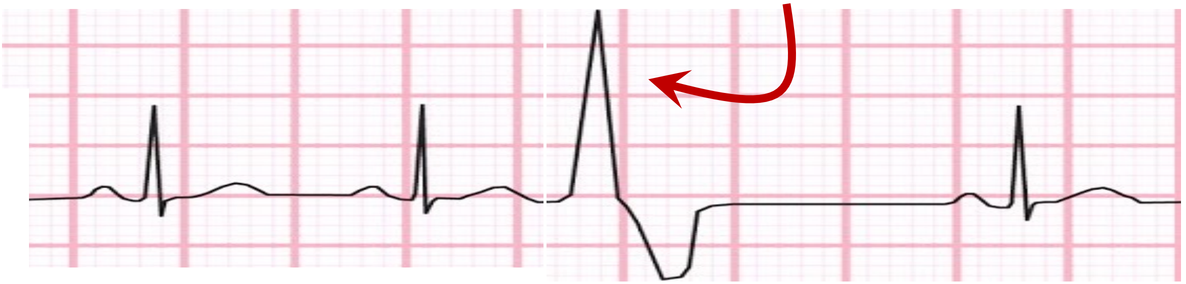
QLSC 600

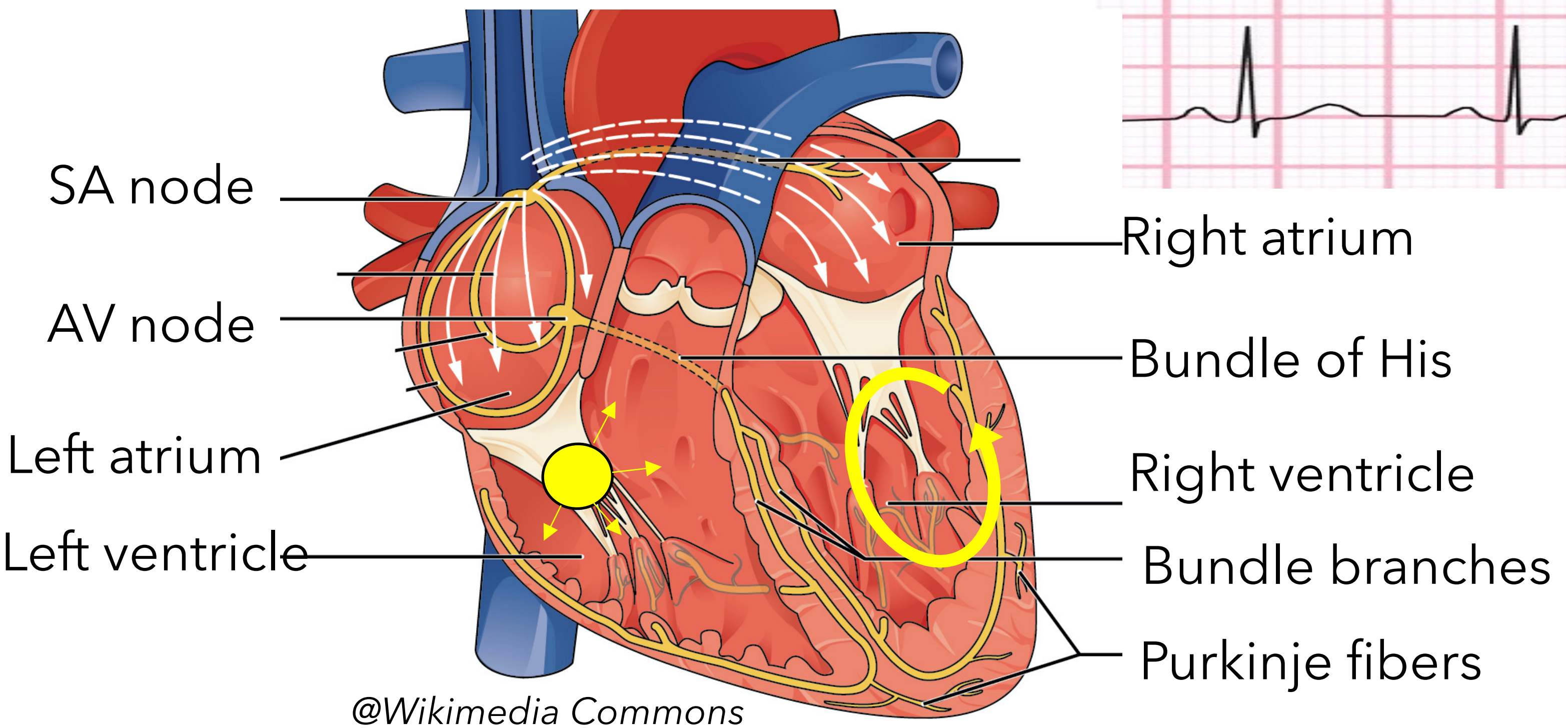
Cardiac arrhythmia

Instructors: Thomas Bury, Leon Glass

Ventricular arrhythmia

PVC = Premature Ventricular Complex





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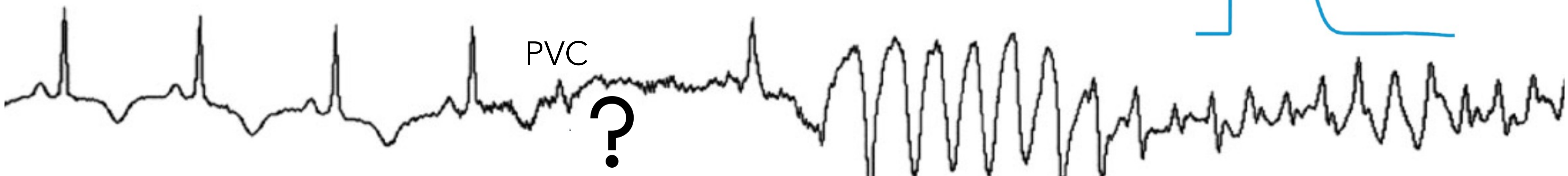
Initiation mechanisms

1. Ectopic pacemaker
2. Reentry
3. Triggered activity



Sudden Cardiac Death Database (www.physionet.org)

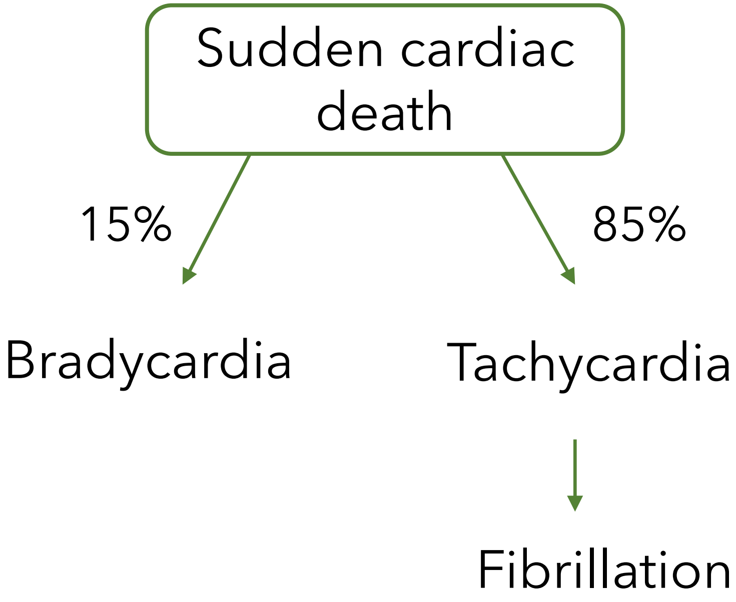
Sudden cardiac death – epidemiology

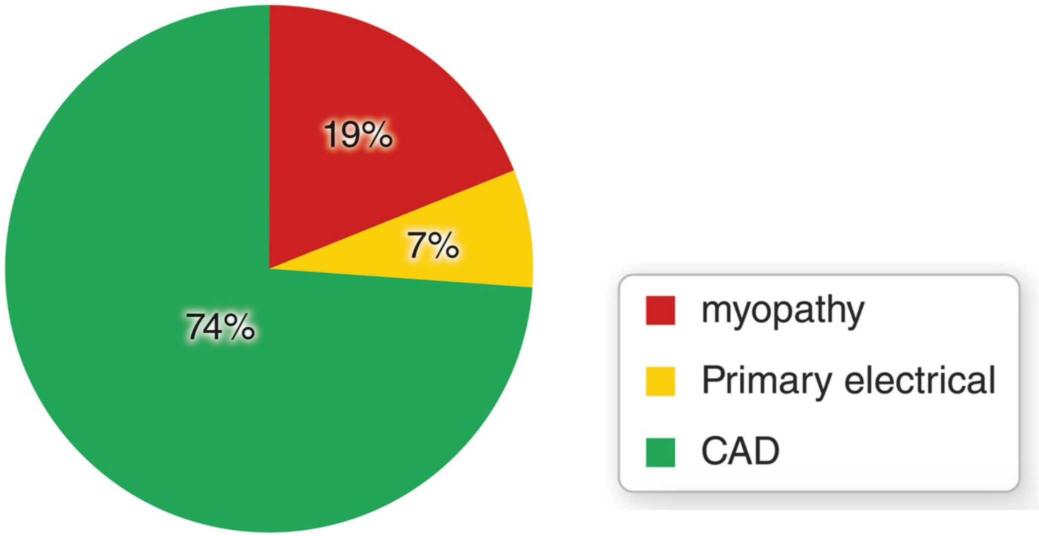
- Cardiovascular disease is a leading cause of death (31% of all global deaths)

The World Health Organisation

- 50% are cases of 'sudden cardiac death' – death within 1 hour after the onset of symptoms

Gerber et al. Secular trends in deaths from cardiovascular diseases: a 25-year community study. Circulation.





J. Anthony Gomes. Heart Rhythm disorders: History, Mechanisms, and Management Perspectives, Springer.

Why analyse PVC dynamics?

- Frequent PVCs show increased risk of cardiac death

Dukes et al. Ventricular ectopy as a predictor of heart failure and death. JACC (2015)

- Ventricular fibrillation is often preceded by frequent PVCs

Deyell et al. Sudden Cardiac Death Risk Stratification. Circulation research. (2015)

- PVC dynamics in patients are rich but poorly understood – still cannot reliably infer mechanism from pattern

- Problem of risk stratification for sudden cardiac death

How can we analyse PVC dynamics?

Holter recording

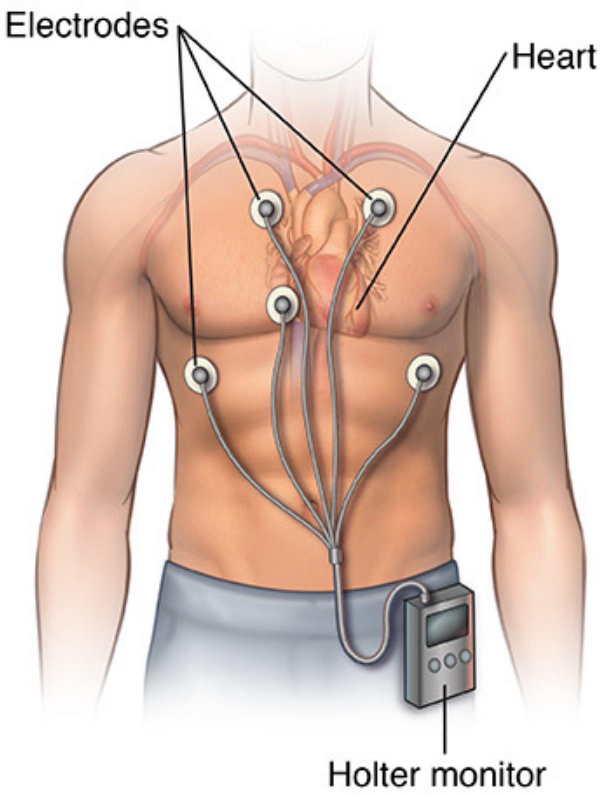
1947 - Norman Holter

Wikipedia. The original Holter biotelemetry apparatus in 1947 weighing 85 lb

1954 – Briefcase recorder

Image courtesy of National Museum of American History

1960 – Tape recorder



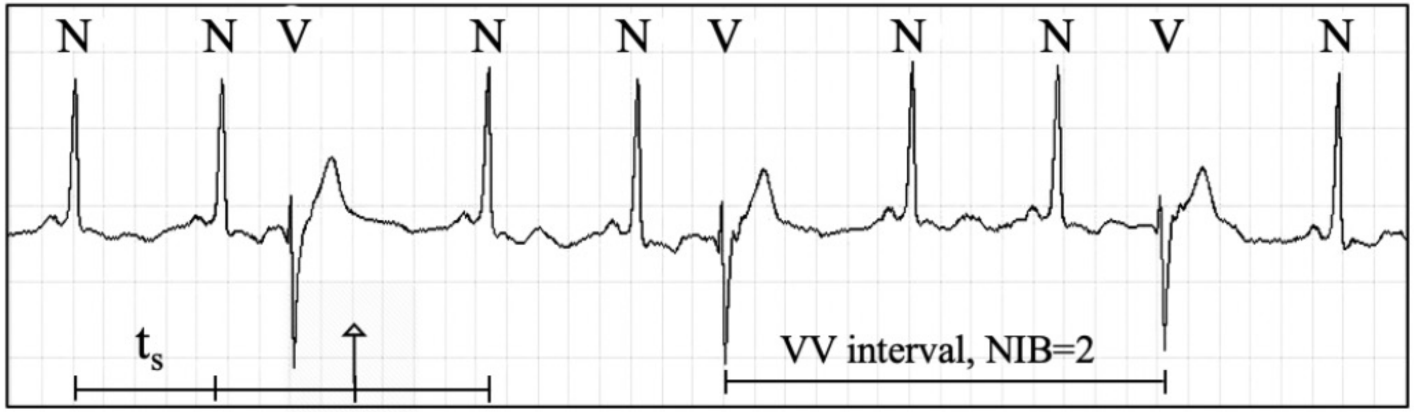
H L Kennedy. The history, science and innovation of Holter technology. Annals of Noninvasive Electrocard. (2006)

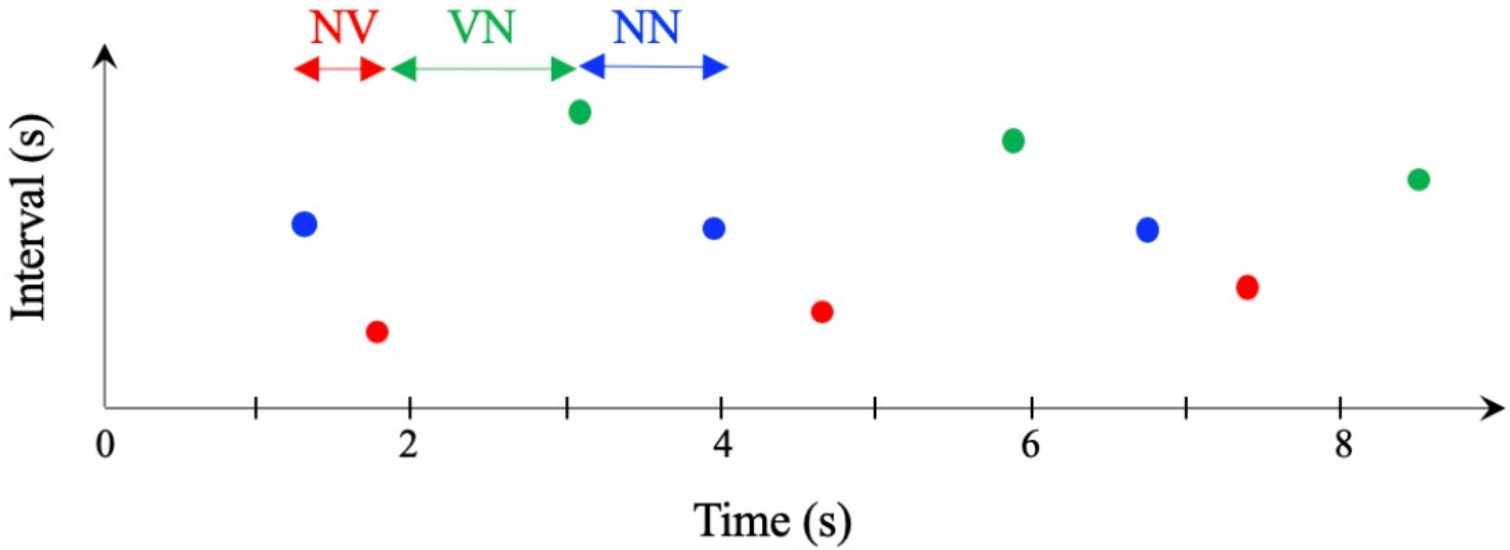
2010 onwards:

Icentia cardioSTAT

Apple watch

ECG data processing





Beat detection algorithm (Icentia)

N – normal (sinus) beat

V – premature ventricular complex (PVC)

Timing – precise to 250Hz

Beat-to-beat interval plot

NV – coupling interval

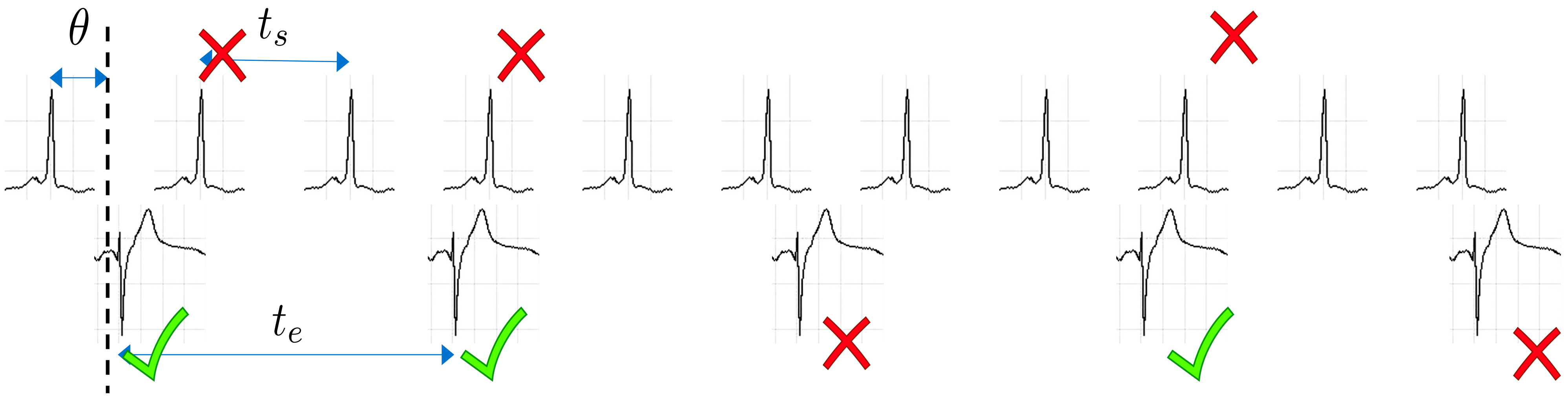
VN – compensatory pause

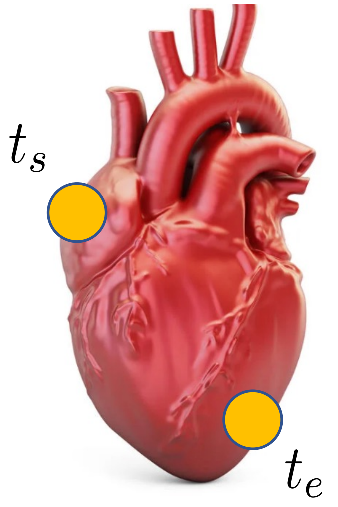
NN – sinus interval

App demonstration

Pure parasystole

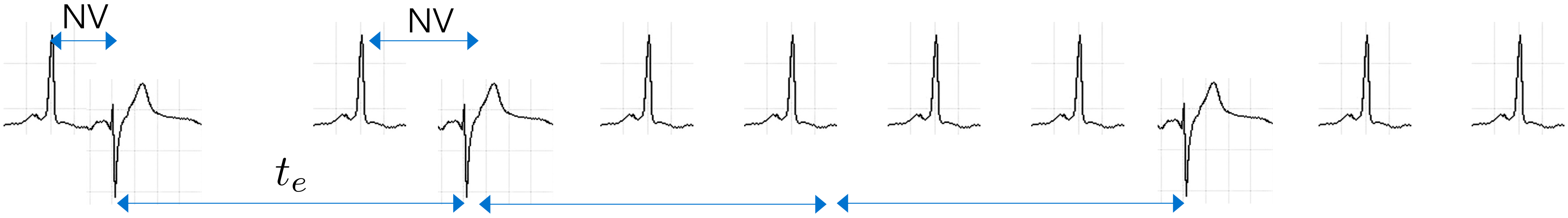
- Ectopic pacemaker independent of sinus pacemaker





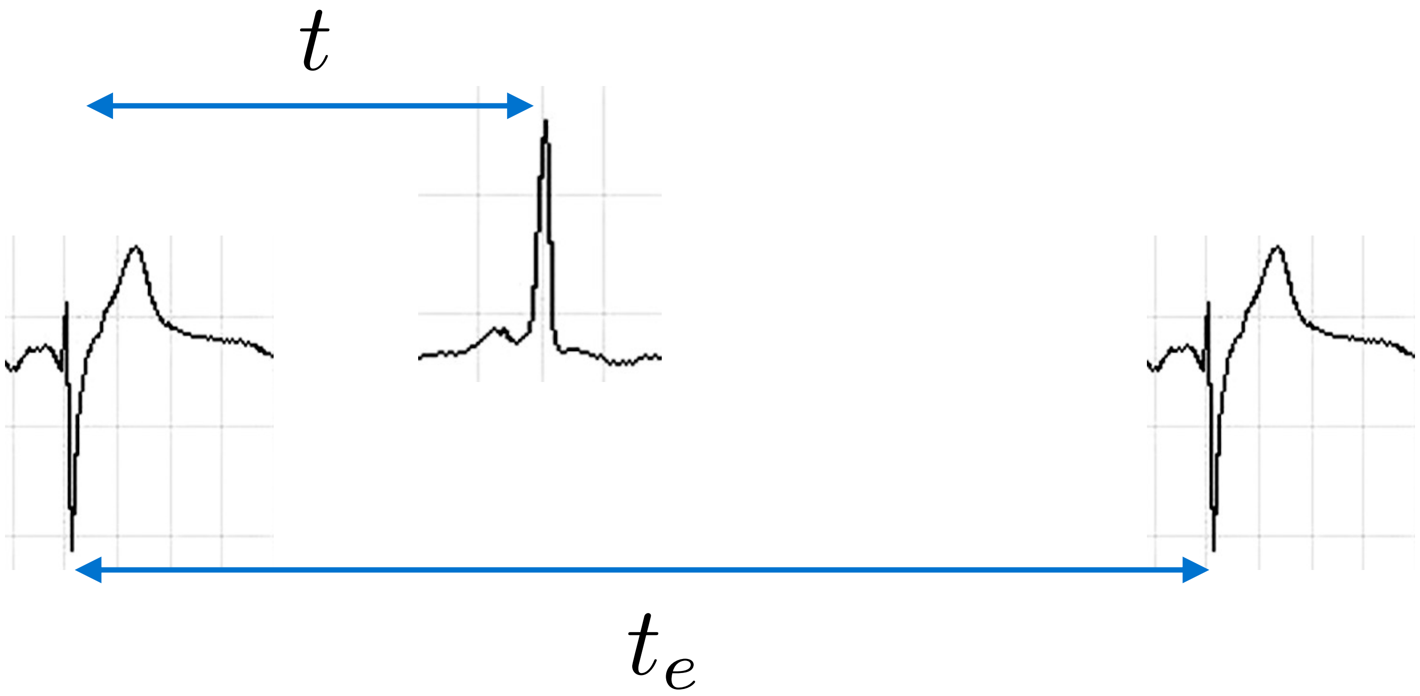
Assumptions

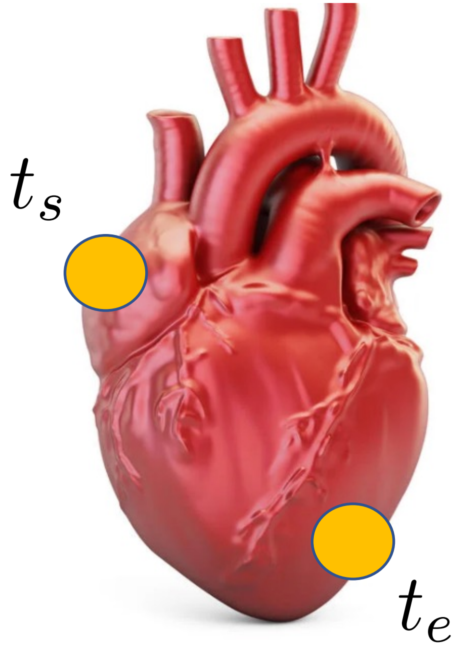
1. Ectopic beat blocked if it falls inside refractory period, θ
2. Ectopic beat expressed if it falls outside of refractory period, θ
3. Sinus beat following an expressed ectopic beat is blocked (compensatory pause)



Difference equation for phase

ϕ_i Phase of the i^{th} sinus beat (expressed or not) in the ectopic cycle





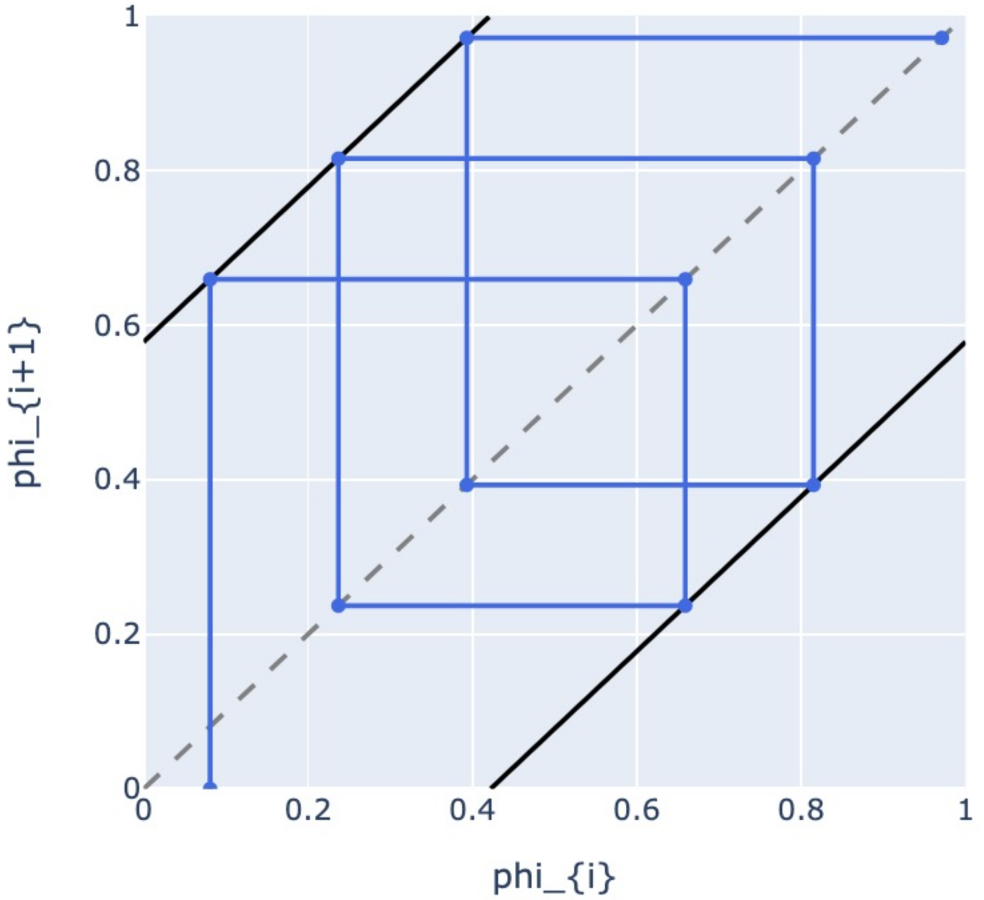
$$\phi = \frac{t}{t_e}$$

Find the expression for ϕ_{i+1} in terms of ϕ_i and make a cobweb plot.

$$\phi_{i+1} = \begin{cases} \phi_i + \frac{t_s}{t_e} & 0 \leq \phi_i < 1 - \frac{t_s}{t_e} \\ \phi_i + \frac{t_s}{t_e} - 1 & 1 - \frac{t_s}{t_e} \leq \phi_i < 1 \end{cases}$$

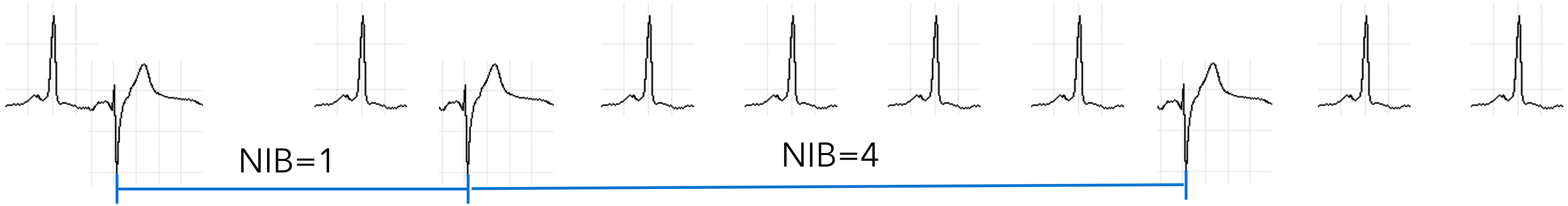
Or put more simply...

$$\phi_{i+1} = \phi_i + \frac{t_s}{t_e} \pmod{1}$$



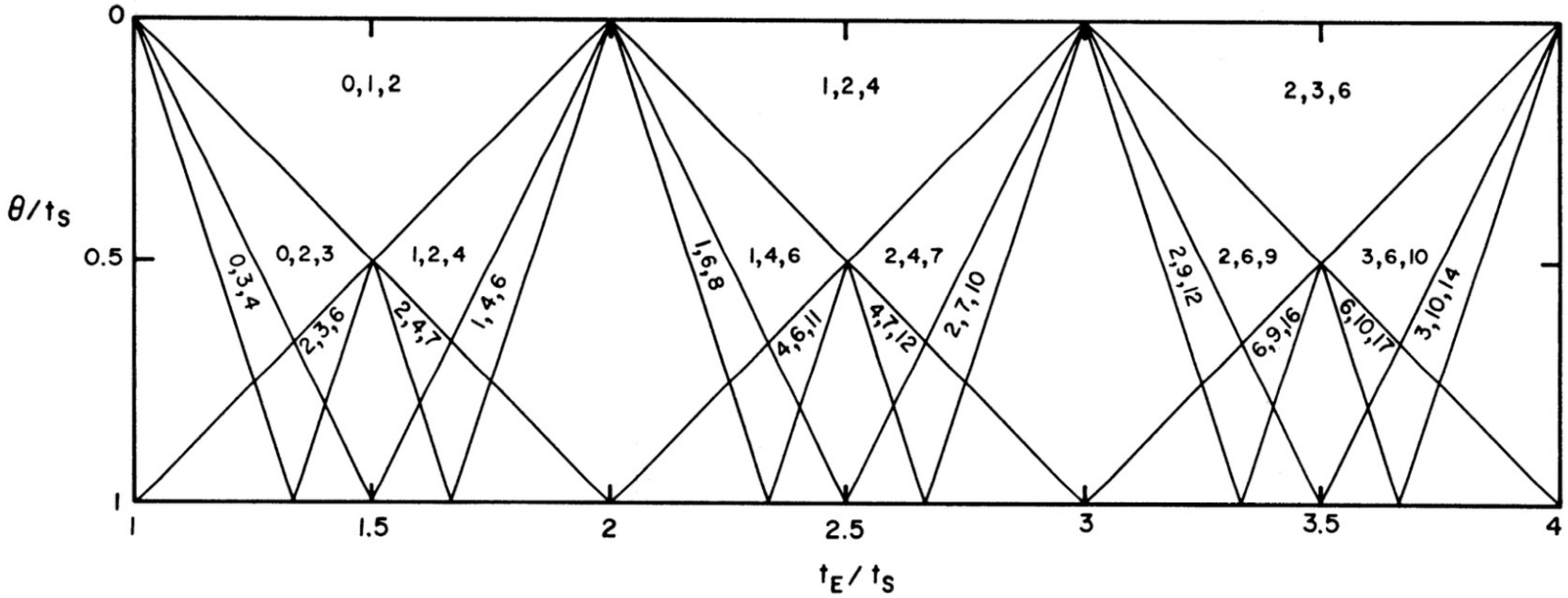
Pure parasystole

NIB: Number of intervening sinus beats between two ectopic beats



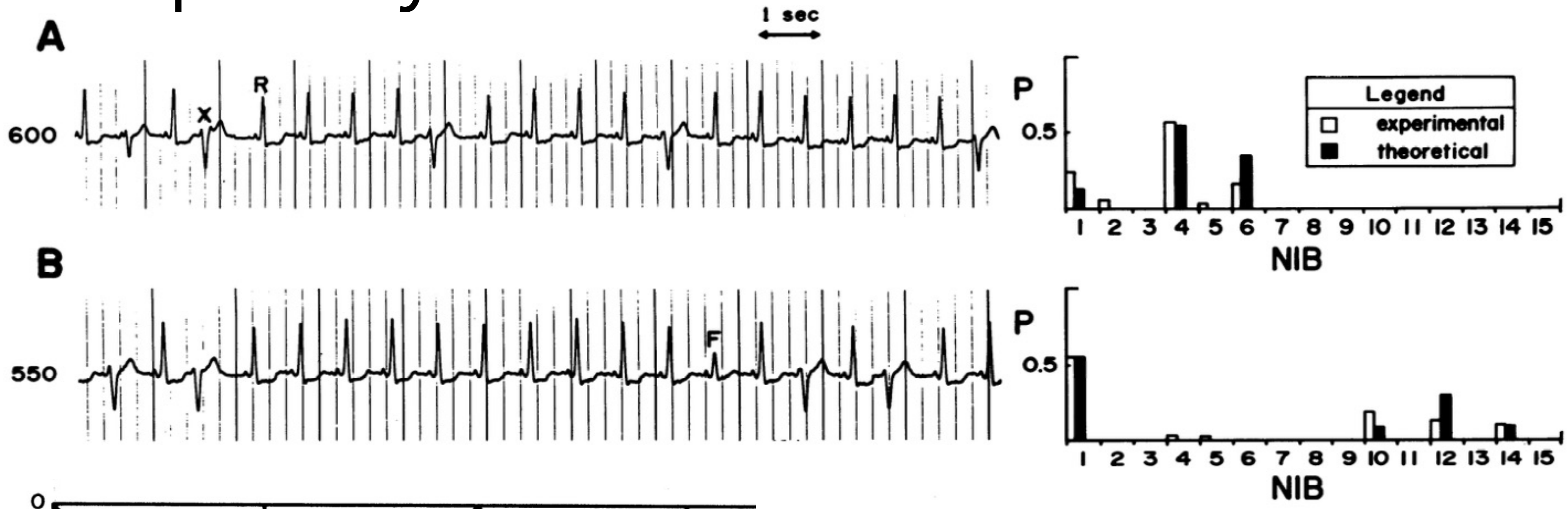
Rules

1. Three different values
2. One of which is odd
3. Sum to two smaller values < largest value

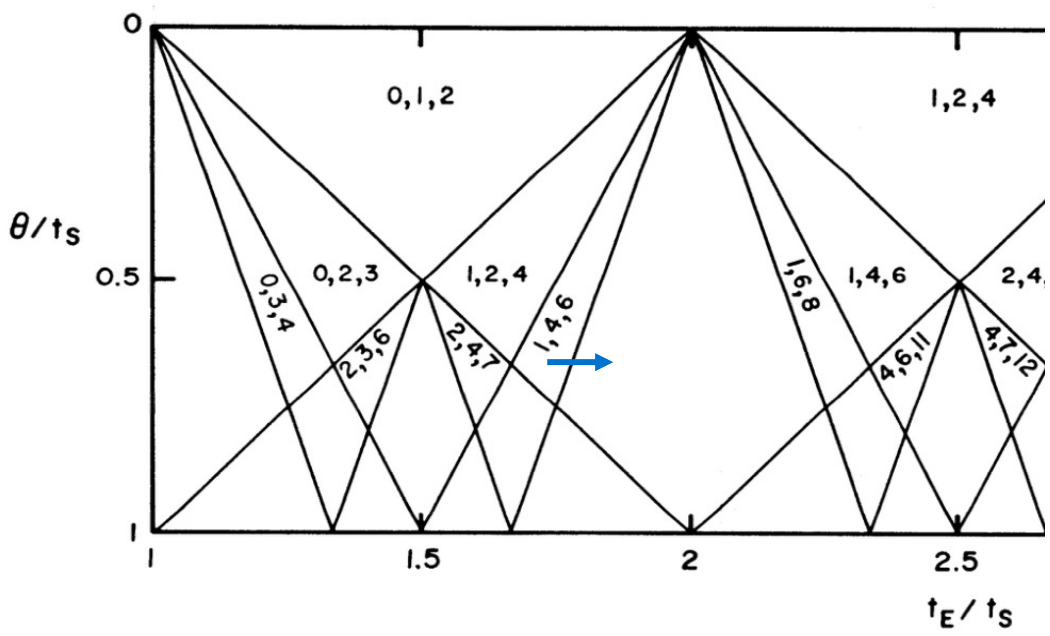


Glass et al., Dynamics of pure parasystole. American Journal of Physiology (1986).

Pure parasystole



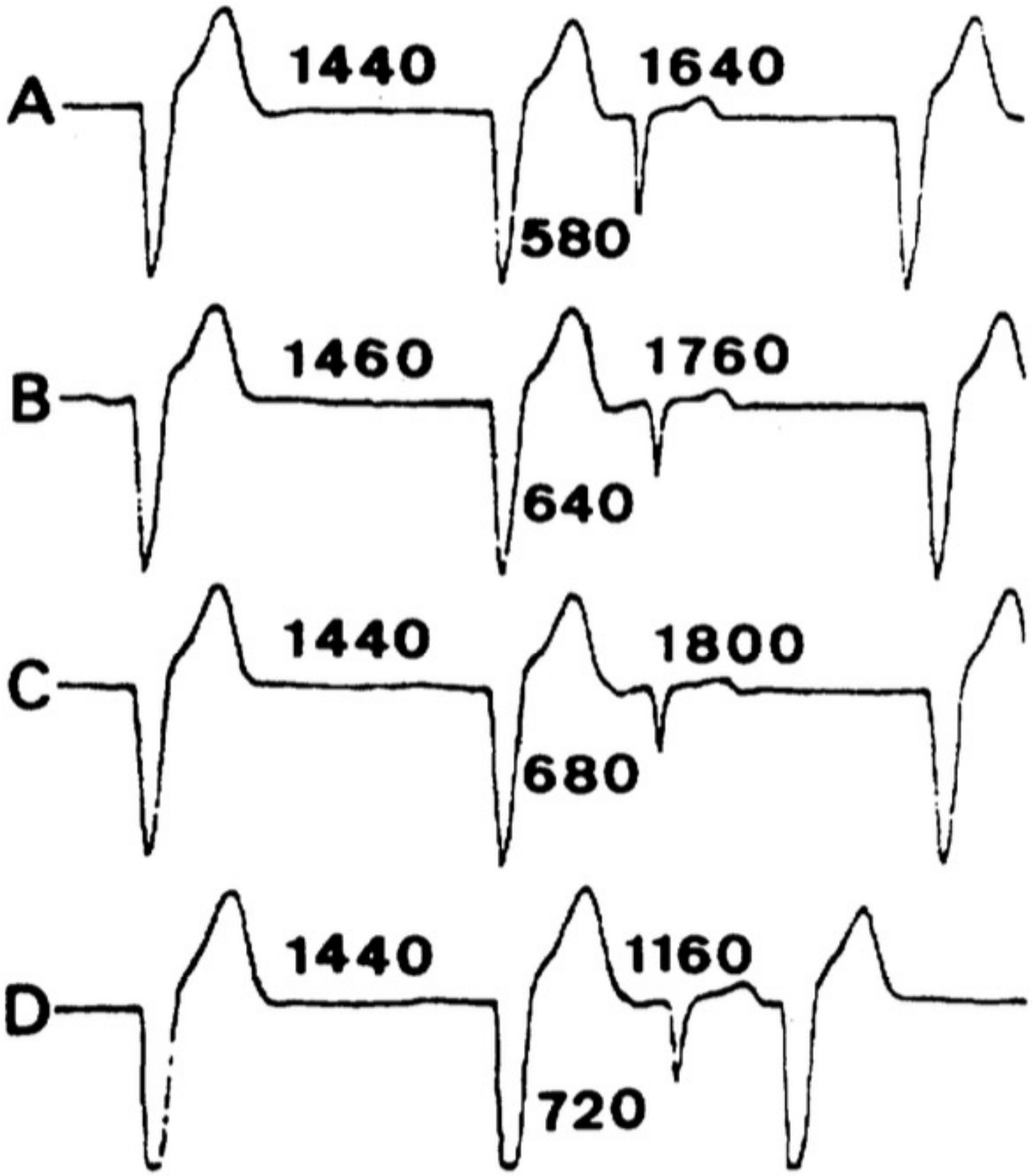
$$\theta/t_s = 0.6$$
$$t_e = 1050\text{ms}$$

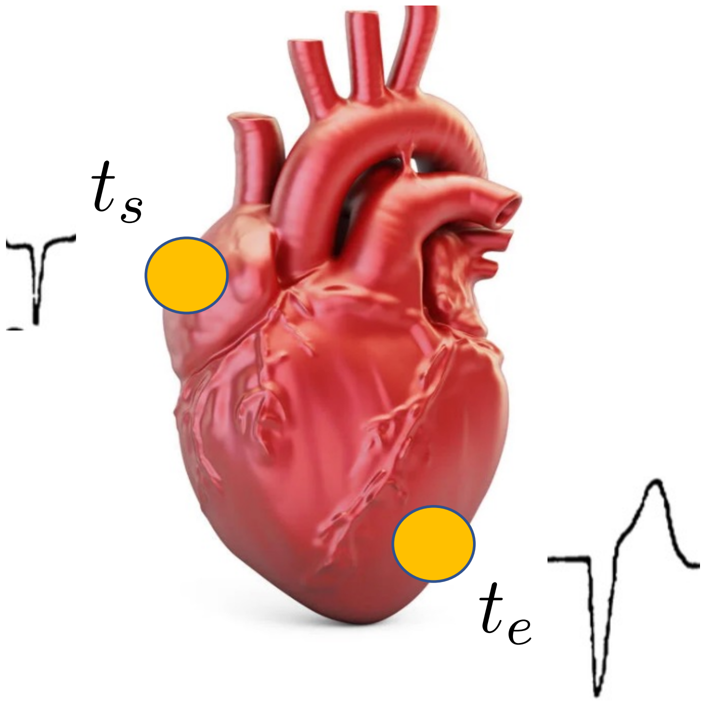


Courtemanche et al., Beyond pure parasystole: promises and problems in modeling complex arrhythmias. American Journal of Physiology (1989)

Factors not included

1. Modulation of ectopic focus
2. Conduction time to and from ectopic focus
3. Variable refractory period
4. Stochasticity in parameters



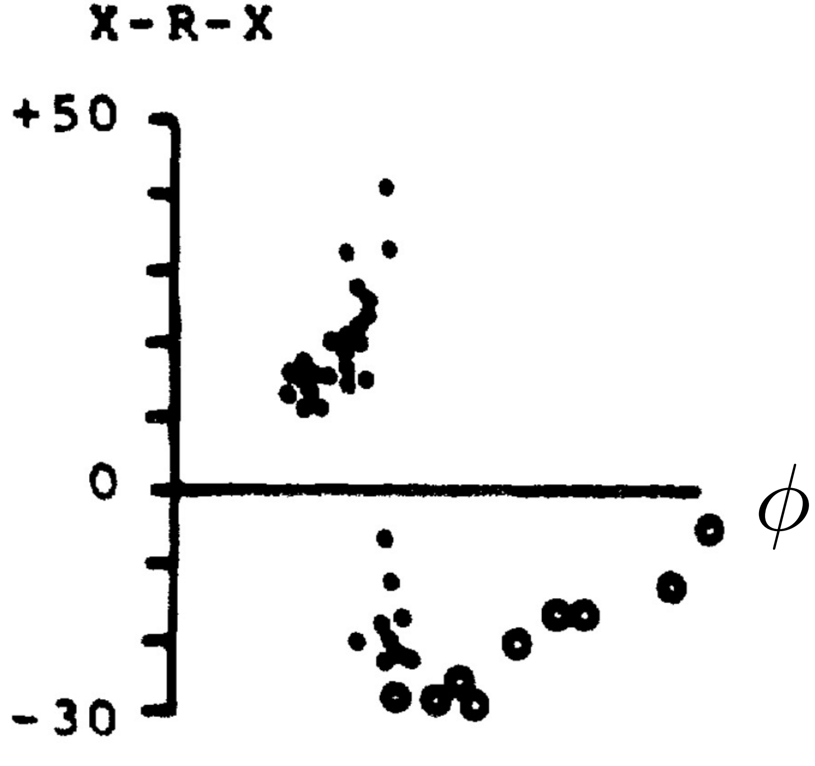


Nau et al., Modulation of Parasystolic Activity by Nonparasystolic Beats. Circulation (1982)

Modulated parasystole

Pacemakers are influenced by external stimuli

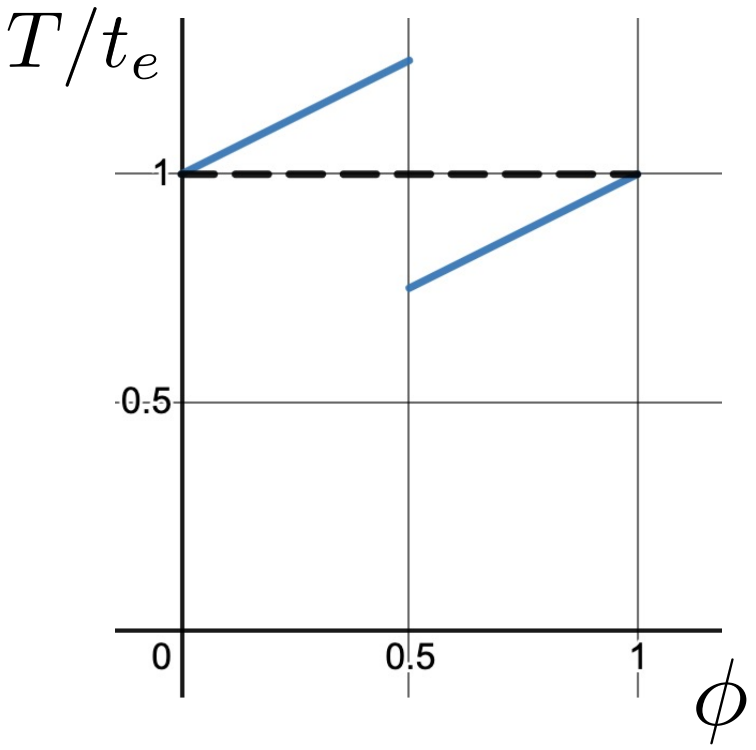
$$\frac{T - t_e}{t_e}$$ Normalized change in ectopic cycle length



Nau et al., Modulation of Parasystolic Activity by Nonparasystolic Beats. Circulation (1982)

$$\frac{T}{t_e} = \begin{cases} k\phi + 1 & 0 \leq \phi < 0.5 \\ k(\phi - 1) + 1 & 0.5 \leq \phi < 1 \end{cases}$$

k is the strength of resetting

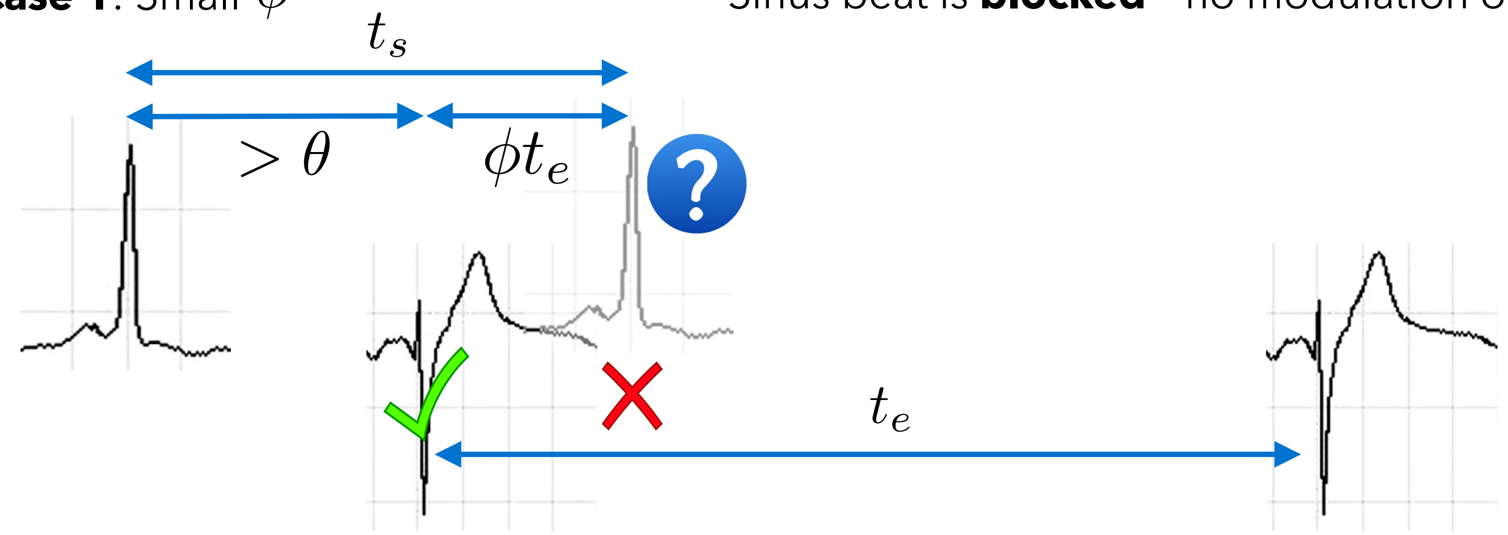


Difference equation

Courtemanche et al., American Journal of Physiology (1989)

Case 1: Small ϕ

Sinus beat is **blocked** – no modulation of ectopic focus

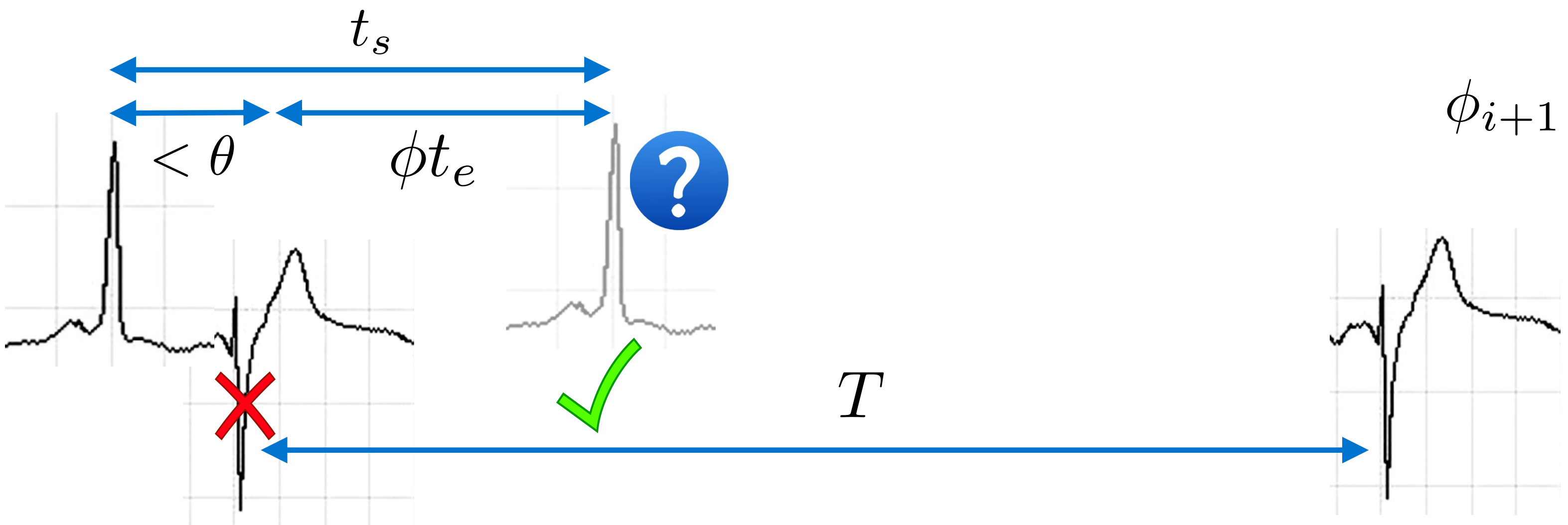


$$\phi_{i+1} = \phi_i + \frac{t_s}{t_e} \mod 1$$

$$0 \le \phi_i < (t_s - \theta)/t_e$$

Case 2: Large ϕ

Sinus beat is **expressed** – modulation of ectopic focus



Shift in phase due to modulation

$$\phi_{i+1} = \phi_i + \frac{t_s}{t_e} + \boxed{1 - \frac{T(\phi_i)}{t_e}} \mod 1$$

$$(t_s - \theta)/t_e \le \phi_i < 1$$

Difference equation

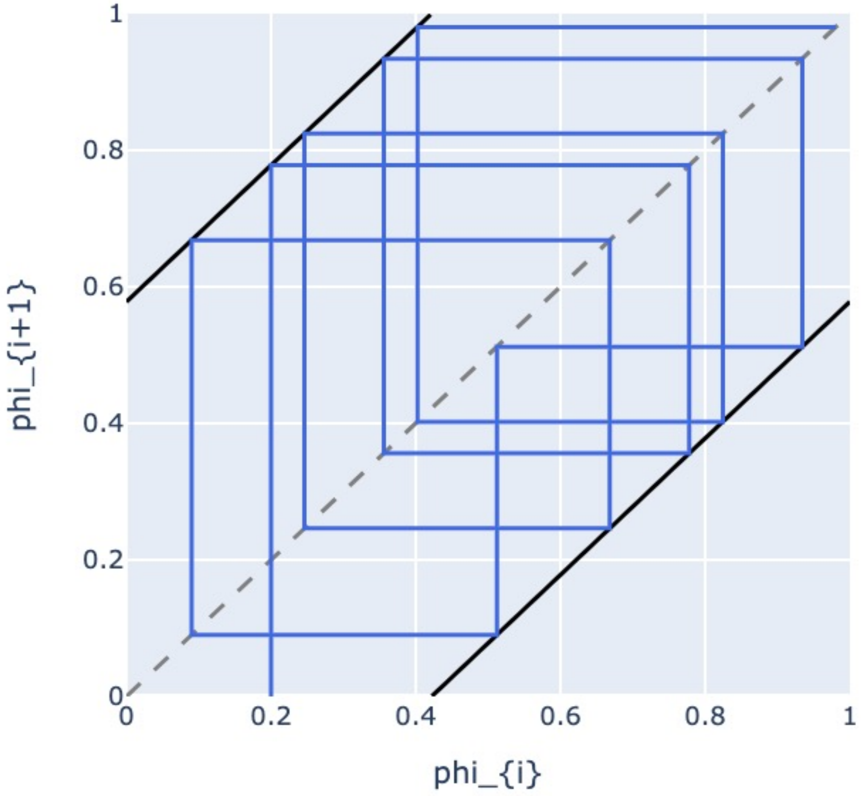
Courtemanche et al., American Journal of Physiology (1989)

Investigate dynamics of modulated parasystole using online app
https://modulated-parasystole-cobweb.herokuapp.com/

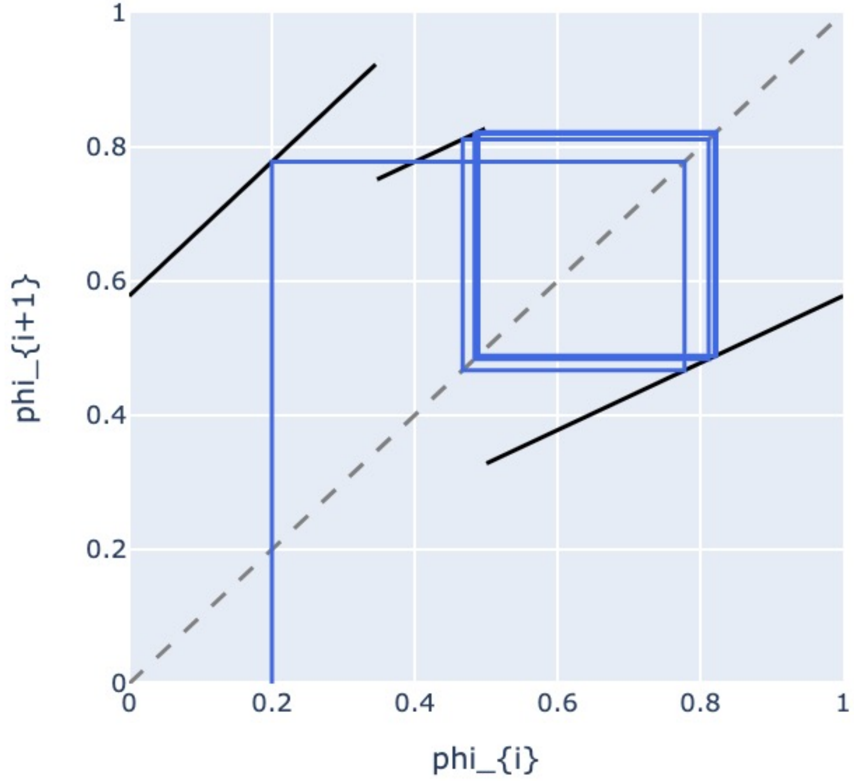
How does this differ qualitatively from pure parasystole (k=0)?

$$\phi_{i+1} = \begin{cases} \phi_i + \frac{t_s}{t_e} & 0 \leq \phi_i < \frac{t_s - \theta}{t_e}, \\ \phi_i + \frac{t_s}{t_e} + 1 - f(\phi_i) & \frac{t_s - \theta}{t_e} \leq \phi < 1, \end{cases}$$

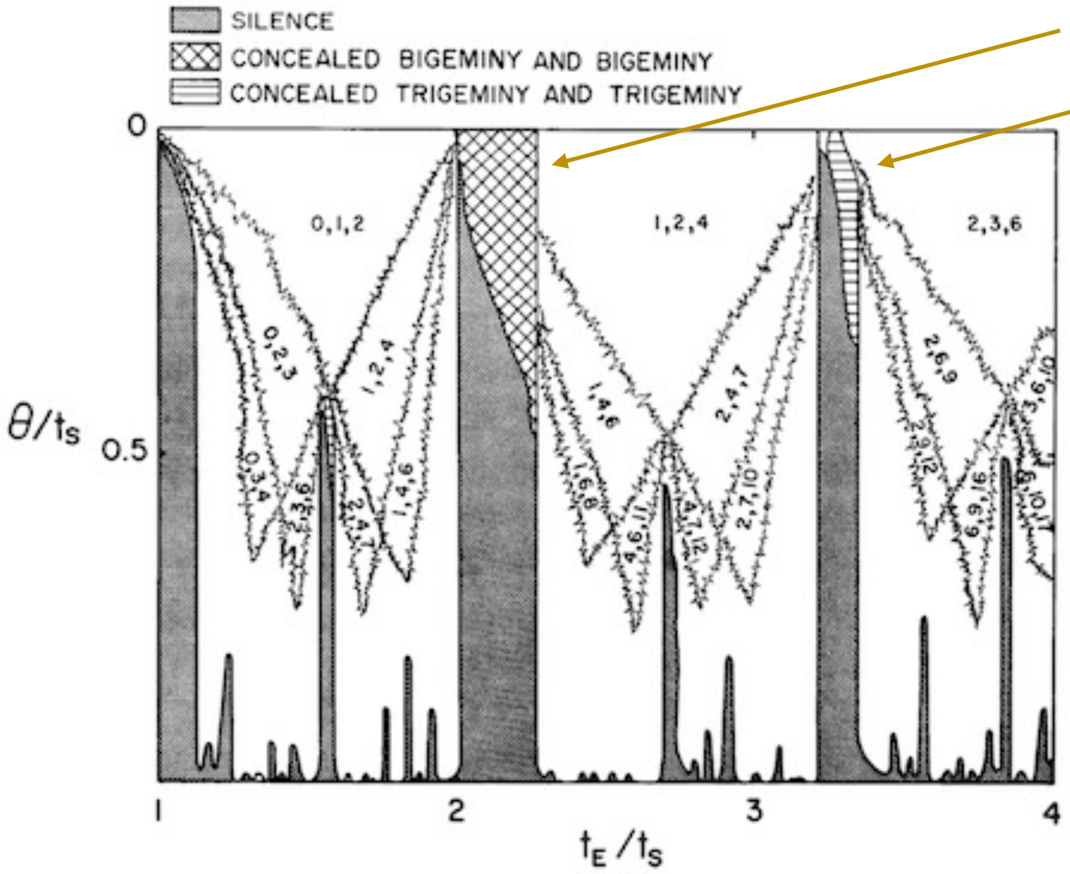
k=0 : Pure parasystole



k=0.5 : Modulated parasystole



Entrainment



Courtemanche et al., American Journal of Physiology (1989)

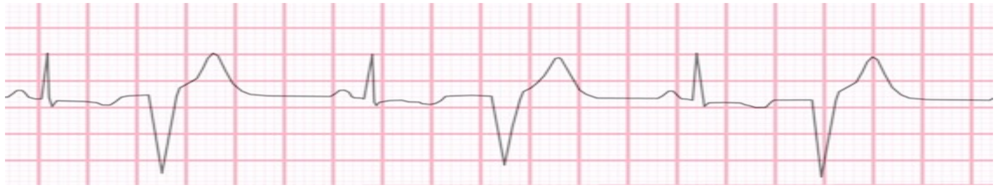
2:1 entrainment zone

3:1 entrainment zone

Modulated ectopic period is an integer multiple of sinus period

$$\phi_{i+1} = \begin{cases} \phi_i + \frac{t_s}{t_e} & 0 \leq \phi_i < \frac{t_s - \theta}{t_e}, \\ \phi_i + \frac{t_s}{t_e} + 1 - f(\phi_i) & \frac{t_s - \theta}{t_e} \leq \phi < 1, \end{cases}$$

2:1 entrainment



3:1 entrainment