Electrocardiograph (ECG)

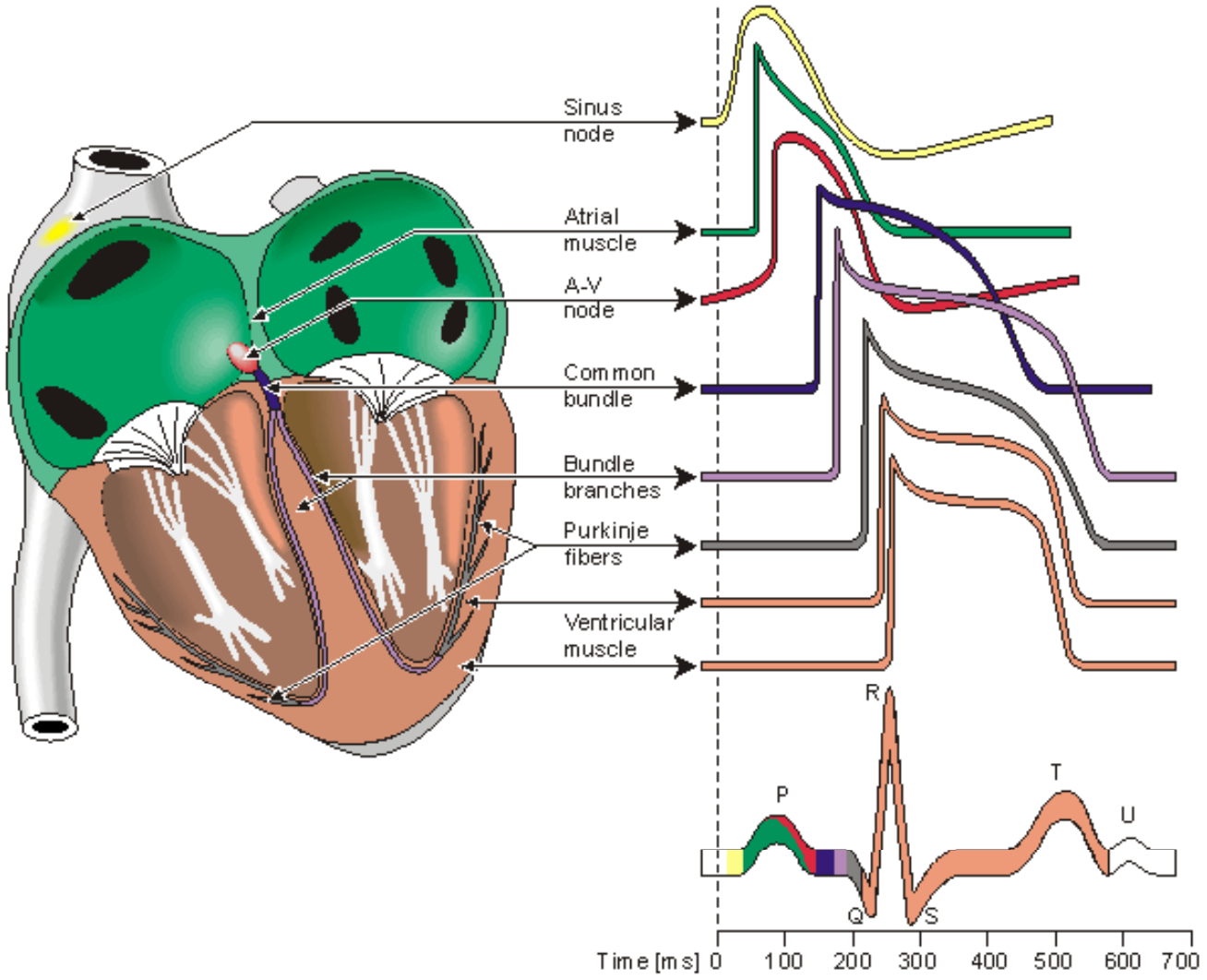
Hsiao-Lung Chan, Ph.D.

Dept Electrical Engineering

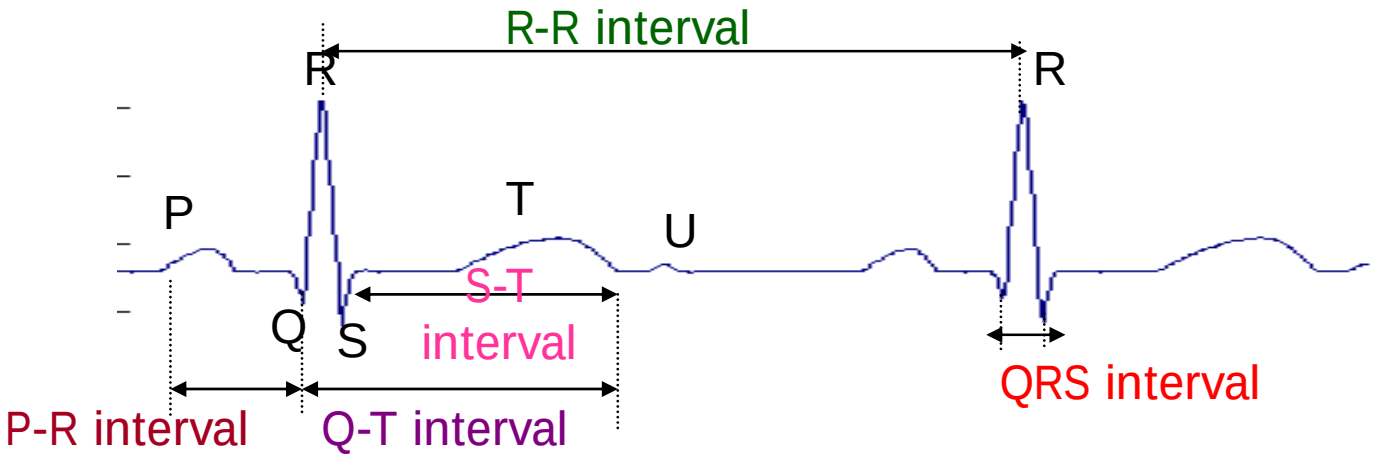
Chang Gung University, Taiwan

chanhl@mail.cgu.edu.tw

Heart and electrocardiogram (ECG, EKG)

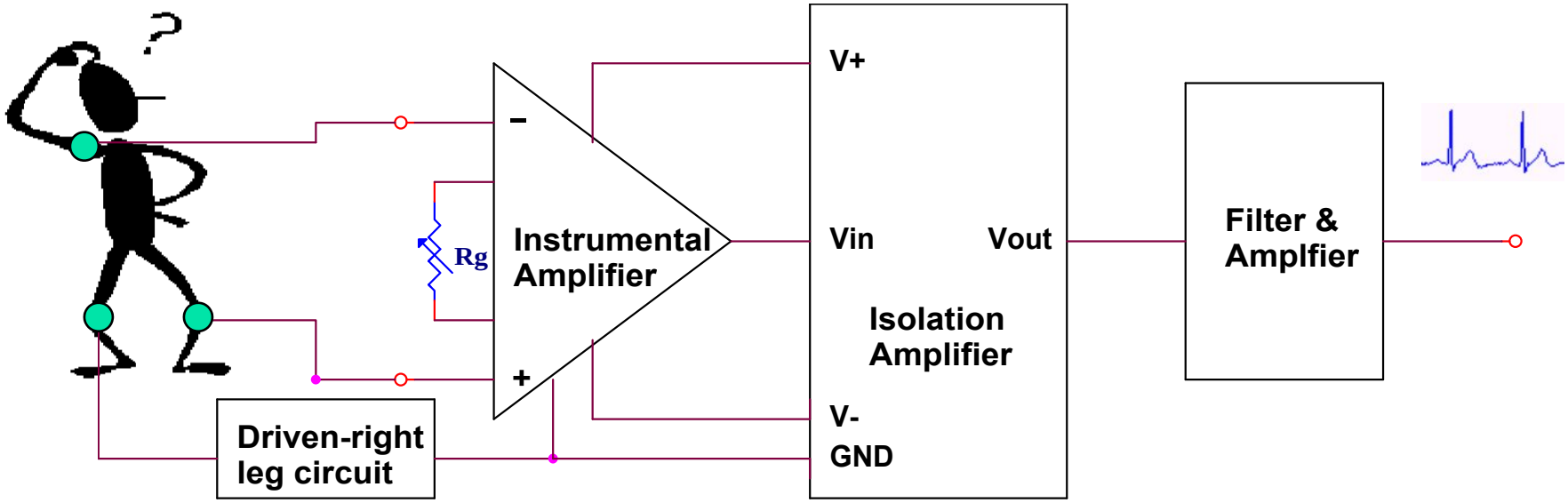


ECG features

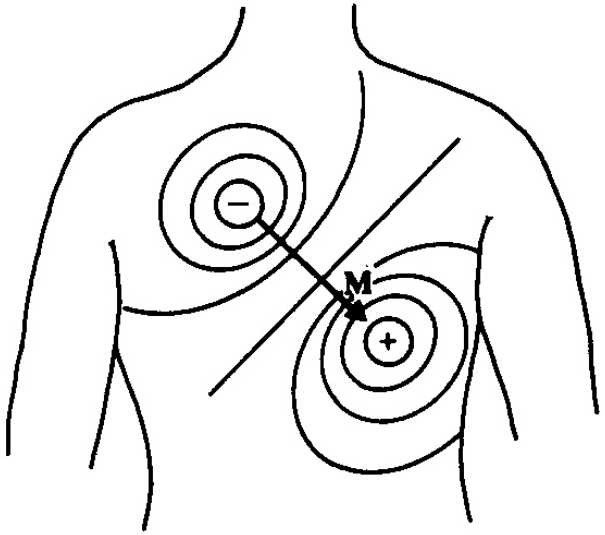


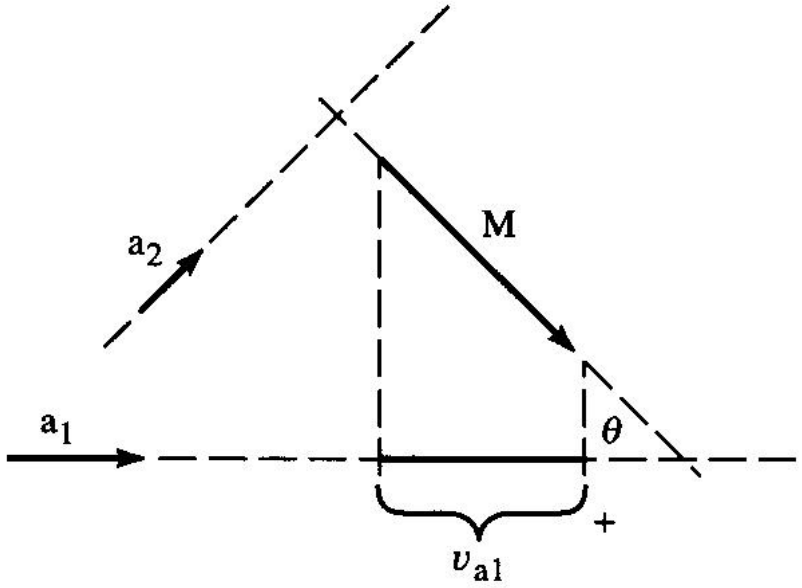
P wave : Atrial depolarization
QRS complex : Ventricular depolarization
T wave : Ventricular repolarization
U wave : Slow repolarization of ventricular muscle
R-R : Heart period
P-R : Conduction delay in the AV-node
S-T : Ventricular repolarization time

ECG amplifier

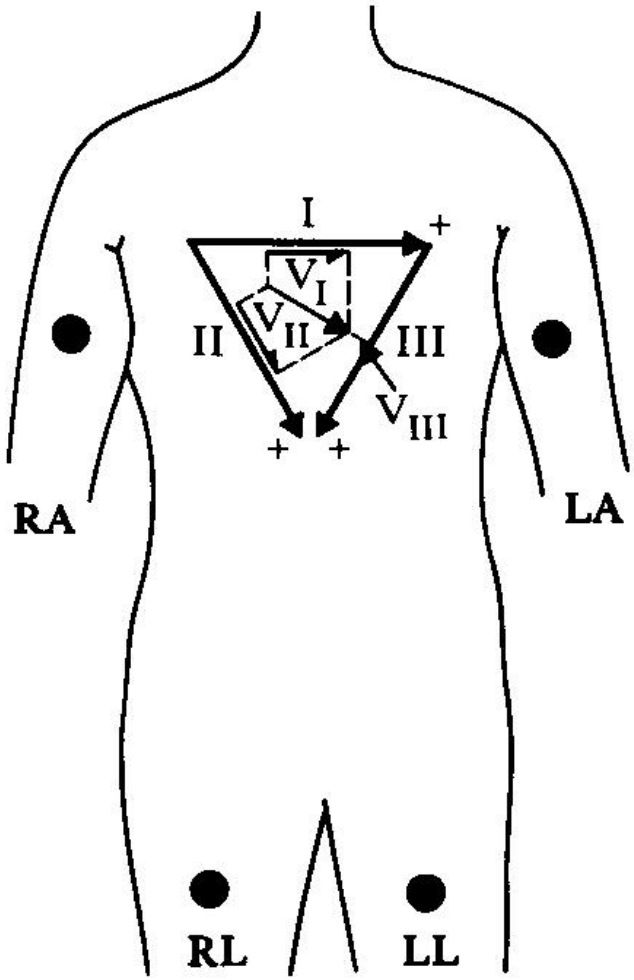


Dipole field of heart when R is maximum





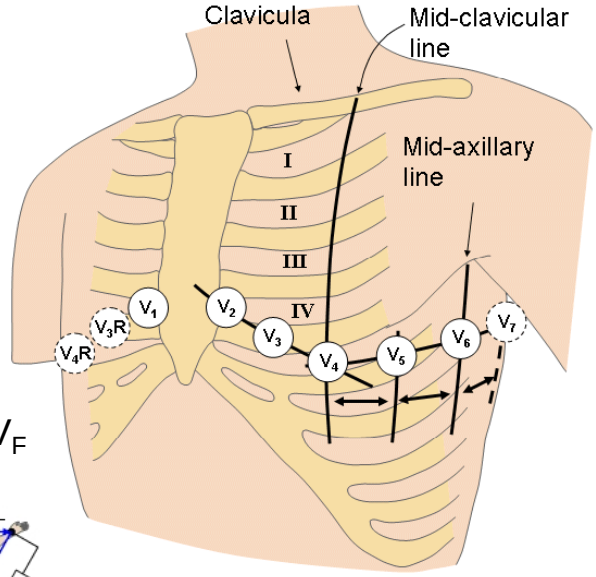
Electrocardiogram (ECG) measurements



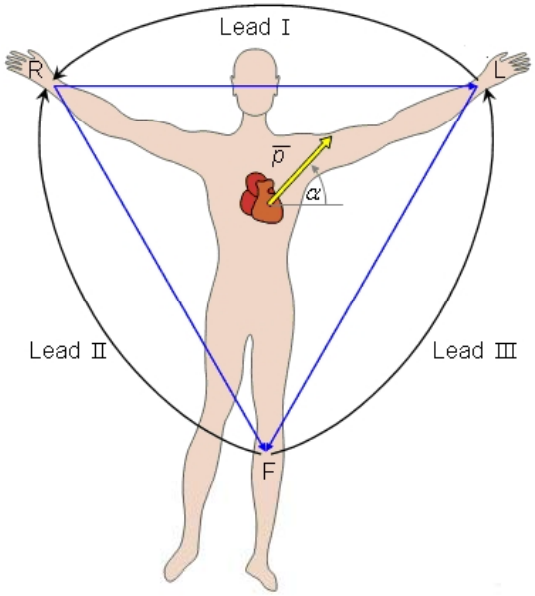
$$I - II + III = 0$$

12-Lead ECG

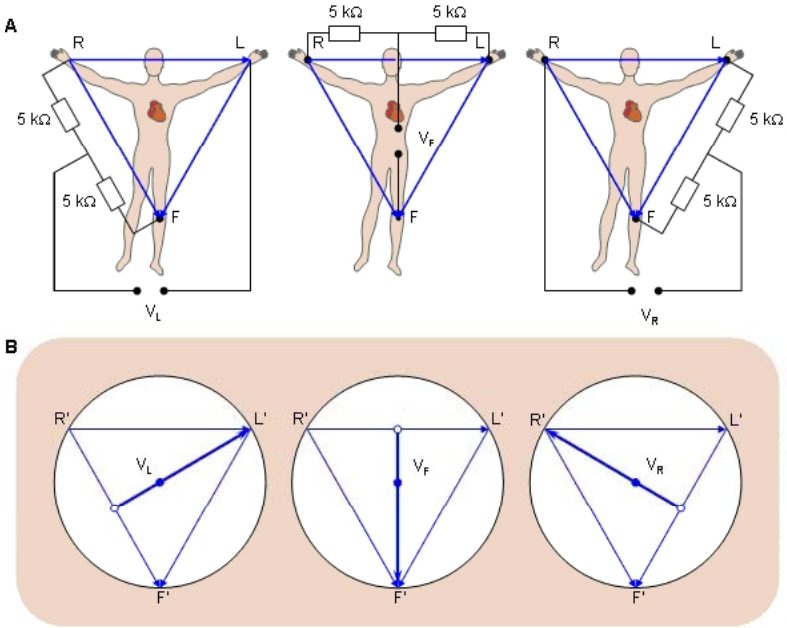
Precordial leads: V_1-V_6



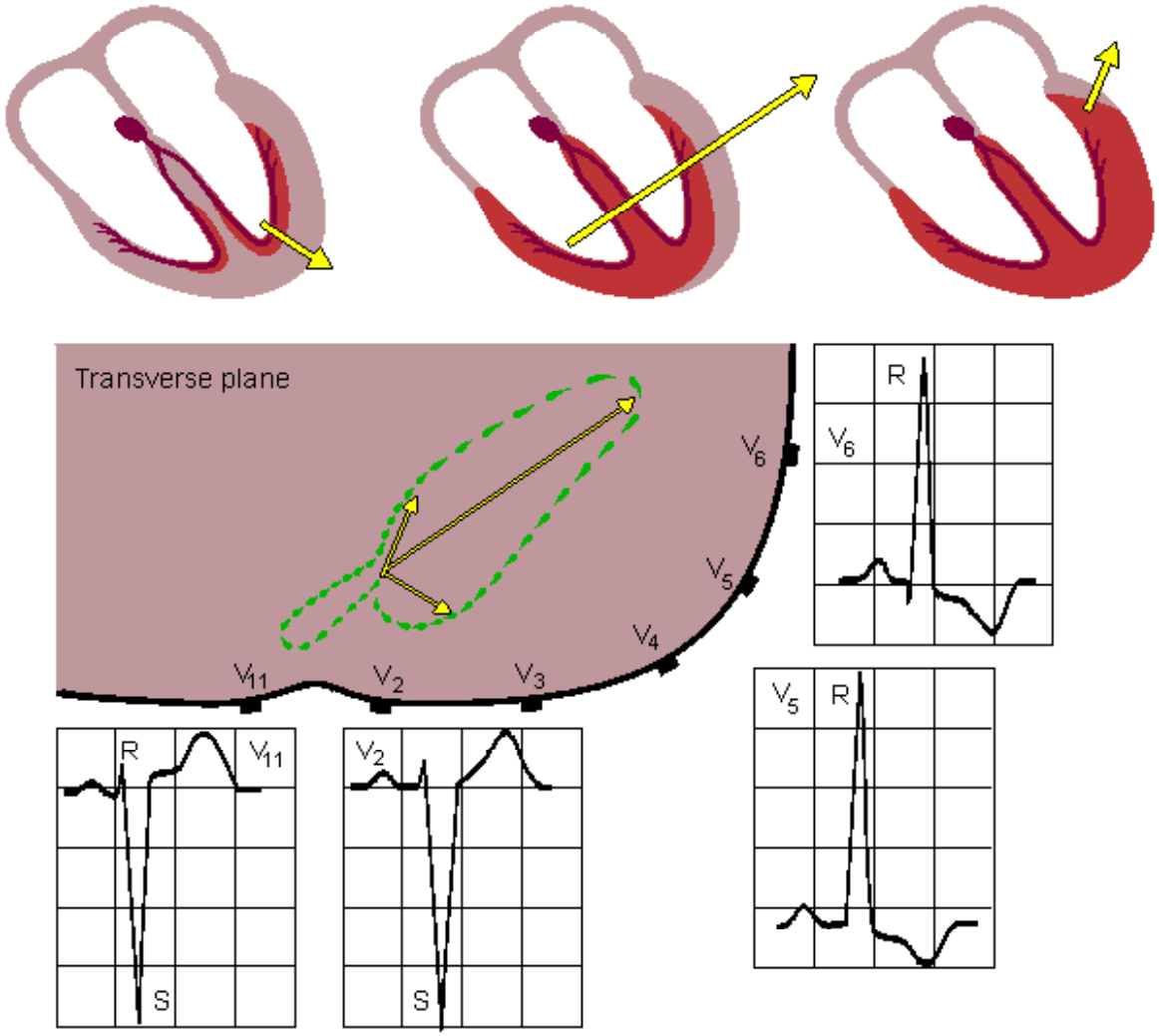
Einthoven leads: I, II & III



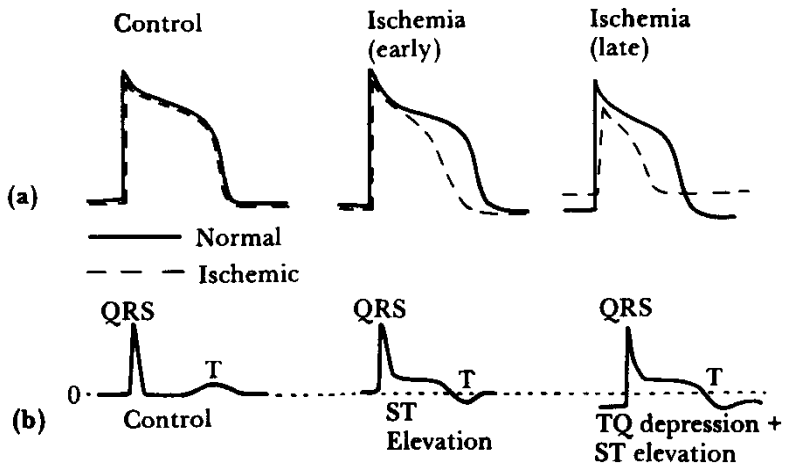
Goldberger augmented leads: V_R, V_L & V_F



ECG at chest leads



ST-segment elevation



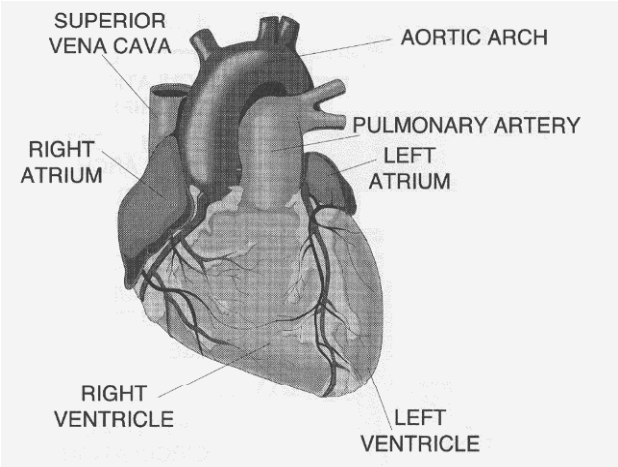
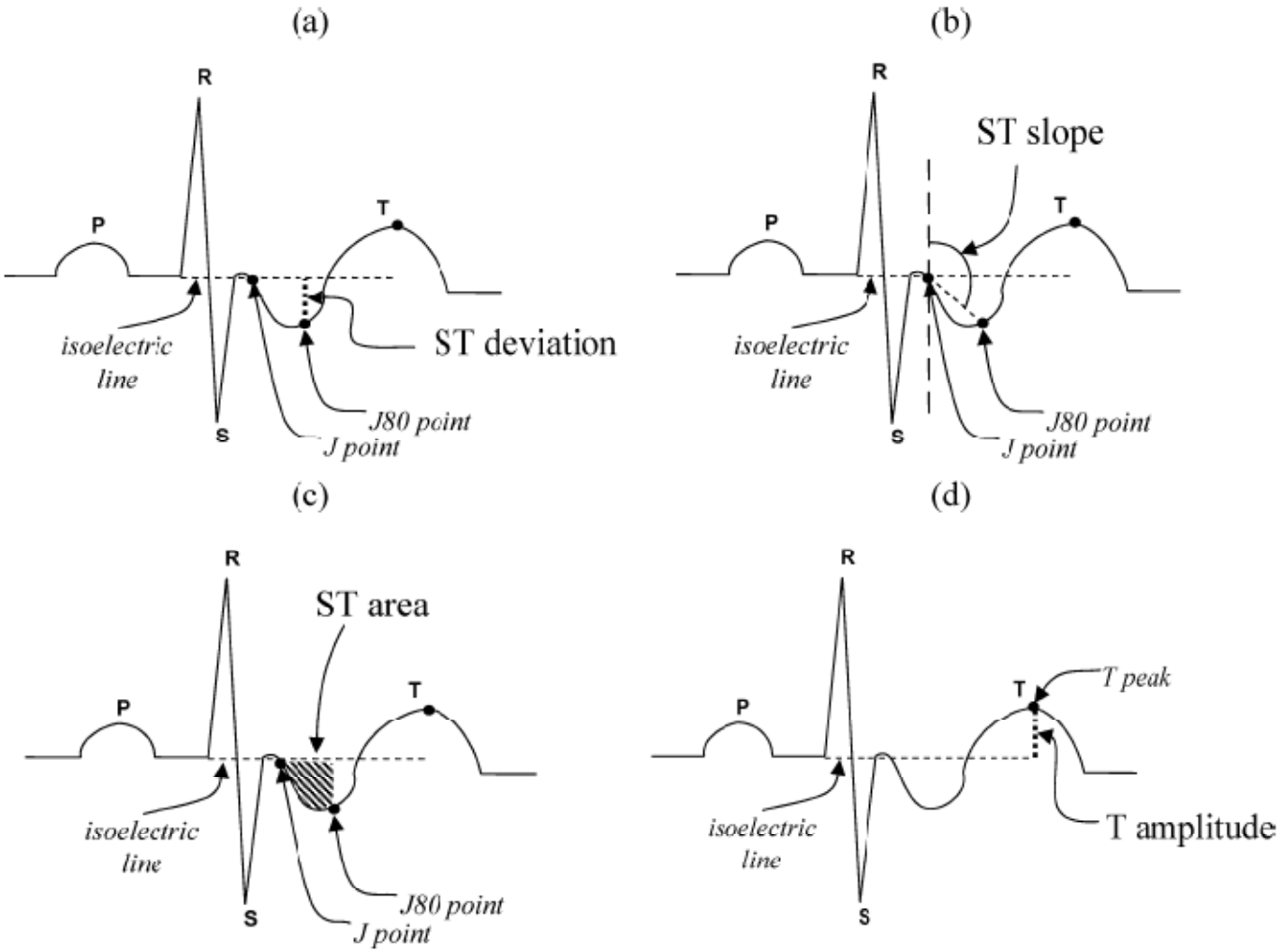


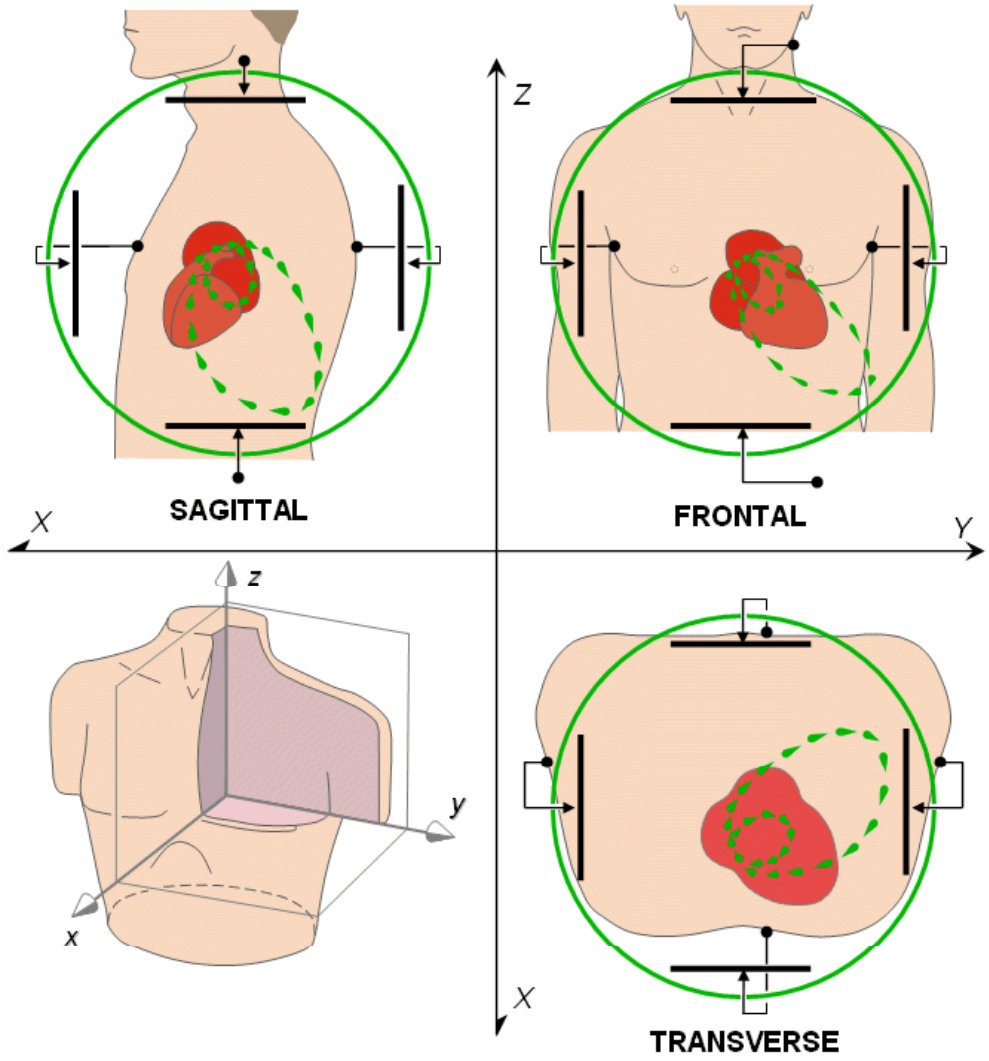
Figure 4.21 (a) Action potentials recorded from normal (solid lines) and ischemic (dashed lines) myocardium in a dog. Control is before coronary occlusion. (b) During the control period prior to coronary occlusion, there is no ECG S–T segment shift; after ischemia, there is such a shift. (From Andrew G. Wallace, "Electrophysiology of the Myocardium," in *Clinical Cardiopulmonary Physiology,* 3rd ed. New York: Grune & Stratton, 1969; used with permission of Grune & Stratton. Based on data by W. E. Sampson and H. M. Scher, "Mechanism of S–T Segment Alteration During Acute Myocardial Injury," 1960, *Circulation Research,* **8,** by permission of The American Heart Association.)

John G. Webster, Medical Instrumentation, application and design, 3rd Ed., Houghton Mifflin, 2000.

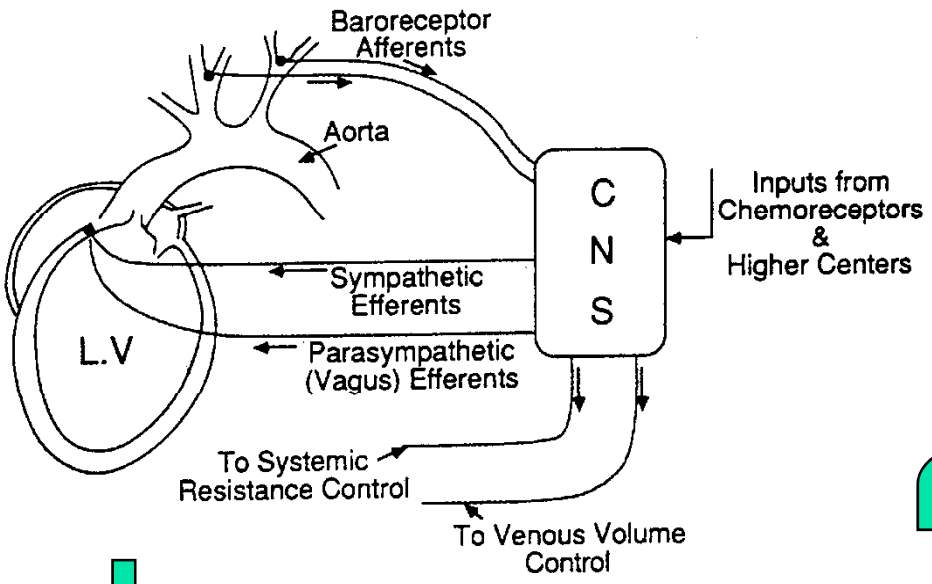
ST-segment depression (mostly in myocardial ischemia)



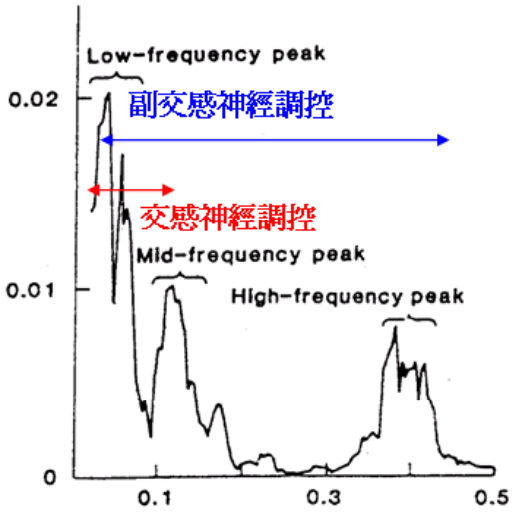
Vectorcardiogram (VCG)



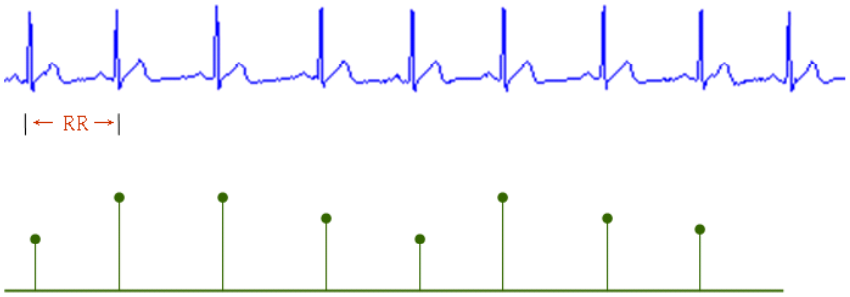
Heart rate variability (HRV, 心率變異度)

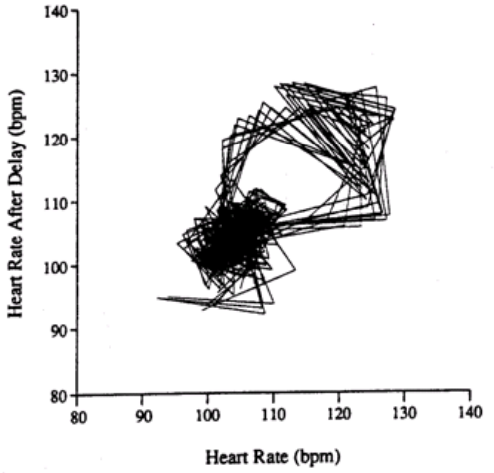


線性分析

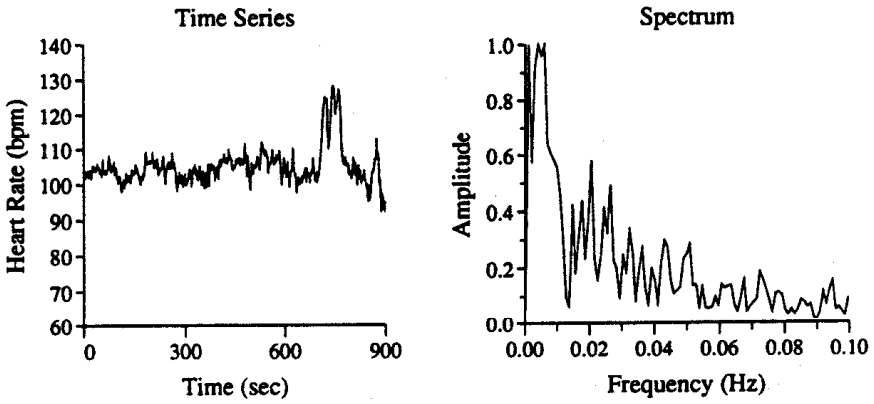


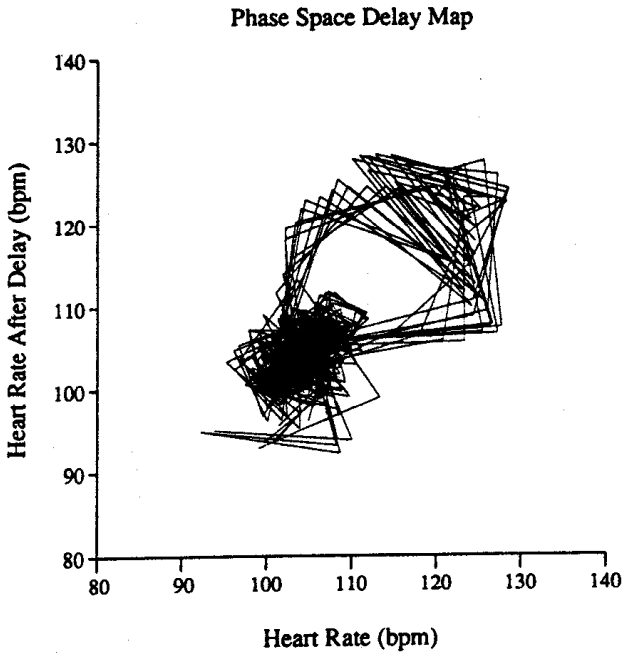
非線性分析



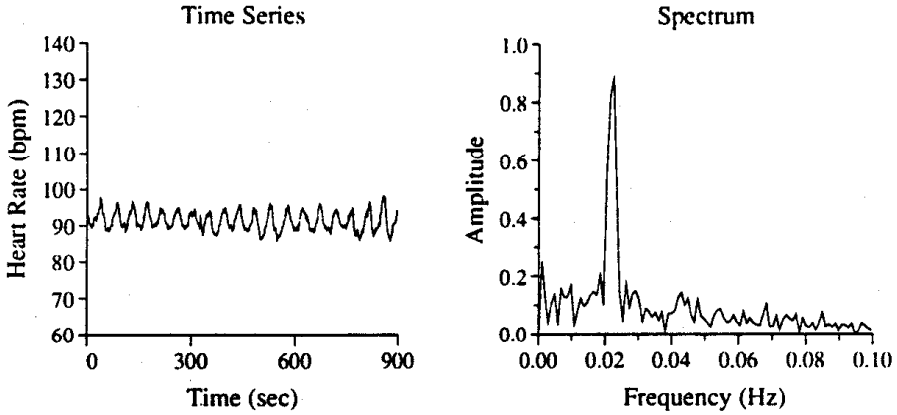


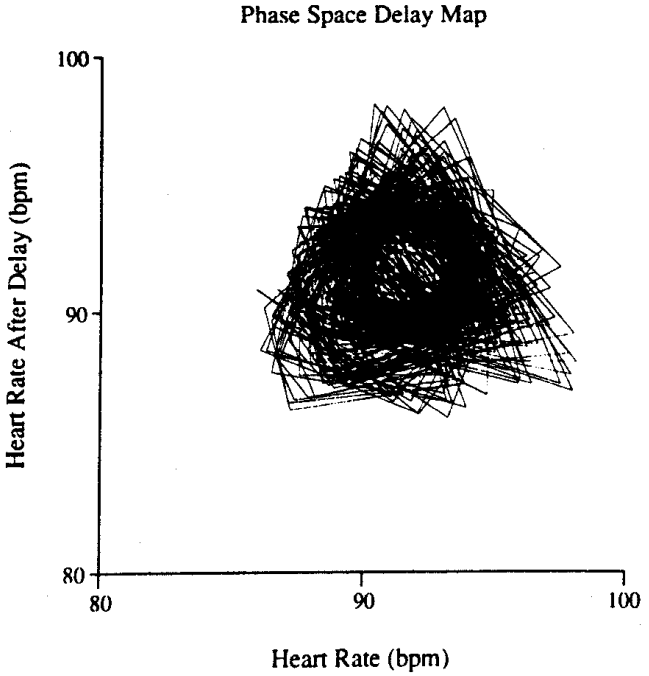
Normal Subject





Cardia arrest due to ventricular tachyarrhythmia 8 days later



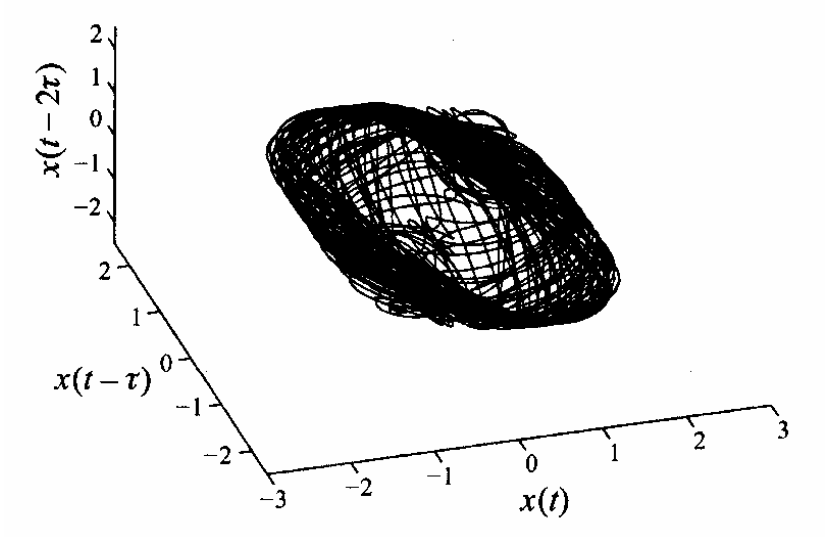


Goldberger *et al*, , Scientific American, 1990.

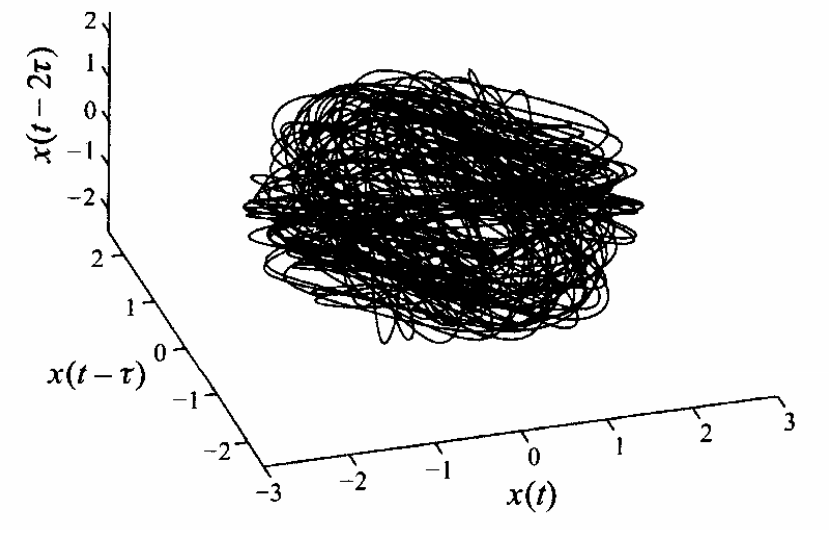
Is HRV chaotic (渾沌)?

- Chaotic: 隱含一種亂中有序
- Random: 隨機

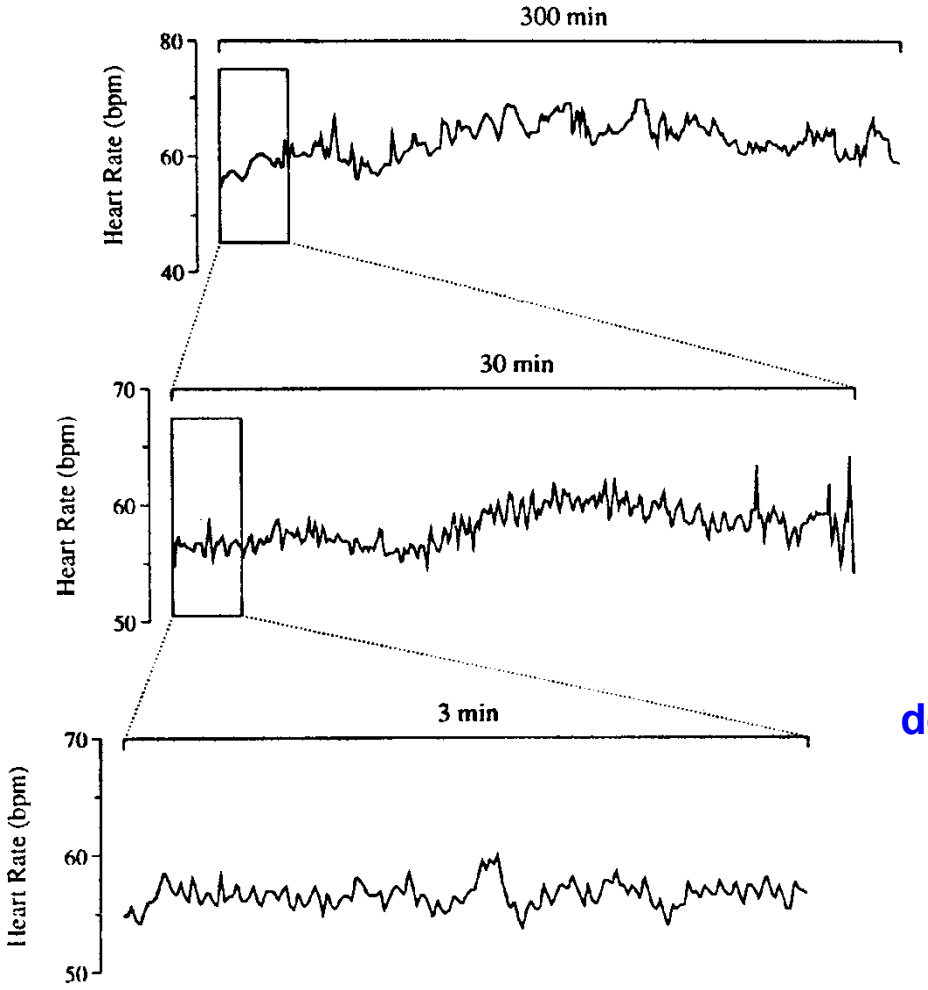
Chaotic



Near random



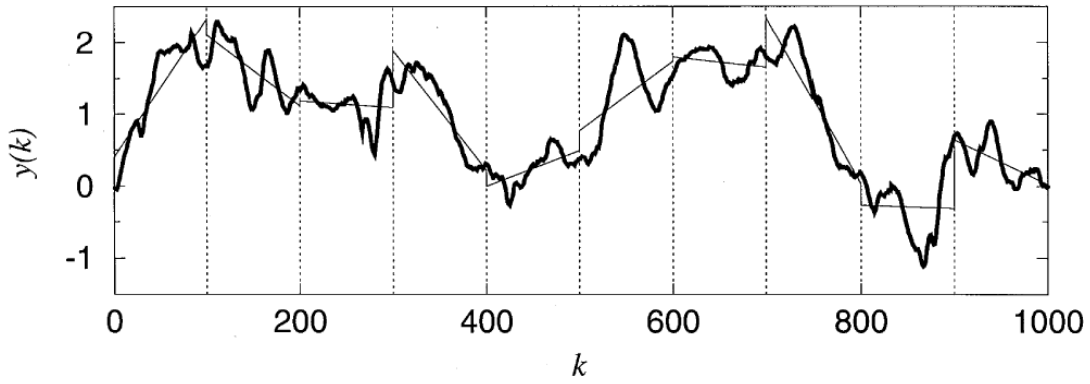
Self-similarity (自我相似性) in HRV

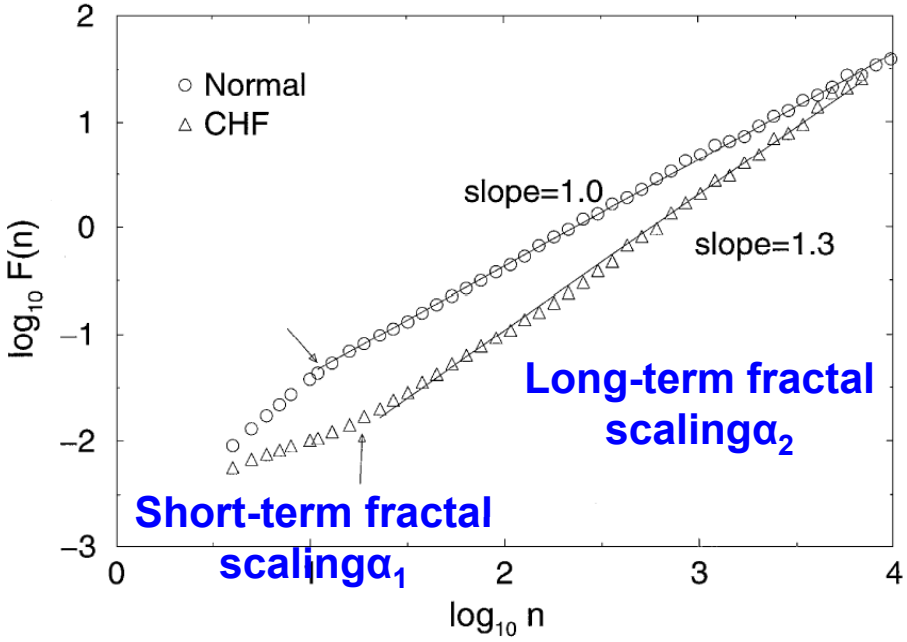


It would be better delineated by fractal (碎型) characteristics

Goldberger *et al*, Scientific American, 1990.

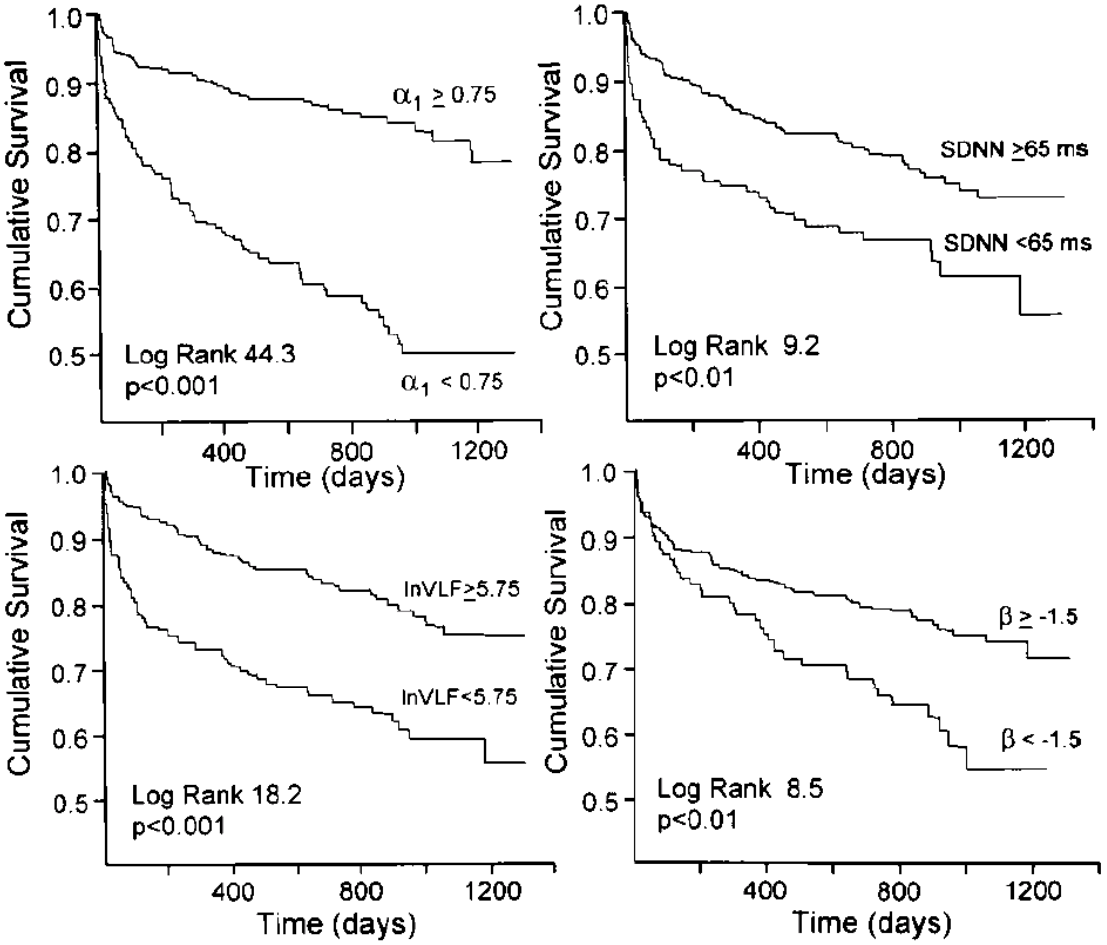
Detrend fluctuation analysis (DFA)





HE Stanley *et al*, , Physica A, 1999

Survival curves after acute myocardial infarction using HRV



ECG classification

- Premature ventricular contraction
- Ventricular tachycardia, ventricular fibrillation
- Human identification

Cardiac arrhythmia: premature ventricular contraction (PVC)

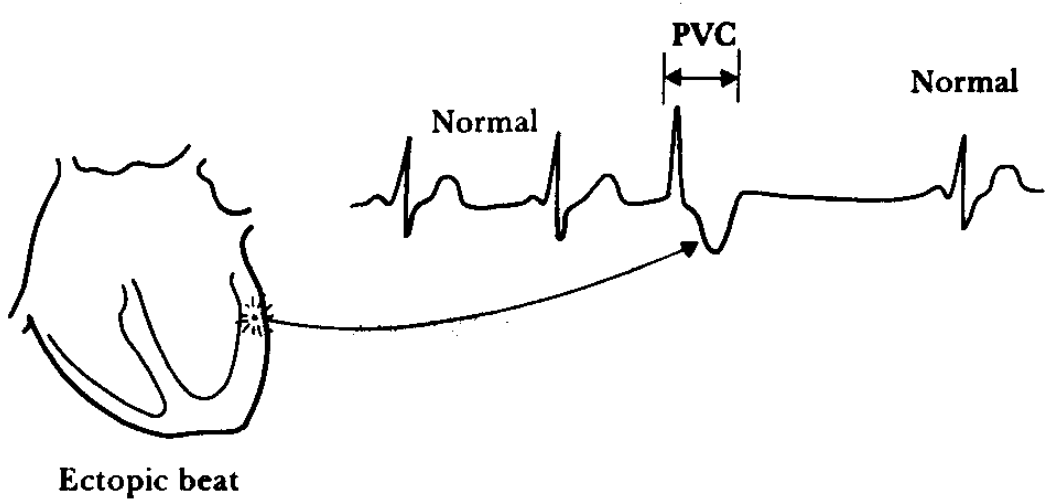
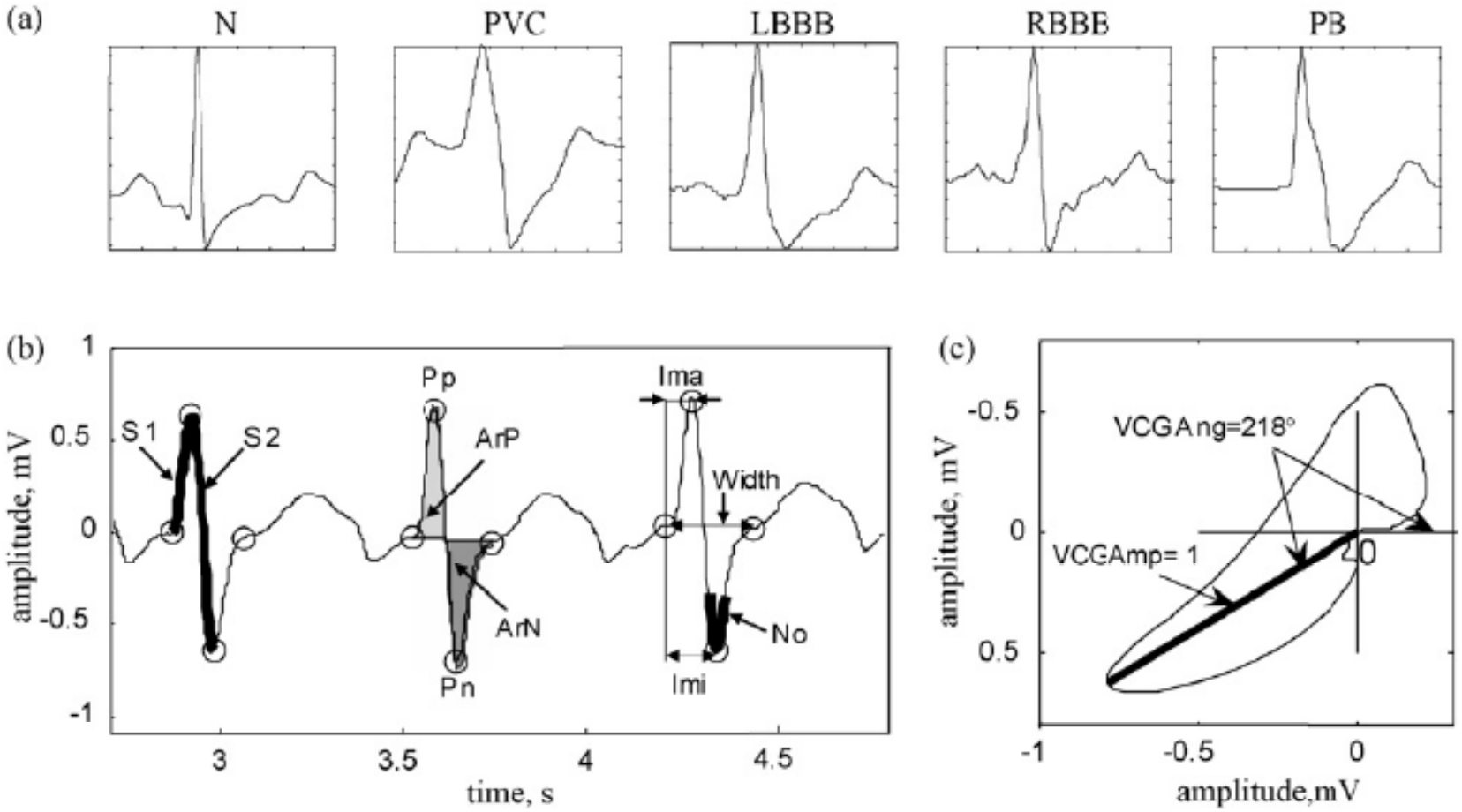


Figure 4.18 Normal ECG followed by an ectopic beat An irritable focus, or *ectopic pacemaker,* within the ventricle or specialized conduction system may discharge, producing an extra beat, or *extrasystole,* that interrupts the normal rhythm. This extrasystole is also referred to as a premature ventricular contraction (PVC). (Adapted from Brendan Phibbs, *The Human Heart,* 3rd ed., St. Louis: The C.V. Mosby Company, 1975.)

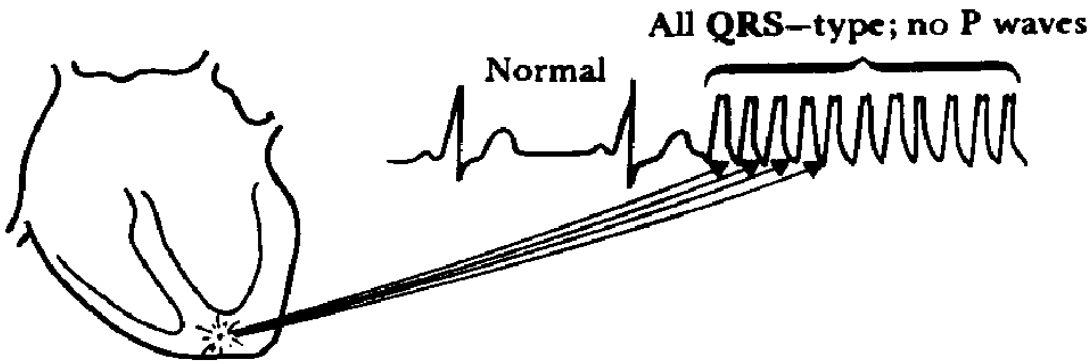
John G. Webster, Medical Instrumentation, application and design, 3rd Ed., Houghton Mifflin, 2000.

ECG features (Jekova et al, 2007)

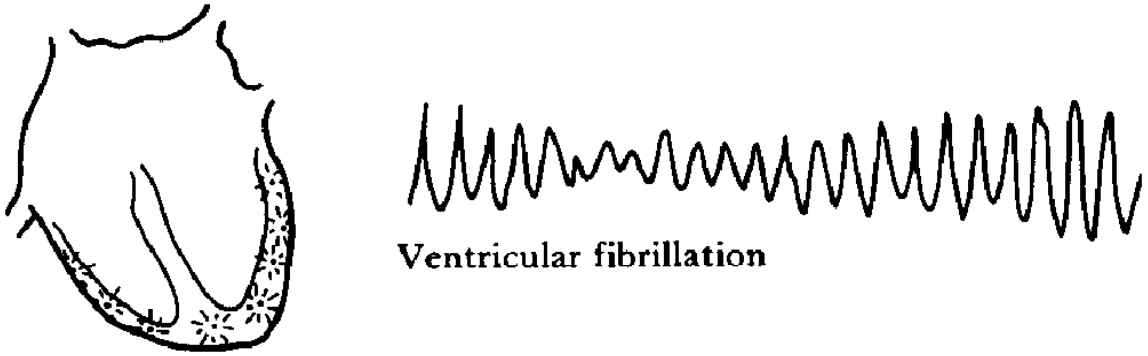


Life-threatening arrhythmia

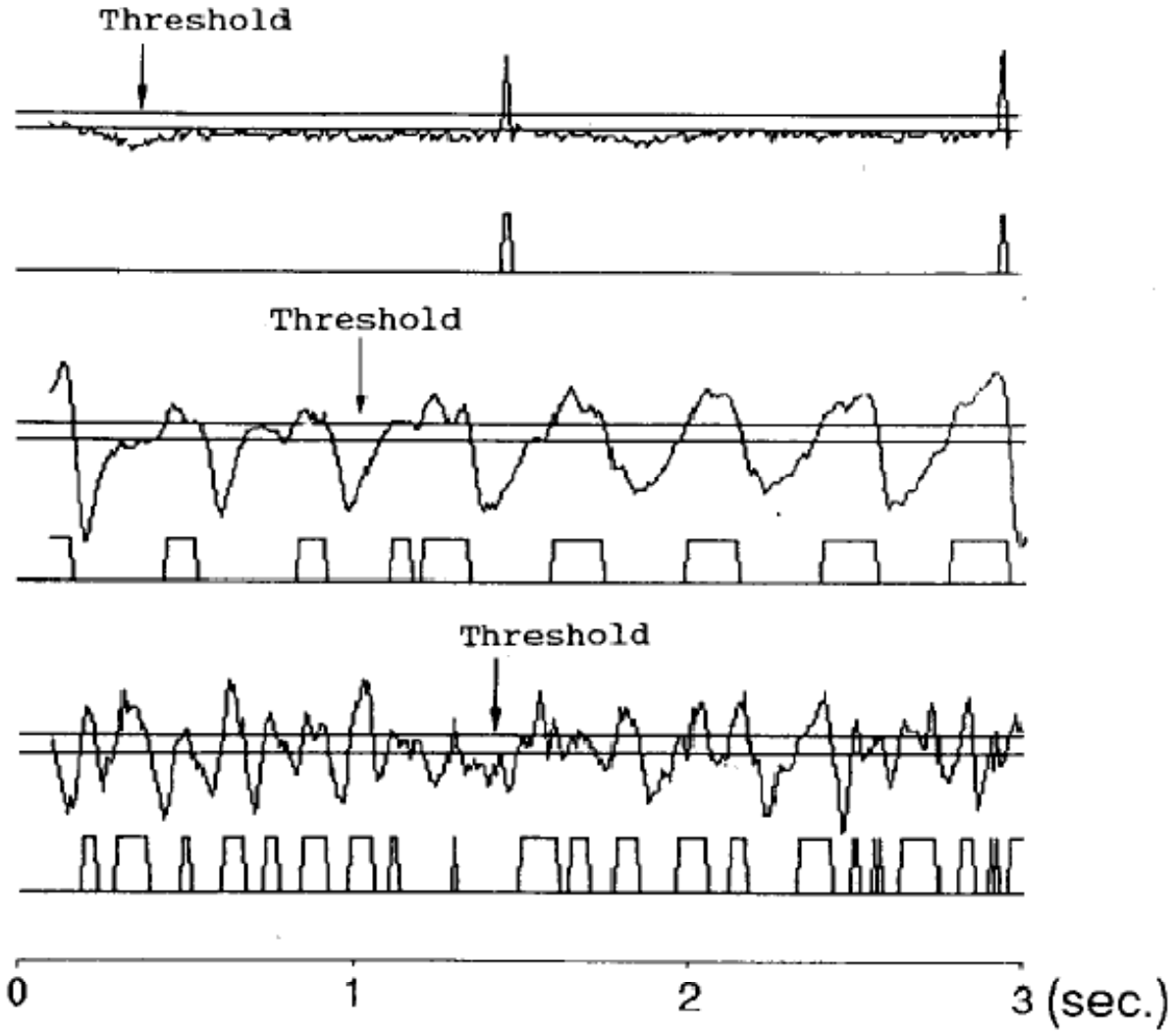
Ventricular Tachycardia



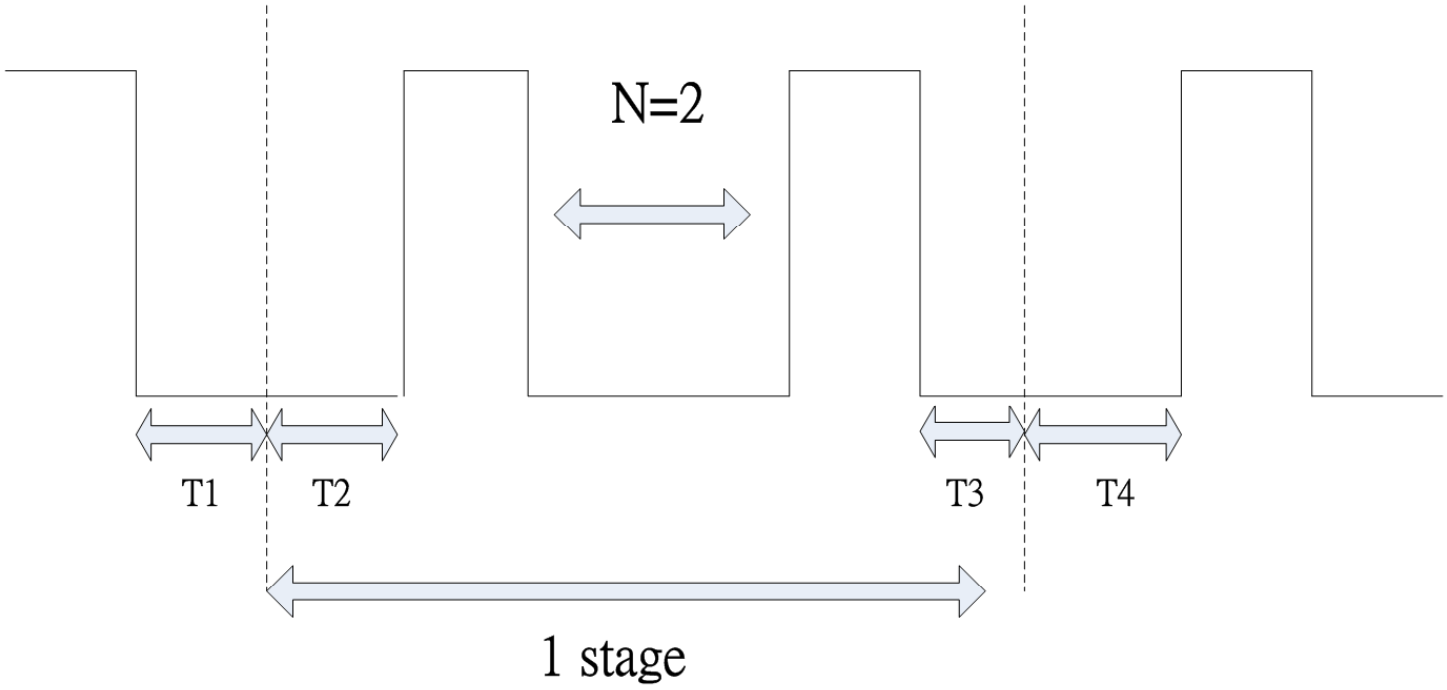
Ventricular fibrillation



Detecting VT and VF by TCI
Thaker et al, IEEE Trans. Biomed. Eng. 1990

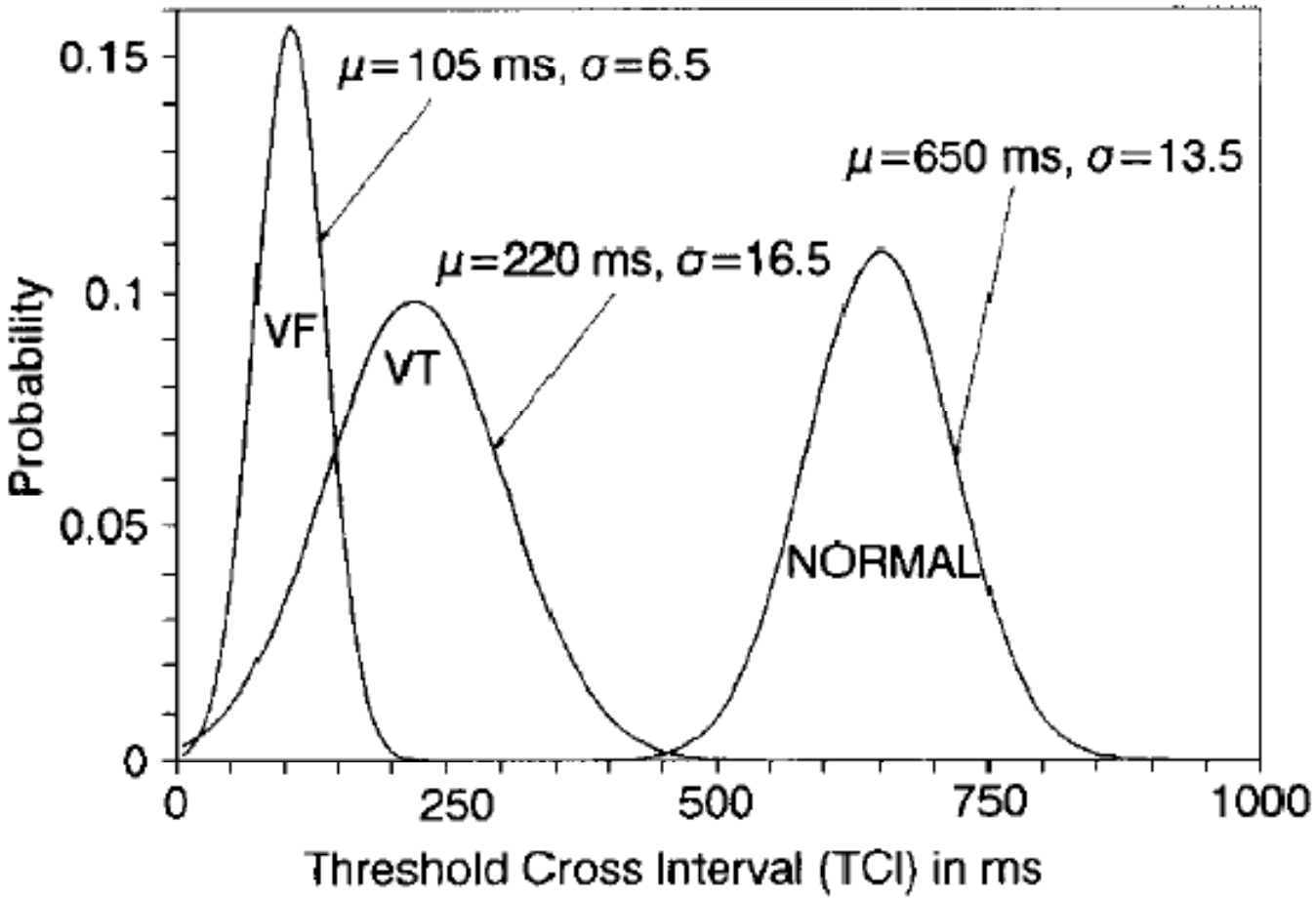


Threshold crossing interval (TCI)

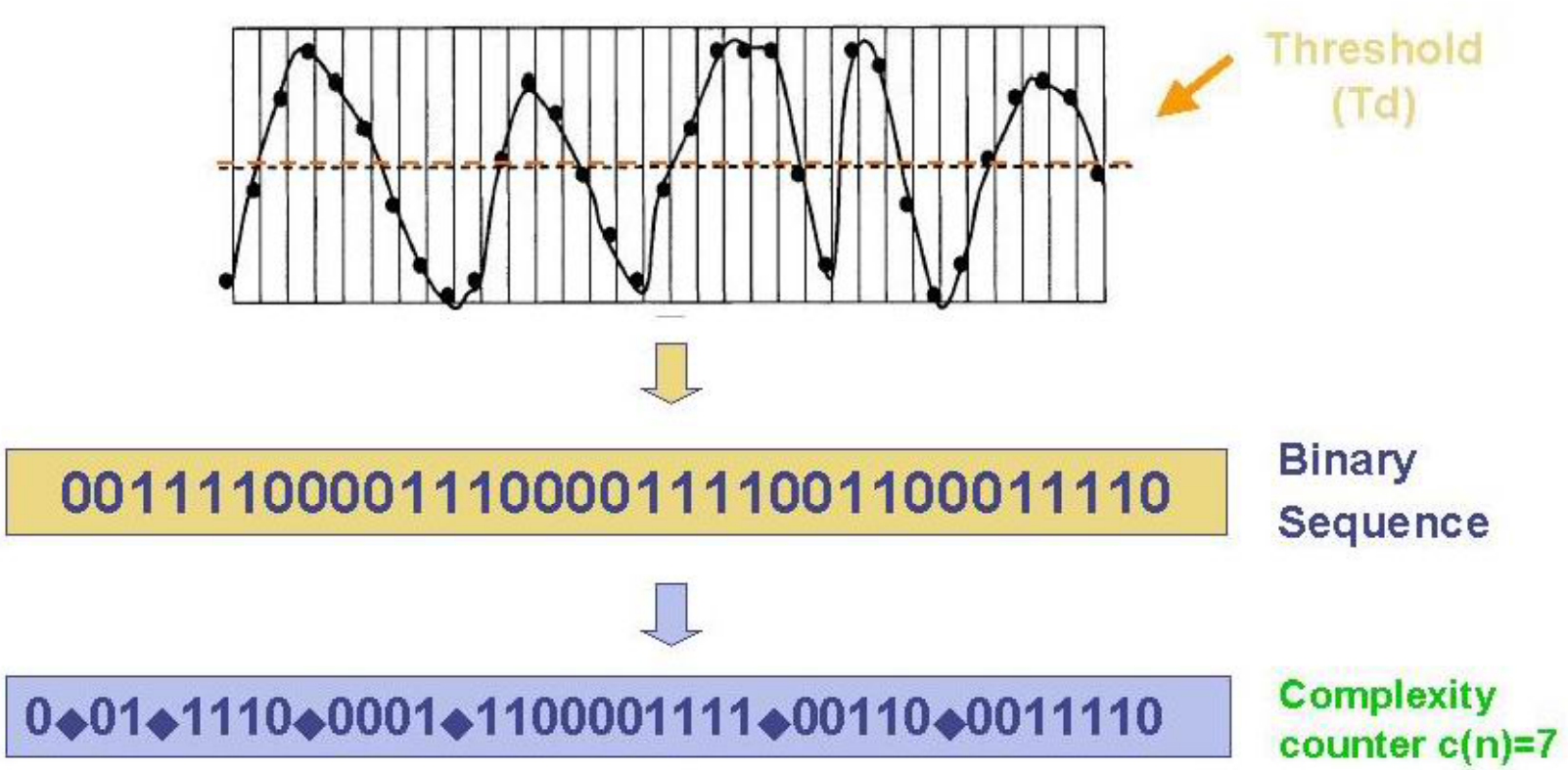


$$TCI = \frac{1000}{(N-1) + \frac{T2}{T1+T2} + \frac{T3}{T3+T4}}$$

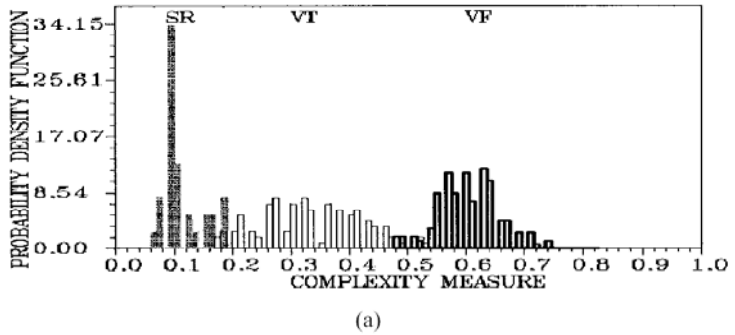
Detecting VT and VF by TCI



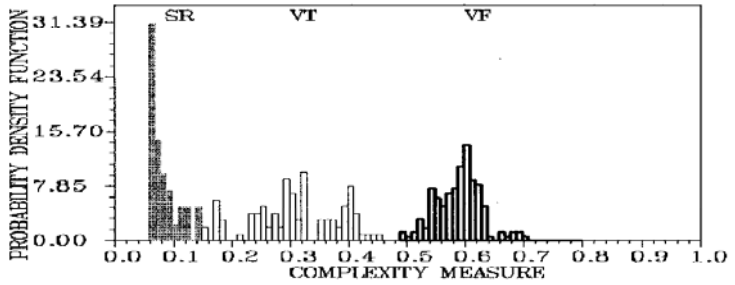
Lempel-Ziv complexity (複雜度)



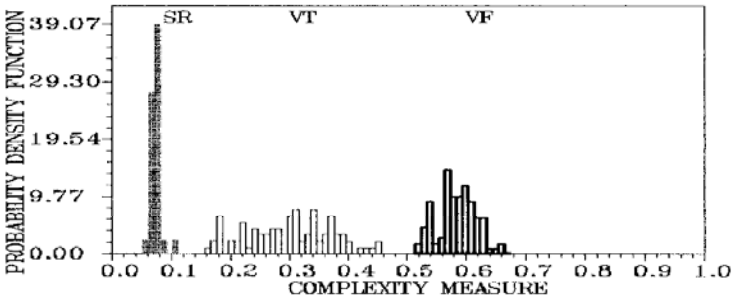
Detecting Ventricular Tachycardia and Fibrillation by Complexity Measure (Xu-Sheng Zhang, et al, 1999)



(a)



(b)



(c)

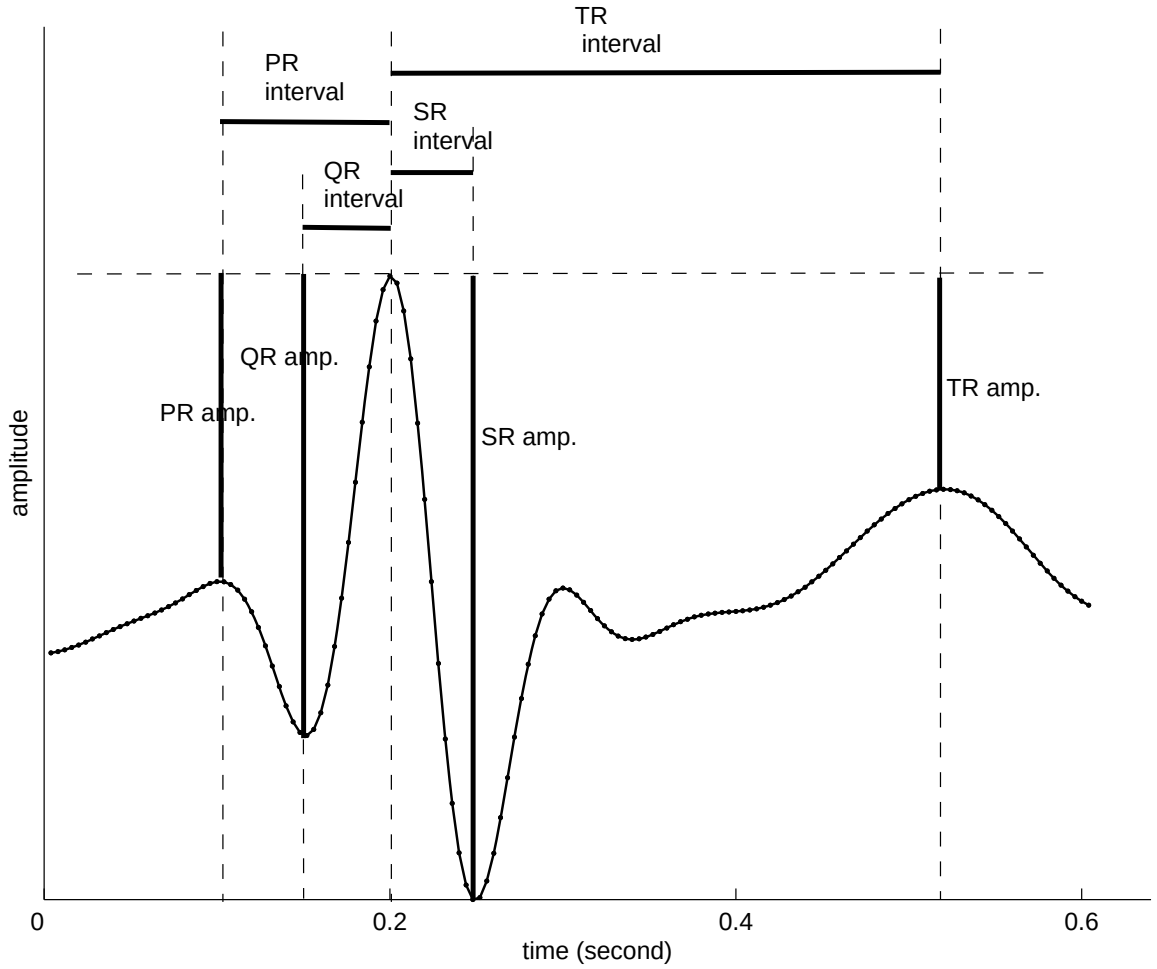
window length

3 s

5 s

7 s

Biometrics (生物辨識) by ECG features



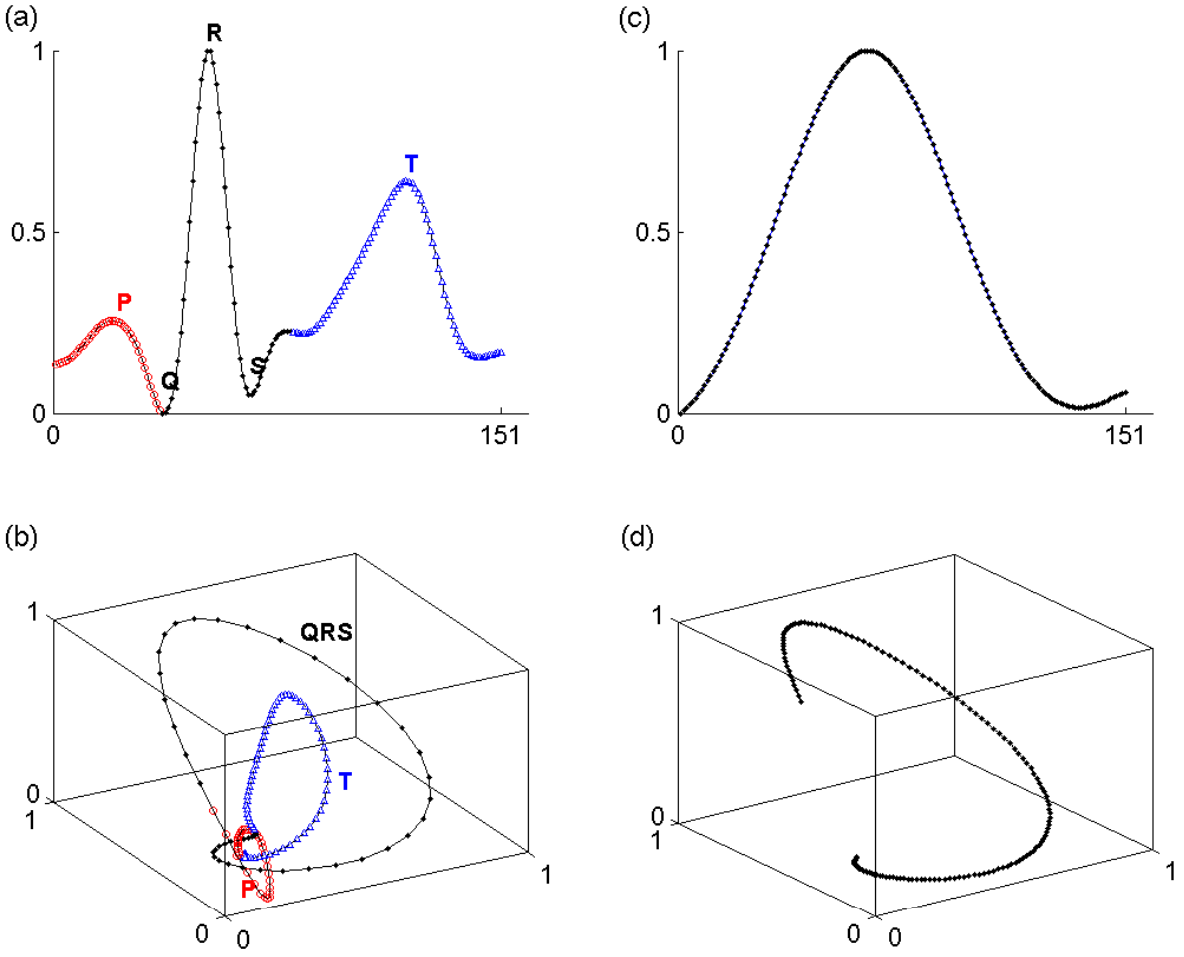
Human identification (身份識別) by ECG features

Classification performance on various configurations in characteristic-point comparison methods.

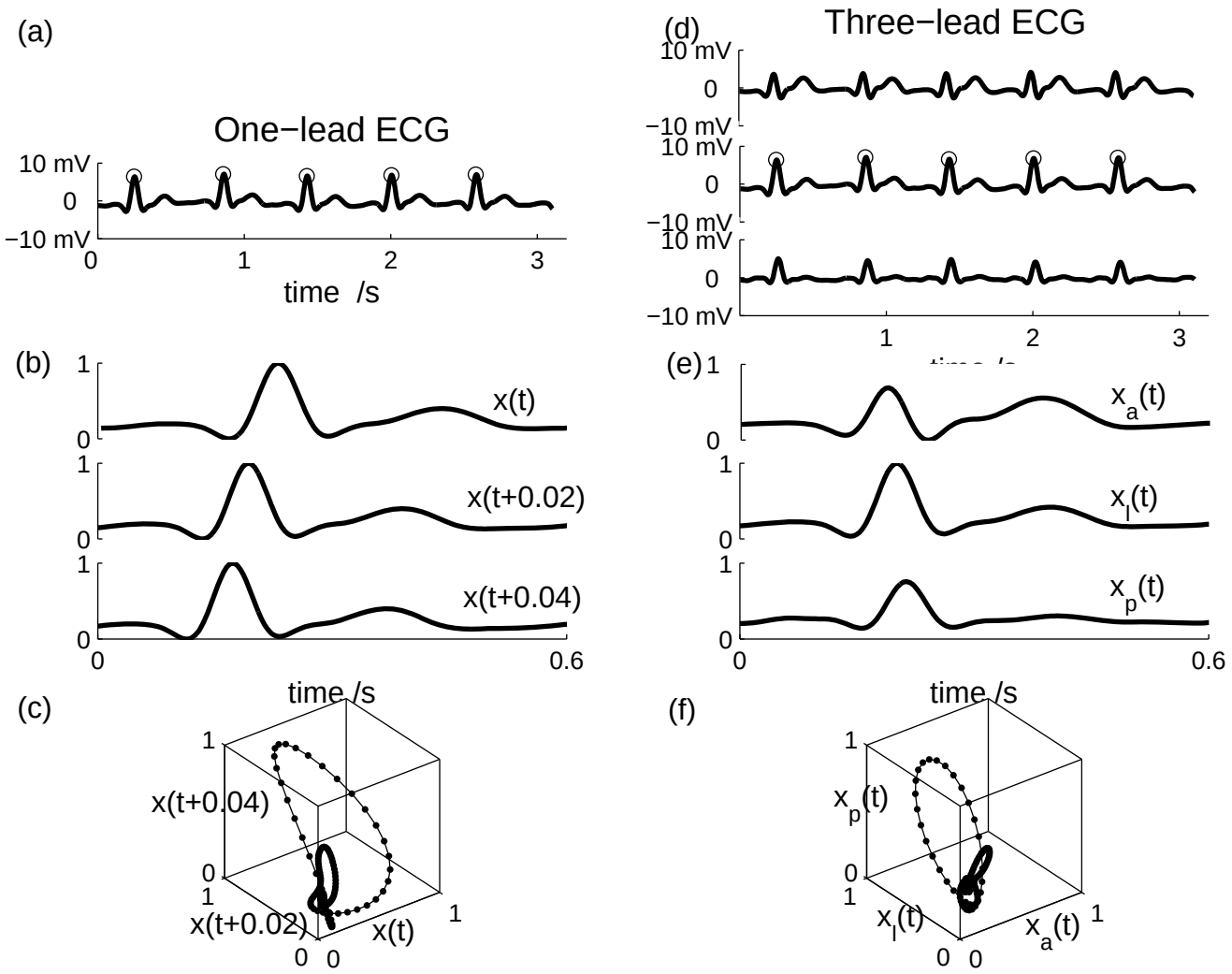
ECG leads	ECG features	Comparison method	Sensitivity (%)	Specificity (%)	Accuracy (%)
1	8/4*	BP20	89/95	86/67	87/81
3	24/9*	BP20	95/94	95/86	95/90
1	8/4*	RB10	86/74	91/81	89/77
3	24/9*	RB10	97/100	98/93	98/96
1	8/4*	PD	93/93	93/93	93/93
3	24/9*	PD	100/100	95/95	98/98

For 1-channel anterior-lead ECG, input with eight extracted features or four major principal components (4*). For 3-channel ECG, input with 24 extracted features or nine major principal components (9*). BP 20: backpropagation with 20 hidden neurons; RB10: radial basis function with spread constant 10; PD: point distance in multi-dimensional space. Sensitivity, specificity and accuracy were defined as Fig. 6.

Phase-space reconstruction of ECG



Phase-space reconstruction of ECG



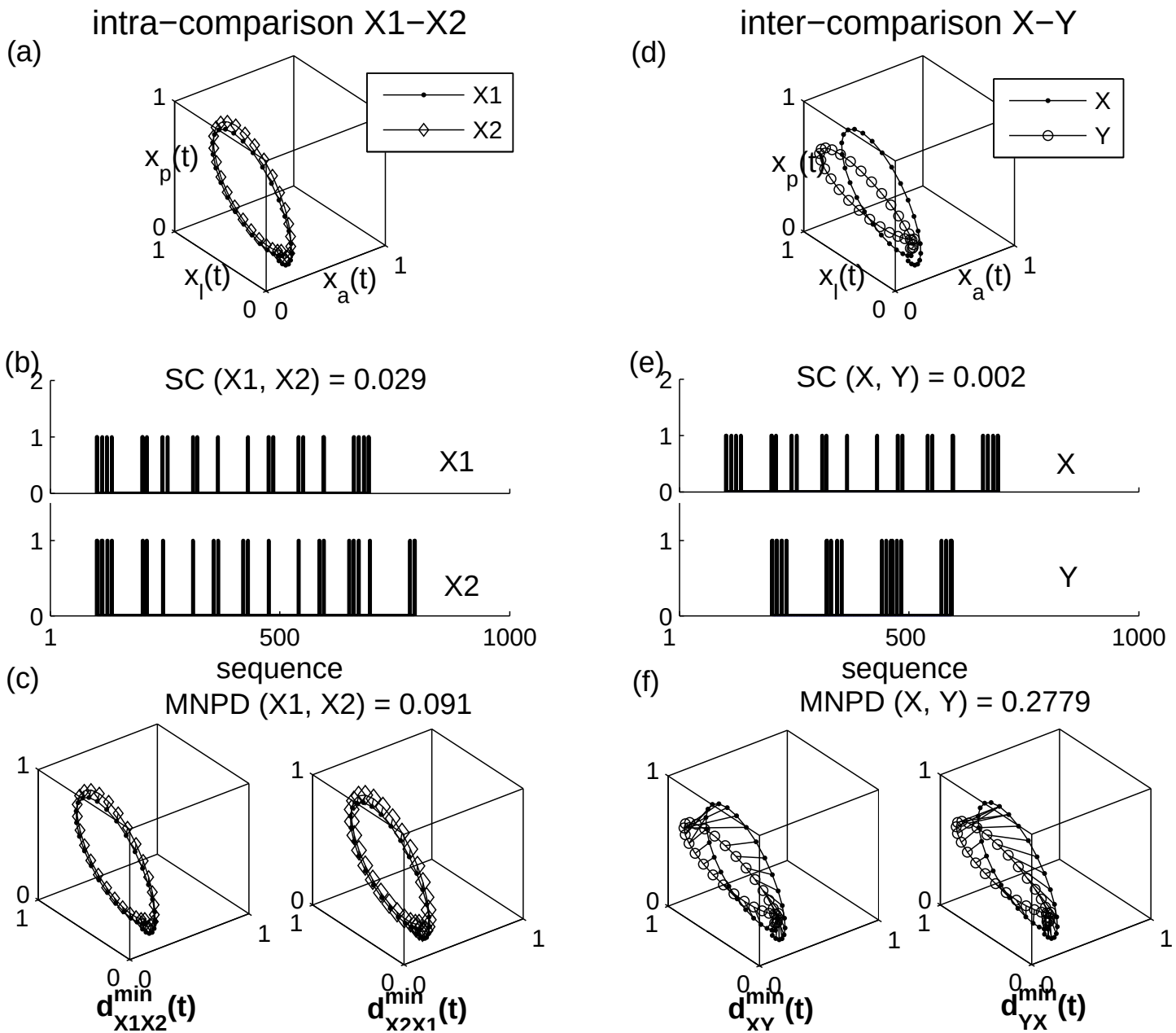
Measures of differences between phase-space trajectories

Spatial correlation (SC)

$$SC(\mathbf{X},\mathbf{Y}) = \frac{\sum_{1\le i,j,k\le M} N_{\mathbf{X}}(i,j,k)\times N_{\mathbf{Y}}(i,j,k)}{M^3 - 1}$$

Mutual nearest point distance (MNPD)

$$MNPD(\mathbf{X},\mathbf{Y}) = \frac{\sum_{t=t_1}^{t_P} d_{\mathbf{XY}}^{\min}(t) + \sum_{t=t_1}^{t_P} d_{\mathbf{YX}}^{\min}(t)}{2\times P}$$


intra−comparison X1−X2
(a)
X1
X2
$x_p(t)$
$x_l(t)$
$x_a(t)$
(b)
SC (X1, X2) = 0.029
X1
X2
sequence
(c)
MNPD (X1, X2) = 0.091
$d^{min}_{X1X2}(t)$
$d^{min}_{X2X1}(t)$
inter−comparison X−Y
(d)
X
Y
$x_p(t)$
$x_l(t)$
$x_a(t)$
(e)
SC (X, Y) = 0.002
X
Y
sequence
(f)
MNPD (X, Y) = 0.2779
$d^{min}_{XY}(t)$
$d^{min}_{YX}(t)$

Human identification over phase space of ECG

Classification performance on various configurations in portrait comparison methods.

ECG leads	ECG points	Comparison method	Sensitivity (%)	Specificity (%)	Accuracy (%)
1	31	MNPD	98	88	93
1	151	MNPD	95	89	92
3	31	MNPD	99	98	99
3	151	MNPD	98	95	97
1	31	SC 10	96	87	92
1	151	SC 10	89	75	82
3	31	SC 10	97	96	97
3	151	SC 10	98	86	91

Spatial correlations SC 10 computed upon 10×10×10 phase space partitions; MNPD: mutual nearest point distance. Sensitivity, specificity and accuracy were defined as Fig. 6.

Reference

- JJ.Carr, JM.Brown, Introduction to Biomedical Equipment Technology, 4nd Edition, Prentice-Hall, 2000.
- J. Enderle, Introduction to Biomedical Engineering, Academic Press, 2000.
- JG. Webster, Medical Instrumentation, application and design, 3rd, Houghton Mifflin, 2000.