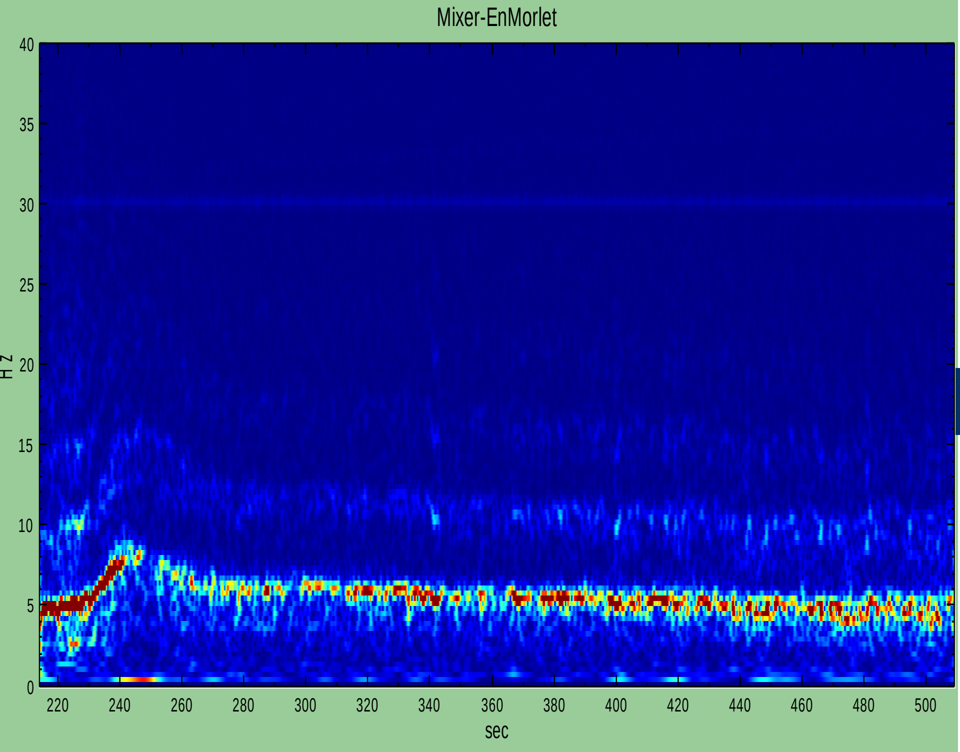
# Detecting hidden information in ventricular fibrillation

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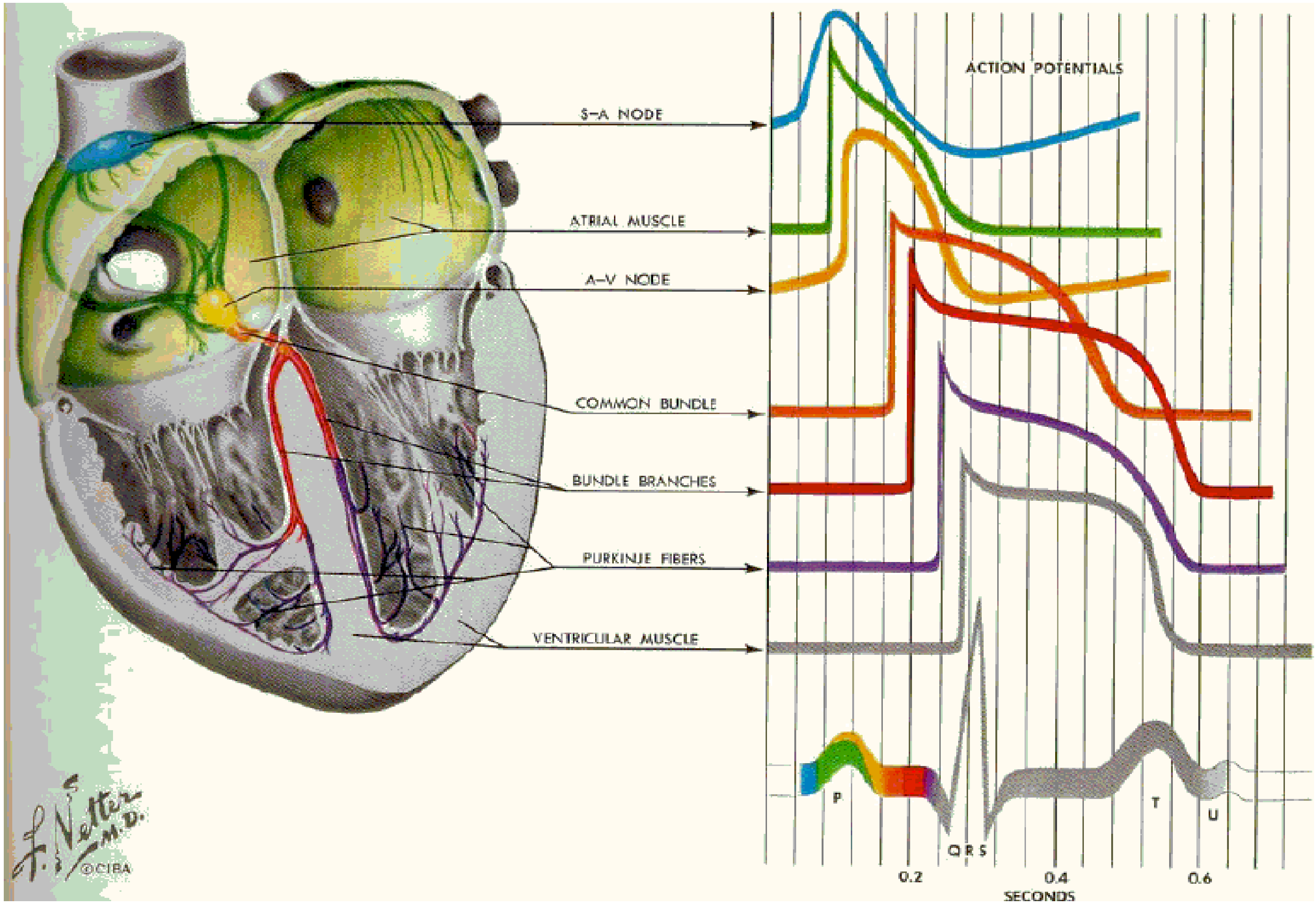
9/2/2008

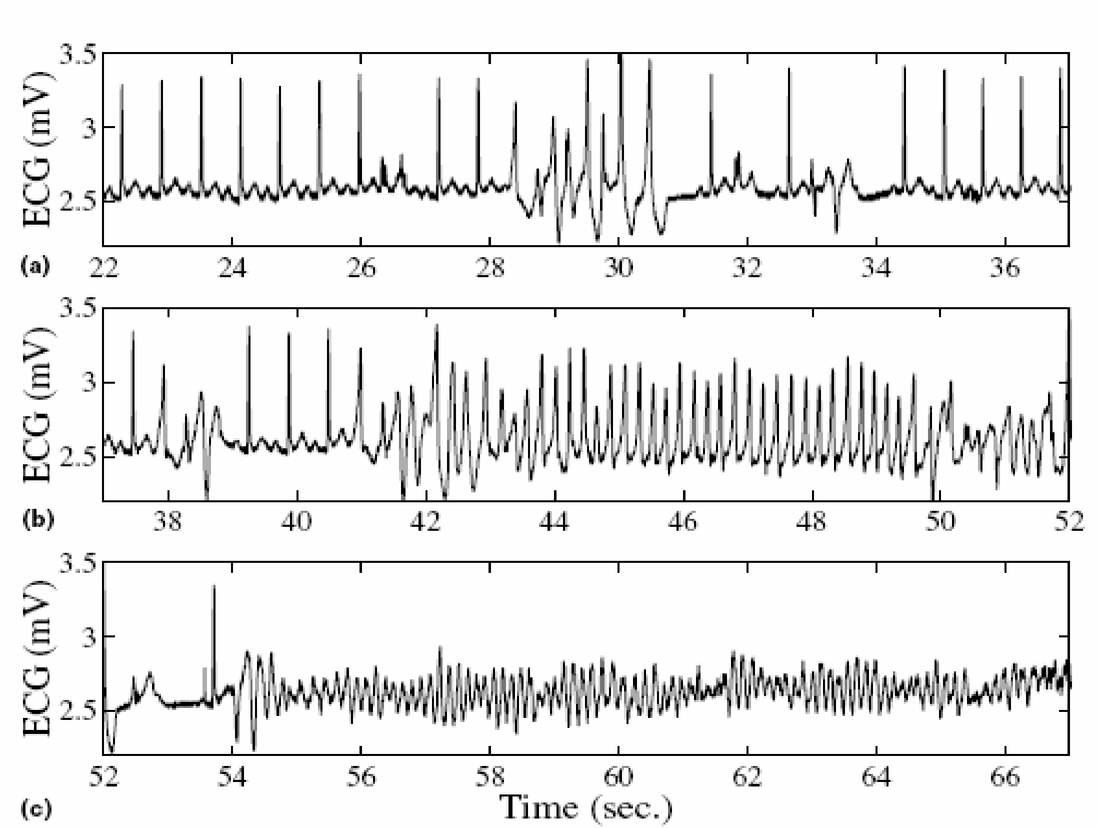
# Outline

- Cardiology: ventricular fibrillation (VF)
- Time series analysis: fast Fourier transform (FFT), wavelet transform, and empirical mode decomposition (EMD)
- Simulated cardiology: a powerful and efficient strategy
- Statistical signatures of myocardial fibrosis for VF patients: a link between simulated predictions and experimental findings

# Action potential and electrocardiogram



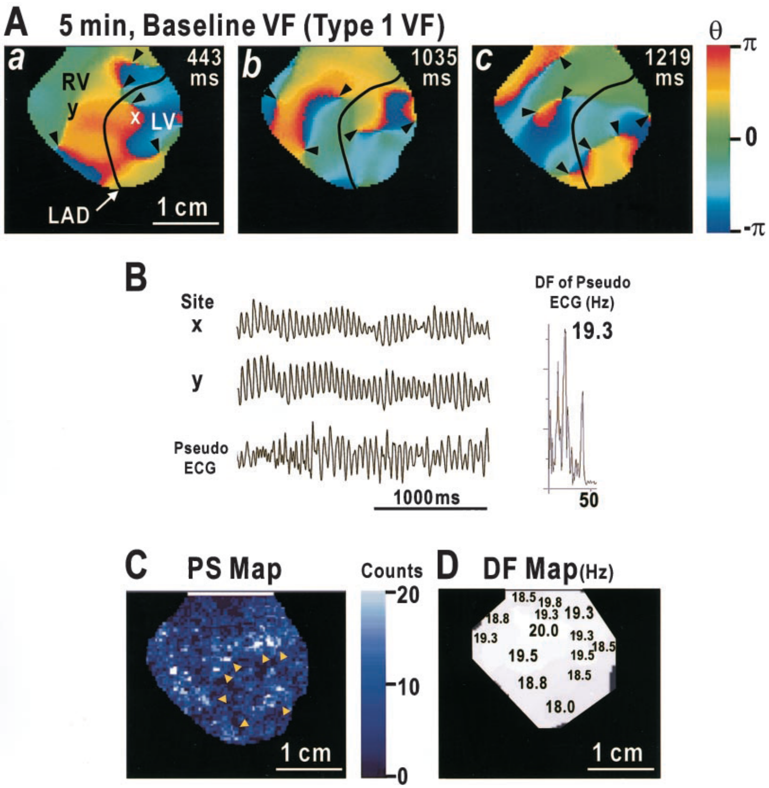
# VT and VF in electrocardiograms

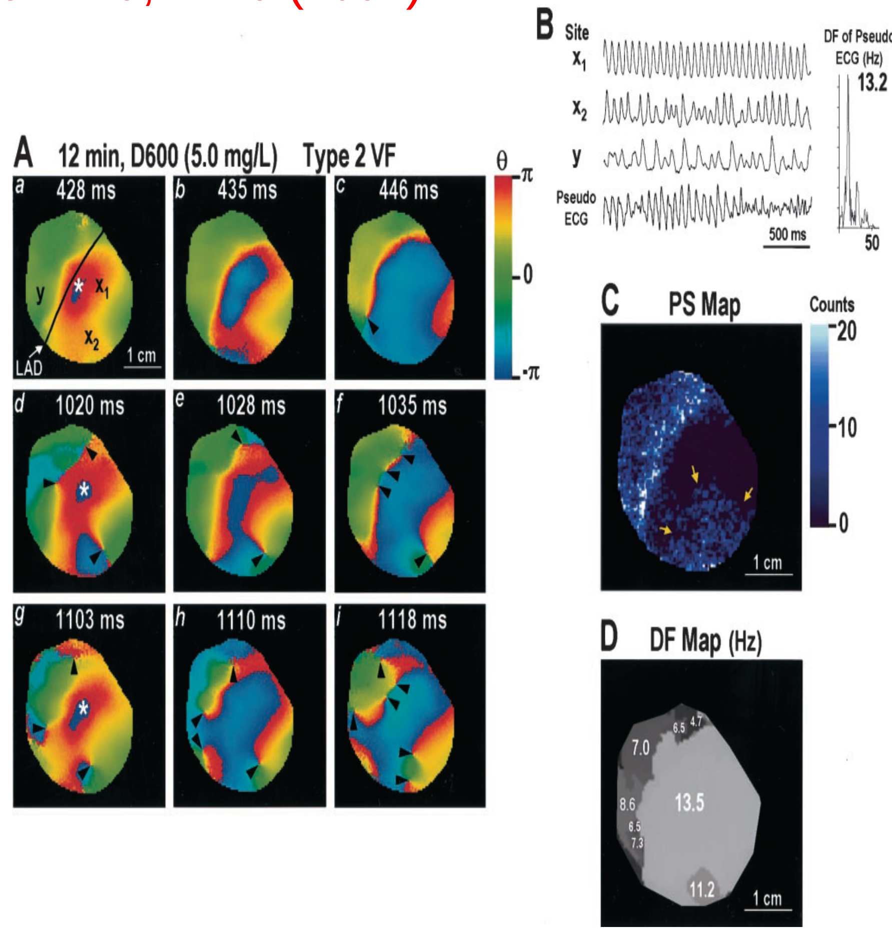



**Reference: Chaos, Solitons and Fractals Vol.13 (2002) 1755.**

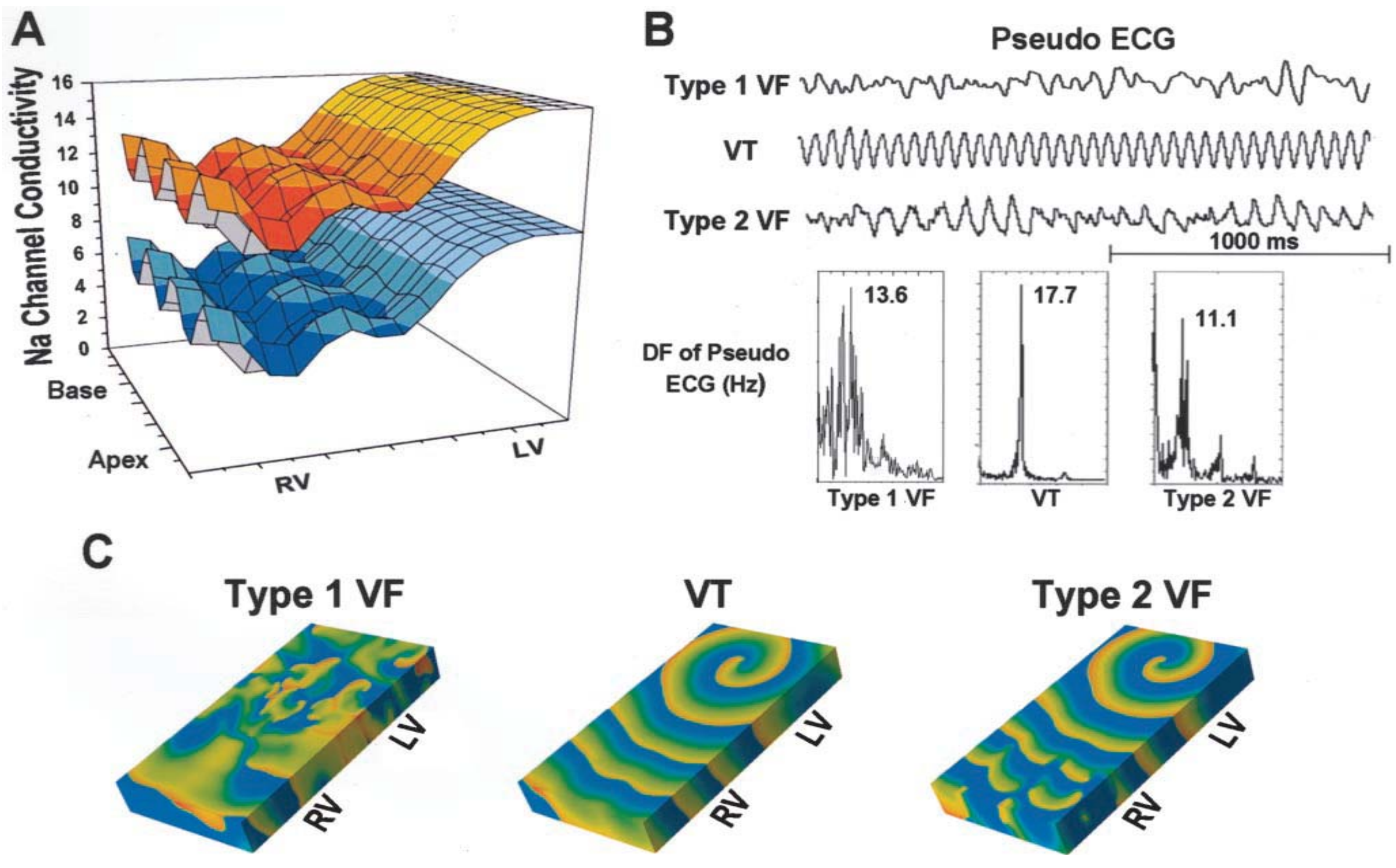
# Type 1 and Type 2 VF: experimental results

Wu et al., Circulation 110, 2110 (2004)

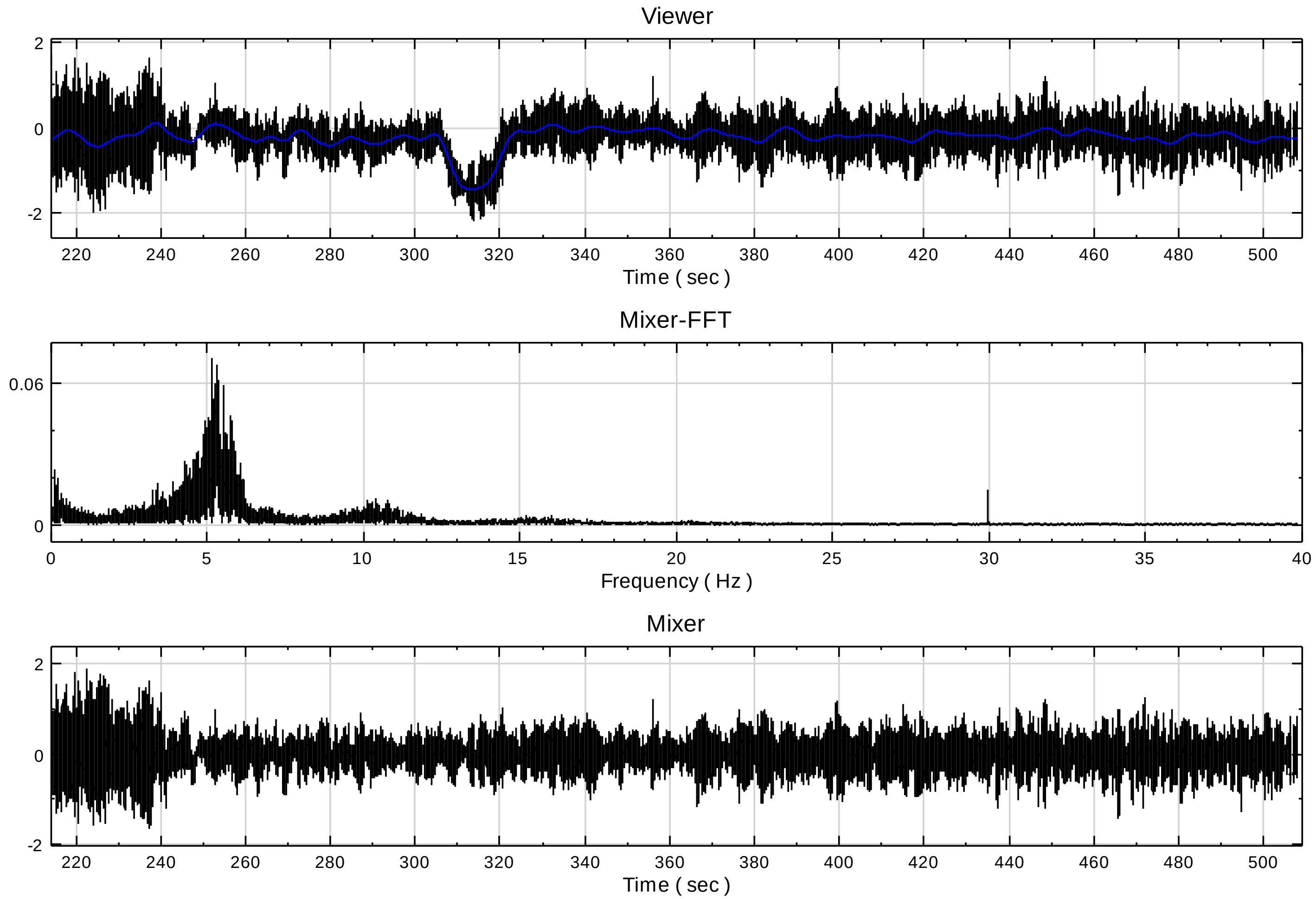


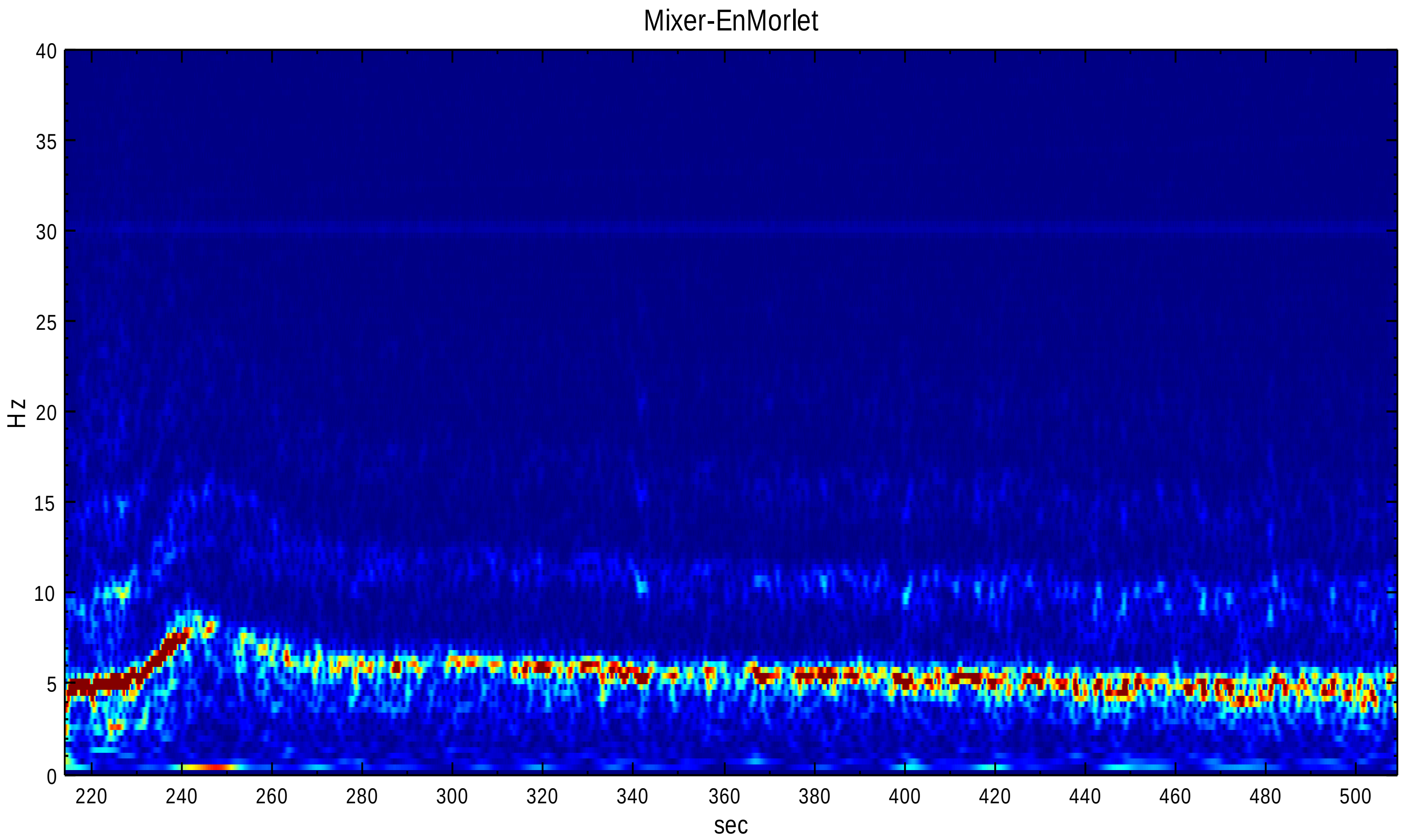
# Numerical results



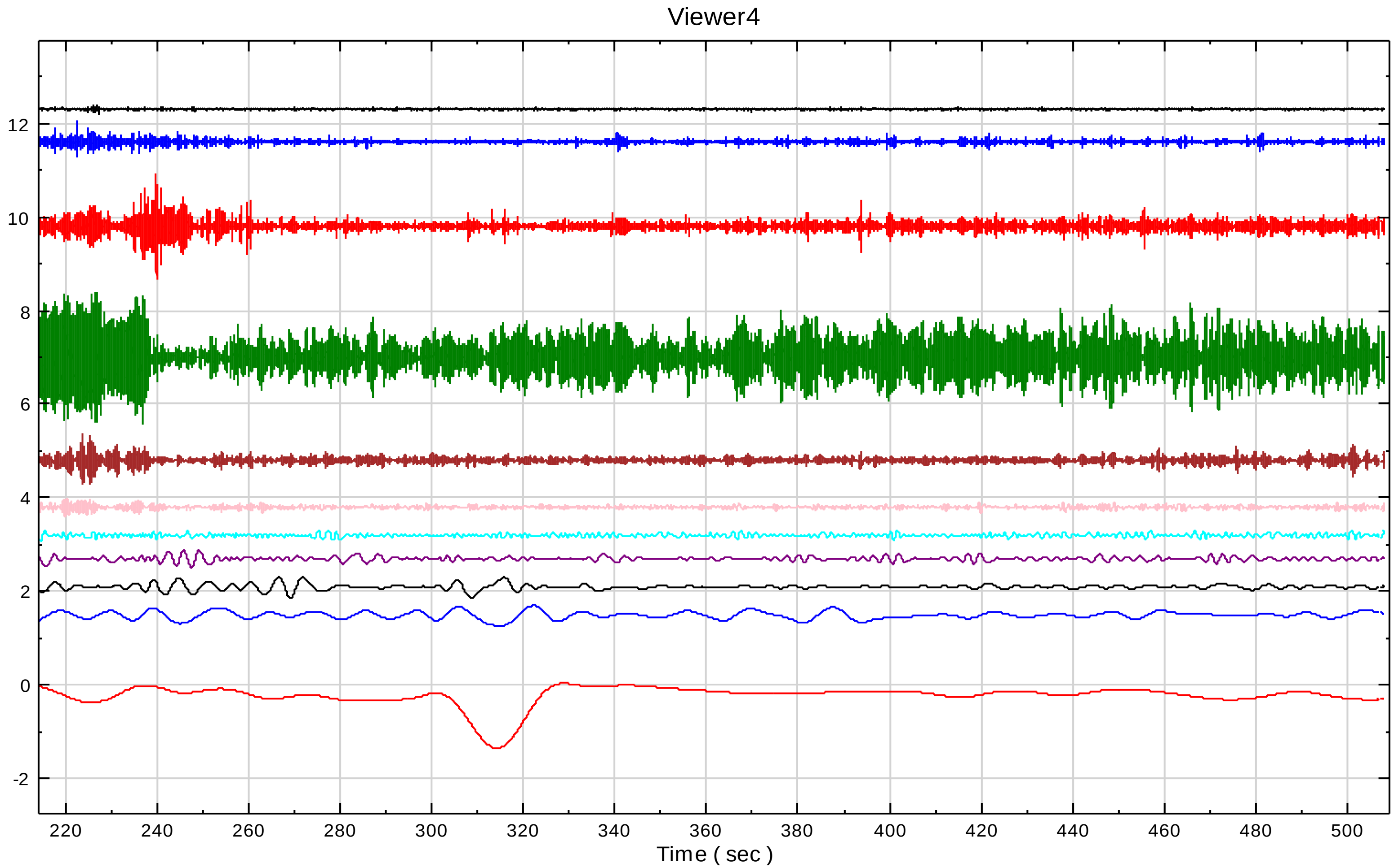
# FFT analysis: Not real time

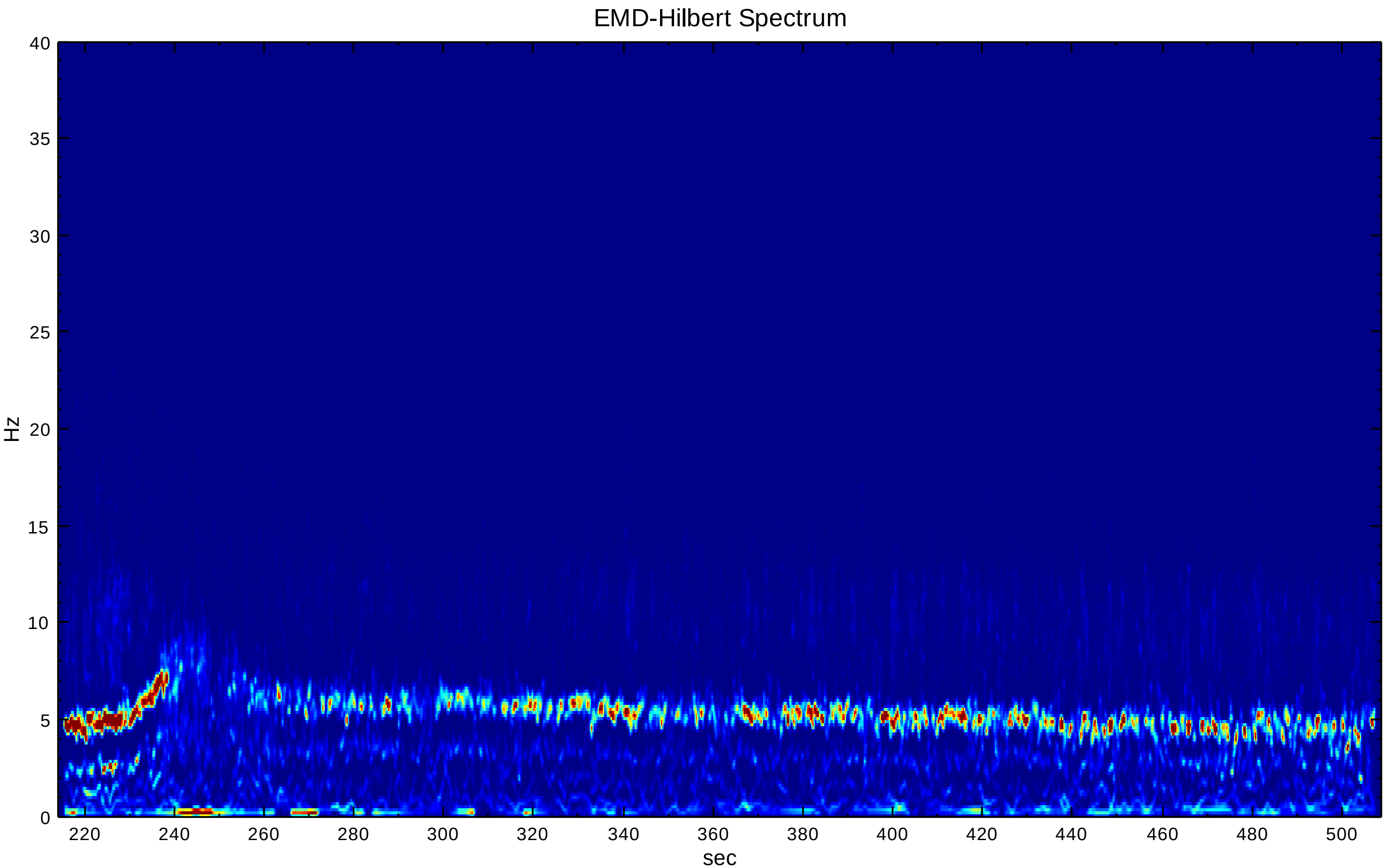


# Wavelet analysis: A real time display

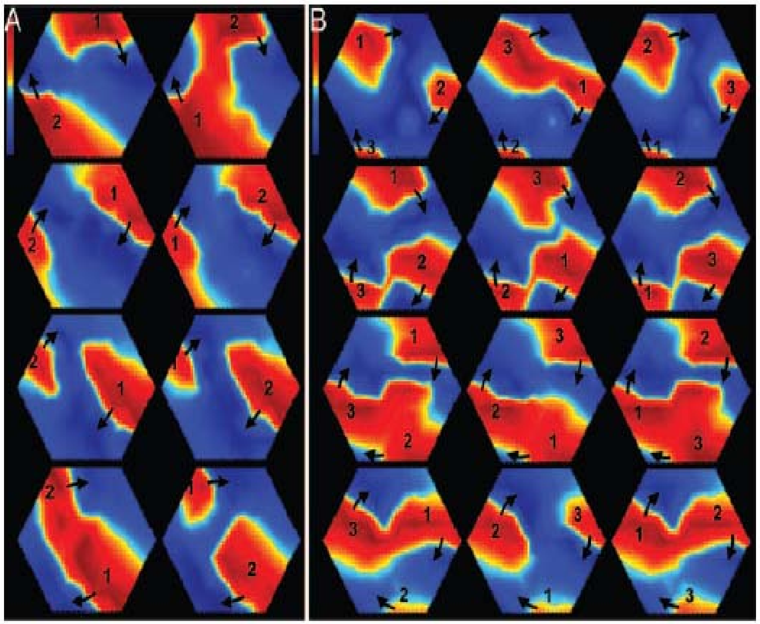


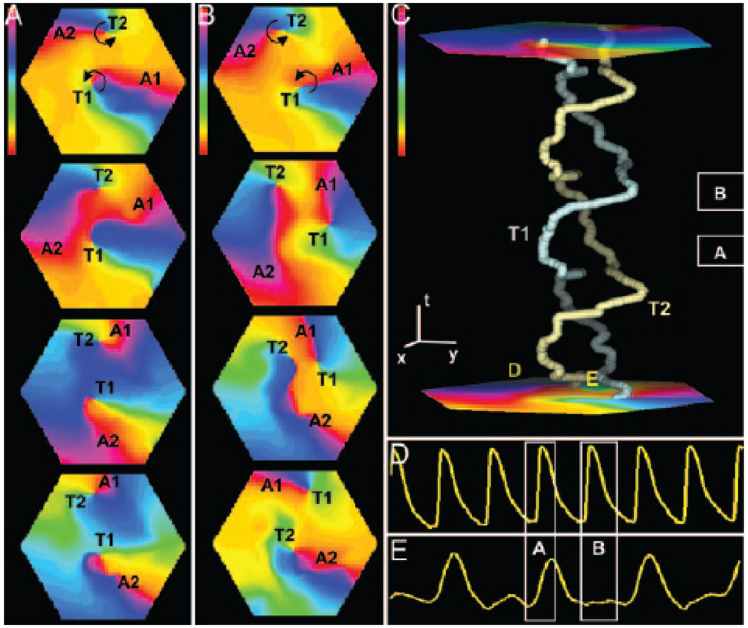
# EMD analysis: A novel approach




EMD-Hilbert Spectrum
Hz
sec
0
5
10
15
20
25
30
35
40
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500

# Experimental results for multi-armed spirals in cardiac tissue



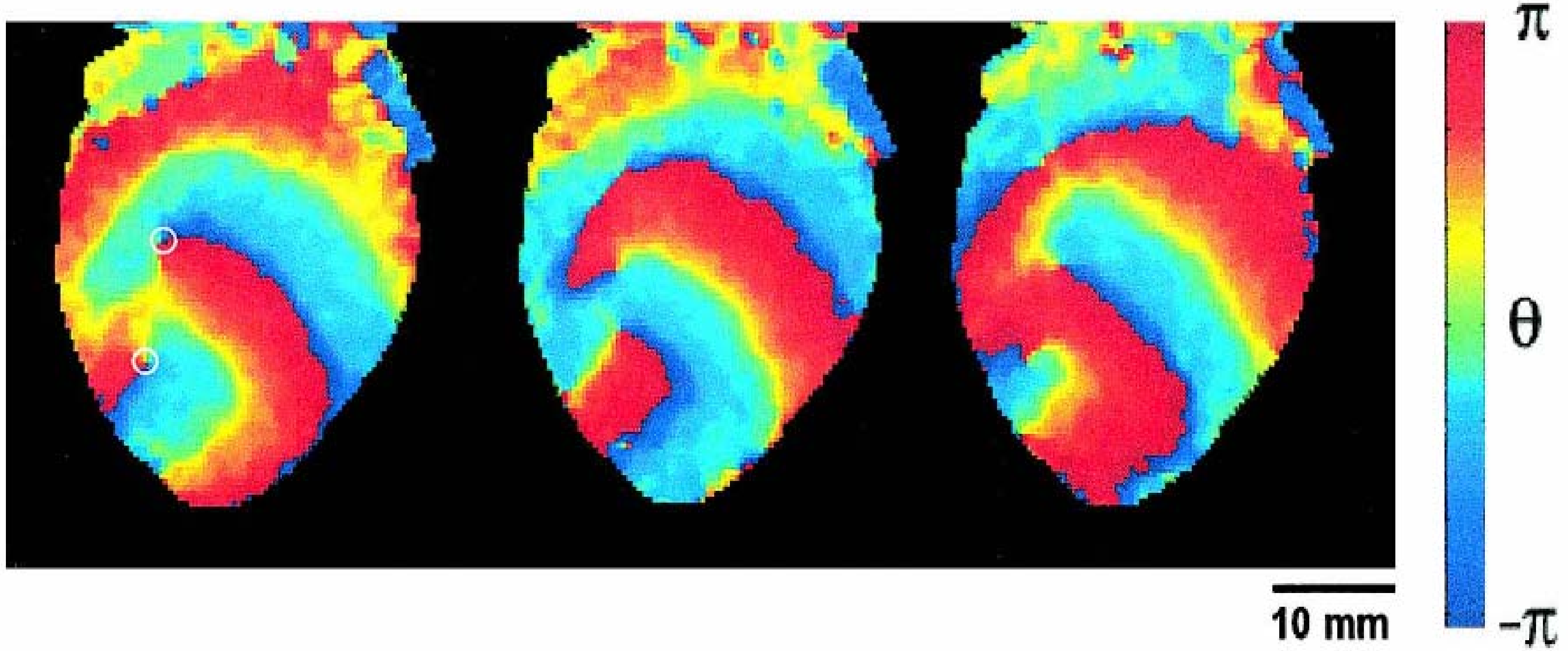




Reference: PNAS, vol. 101, p15530 (2004).

# Stable Bound Pair of Spiral Waves in Rabbit Ventricles

TSU-JUEY WU, M.D., MARK-ANTHONY BRAY, M.S.E.,* CHIH-TAI TING, M.D., PH.D., and SHIEN-FONG LIN, PH.D.†

J Cardiovasc Electrophysiol, Vol. 13, p. 414, April 2002.



## Fractal correlation measure : DFA

### ❑ [2] Detrended Fluctuation Analysis(DFA,QISA)

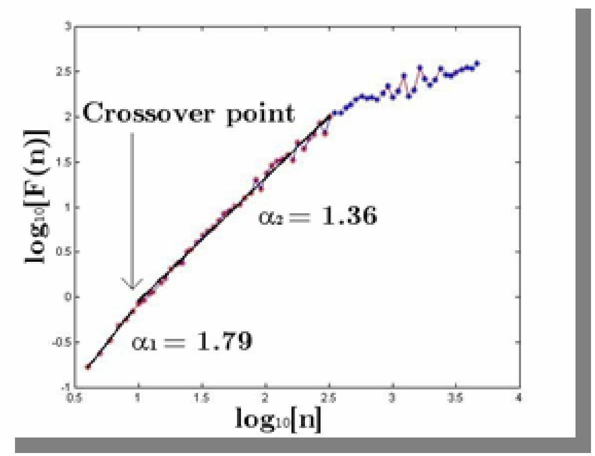
- **To quantify the fractal-like scaling properties of the R-R interval time series at different temporal scales**
- **Scaling exponent represents the slope(α) of regression line which related log(fluctuation) to log(window size)**

➔ **Low exponent values : magnitude of beat-to-beat HRV is close to magnitude of long-term variability(Anti correlation)**

➔ **High exponent values : magnitude of long-term variability is substantially higher than beat-to-beat variability(Strong correlation)**

- **Scaling-law exponent($\beta=2\alpha-1$)[1)]**

**- fractal-like signal : $\alpha = 1$**
**- White noise : $\alpha = 0.5$ (ACor : $\alpha<0.5$, Cor : $\alpha>0.5$)**
**- Brownian motion : = 1.5**




### DFA algorithm

**1. Integrating** $y[k] = \sum_{i=1}^{k} [B(i) - \overline{B}]$

$B(i)$ **: i-th interbeat interval time series**

$\overline{B}$ **: average interbeat interval**

**2. Divided into boxes of equal length n**

**3. In each box of length n, least-squares line fitting**

➔ $y_n[k]$ **: local trend in each box(order l)**

**4. Calculating**

$$F[n] = \sqrt{\frac{1}{\tilde{N}} \sum_{k=1}^{\tilde{N}} (y[k] - y_n[k])^2}$$


1) N. Iyengar, C. Peng, R. Morn, A. Goldberger and L. Lipsitz, Age-related alterations in the fractal scaling of cardiac interbeat interval dynamics, Am. J. Physiol. 271, R1078-R1084(1996).
2) H. Shono et al., Changes in fractal structure of heart rate variability during a nap in one case, Psychiatry Clin. Neurosci. 55, 175-176(2001)

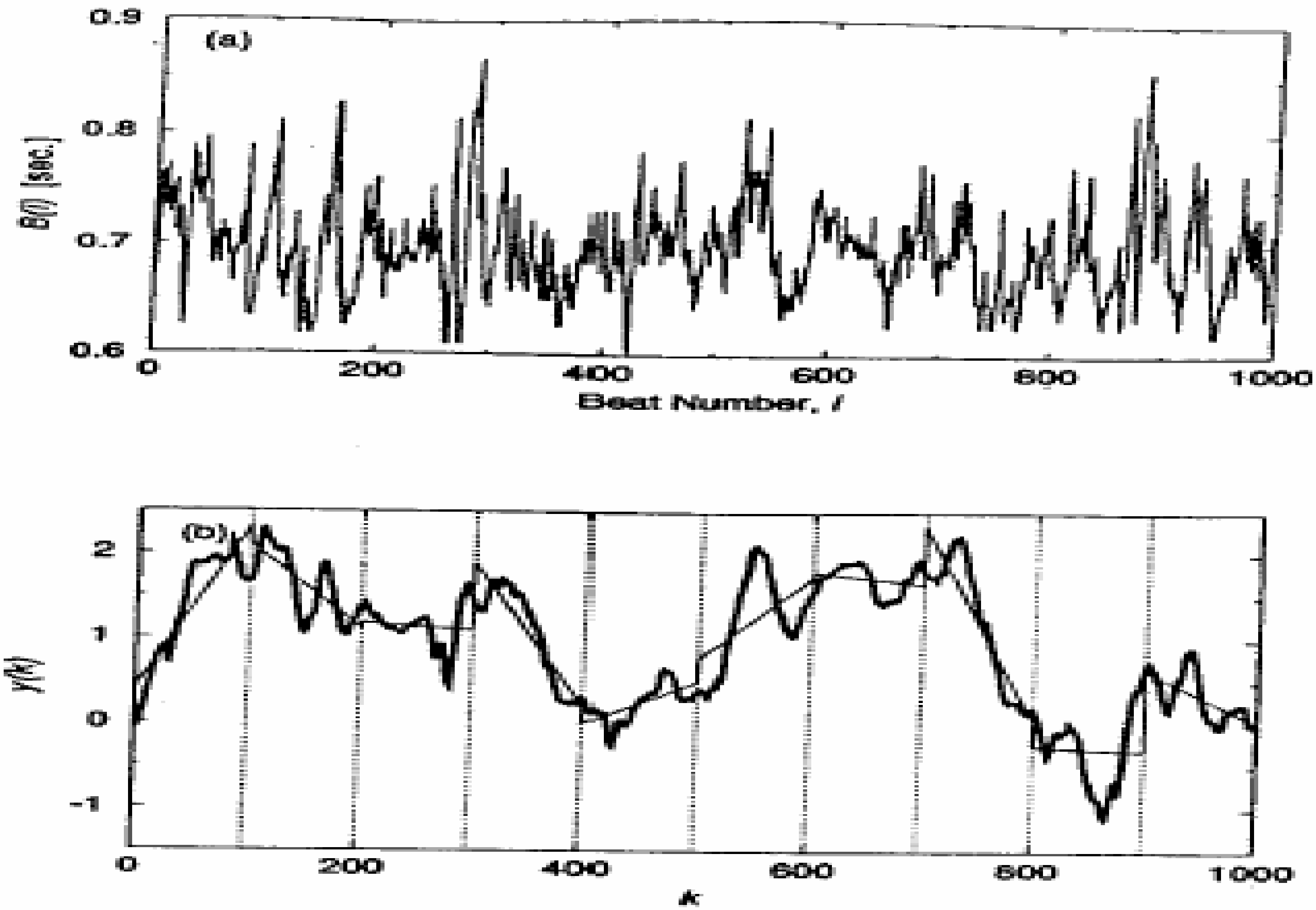



FIG. 1. (a) The interbeat interval time series $B(i)$ of 1000 beats. (b) The integrated time series: $y(k)=\sum_{i=1}^{k}[B(i)-B_{ave}]$, where $B(i)$ is the interbeat interval shown in (a). The vertical dotted lines indicate box of size $n=100$, the solid straight line segments represent the "trend" estimated in each box by a least-squares fit.

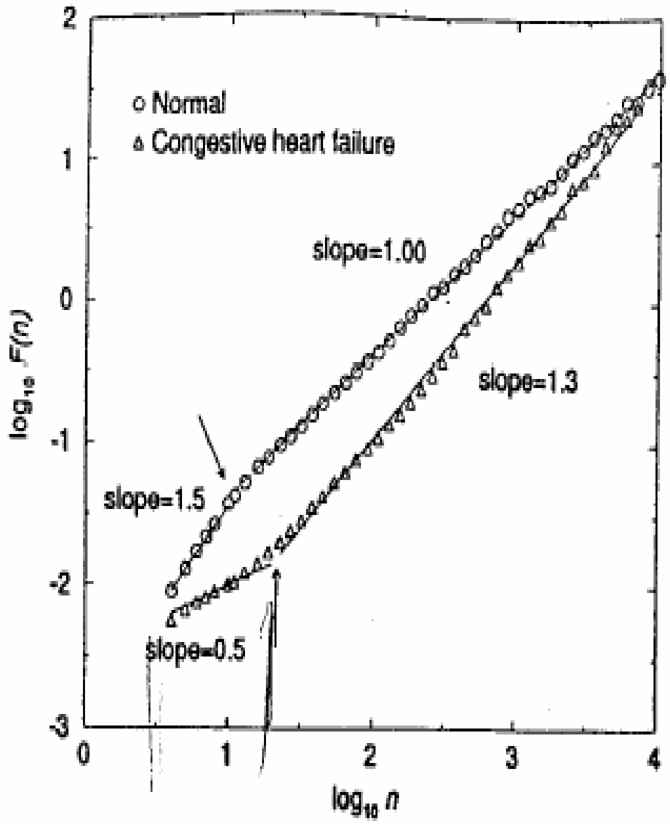



FIG. 2. Plot of log $F(n)$ vs log $n$ (see description of DFA computation in text) for two very long interbeat interval time series (~24 hours). The circles are from a healthy subject while the triangles are from a subject with congestive heart failure. Arrows indicate "crossover" points in scaling.

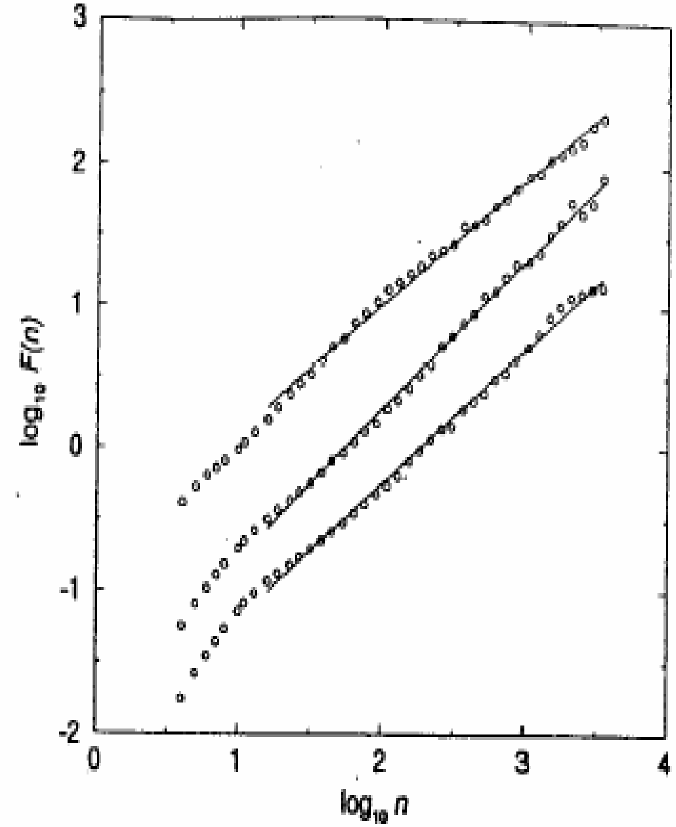



FIG. 3. Plot of log $F(n)$ vs log $n$ of 3 data subsets (each contains approximately 8 hours of data) from the same subject. The resulting plots were shifted vertically for purpose of display. The $\alpha$ exponents obtained over the same fitting range (from 16 to 3400 beats) are very similar: 0.90, 1.05 and 0.95, respectively. Note that not all three data sets exhibit crossover in scaling behavior.

♦ ORIGINAL ARTICLE ♦

Taylor & Francis healthsciences

# Differences in the activation patterns between sustained and self-terminating episodes of human ventricular fibrillation

*Timo H Mäkikallio[1,2], Heikki V Huikuri[2], Robert J Myerburg[1], Tapio Seppänen[2], Martin Kloosterman[1], Alberto Interian Jr.[1], Agustin Castellanos[1] and Raul D Mitrani[1]*

**BACKGROUND.** Experimental studies have suggested that R-R interval dynamics during ventricular fibrillation (VF)

Keywords: organized dynamics; tachyarrhythmias; ventricular fibrillation.

*Ann Med* 2002; 34: 130–135


**Figure 1.** An example of a recording situation before the termination of ventricular fibrillation by DC-shock. Local activation time intervals were measured from right ventricular apex by bipolar electrode catheter. Analysis of dynamic behavior of these intervals was then carried on to evaluate the dynamic nature of recorded signals. Figure shows only short segment of the VF just before DC-shock.

## Key messages

- Spontaneously terminating VF episodes have more structured dynamics than sustained VF episodes.

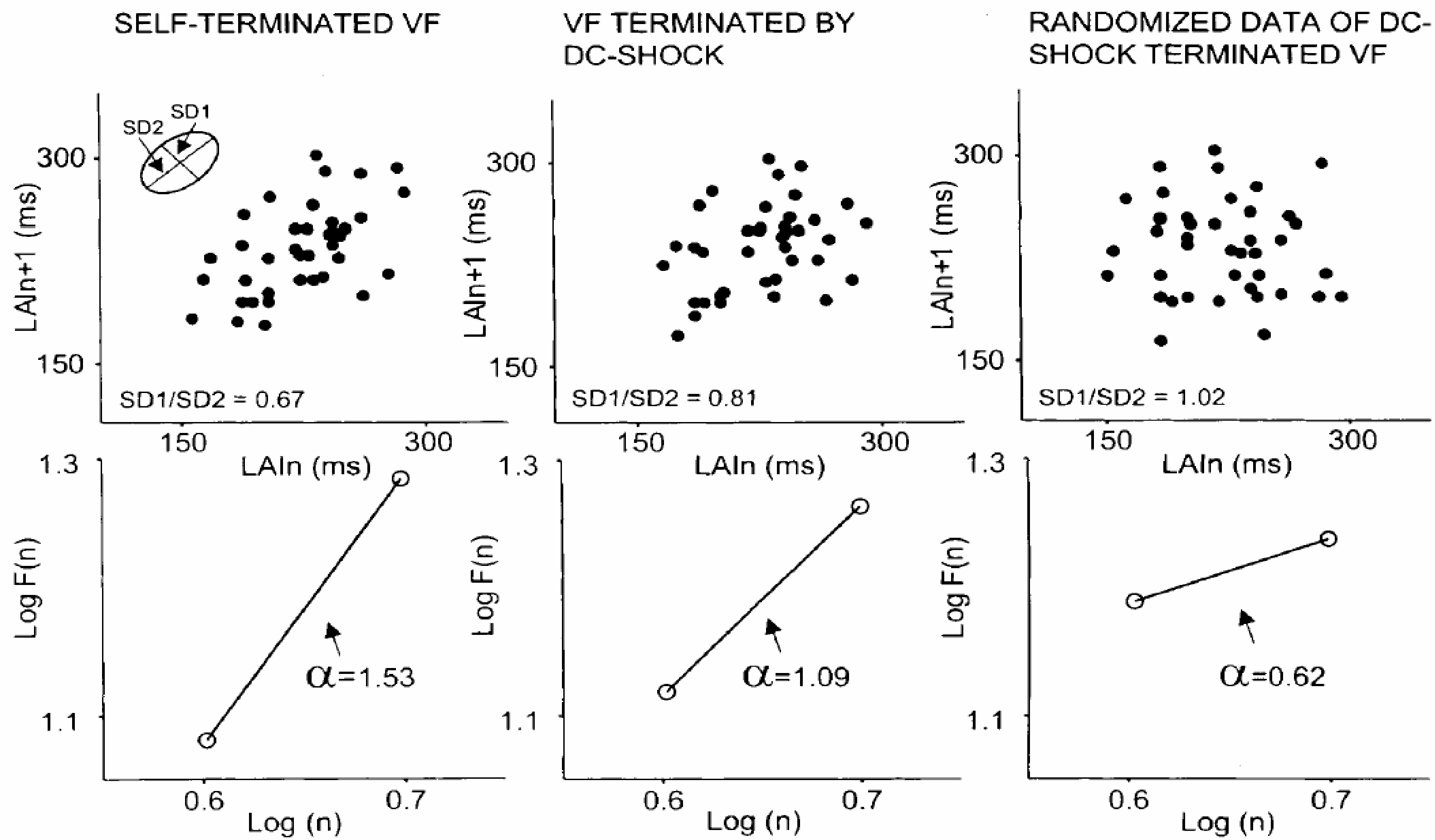



**Figure 2.** Examples of Poincarè plot and detrended fluctuation analysis data from a self-terminated ventricular fibrillation, ventricular fibrillation terminated by DC-shock and randomized data of DC-shock-terminated ventricular fibrillation. Self-terminated ventricular fibrillation typically shows ellipse-shaped plot and highly correlated fractal exponent value >1.0. Also, ventricular fibrillation terminated by DC-shock shows non-random local activation interval behavior with modest ellipseshaped scatter plot and fractal exponent value near 1.0. In contrast, randomized data of ventricular fibrillation shows ball-shaped scatter plot and fractal exponent value around 0.5 indicating random signal behavior. F(n) = the amount of variability; n = window size; SD1 = standard deviation of instantaneous local activation interval variability; SD2 = standard deviation of continuous activation interval variability; α = fractal scaling exponent; LAI = local activation time interval.