Recurrence Plot Based Analysis
of Heart Rate Variability Before the Onset of Ventricular Tachycardia

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BACKGROUND

In this study new developed recurrence plot (RP) based complexity measures were applied to find early signs of ventricular tachy-arrhythmias (VT) in patients with an implanted cardioverter-defibrillator based on heart rate variability (HRV) data.

The method of RPs was introduced to visualize the behaviour of trajectories in the m-dimensional phase space, which represent the systems' dynamics. It pictures the recurrence of the phase space trajectory to a certain state by plotting black dots in a $N \times N$ matrix (cf. Fig. 1). The recurrence plot exhibits characteristic patterns which are caused by typical dynamical behavior, e. g. diagonals (similar local evolution of different parts of the trajectory) or horizontal and vertical black lines (state does not change for some time).

The recently introduced recurrence quantification analysis (Webber et al., 1994) provides measures based on the diagonal structures, e. g. recurrence rate, determinism and maximal length of diagonal structures (L_{max}).

We have introduced three new RP based measures of complexity, the laminarity (Λ), trapping time (T) and maximal length of vertical structures in the RP (V_{max}). The laminarity enables us generally to detect laminar states in a dynamical system. The trapping time contains information about the frequency of the laminar states and their lengths. The maximal vertical length reveals information about the time duration of the laminar states thus making the investigation of intermittency possible.

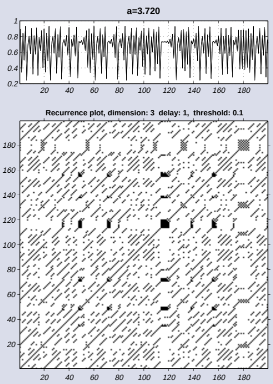

Figure 1: Recurrence plot of a chaotic time series (logistic map, a=3.720). Diagonals mark similar local evolution of different parts of the trajectory; horizontal and vertical black lines occure when states does not change for some time (laminar states).

DATA

Heart rate variability (HRV) typically shows a complex behavior (Task Force, 1996) and it is difficult to identify disease specific patterns. A fundamental challenge in cardiology is to find early signs of ventricular tachy-arrhythmias (VT) in patients with an implanted cardioverter-defibrillator (PCD 7220/7221, Medtronic) based on HRV data.

Using two nonlinear approaches, we have recently found significant differences between control and VT time series based mainly on laminar phases in the data before a VT (Wessel et al., 2000). Therefore, the aim of our investigation is to test whether our RP approach is suitable to identify and quantify these laminar phases. We reanalyze these intervals from 17 chronic heart failure patients just before the onset of a VT and at a control time, i. e. without a following arrhythmic event.

RESULTS AND DISCUSSION

We calculate all standard RQA parameters as well as the new measures laminarity Λ, trapping time T and maximal vertical line length V_{max} (in similarity to the maximal diagonal line length L_{max}) for different embedding dimensions m and nearest neighbouring radii ε. We find differences between both groups of data for several of the parameters mentioned above (Figs. 2 and 3). However, the most significant parameters are V_{max} and L_{max} for rather large radii (Marwan et al., 2002). The vertical line length V_{max} is more powerful in discriminating both groups than the diagonal line length L_{max} and the parameters described in Wessel et al. (2000), as can be recognized by the higher p-values for V_{max} (cf. Table 1).

In conclusion, this study has demonstrated that the RQA based complexity measures could play an important role in the prediction of VT events even in short term HRV time series.

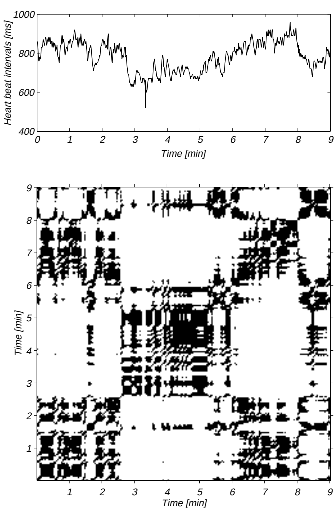

Figure 2: Recurrence plots of the heart beat interval time series at a control time with an embedding of 6 and a radius of 110. The RP from the control series shows only small rectangles.

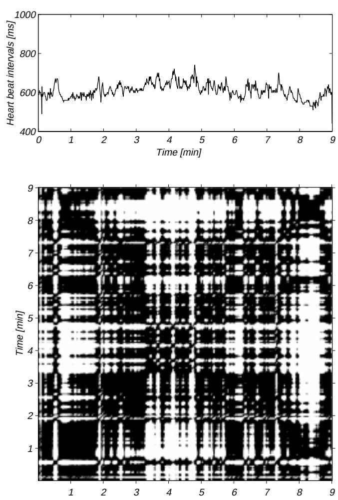

Figure 3: Recurrence plots of the heart beat interval time series before a VT with an embedding of 6 and a radius of 110. The RP before a life-threatening arrhythmia is characterized by big black rectangles.

m	ε	VT	Control	p
Maximal diagonal line length L_{max}				
3	77	396.6 ± 253.8	261.5 ± 156.6	n.s.
6	110	447.6 ± 269.1	285.5 ± 160.4	*
9	150	504.6 ± 265.9	311.6 ± 157.2	*
12	170	520.7 ± 268.8	324.7 ± 180.2	*
Maximal vertical line length V_{max}				
3	77	261.4 ± 193.5	169.2 ± 135.9	*
6	110	283.7 ± 190.4	179.5 ± 134.1	**
9	150	342.4 ± 193.6	216.1 ± 137.1	**
12	170	353.5 ± 221.4	215.1 ± 138.6	**

Table 1: Results of maximal diagonal and vertical line length shortly before VT and at control time, nonparametric Mann-Whitney U-test, p – significance (* – p < 0.05; ** – p < 0.01; n.s. – not significant p > 0.05)

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