [1]. Reentrant activity is known to correlate with body surface ECG fibrillation frequency so the complexity of the underlying VF sources is expected to be reflected in the spectra of the ECG [2]. VF is fatal if the arrhythmia is not terminated within minutes by defibrillation. This very much restricts the opportunities for studying human VF. Clinically, VF occurs spontaneously and is the leading cause of sudden cardiac death. A human model of VF utilises fast pacing to initiate VF during cardiac surgery or electrophysiological study. Such studies are limited by the considerable ethical issues arising from inducing a potentially fatal abnormal heart rhythm in patients. Additionally, the opportunities to record spontaneously occurring VF in humans are limited to opportunistic occurances during monitoring. However, high risk patients who are hospitalised are routinely continuously monitored by ECG and this facilitates simple, non-invasive measurement of spontaneous human VF. For example, such recordings have been used to describe changes in dominant frequency of fibrillation [3,4]. Dominant frequency is an often reported characteristic of VF, however, dominant frequency alone neglects the rich spectral content contained in the ECG of VF. The dynamic spectra of VF ECG recordings might reveal important information about the organisation of human VF. In terms of the organisation or complexity of the underlying electrical activity, VF is complex compared with more organised ventricular arrhythmias such as MVT. The aim here was to quantify the dynamics of spectral characteristics of VF and to compare these to the dynamics of MVT.

2. Methods

The ECGs of 10 patients, 5 with MVT and 5 with VF were analysed. Arrhythmia ECGs were recorded from patients on the ICU at Freeman Hospital using an automated system [5]. The length of the recordings ranged from 26 s to 110 s and the sample rate was 250 Hz. A 20 s extract of each of the recordings is shown in figure 1. The power spectral density at time steps of 0.04 s across the ECG was estimated by the periodogram using a 2048 point FFT and Bartlett-Hann window providing a frequency resolution of 0.12 Hz. At each time step discrete spectral peaks were automatically identified as peaks above the noise threshold. Figure 2 shows examples of the spectra obtained at a single time step. An estimate of the spectral noise was obtained from the maximum power in the range 1 to 3 Hz which was outside the range of frequencies of VF and MVT. Dynamics of the spectra were measured by tracking changes in power and frequency of the spectral peaks. Peaks were considered to evolve continuously if the change in frequency of the peaks from time step to time step was less than or equal to 0.12 Hz (the spectral

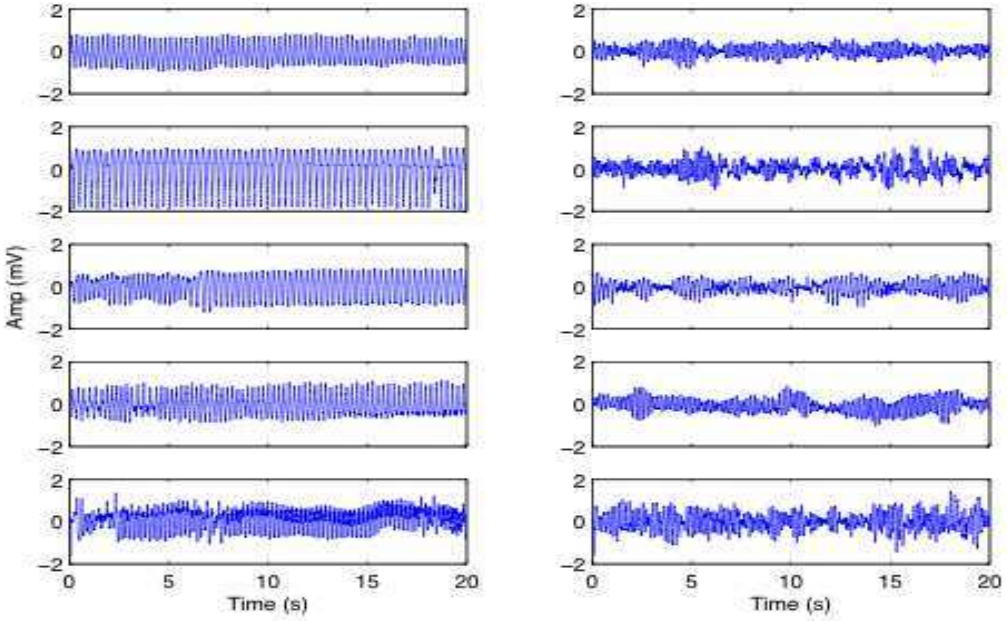

Figure 1. 20 s segments of ECGs analysed during this study. MVT (left column) and VF (right column).

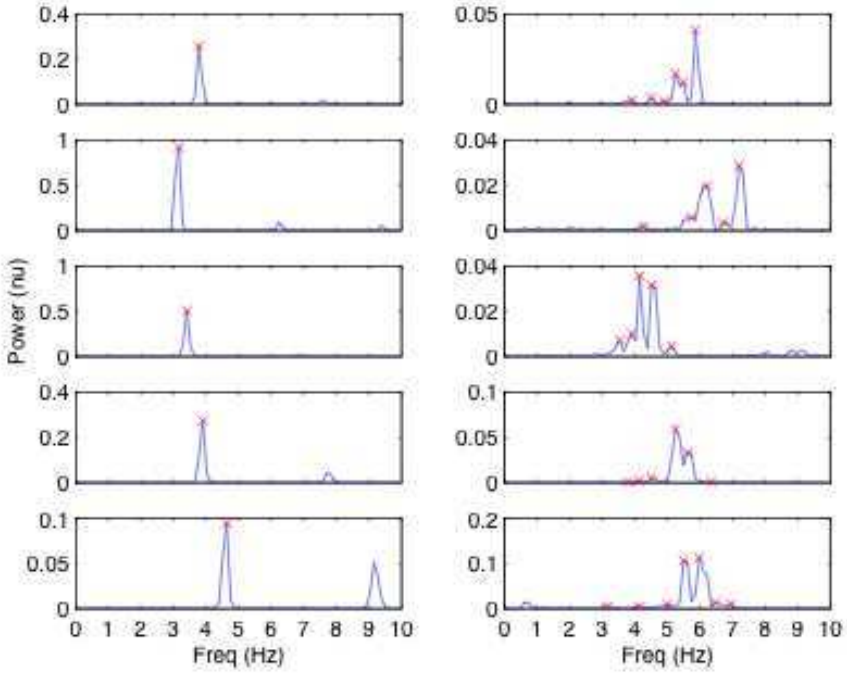

Figure 2. Example spectra and spectral peaks of ECGs correspondingly illustrated in figure 1. The spectra were calculated from a segment of ECG of duration approximately 8 s (2048 sample points). Spectra are normalised to the ECG with the greatest amplitude illustrated in Figure 1 (1st column, 2nd row).

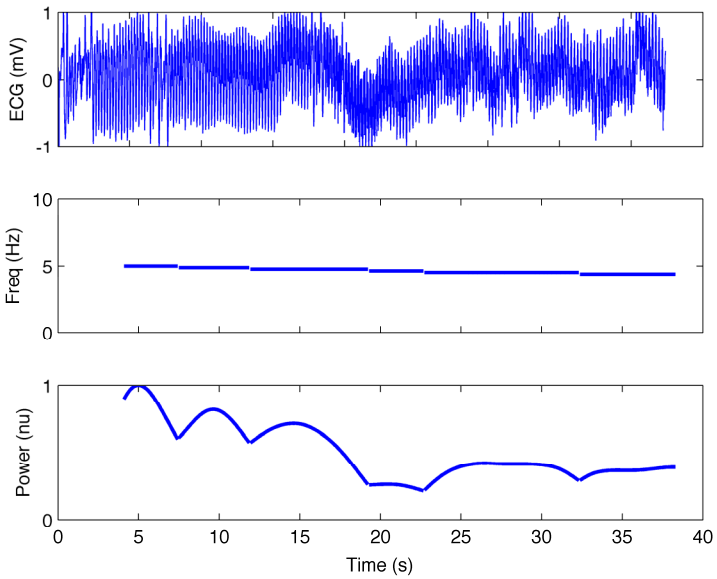

Figure 3. Spectral tracking algorithm applied to the ECG of a patient with MVT. Panel 1 shows the ECG. Panel 2 shows the evolution of frequency of the single spectral peak. Panel 3 shows the evolution of the power of the spectral peak. Note that throughout the recording the tachycardia was characterised by a single spectral peak.

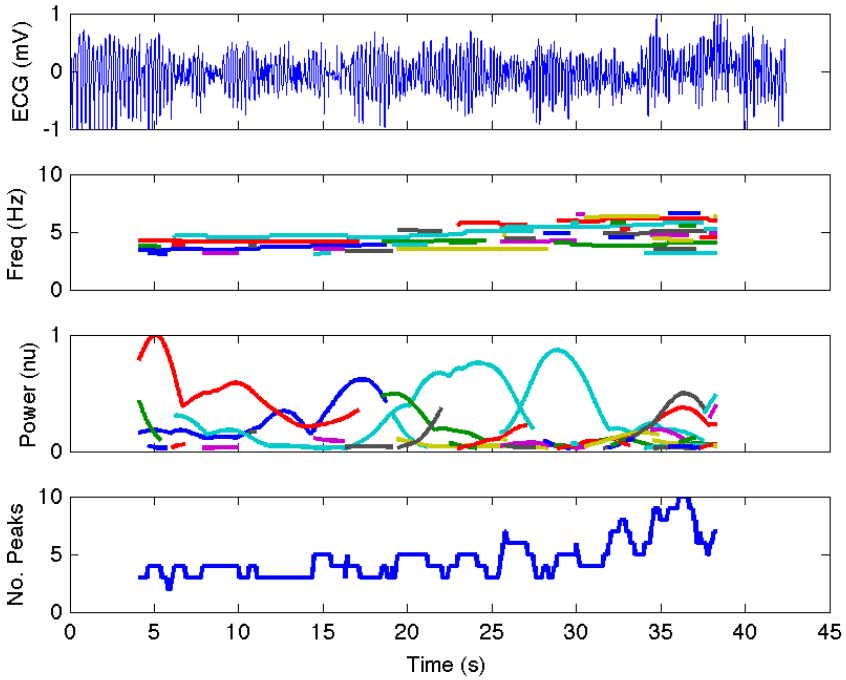

Figure 4. Spectral tracking algorithm applied to the ECG of a patient with VF. Panel 1 shows the ECG. Panel 2 shows the evolution of frequencies of the spectral peaks. Panel 3 shows the evolution of the power of the spectral peaks and panel 4 shows the evolution of the number of spectral peaks. Note how the number and frequency of peaks increase.

resolution) and the power was greater than the noise threshold. At each time step the number of peaks was calculated. Peaks corresponding to harmonics of the fibrillatory frequencies were discounted. The durations of the longest sustained peaks was also calculated.

3. Results

Figure 3 and 4 illustrate examples of the results obtained for MVT and VF recordings using the spectral tracking algorithm. In all cases of MVT the dynamic spectra comprised a single spectral peak lasting for the full duration of the recording. In four cases the frequency of the spectral peak gradually reduced throughout the recording as illustrated in the example shown in figure 3, while in the remaining case the frequency was constant throughout the recording. In VF there were more spectral peaks and the average number of peaks across recordings ranged from 3.8 to 5.7 with on average 4.6 spectral peaks for this group. Figure 4 provides an example to illustrate how the frequency, power and number of spectral peaks was tracked during an episode of VF. In this example the maximum number of peaks reached 10 towards the end of the recording. The longest sustained peaks in each recording lasted for durations ranging from 19 to 28 s with an average of 21.9 s.

4. Discussion and conclusions

The algorithm automatically tracked changes in spectral parameters during ventricular tachyarrhythmias. The complexity of the spectra of these arrhythmias reflects the complexity of the underlying electric sources. We have shown that VF is characterised by more spectral peaks than MVT which is know to be a highly organised arrhythmia. The algorithm requires testing to establish the consistency of the results under a range of algorithm parameters such as sample rate, number of points used, frequency resolution and power spectral density estimator.

The number of spectral peaks might provide a non-invasive surrogate for the number of underlying re-entrant paths sustaining the arrhythmia. However, this hypothesis remains to be tested.

Acknowledgements

PL is supported by a UK EPSRC Advanced Research Fellowship.

References

[1] Ten Tusscher KHWJ, Hren R, Panfilov AV. Organization of ventricular fibrillation in the human heart. Circ Res. 2007;100:e87-e101.

[2] Mandapati R, Asano Y, Baxter WT, Gary R, Davidenko J, Jalife J. Quantification of effects of global ischemia on dynamics of ventricular fibrillation in isolated rabbit heart. Circulation 1998;98:1688–96.

[3] Clayton RH, Murray A, Campbell RWF. Changes in the surface electrocardiogram during the onset of spontaneous ventricular fibrillation in man. European Heart Journal 1994;15:184-8.

[4] Patwardhan A, Moghe S, Wang K, Leonelli F. Frequency modulation within electrocardiograms during ventricular fibrillation. Am J Physiol Heart Circ Physiol 2000;279:H825–H835.

[5] Clayton RH, Murray A, Whittam AM, Campbell RWF. Automatic recording of ventricular fibrillation. In: Computers in Cardiology 1991. IEEE Computer Society Press 1992, 685-8.

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