Perioperative Electrophysiology Training Program

Pacemaker Anatomy and Physiology

Lecture #1

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Photo by DS

I have no conflict of Interest

1

Learning Electrophysiology is a Long Road

2

Learning about Pacemakers is a Long Road

- Your developing a core understanding of these devices will give you a critical platform from which you can continue learning about each pacer encountered in the clinical setting

EP Physicians | Company Reps | Industry Tech Support

3

What I will discuss in this Lecture Series?

1. Pacemaker Anatomy and Physiology
2. Pacemaker Capture and Sensing
3. Pacemaker Modes
4. Timing Cycles
5. CXR and EKG Interpretation

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Lecture Series, cont.

6. Magnets
7. Special Functions
8. Perioperative Management of ICDs
9. Electrocautery and pacers and ICDs
10. How to perform an Interrogation

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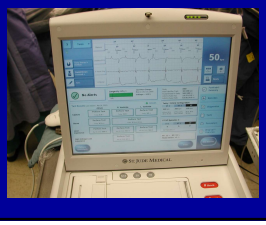
Ultimate Goal

- Learn how to use the programmers so that you can safely take care of any pacemaker or ICD issue yourself



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Lecture #1

- Basic components of the pacemaker
  - Pulse generator
  - Leads
- Basic pacemaker-related physiology
  - Electricity/Batteries
  - Action Potential

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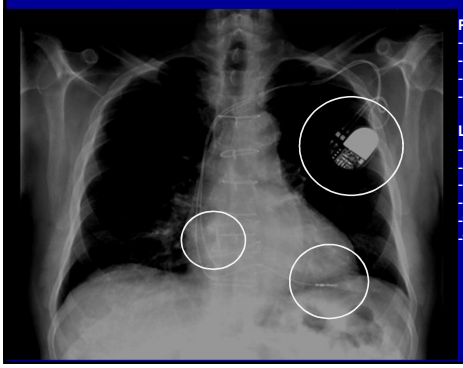
Pacemaker Anatomy



Pulse Generator
-case
-battery
-circuitry
-header

Leads
-connecting pin
-conductor
-insulation
-ring electrode
-tip electrode
-fixation mech.

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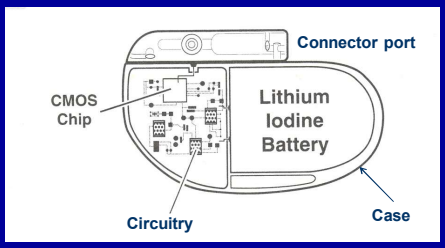
Pacemaker Pulse Generator



CMOS=complementary metallic oxide semiconductor

Circuit attached to the battery and hermetically sealed in a metal covering—can then be attached to leads forming the complete pacing system

Moses; Practical Guide to Cardiac Pacing, p.28

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Pacemaker Generator Circuitry

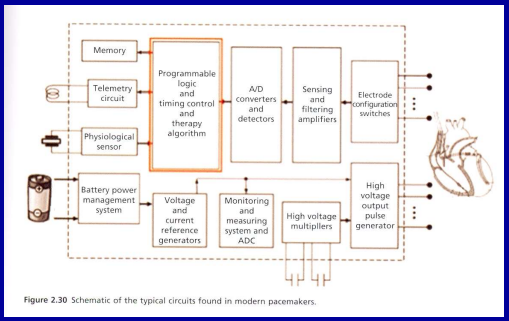

Figure 2.30 Schematic of the typical circuits found in modern pacemakers.

Ellenbogen; Cardiac Pacing and ICDs, p.67

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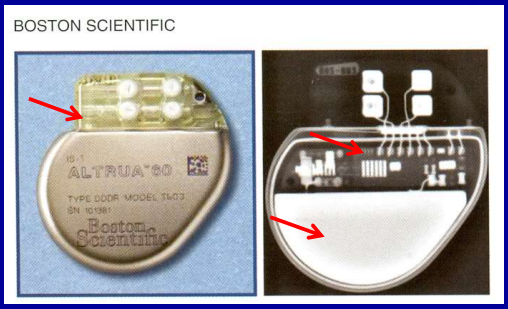
Pacemaker Generator



Header---battery---circuitry—sensing, pacing, timers, accelerometers etc.

Ellenbogen, Clinical Cardiac Pacing and ICDs

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Pacemaker Lead

- Senses intrinsic myocardial electrical activity
- Delivers electric pulses to the myocardium

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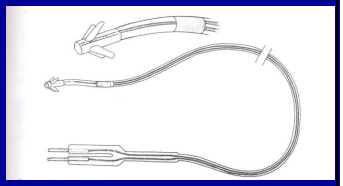
Pacemaker Lead Components

- Connector pin(s)
- Insulation
- Conductor
- Ring electrode
- Tip electrode
- Fixation mechanism



Moses, WH: Practical Guide to Cardiac Pacing p. 29

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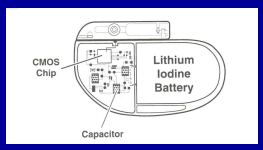
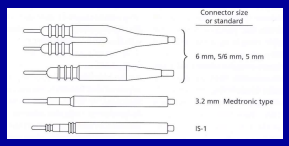
Connector Pins

- Attach the lead to the header of the PG
- All current bipolar pacing leads are compatible with all current manufacturer header designs





Ellenbogen, Cardiac Pacing and ICDs, p.59

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Connector Pins

- Connector pin must extend beyond the distal set screw in the header block
  - Sensing artifact or failure to pace will occur if not

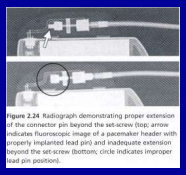

Figure 2.24 Radiograph demonstrating proper extension of the connector pin beyond the set-screw (top; arrow indicates fluoroscopic image of a pacemaker header with properly implanted lead pin) and inadequate extension beyond the set-screw (bottom; circle indicates improper lead pin position).

Ellenbogen, Cardiac Pacing and ICDs, p.60

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Connector Pins

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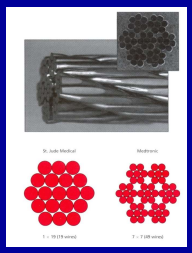
Conductors

- **Transfer electrons well**
- Comprised of cobalt, nickel, chromium, molybdenum, silver, platinum, and or iridium
- Typically multifilar and coiled to increase reliability and flexibility



Ellenbogen, Cardiac Pacing and ICDs, p.56

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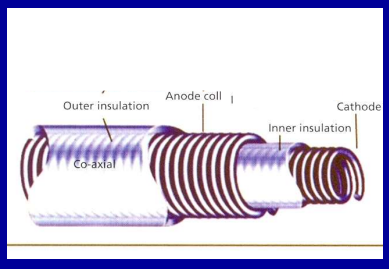
Co-axial Lead



Two conductors are wound in parallel and insulated from each other

Ellenbogen, Cardiac Pacing and ICDs, p.50

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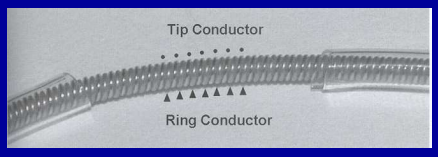
Insulation

- Polyurethane (Teflon)
  - Thinner and is also more slippery than silicone
- Silicone
  - Larger and less slippery but more durable



Ellenbogen, Cardiac Pacing and ICDs

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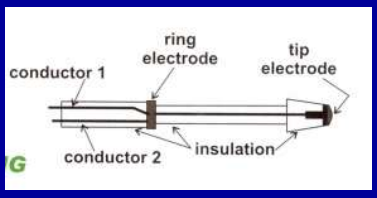
Electrodes

- Tip electrode (cathode)
- Ring electrode (anode)
- Platinum-iridium, Elgiloy, etc



Barold, Cardiac Pacemakers and Resync., p. 31

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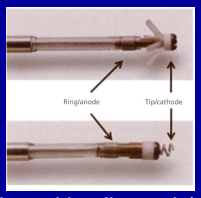
Fixation Mechanism

- Passive
  - Tines that becomes entrapped in trabeculae
    - Limited sites for insertion
  - Unlikely to perforate heart
  - Difficult to remove
- Active
  - Screw-in electrode
  - May cause perforation
  - Easier to remove (less fibrosis and isodiametric)



Ellenbogen, Cardiac Pacing and ICDs, p.51

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Active Fixation Lead

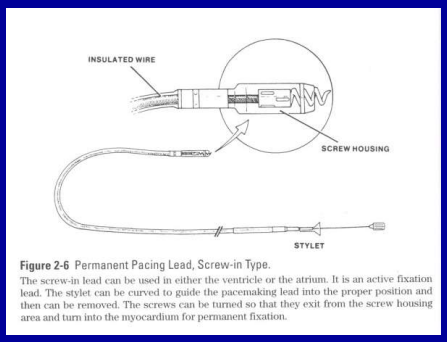

Figure 2-6 Permanent Pacing Lead, Screw-in Type.
The screw-in lead can be used in either the ventricle or the atrium. It is an active fixation lead. The stylet can be curved to guide the pacemaking lead into the proper position and then can be removed. The screws can be turned so that they exit from the screw housing area and turn into the myocardium for permanent fixation.

Moses, WH: Practical Guide to Cardiac Pacing p. 30

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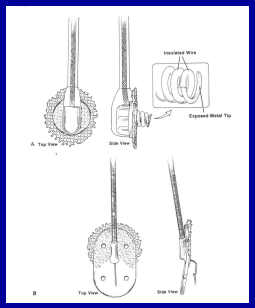
Epicardial Active Fixation Electrodes



Ventricle

Atrial

Moses, WH: Practical Guide to Cardiac Pacing p. 32

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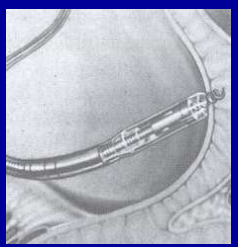
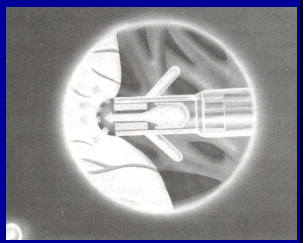
Fixation Mechanism





Electrodes can be active fixation or passive fixation
Often elute steroid to decrease scar thickness

Ellenbogen Clinical Cardiac Pacing 1st ed

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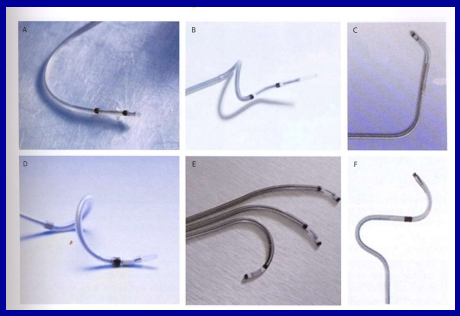
Coronary Sinus Leads



Ellenbogen, Cardiac Pacing and ICDs, p.53

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Modern Bipolar Lead

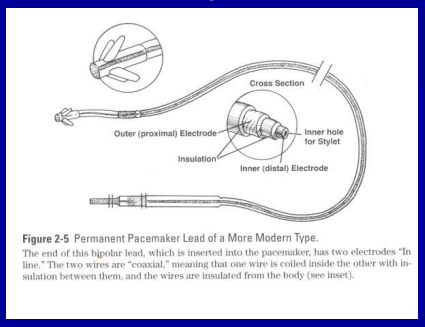

Figure 2-5 Permanent Pacemaker Lead of a More Modern Type.
The end of this bipolar lead, which is inserted into the pacemaker, has two electrodes "In line." The two wires are "coaxial," meaning that one wire is coiled inside the other with insulation between them, and the wires are insulated from the body (see inset).

Moses, WH: Practical Guide to Cardiac Pacing p. 30

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Clinical Concepts

- Active fixation leads are more readily secured than passive ones
- Passive fixation leads are harder to extract
- Coronary sinus leads used for CRT are most susceptible to dislodgement
- If you are going to place a PA line within one month of a new lead implant, consider using fluoroscopic guidance

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Pacemaker Physiology

- Basic Electrical Circuit
- Terminology
- Pacemaker Batteries
- Action Potentials

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Simplified Pacemaker Circuit

- Free electrons are created in the pacer battery's anode
- These electrons flow through an insulated lead to the lead's distal electrode then escape into the myocardium
- Free electrons flow back into the lead's proximal electrode back to the battery's cathode, completing the circuit

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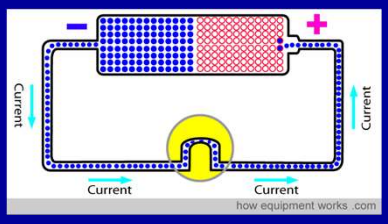
Simplified Pacemaker Circuit

- An electric circuit must consist of a complete, closed loop for current to flow through it



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Electrical Terminology

- **Coulomb**
- **Volt**
- **Current**
- **Ampere**
- **Resistance**
- **Impedance**
- **Ohm**
- **Joule**

Basic Electrical Variables

Variable	Symbol	Unit
Time	t	sec
Charge	Q	Coulomb
Current	I	Ampere
Voltage	V	Volts
Power	P	Watts
Energy	W	Joule
Resistance	R	Ohms
Conductance	G	Seimens, mho

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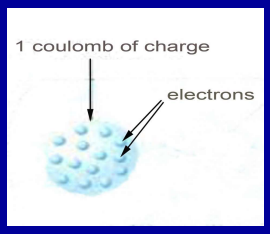
Coulomb

- Unit of charge; represents the charge of approx 6.24 x 10^{18} electrons



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Volt (V)

- Unit of electric pressure or "electromotive force" that causes current to flow
  - The difference in potential energy between two points with an unequal electron population
  - A measure of electric potential that refers to the energy that could be released if electric current is allowed to flow

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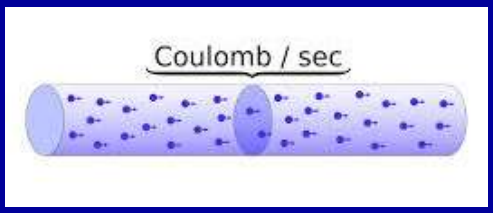
Electric Current (I)

- Movement of electric charge, usually through a wire, measured in coulombs per sec



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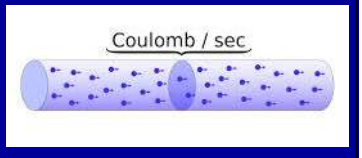
Ampere (A)

- Measurement unit of electric current
  - Represents a charge moving at the rate of 1 coulomb per sec
  - 6.241 x 10^{18} charge carriers per sec
  - Pacers: mA



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Resistance (R)

- Simplified measure of the opposition to the flow of electric current

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Impedance (R)

- Overall opposition to flow of current across an electrical circuit in a pacemaker
  - Total impedance includes:
    - Resistance across the lead conductor
    - Resistance to current flow from the lead electrode to the myocardium
    - Resistance due to stimulus polarization at the electrode-tissue interface
  - Measured in ohms

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Ohm (Ω)

- **Measurement u**nit of resistance
  - 1 ohm is the resistance that results in a current of 1 ampere when a potential of 1 volt is placed across the resistance
  - A typical pacemaker lead has an impedance between 300-800 ohms

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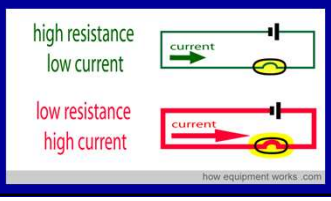
Ohm's Law

- V=IR
  - Voltage = Current x Resistance
  - Current = Voltage / Resistance



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Joule (J)

- Unit of work or energy
  - Equal to the energy transferred (or work done) when passing a current of one ampere through a resistance of one ohm for one second
  - Voltage x Current X Time
  - Pacer pulse has amplitude (mA) and duration (msec) and therefore delivers microjoules of energy with each pacing pulse

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Electricity Summary

- **Voltage (V)**
  - Voltage is the force, or "push," that causes electrons to move through a circuit
  - Provided by the pacemaker battery
- **Current (I)**
  - Determined by the amount of electrons that move through a circuit
  - Cause myocardial cells to depolarize
- **Impedance (R or Ω)**
  - The opposition to current flow
  - All resistance: conductor, electrode, myocardium

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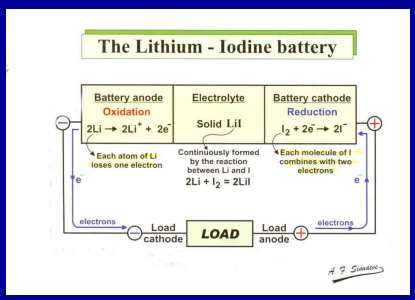
Electrical Circuit of a Pacemaker



Barold, Cardiac Pacemakers and Resynchronization p.16

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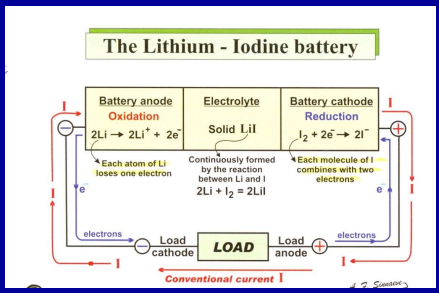
Current vs Electron Movement



Barold, Cardiac Pacemakers and Resynchronization p.16

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Battery Life in a Pacemaker

- The lithium iodide that forms during the battery use is a solid that gradually increases the separation between the lithium and the iodine in the battery. This separation slowly increases the battery's internal resistance.
- The battery does not "run down" due to depletion of chemicals, but rather because the internal resistance of the battery rises, causing the voltage to drop.
- When we assess a pacemaker's battery life we measure the internal resistance of the battery, which reflects its remaining life expectancy.

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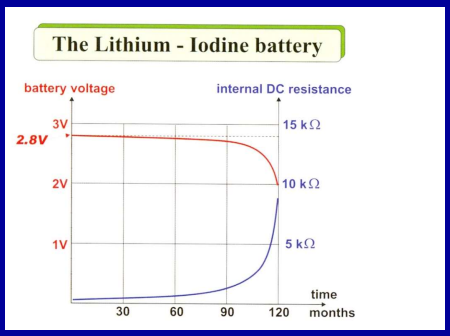
Pacemaker Battery



Barold, Cardiac Pacemakers and Resynchronization p.17

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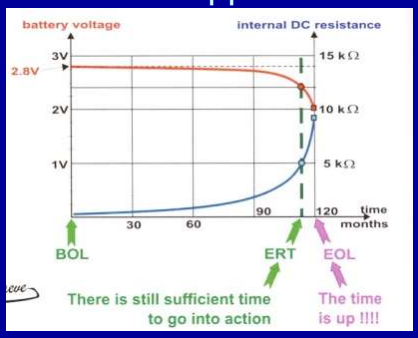
Clinical Application



Barold, Cardiac Pacemakers and Resynchronization, p. 276

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Action Potential Generation

- If the electric current delivered by the battery and lead is sufficient to activate the viable and resting myocardium contiguous with the lead's electrode, an action potential is generated and the heart depolarizes

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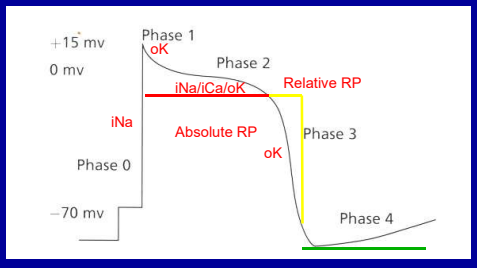
Action Potential Review



Ellenbogen, Cardiac Pacing and ICDs, p.35

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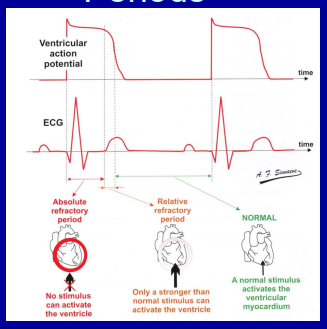
Cardiac Physiology: Refractory Periods



Barold, Cardiac Pacemakers and Resynchronization, p. 20

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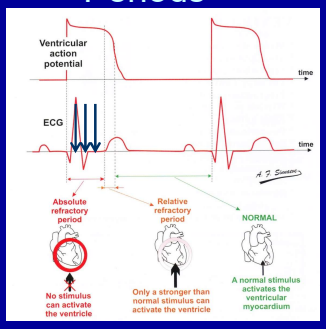
Cardiac Physiology: Refractory Periods



Pacer spikes in the ARP will NOT capture

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Lecture #1 Take Home Points

- The Overall Goal of this program is to help each of you develop the ability to manage Pacers and ICDs in the perioperative period on your own

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Lecture #1 Take Home Points

- A pacemaker consists of the pulse generator and 1-3 leads
- Leads can be fixated passively, actively, or geometrically
  - The coronary sinus leads are most susceptible to being dislodged during surgery
- Leads less than one month old are most susceptible to displacement during PA line insertion or cardiac surgery

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Lecture #1 Take Home Points

- If the lead-battery connection lost, if the conductor fractured, if the insulation compromised, or if the electrode is dislodged →current will not flow to the myocardium and the pacemaker will not work
- If myocardium is suboptimal, a fully functional pacemaker may not pace the heart.

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Lecture #1 Take Home Points

- V=IR or I=V/R
- Electric pressure—Volts
- Electric current—Amps
- Resistance—Ohms
- As a pacer battery depletes, its internal resistance increases

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Lecture #1 Take Home Points

- A pacing stimulus cannot capture myocardial cells that are in the absolute refractory period (phase 2 or QRS-ST seg)
- A pacing stimulus can capture myocardium in the relative refractory period (phase 3 or T-wave) if the stimulus is strong enough

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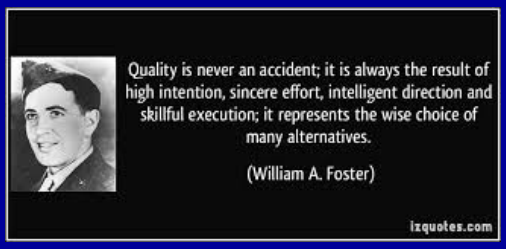
The End



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