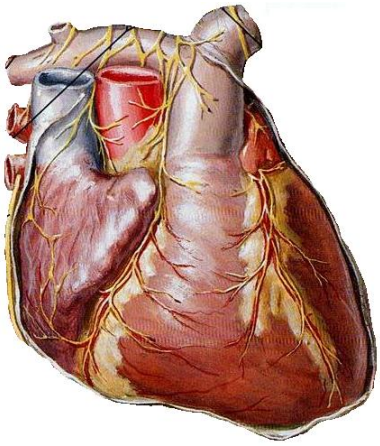
CARDIAC PACING

Hilton M Kaplan, MD



University of Southern California

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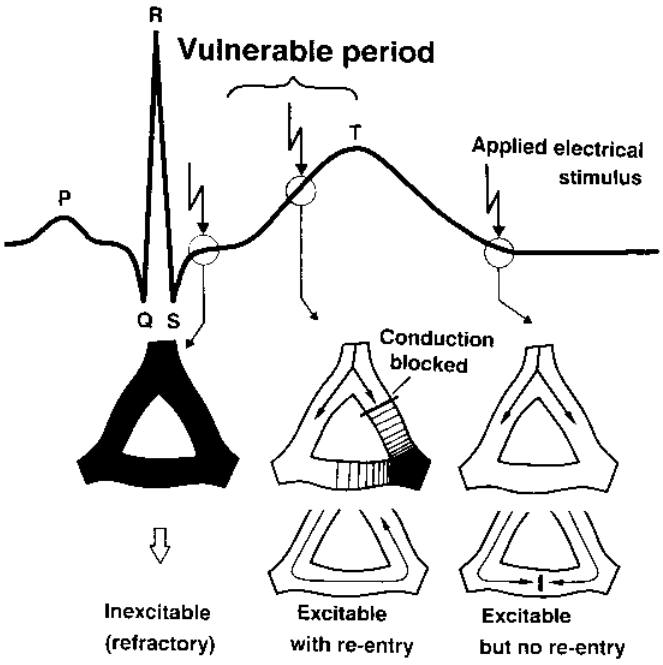
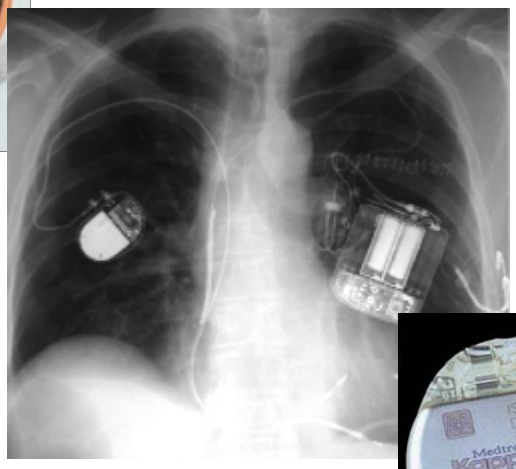


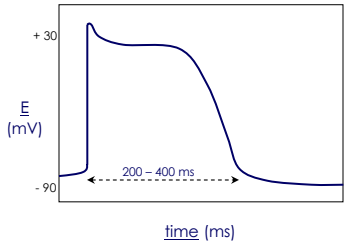
Siemens 1958: 1st pacemaker implanted



today

re-entry loops

prevented by 1) long refractory period (300 ms)



2) fast conduction velocity (1 m/s)

1 m/s for 300 ms → 30cm refractory zone

! shortening of either → re-entry loops !

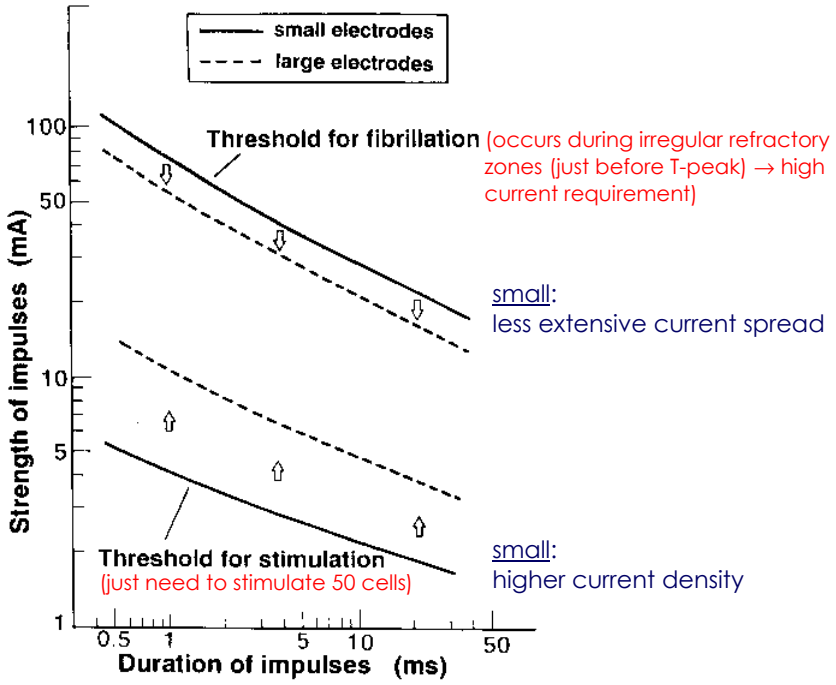
re-entry loops

refractory period ↓ (50%)

1. ↑ HR (interval dependant)
2. ischemia (shorter AP's)
3. adjacent conduction block
   - speeds repolarization of active membrane

conduction velocity ↓ (90-99%)

1. K^+ & epinephrine
   - K^+ → slows repolarization; slows fast inward current (Na^+)
   - epi → enhances slow inward current (Ca^{++})
   - "slow response AP" = 0.1 m/s ; Purkinje re-entry loop < 15 mm
2. ischemia (inexcitable segments)
   - "slow response AP" = 0.01 m/s ; Purkinje re-entry loop < 3 mm
3. anisotropy
   - conduction velocity varies with direction (esp. after MI)



(occurs during irregular refractory zones (just before T-peak) → high current requirement)

small:
less extensive current spread

small:
higher current density

implantable pacemakers

48 yrs

250g → 25g

400,000 pt.s pa

dual chamber
multi-programmable
diagnostic
rate responsive
data collection
reliability
Li-ion powered (10+ yrs)

3 components

pulse generator	battery	
	sensing circuit	
	stimulation circuit	
leads	→ & ← the heart	
programmer	2-way telemetry	alter programs
		retrieve data

indications

bradyarrhythmias / blocks

symptomatic (rest, exercise)	QOL
functional impairment	mortality

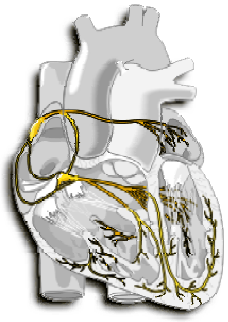
symptoms

syncope, fatigue, exercise intolerance

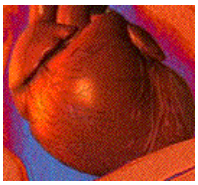
pathology

1) Heart Block: complete (AVN) / partial
2) Sick Sinus Syndrome: bradycardia / sinus arrest
3) MI: conduction disturbances
4) Hypersensitive Carotid Sinus Syndrome: syncope

Complete Heart Block

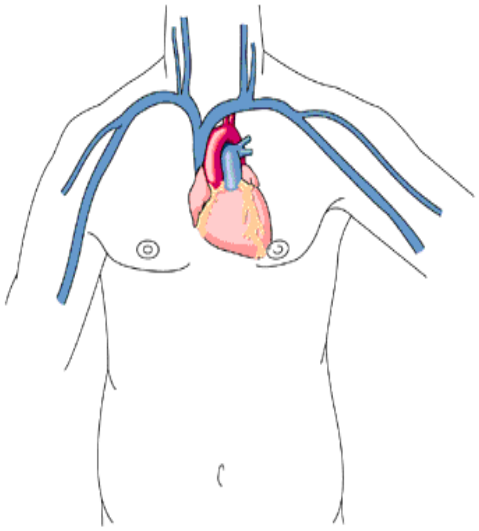


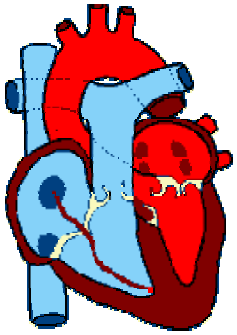
P every 0.6 s = 100 bpm
QRS every 2 s = 30 bpm



pacemaker hierarchy

SAN		70 bpm
AVN & His-Purkinje System		40-60 bpm
Autorhytmicity		30-40 bpm
• SA block	→	AVN rate
• Complete Heart Block	→	atria & ventricles unsynchd.
• BBB	→	beat duration ↑
Ca^{++} Channel Blockers		slow AVN conduction (*verapamil*)





pacing codes

1st ltr **Chamber Paced**	2nd ltr **Chamber Sensed**	3rd ltr **Response to Sensed Beat**	4th ltr **Programmability Rate Modulated**
V Ventricle	**V** Ventricle	**T** Triggered	**P** Simple Programmability
A Atrium	**A** Atrium	**I** Inhibited	**M** Multiprogrammable
D Dual (Both Chambers)	**D** Double (Atrial Triggered & Ventricular Inhibited)	**D** Double (Atrial Triggered & Ventricular Inhibited)	**C** Communicating (Telemetry)
O None	**O** None	**O** None	**R** Rate Responsive
North American Society of Pacing & Electrophysiology (NASPE) *British Pacing & Electrophysiology Group (BPEG)*			**O** None

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VVI mode
- paces ventricle
- senses ventricle
- inhibited by a sensed ventricular event

AAT mode
- paces atrium
- senses atrium
- triggers stimulus within P-wave

DDD mode
- both chambers can be sensed & paced
- requires: 2 leads (in atrium & ventricle); or
  - single tripolar lead (senses atria; senses or paces ventricle)

pulse generator

pacing & sensing
- power source
- output circuit
- sensing circuit + processor (if rate adaptive)
- timing circuit
- telemetry coil
- memory — 2 Kb ROM (output & sensing) + 0.5 Kb RAM (data storage)
  fully RAM based (> storage + reprogrammable firmware)

hermetic
- titanium case + connector block

ID — laser etched, radio-opaque symbols, ID codes, characteristic shapes

sensing circuit

signal — intrinsic depolarization of a chamber

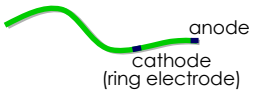
noise — far field cardiac events
diastolic potentials
skeletal muscle contraction
pacing stimuli

2 configurations (for sensing & pacing):

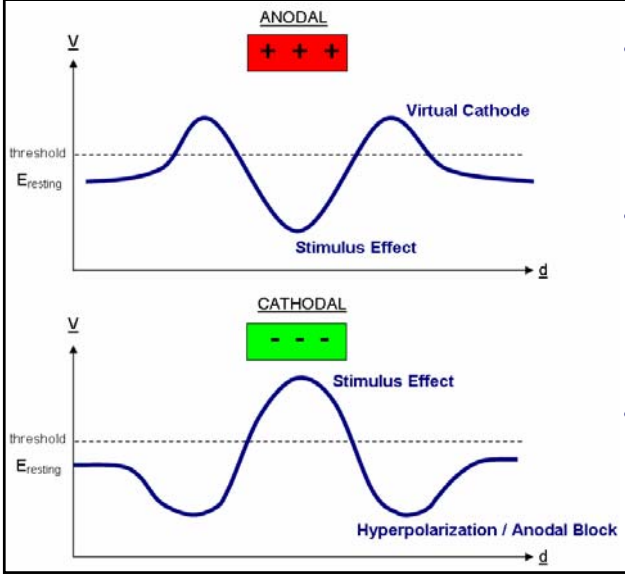
unipolar

(↑ risk of non-cardiac signals)

bipolar

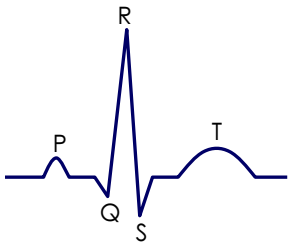


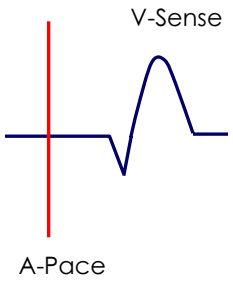
anodal or cathodal stimulation?



- lower threshold for APs?
  cathodal
  anodal relies on virtual cathodes (~ 1/2 the absolute magnitude of the stimulus)
- increased risk of latency?
  cathodal
  AP must pass through areas of hyperpolarization (anodal block)
- faster / more effective propagation?
  anodal
  no areas of hyperpolarization for AP's to cross

sensing circuit

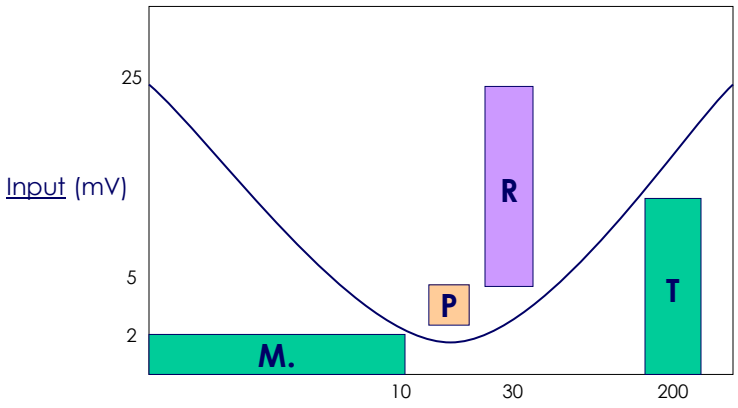




ECG: surface vector of all depolarizing cardiac m.

V EGM (intracardiac electrogram): potentials measured between lead electrodes (↓ noise & ↑ accuracy).

sensing circuit



P-waves	50 Hz	2-6 mV
R-waves	10-30 Hz	5-25 mV
T-waves	5 Hz	10 mV
MUSCLE	10-200 Hz	2 mV

V EGM enters sensing circuit …

1) Bandpass Filter	f_c = 30 Hz → R-waves
2) Compare	reference voltage adjustable (sensitivity) 2:1 safety margin (set at surgery) (sensitivity : intracardiac signal)
3) Slew Rate ($^{dV}/_{dt}$)	0.75-2.5 V/s (set at surgery)
4) "Blind" Periods	Blanking Periods (sensing circt off) Refractory Periods (stimulation off) (esp. in dual chamber pacers eg Heart Block)

electromagnetic interference (EMI) ?

- ✘ arc welders
- ✘ high voltage generators
- ✘ radar antennae
- ☒ electrocautery / diathermy
- ☒ defibrillators / cardioversion
- ☒ MRI
- ☒ lithotripsy
- ☒ TENS
- ☒ radiotherapy

- ✓ retail antitheft
- ✓ airport screening
- ✓ microwave
- ✓ ham radios
- ✓ video games
- ✓ computers
- ✓ office equipment

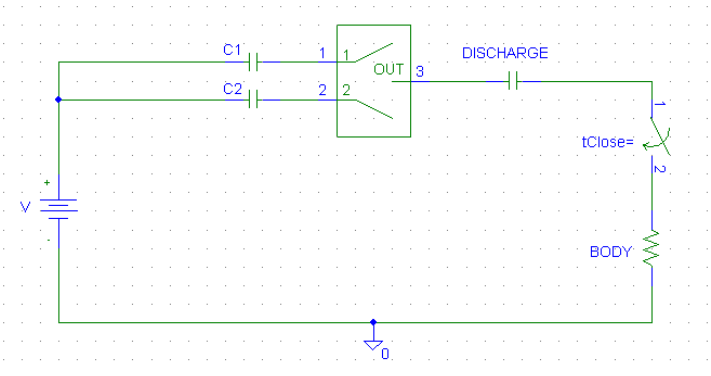
- ? cellphones (30 cm)

output circuit

main power drain	high enough for safety threshold (output stimulus : stimulation threshold)
V constant (programmed V source)	I & Z vary
pulse amplitude	0.8 – 5 V (10V for troubleshooting / pediatric)
pulse duration	0.05 – 1.5 ms
pulse source	2.8 V battery (via voltage multipliers to Discharge Cap.)
pulse rate	timing circuit (inhibited by cardiac signals)

output circuit

pulse source	2.8 V battery (via voltage multipliers to Discharge Cap.)



timing circuit

controls	cycle length Refractory & Blanking periods pulse duration atrio-ventricular coordination
crystal oscillator (kHz)	timing & logic circuits
runaway protection	rate-limiting circuit (180-220 ppm) (in case of component failure)

telemetry circuit

PG transmits	RF antenna (300 Hz)
PG receives	RF decoder (300 Hz)
real-time telemetry	pulse amplitude pulse width lead Z, I battery Z, V capacitor charge energy delivery

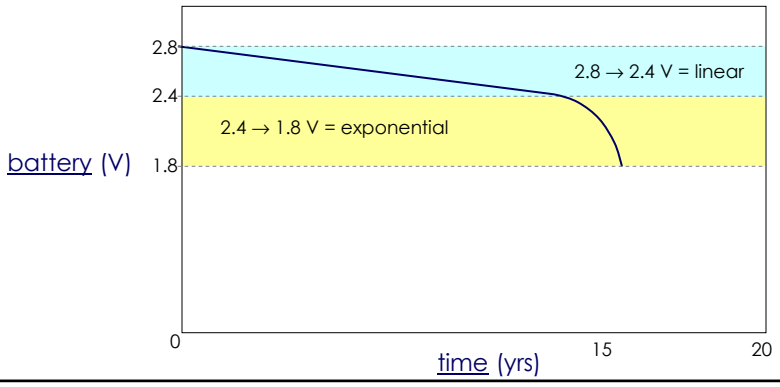
programming & data retrieval / diagnostic

prevent ambient RF & EMI effects
prevent other co.s programmers

power source

1960's Hg-Zn hours H_2-gas !

2000's Li-I 15 years
semi-solid layer, gradually thickens → V ↓

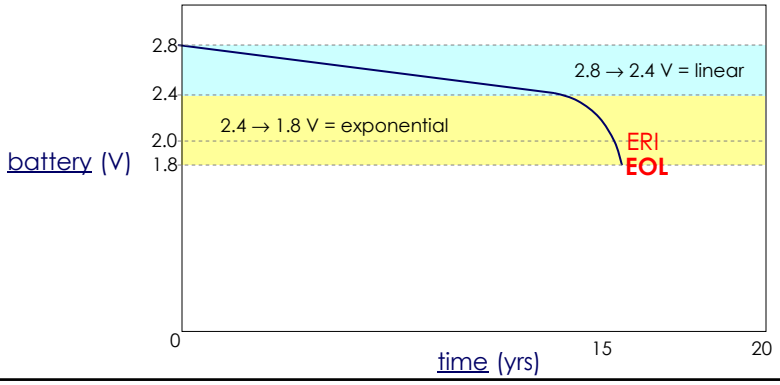


power source

2.0 V
↑
($^{3\text{-}4}/_{12}$)
↓
1.8 V

"ERI" (Elective Replacement Indicators):
- signature rate Δ
- pulse duration ↑
- mode Δ
- telemetered bat. V

"**EOL**" (End Of Life status): erratic behavior



leads

4 components	electrodes conductor insulation pin	
conductor	1 or 2 leads strong & pliable	coiled multifilar coaxial Ni alloy lumen (insertion)
insulation	silicone / polyurethane Si: high coeff. of friction in blood (2 in same vein ?)	
pin	ISO	

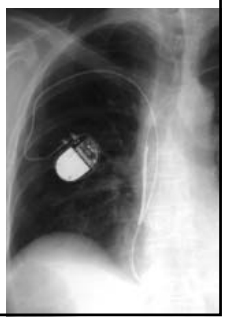
electrodes

small radius	↑ current density → ↓ stim. threshold 6-8 mm^2 ; 1.5 mm^2 "high-Z electrodes" (↓ current drain → ↑ battery life; but poorer sensing) … porous tip high-Z electrodes
alloys	Pt-Ir
steroid-eluting	1mg Dexamethasone reservoir (yrs) avoids dramatic ↑ in threshold at $^3/_{12}$
fixation	passive: tines (tangle in trabeculae) ✓ atraumatic ✘ difficult to remove active: corkscrew, barbs, … ✓ unlimited sites ✘ "invasive" ✓ easy to remove

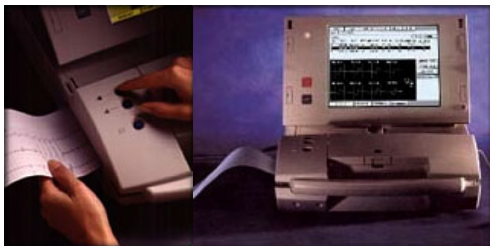
lead placement

endocardial	better long-term via Subclavian / Cephalic veins
epicardial	venous occlusion abdominal PG (thoracic radiation) pediatric (allows growth)
method	wire stent in lumen fluoroscopic guidance

! leads – 99% reliability at 3 years !

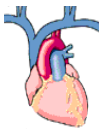


programmers



functions	testing, reprogramming, retrieval of data
1960's	Keith needle adjustment of controlling knob
1970's	Reed switches (magnetic)
1980's	RF coupling (with ext. hardware)
1990's	PC-based

system operation

dual chamber pacing 

rate responsive systems

Activity Sensor:
piezoelectric accelerometers detect movement (vibrations)

Transthoracic Impedance Sensor:
calculates minute ventilation (= Rate x Vol.)

SV, BP, pH, SATS ...

clinical outcome