# Fundamentals of Pacing Therapy

**Electrical Terms and Concepts**
This presentation is provided with the understanding that the slide content must not be altered in any manner as the content is *subject to FDA regulations*.

This presentation is to be used in conjunction with other resource material including the applicable Boston Scientific device *physician’s manual* and any *implant accessories instructions* for use.

This presentation is not intended to replace implant training.

Proper surgical procedures and techniques are the responsibilities of the medical professional.

If this presentation is not used in its entirety, the following information must be included:

- Appropriate Indications
- Contraindications
- Warnings
- Precautions and Adverse Events
When we complete this program you will be able to:

- **Define** basic electrical terms
- **Explain** how these terms relate to device function
- **Discuss** the relationship between voltage, current, and resistance
- **Define** stimulation threshold and factors affecting it
- **Explain** pacemaker sensing and factors affecting it
Overview

Electrical Terms and Concepts:

- Ohm’s Law
  - Voltage
  - Current
  - Impedance

- Energy

- Stimulation Threshold

- Sensing
  - Slew Rate
**Ohm’s Law**

Ohm’s Law: \( V = I \times R \)

Describes the relationship between voltage, current, and resistance: \( V = I \times R; I = V/R; R = V/I \)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>The electrical force that makes current move through a conductor – <em>measured</em> in volts (V)</td>
</tr>
<tr>
<td>Impedance</td>
<td>The total opposition presented to the flow of current by an electrical circuit or device – <em>measured</em> in ohms (R)</td>
</tr>
<tr>
<td>Current</td>
<td>The transfer of electrical charge (electrons) through a cross-section of a conductor – <em>measured</em> in amperes (I)</td>
</tr>
</tbody>
</table>
**Voltage:**

- The force or “push” that causes electrons to move through a circuit
- Measured in volts
- Represented by the letter “V”
- Often referred to as amplitude
Current:

- The flow of electrons in a completed circuit
- Measured in mA (milliamperes)
- Represented by the letter “I”
**Impedance:**

- The opposition to current flow
- Measured in ohms
- Represented by the letter “R” (W for numerical values)
- Often referred to as resistance
Ohm’s Law Can Be Used to Find Current

Example 1:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>= 5 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance</td>
<td>= 500 Ω</td>
</tr>
</tbody>
</table>

What will the current be?

\[ I = \frac{V}{R} \]

\[ 5 \text{ V} \div 500 \Omega = 0.010 \text{ Amperes} \times 1000 = 10 \text{ mA} \]
Example 2:

<table>
<thead>
<tr>
<th>Term</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>2.5 V</td>
</tr>
<tr>
<td>Impedance</td>
<td>500 Ω</td>
</tr>
</tbody>
</table>

What will the current be?

\[ I = \frac{V}{R} \]

\[ 2.5 \text{ V} \div 500 \text{Ω} = 0.005 \text{ Amperes} \]

\[ 0.005 \times 1000 = 5 \text{ mA} \]
**Example 3:**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>= 5 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance</td>
<td>= 250 Ω</td>
</tr>
</tbody>
</table>

What will the current be?

\[ I = \frac{V}{R} \]
\[ 5 \text{ V} \div 250 \Omega = 0.020 \text{ Amperes} \]
\[ 0.020 \times 1000 = 20 \text{ mA} \]
Ohm’s Law
Electrical Analogy

Voltage = Current x Resistance

- **Current** is similar to the flow of water
- **Voltage** is analogous to water pressure
- **Resistance** can be compared to resistance to flow

- **“Normal” Resistance**
- **“Low” Resistance**
- **“High” Resistance**
- **“Normal” Current**
- **“High” Current**
- **“Low” Current**
Current is Escaping:

- Decreased Resistance
- Increased Current Drain
- Increased Energy Usage
Current Cannot Reach Heart:

- Increased Resistance
- Decreased Current Drain
- Decreased Energy Usage
Reducing Electrode Size:

- Increases impedance
- Decreases current drain
- Increases longevity

Larger current drain

Smaller current drain
<table>
<thead>
<tr>
<th>Impedance Level</th>
<th>Effect on Battery Current Drain</th>
<th>Effect on Battery Longevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Impedance</td>
<td><em>Decreases</em></td>
<td><em>Increases</em></td>
</tr>
<tr>
<td>Low Impedance</td>
<td><em>Increases</em></td>
<td><em>Decreases</em></td>
</tr>
</tbody>
</table>
Device Function
Constant Voltage Pacemakers

Medical Education

Electrical Terms and Concepts

- Disclaimer
- Objectives
- Overview
- Ohm’s Law

Device Function

Stimulation
Threshold

Energy

Sensing

Questions

V = \downarrow IR \uparrow

\overline{V} = \uparrow IR \downarrow
Definition:

The minimum electrical stimulus needed to consistently capture the heart outside of the heart’s refractory period.
The voltage delivered by the electrical pacing stimulus (volts)

Amplitude

Pacing Pulse
Duration of the electrical pacing pulse (milliseconds)

Pacing Pulse

Pulse Width
Stimulation Threshold

- Amplitude (V) + Pulse Width (ms) = Output
- Lowest Output that Captures Outside of Refractory = Threshold
Why Measure?

- Assure proper lead placement
- Determine safety margin
Stimulation Threshold

**Affected by:**

- Lead Maturation
- Lead Technology
- Medications
- Lead Location
Chronic Electrode:

- Excitable Tissue
- Non-Excitable Fibrotic Tissue
- Virtual Electrode
- Electrode
Stimulation Thresholds
Effect of Steroid

Pulse Width = 0.5 msec

S. Furman, D. Hayes, D Holmes; "A Practice of Cardiac Pacing" 2nd Revision, 1989; p.36
Stimulation Threshold
Strength Duration Curve

- Pulse Amplitude
- Capture
- Noncapture
- Pulse Width (ms)

1.0
Stimulation Threshold
Strength Duration Curve

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Disclaimer
Objectives
Overview
Ohm’s Law
Device Function

Stimulation Threshold
Energy
Sensing
Questions

Voltage Stimulation Threshold (Volts)

Pulse Width (ms)

0.5 1.0 1.5 2.0 2.5 3.0
Energy

\[ E = \frac{V^2}{R} \]

- **E** = Energy
- **V** = Voltage
- **T** = Time
- **R** = Resistance
Energy

2x Voltage = 4x Energy

2x Pulse Width = 2x Energy
Energy

5.0^2 (.50ms) / 500

25 \mu J
Energy

6.25 μJ

\[
\frac{2.5^2 (\text{.50ms})}{500}
\]
Energy

5.0^2 (0.25ms) / 500

12.5 \mu J
**Definition:**

Sensing is the ability of the pacemaker to “see” when an intrinsic depolarization is occurring.
Accurate sensing requires filtering out extraneous signals

Unwanted signals include:

- T-waves
- Far-field events
- Myopotentials
Sensing may be affected by:

- Electrophysiological properties of the myocardium
- Characteristics of the electrode
- Lead placement
- Sensing amplifiers of the pacemaker
- Lead polarity
- Lead integrity
- EMI
Review of Sensitivity:

- 4.0 mV
- 2.0 mV *
- 1.0 mV

*programmed sensitivity
Review of Sensitivity:

Programming a higher setting decreases the sensitivity of the device – fewer signals are sensed.
Review of Sensitivity:

Programming a **lower** setting increases the sensitivity of the device – more signals are sensed.
Slew Rate:

\[ \frac{\Delta V}{\text{Time}} = \text{Slew Rate} \]