

# Measurement of Heart Rate Variability during Recurrent Episodes of Ventricular Tachyarrhythmia in One Patient Using Wavelet Transform Analysis

I Romero Legarreta<sup>1</sup>, MJ Reed<sup>2</sup>, PS Addison<sup>1,3</sup>, NR Grubb<sup>4</sup>,  
GR Clegg<sup>2</sup>, CE Robertson<sup>2</sup>, JN Watson<sup>3</sup>

<sup>1</sup>Faculty of Engineering and Computing, Napier University, Edinburgh, UK

<sup>2</sup>Department of Emergency Medicine, Royal Infirmary of Edinburgh, Edinburgh, UK

<sup>3</sup>Cardiodigital, Elvingston, UK

<sup>4</sup>Department of Cardiology, Royal Infirmary of Edinburgh, Edinburgh, UK

## Abstract

Changes that occur in heart rate characteristics prior to episodes of ventricular tachyarrhythmia (VTA) have been studied previously in an attempt to gain a better understanding as to when these potentially fatal events may occur and to guide potential therapies. In this paper we have the unique opportunity to study the electrocardiogram of one patient over a period of 36 hours, during which multiple VTA episodes occurred. We studied the evolution of the most common Heart Rate Variability (HRV) parameters both prior to and after the onset of the initial VTA. The patient was treated by angiography, ballooning and stenting, and HRV parameters were then studied for a further 24 hours. By studying such patients, a better understanding of the changes occurring in the heart around such VTAs may be gained.

## 1. Introduction

Given the current dismal survival rates of cardiac arrest occurring in the community, efforts directed towards the early detection of ventricular tachyarrhythmias (VTAs) are crucial [1]. The aim of this study was to see whether a better understanding of heart rate variability changes around VTA events could be gained by studying a single patient experiencing multiple episodes of VTAs.

## 2. Theory

The wavelet transform of a continuous time signal,  $x(t)$ , is defined as:

$$T(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) \psi^* \left( \frac{t-b}{a} \right) dt \quad (1)$$

where  $\psi^*(t)$  is the complex conjugate of the wavelet function  $\psi(t)$ ,  $a$  is the dilation parameter of the wavelet

and  $b$  is the location parameter of the wavelet. In order to be classified as a wavelet, the function must satisfy certain mathematical criteria. These are:

1 - A wavelet must have finite energy:

$$\text{i.e. } E = \int_{-\infty}^{+\infty} |\psi(t)|^2 dt < \infty \quad (2)$$

2 - If  $\hat{\psi}(f)$  is the Fourier transform of  $\psi(t)$ ,

$$\text{i.e. } \hat{\psi}(\omega) = \int_{-\infty}^{+\infty} \psi(t) e^{-i(\omega)t} dt \quad (3)$$

then the following condition must hold:

$$C_g = \int_0^{\infty} \frac{|\hat{\psi}(\omega)|^2}{\omega} d\omega < \infty \quad (4)$$

This implies that the wavelet has no zero frequency component, i.e.  $\hat{\psi}(0) = 0$ , or to put it another way, it must have a zero mean. Equation 4 is known as the *admissibility condition* and  $C_g$  is called the *admissibility constant*. The value of  $C_g$  depends on the chosen wavelet.

3 - For complex (or analytic) wavelets, the Fourier transform must both be real and vanish for negative frequencies.

The contribution to the signal energy at the specific  $a$  scale and  $b$  location is given by the two-dimensional wavelet energy density function known as the scalogram:

$$E(a,b) = |T(a,b)|^2 \quad (5)$$

The total energy in the signal may be found from its wavelet transform as follows:

$$E = \frac{1}{C_g} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} |T(a,b)|^2 da db \quad \left[ = \int_{-\infty}^{+\infty} x(t)^2 dt \right] \quad (6)$$

In practice a fine discretisation of the continuous wavelet transform is computed where usually the  $b$  location is discretised at the sampling interval and the  $a$  scale is discretised logarithmically. The  $a$  scale discretisation is often taken as integer powers of 2, however, we use a finer resolution in our method where the  $a$  scale discretisation is in fractional powers of two. The discretised continuous wavelet transform (CWT) is made distinct from the discrete wavelet transform (DWT) in the literature. In its basic form, the DWT employs a dyadic grid (integer power of two scaling in  $a$  and  $b$ ) and orthonormal wavelet basis functions and exhibits zero redundancy. Our method, i.e. using a high resolution in wavelet space as described above, allows individual maxima to be followed accurately across scales, something that is often very difficult with discrete orthogonal or dyadic stationary wavelet transforms incorporating integer power of two scale discretisation. Further background information concerning continuous wavelets can be found in references [2] and [3].

### 3. Methods

Equipment was installed within the Coronary Care Unit of the Royal Infirmary of Edinburgh to collect ECG signals continuously from all six beds within the unit over an 18-month period [4]. The signals were sampled at 500 Hz using 16 bits per sample. The ECG signals from all patients who had an episode of ventricular tachyarrhythmia (VTA) during their stay were scrutinized. A 36-hour section of ECG signal from one patient, who developed multiple episodes of VTAs during a 7-hour period, complicating an acute myocardial infarction, was analysed. The ECG signal from the five-hour period prior to the initial VTA, and the subsequent 24-hour period was studied.

The R points were found using a wavelet transform based algorithm [5]. NN intervals were obtained from the RR series by correcting the RR intervals that differed by more than 25% from the previous NN interval. Ectopics were moved to the halfway point between the previous normal beat and the next normal beat. Time domain and wavelet domain HRV parameters were calculated. In the time domain, we considered the NN50 and the SDNN. The Mexican Hat wavelet was used and we considered the energy of the three standard bands, high frequency (HF; 0.15–0.40 Hz), low frequency (LF; 0.04–0.15 Hz) and very low frequency (VLF; 0.003–0.04 Hz), and also the LF/HF ratio. The change in these parameters was then plotted.

### 4. Results

During the 7 hours from the patient's initial VTA until definitive treatment with angiography, ballooning and

stenting, the patient suffered multiple VTAs. These comprised 15 ventricular fibrillation cardiac arrests and 4 cardiac arrests of pulseless ventricular tachycardia which were all successfully electrically cardioverted.

The patient's heart rate showed much variability prior to his VTAs and had a mean of 70 beats per minute. 30 minutes prior to the first VTA episode there was a fall in heart rate [Figure 1]. SDNN rose 40 minutes prior to the first VTA event [Figure 2], NN50 rose 28 minutes prior to the event [Figure 3], and there was an increase in ectopic beat frequency for half an hour prior to the first VTA [Figure 4].

There was also a rise in all energy band frequencies just prior to the VTA [Figures 5-7], and a fall in LF/HF ratio [Figure 8]. Following revascularization and drug therapy, mean heart rate dropped to 60 beats per minute and there was less variability in all the HRV parameters [Figures 9-10]. In figures 9 and 10, a peak is seen towards the end of the hour. This is probably explained by a misdetection in the ectopic beat removal algorithm. Ectopic beat detections algorithms show good accuracy when used on regular sinus rhythms with little noise, and no ischemia. They are not however accurate enough to remove all ectopic beats when faced with more complex traces. In a previous study we removed all ectopic beats using a manual technique, however this becomes difficult when analysing large quantities of ECG signal as was done in this study. Figures 9 and 10 demonstrate how the misdetection of one ectopic beat can have a significant effect on the HRV tracings.

### 5. Discussion and conclusions

In conclusion, the study of a large quantity of data collected from a single patient exhibiting multiple VTAs, has enabled us to follow the acute changes occurring in HRV both before and after VTA episodes, and to also examine the effect of medical therapy on the HRV signal.

This study confirms the belief that there are unquestionably changes in HRV prior to the development of a VTA. The effect of drug therapy and angiography in our patient led to a successful clinical outcome, with the patient surviving to hospital discharge. This was associated with a reduction in variability of all HRV parameters post medical therapy. The mechanism by which this change occurs is unclear. It has been shown previously that a reduction in HRV is associated with a poor long term survival post myocardial infarction [6] and cardiac arrest [7], however our study raises the possibility that it may be of positive benefit immediately post VTA event.

Whilst this study is only of a single patient, the data collection and detailed analytical techniques used can be applied to the larger population that would be required in order to further validate these findings.

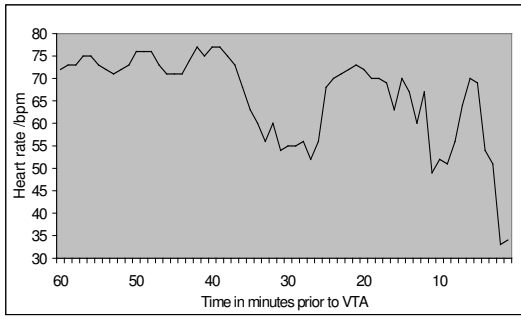


Fig. 1. Changes in heart rate in the one-hour period prior to the first VTA event in our patient.

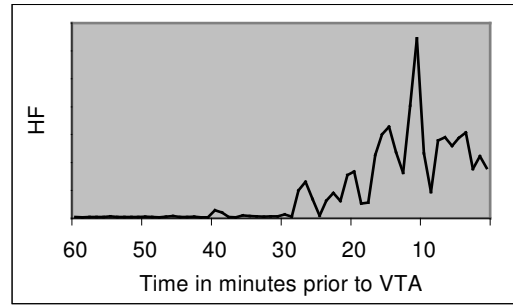


Fig. 5. Changes in high frequency energy band in the one-hour period prior to the first VTA event in our patient.

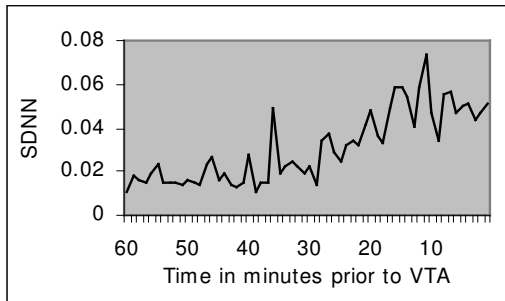


Fig. 2. Changes in SDNN in the one-hour period prior to the first VTA event in our patient.

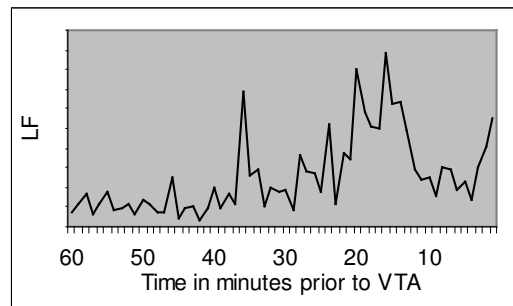


Fig. 6. Changes in low frequency energy band in the one-hour period prior to the first VTA event in our patient.

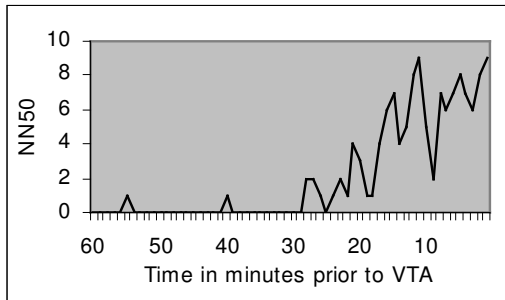


Fig. 3. Changes in NN50 in the one-hour period prior to the first VTA event in our patient.

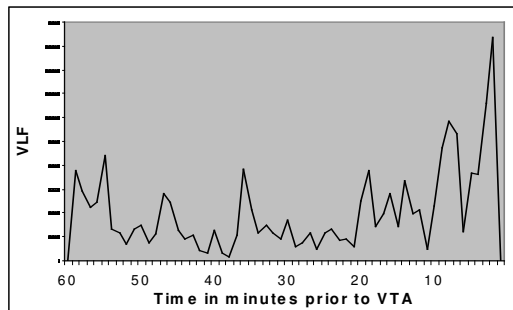


Fig. 7. Changes in very low frequency energy band in the one-hour period prior to the first VTA event in our patient.

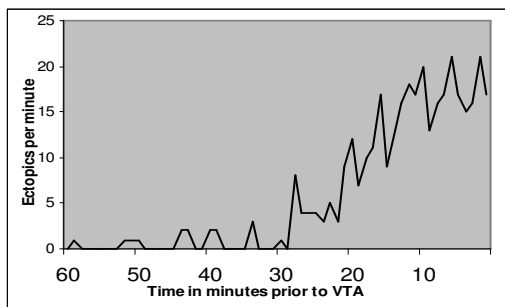


Fig. 4. Changes in ectopic beat frequency in the one-hour period prior to the first VTA episode.

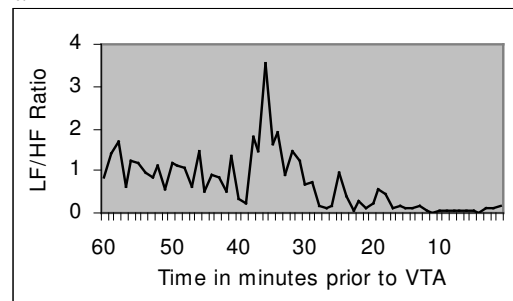


Fig. 8. Changes in LF/HF ratio in the one-hour period prior to the first VTA event in our patient.

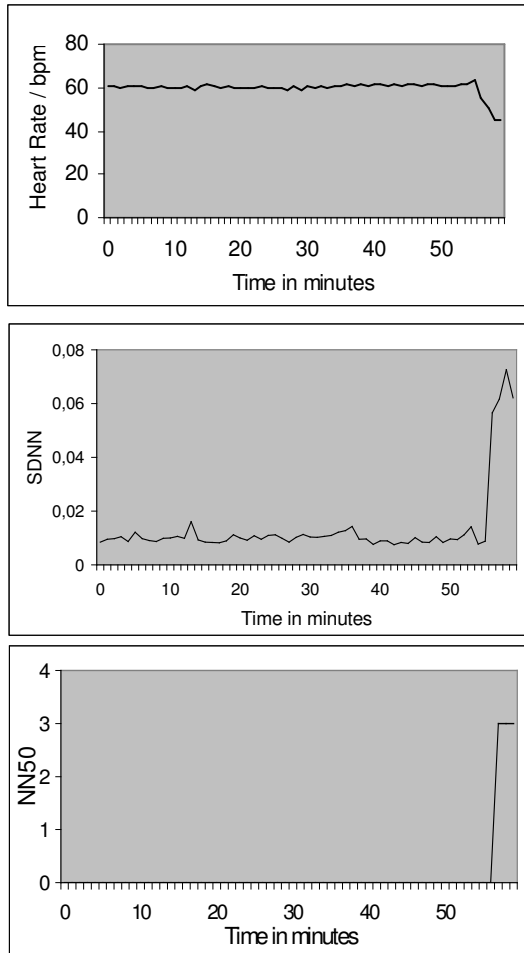


Fig. 9. Evolution of the different HRV parameters in time domain 1 hour after treatment with ballooning.

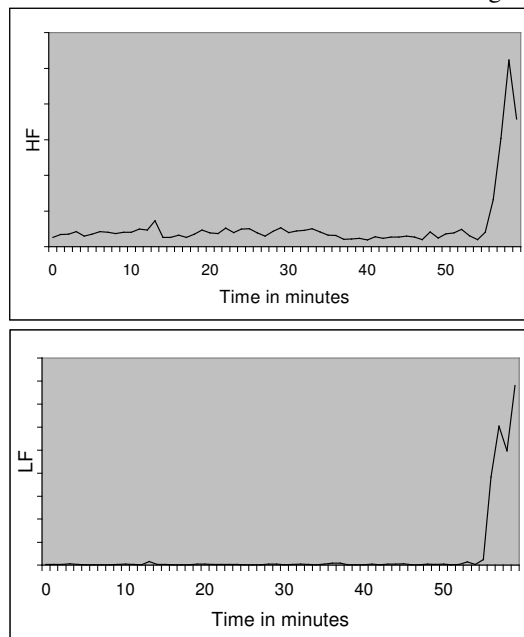


Fig. 10. Evolution of the different HRV parameters in wavelet domain 1 hour after treatment with ballooning.

## References

- [1] Holmberg M, Holmberg S, Herlitz J et al. Survival after cardiac arrest outside hospital in Sweden. *Resuscitation* 36(1): 29-36, 1998 Jan.
- [2] Addison PS. *The Illustrated Wavelet Transform Handbook: Applications in Science, Engineering, Medicine and Finance*. Institute of Physics Publishing, Bristol, 2002.
- [3] Addison PS, Watson JN, Feng T. Low-Oscillation Complex Wavelets. *Journal of Sound and Vibration* 2002; 254: 733-762.
- [4] Romero Legarreta I, Reed MJ, Watson JN et al. Long Term Continuous Collection of High Resolution ECG Signals from a Coronary Care Unit. *Computers in Cardiology* 2003;30:407-9
- [5] Romero Legarreta I, Addison PS, Reed MJ et al. Continuous Wavelet Modulus Maxima and the Analysis of the Electrocardiogram: Beat Characterisation and Interbeat Measurement. *International Journal of Wavelets, Multiresolution and Information Processing* (in press).
- [6] Wolf MM, Varigos GA, Hunt D et al. Sinus arrhythmia in acute myocardial infarction. *Med J Australia* 1978; 2: 52-3.
- [7] Dougherty CM, Burr RL. Comparison of heart rate variability in survivors and nonsurvivors of sudden cardiac arrest. *American Journal of Cardiology*. 70(4): 441-8, 1992 Aug 15.

Address for correspondence

Iñaki Romero Legarreta,  
 Faculty of Engineering and Computing,  
 Napier University,  
 10 Colinton Road,  
 Edinburgh EH10 5DT, UK.  
 inaki@napier.ac.uk