Basic Pacing Concepts
Implantable Pacemaker Systems Contain the Following Components:

- Implantable pulse generator (IPG)
- Lead wire(s)
Pacemaker Components Combine with Body Tissue to Form a Complete Circuit

- Pulse generator: power source or battery
- Leads or wires
- Cathode (negative electrode)
- Anode (positive electrode)
- Body tissue
The Pulse Generator:

- Contains a battery that provides the energy for sending electrical impulses to the heart
- Houses the circuitry that controls pacemaker operations
Leads Are Insulated Wires That:

- Deliver electrical impulses from the pulse generator to the heart
- Sense cardiac depolarization
Types of Leads

- Endocardial or transvenous leads
- Myocardial/Epicardial leads
Transvenous Leads Have Different “Fixation” Mechanisms

- **Passive fixation**
  - The tines become lodged in the trabeculae (fibrous meshwork) of the heart
Transvenous Leads

- **Active Fixation**
  - The helix (or screw) extends into the endocardial tissue
  - Allows for lead positioning anywhere in the heart’s chamber
Myocardial and Epicardial Leads

Leads applied directly to the heart

- Fixation mechanisms include:
  - Epicardial stab-in
  - Myocardial screw-in
  - Suture-on
An electrode that is in contact with the heart tissue.

Negatively charged when electrical current is flowing.
Anode

- An electrode that receives the electrical impulse after depolarization of cardiac tissue
- Positively charged when electrical current is flowing
Body tissues and fluids are part of the conduction pathway between the anode and cathode.
During Pacing, the Impulse:

- Begins in the pulse generator
- Flows through the lead and the cathode (−)
- Stimulates the heart
- Returns to the anode (+)
A Unipolar Pacing System Contains a Lead with Only One Electrode Within the Heart; In This System, the Impulse:

- Flows through the tip electrode (cathode)
- Stimulates the heart
- Returns through body fluid and tissue to the IPG (anode)
A Bipolar Pacing System Contains a Lead with Two Electrodes Within the Heart. In This System, the Impulse:

- Flows through the tip electrode located at the end of the lead wire
- Stimulates the heart
- Returns to the ring electrode above the lead tip
Unipolar and Bipolar Leads
Unipolar leads may have a smaller diameter lead body than bipolar leads.

Unipolar leads usually exhibit larger pacing artifacts on the surface ECG.
Bipolar leads are less susceptible to oversensing noncardiac signals (myopotentials and EMI)
Single-Chamber and Dual-Chamber Pacing Systems
Single-Chamber System

- The pacing lead is implanted in the atrium or ventricle, depending on the chamber to be paced and sensed.
Advantages and Disadvantages of Single-Chamber Pacing Systems

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>✶ Implantation of a single lead</td>
<td>✶ Single ventricular lead does not provide AV synchrony</td>
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<td>✶ Single atrial lead does not provide ventricular backup if A-to-V conduction is lost</td>
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</table>
Dual-Chamber Systems Have Two Leads:

- One lead implanted in the atrium
- One lead implanted in the ventricle
Every Electrical Pacing Circuit Has the Following Characteristics:

- Voltage
- Current
- Impedance
Voltage

Voltage is the force or “push” that causes electrons to move through a circuit.

In a pacing system, voltage is:

- Measured in volts
- Represented by the letter “V”
- Provided by the pacemaker battery
- Often referred to as amplitude
Current

- The flow of electrons in a completed circuit

- In a pacing system, current is:
  - Measured in mA (milliamps)
  - Represented by the letter “I”
  - Determined by the amount of electrons that move through a circuit
Impedance

- The opposition to current flow
- In a pacing system, impedance is:
  - Measured in ohms
  - Represented by the letter “R” ($\Omega$ for numerical values)
  - The measurement of the sum of all resistance to the flow of current
Voltage, Current, and Impedance Are Interdependent

- The interrelationship of the three components can be likened to the flow of water through a hose
  - Voltage represents the force with which . . .
  - Current (water) is delivered through . . .
  - A hose, or lead, where each component represents the total impedance:
    - The nozzle, representing the electrode
    - The tubing, representing the lead wire
Voltage and Current Flow

Spigot (voltage) turned up
(high current drain)

Spigot (voltage) turned low
(low current drain)
Resistance and Current Flow

“Normal” resistance

“Low” resistance

“High” resistance

Low current flow

High current flow
Ohm’s Law is a Fundamental Principle of Pacing That:

- Describes the relationship between voltage, current, and resistance

\[
\begin{align*}
V &= I \times R \\
I &= \frac{V}{R} \\
R &= \frac{V}{I}
\end{align*}
\]
Impedance Changes Affect Pacemaker Function and Battery Longevity

- High impedance reading reduces battery current drain and increases longevity
- Low impedance reading increases battery current drain and decreases longevity

- Impedance reading values range from 300 to 1,000 Ω
  - High impedance leads will show impedance reading values greater than 1,000 ohms
Lead Impedance Values Will Change Due to:

- Insulation breaks
- Wire fractures
An Insulation Break Around the Lead Wire Can Cause Impedance Values to Fall

- Insulation breaks expose the wire to body fluids which have a low resistance and cause impedance values to fall.
- Current drains through the insulation break into the body which depletes the battery.
- An insulation break can cause impedance values to fall below 300 Ω.
A Wire Fracture Within the Insulating Sheath May Cause Impedance Values to Rise

- Impedance values across a break in the wire will increase
- Current flow may be too low to be effective
- Impedance values may exceed 3,000 Ω
Stimulation
Stimulation Threshold

The minimum electrical stimulus needed to consistently capture the heart outside of the heart’s refractory period.
Two Settings Are Used to Ensure Capture:

- Amplitude
- Pulse width
The strength-duration curve illustrates the relationship of amplitude and pulse width.

- Values on or above the curve will result in capture.
Lead Maturation Process

- Fibrotic “capsule” develops around the electrode following lead implantation
Steroid eluting leads reduce the inflammatory process and thus exhibit little to no acute stimulation threshold peaking and low chronic thresholds.
Sensing
Sensing

Sensing is the ability of the pacemaker to “see” when a natural (intrinsic) depolarization is occurring.

- Pacemakers sense cardiac depolarization by measuring changes in electrical potential of myocardial cells between the anode and cathode.
Pacemaker does not “see” the intrinsic beat, and therefore does not respond appropriately.
An electrical signal other than the intended P or R wave is detected.
Sensitivity – The Greater the Number, the Less Sensitive the Device to Intracardiac Events
Sensitivity

Amplitude (mV)

Time
Sensitivity

Amplitude (mV)

Time

5.0
2.5
1.25
Sensitivity

Amplitude (mV) vs. Time

- 5.0
- 2.5
- 1.25
Accurate Sensing Requires That Extraneous Signals Be Filtered Out

- Sensing amplifiers use filters that allow appropriate sensing of P waves and R waves and reject inappropriate signals.

- Unwanted signals most commonly sensed are:
  - T waves
  - Far-field events (R waves sensed by the atrial channel)
  - Skeletal myopotentials (e.g., pectoral muscle myopotentials)
Unipolar Sensing

- Produces a large potential difference due to:
  - A cathode and anode that are farther apart than in a bipolar system
Bipolar Sensing

- Produces a smaller potential difference due to the short interelectrode distance
  - Electrical signals from outside the heart such as myopotentials are less likely to be sensed
Rate Responsive Pacing
Rate Response

Rate responsive (also called rate modulated) pacemakers provide patients with the ability to vary heart rate when the sinus node cannot provide the appropriate rate.

Rate responsive pacing is indicated for:

- Patients who are chronotropically incompetent (heart rate cannot reach appropriate levels during exercise or to meet other metabolic demands)
- Patients in chronic atrial fibrillation with slow ventricular response
A Variety of Rate Response Sensors Exist

Those most accepted in the market place are:

- Activity sensors that detect physical movement and increase the rate according to the level of activity
- Minute ventilation sensors that measure the change in respiration rate and tidal volume via transthoracic impedance readings
The NASPE/BPEG Generic (I.C.H.D.)
### The NASPE/BPEG Generic (NBG) Code

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VOO

- Ventricular pacing
- No sensing
- Ventricular asynchronous pacing at lower programmed pacing rate
VVI

- Ventricular pacing
- Ventricular sensing
- Sensed intrinsic QRS inhibits ventricular pacing
Atrial lead

AOO

- Atrial pacing
- No sensing
- Atrial asynchronous pacing at lower programmed pacing rate
Atrial lead

**AAI**

- Atrial pacing
- Atrial sensing
- Intrinsic P wave inhibits atrial pacing
Dual Chamber Modes
Tracking modes
DDD

- Pacing in both the atrium and ventricle
- Sensing in both the atrium and ventricle
- Intrinsic P wave and intrinsic QRS can inhibit pacing
- Intrinsic P Wave can “trigger” a paced QRS
DDD pacing

- Dual-chamber pacing capable of pacing and sensing in both the atrial and ventricular chambers of the heart

- 4 distinct patterns can be observed with DDD pacing
  - Sensing in the atrium and sensing in the ventricle
  - Pacing in the atrium and sensing in the ventricle
  - Pacing in the atrium and pacing in the ventricle
Example of sensing in both the atrium and the ventricle (inhibiting in both the atrium and the ventricle)
DDD pacing

Example of pacing in the atrium with sensing (inhibition of pacing) in the ventricle
DDD pacing

Example of sensing in the atrium (inhibition of atrial pacing) and pacing in the ventricle

Also known as “P wave tracking”
Example of atrial pacing and ventricular pacing (no inhibition of pacing)
VDD

- Pacing in ventricle
- Sensing in both atrium and ventricle
- Intrinsic QRS inhibits ventricular pacing
- Intrinsic P wave can trigger ventricular pacing
Non-tracking modes
DDI

- Pacing in the atrium & ventricle
- Sensing in both atrium and ventricle
- NO tracking of P waves (no constant AV delay)
DOO

- Pacing in atrium and ventricle
- Intrinsic P wave and QRS do not affect pacing
- Asynchronous pacing (always pace at lower pacing rate)
Rate modulation/rate responsive mode
Example of Dual-Chamber Rate-Responsive pacing
Atrial fibrillation with A-V block

VVIR
What Device Operation is This?
Is This Normal Device Operation?
Is This Normal Device Operation?
Is This Normal Device Operation?
Is This Normal Device Operation? What Feature Might You Want to Have Programmed On?
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