Introduction To Cardiac Device Function And Trouble Shooting

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Objectives

• What will be covered
  – Basic PPM function
  – Sensing/capture
  – Timing
    • Pacing codes
    • Timing cycles
    • Upper rate behaviour
  – Basic troubleshooting
    • Sensing problems
    • Capture problems
    • Pseudo-malfunction

• What will not be covered
  – Pacing indications
  – Battery technology
    • BOL, EOL, ERI
  – Leads
  – Strength-duration curves
  – Ohms law
  – Rate response sensors
  – Pacemaker mediated tachycardia / endless loop tachycardia
Pacemaker: Basic Function

What is a Pacemaker?

- Sensing algorithm
- Counter
- Pulse generator (pacing algorithm)
- Lithium iodide battery
**Sensing**

- **Definition:**
  - The ability of the pacemaker to sense an *intrinsic* electrical signal (milliVolts mV)
    - The pacemaker does not sense the surface ECG
    - “what is seen by the pacemaker”

- **The programmed sensitivity setting:**
  - Indicates the *minimum* intra-cardiac signal that will be sensed (seen) by the pacemaker to initiate the pacemaker response (inhibited or triggered).

*Sensing is critical to timing cycles*
Sensing

- When programming sensitivity, as you raise the number (sensitivity) you make the pacemaker less sensitive, (allow it to “see” less).

Ideal
- Appropriate detection of intrinsic events.
- Large safety margin.
- Amplitude of ECG may change
- Ectopics
- SR ➔ AF

Undersense = Overpace
Oversense = Underpace
Capture

• **Definition:**
  – The depolarisation and resultant contraction of the atria or ventricles in response to a pacemaker stimulus.

• Pacemaker generates a pulse at
  – Specific **voltage** e.g. 0.4V
  – Specific duration
    • Pulse duration e.g. @0.4ms
Stimulation Threshold

• Definition:
  – The minimum amount of electrical energy that **consistently** produces a cardiac depolarisation
    • Wedensky effect
  – Can be measured in:
    • Voltage
    • **Pulse Width / Duration (Milliseconds)**
    • Milliamperes ,
    • Charge (microcoulombs)
    • Energy (microjoules)
Performing a Manual Threshold Test

• Process
  – Tell the patient what you are going to do
  – Force pacing and periodically lower the test value (Voltage or pulse width)
  – Stop the test once Loss-of-Capture (LOC) is seen on the ECG
  – The value just above LOC is the threshold

• What is the threshold? 1.25V
Pacing Codes and Basic Timing Cycles
# Generic (NBG) Code

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<th>III</th>
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Pacing Codes: What It Means in Practice

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

Before implantation a single chamber PPM is referred to as SSI.
Pacing Codes:
What It Means in Practice

- Atrial pacing
- Atrial sensing
- Intrinsic P wave inhibits atrial pacing
Pacing Codes: What It Means in Practice

- Pacing in both the atrium and ventricle
- Sensing in both the atrium and ventricle

**Response to Sensing: Triggered & Inhibited**

An atrial sense (As):
- Inhibits the next scheduled Ap
- **Triggers** an AV interval (called a Sensed AV Interval or SAV)

An atrial pace (Ap):
- **Triggers** an AV delay timer (the Paced AV or PAV)

A ventricular sense (Vs):
- Inhibits the next scheduled Vp
The 4 modes of DDD pacing

- AsVs
- ApVs
- ApVp
- AsVp

Also referred to as

- Atrial tracking
- P wave tracking mode

The atrial rate is faster than the base rate
(important for upper rate behaviour)
The 4 modes of DDD pacing
Rate Responsive Pacing

In rate responsive pacing sensor(s) are used to detect changes in physiologic needs and increase the pacing rate accordingly

• The sensor
  – Sensors are used to detect changes in metabolic demand
  – “Sensors” detect motion (piezoelectrode crystal or accelerometer) or use a physiologic indicator, i.e., minute ventilation

• The algorithm
  – With-in the software of the pacemaker. Uses the input from the sensor to determine the appropriate paced heart rate for the activity
Timing Cycles: Single Chamber (VVI)

Timing Intervals

Lower rate limit (LRL): The maximum time allowed between one paced or sensed beat and the next.
Timing Cycles: Single Chamber (VVI)

Timing Intervals

Vp or Vs event re-starts the pacing interval (re-sets the clock)
Timing Cycles: Terminology

• **Refractory Period**
  – A programmable (changeable) period of time that starts with
    • Pacing or sensing
  – *Controls the length of time following a paced or sensed beat, during which the pacemaker’s sensing circuit does not respond to sensed events.*
  – All refractory periods begin with a blanking period
    • Blanking period AKA absolute refractory period

V Refractory Period: Prevent T Wave Sensing
Timing Cycles: Dual Chamber (DDD)

Timing Intervals (ventricular based)

V-V = Lower Rate Limit
VA = Atrial Escape Interval (AEI) Derived interval
AV = AV Delay

EXAMPLE
Lower Rate = 60 ppm  V-V = 1000 ms
AV Delay = 200 ms, VA = ?
AV Sequential Pacing

A-pace/V-pace (Ap/Vp)

VA = Atrial Escape Interval: The maximum time from the last Vs or Vp to when the next atrial event is due to keep the rate ≥ LRL
Complete Inhibition

A-Sense/V-Sense (As/Vs)

VA = Atrial Escape Interval: The maximum time from the last Vs or Vp to when the next atrial event is due to keep the rate ≥ LRL
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P Wave Tracking

A-Sense/V-Pace (As/Vp)

AV Delay
VA Interval
*MTR
LRL (V-V)

*MTR: Maximum track rate/interval=Upper Rate Limit (URL)
Timing Cycles: Dual Chamber (DDD)

The basics

\[ V - V = AV + VA \]
Timing Cycles: Dual Chamber (DDD)

What else is needed!

*PVARP = Post Ventricular Atrial Refractory Period
Upper Rate Behaviour

All to do with **Atrial** Refractory Periods

*\[ \text{TARP} = \text{AVD} + \text{PVARP} \]*

2:1 Rate = \( \frac{60,000}{\text{TARP}} \)

*\[ \text{TARP} \]: Total Atrial Refractory Period (derived interval)
PVARP: Upper Rate Behaviour

- PVARP
  - Starts with V activity
  - Acts on atrial channel
  - Prevents the AV interval from restarting due to sensed events (Far-field R-waves or retrograde conduction)
    - PMT
  - P wave falling outside the PVARP starts an AV delay

\[
PVARP = \text{Post Ventricular Atrial Refractory Period}
\]

\[
TARP = AVD + PVARP
\]
Upper Rate Behaviour

Pacemaker Wenckebach/pseudowenckebach

AV delay extension

Atrial Rate > Max Track Rate
Upper Rate Behaviour

Wenckebach (4:3 Block), Group of beats then pause, group of beats then pause

Upper Rate Behaviour
- TARP = AV delay + PVARP
- MTR

Intrinsic Atrial Rate > Max Track Rate
- Not all P waves trigger a ventricular stimulation
Upper Rate Behaviour

- Pacemaker Wenckebach
  - Caused by the atrial rate exceeding the MTR*

This P-wave fell in the PVARP of the previous cycle.

*MTR: Maximum track rate/interval=Upper Rate Limit (URL)
Upper Rate Behaviour

2:1 Block

Occurs when P-waves are faster than TARP ie A-A < TARP

2:1 Rate $= \frac{60,000}{\text{TARP}}$

*MTR: Maximum track rate/interval
Upper Rate Behaviour

2:1 Block

- Every 2\textsuperscript{nd} P wave falls in PVARP (AS, AR, AS, AR .......)
- Sudden drop in rate with exercise
  - Occurs when P-waves are faster than TARP ie A-A<TARP
Upper Rate Behaviour: Summary

Upper rate behaviour is determined by TARP & MTR

* TARP = AVD + PVARP

2:1 Block

Wenckebach

1:1

TARP
MTR
LRL

PVARP = 250ms, AVD=150ms, TARP=400ms
2:1 rate = 60000/400
= 150bpm
Longer TARP lower 2:1 block rate

2:1 Rate = 60,000 / TARP
Basic Troubleshooting

Potential problems identifiable on an ECG can generally be assigned to five categories:

- Undersensing
- Oversensing
- Loss of capture
- Pseudo-malfunction
- No output
Troubleshooting: Undersensing

Definition: Failure of the pacemaker circuitry to sense intrinsic P or R waves

- Sense in milliVolts (mV)
- Pace in Volts (V)
- Higher the number/wall (sensitivity) the less the pacemaker will see
- Remember Under-sensing = Over-pacing
Troubleshooting: Undersensing

CAUSES:

- Inappropriately programmed sensitivity
- Lead maturation
- Lead failure e.g. Insulation break; conductor fracture; dislodgment
- Medication e.g. Class I drugs
- Change in the native signal e.g. SR → AF

Remember Under-sensing = Over-pacing
Troubleshooting: Undersensing

- Sense in milliVolts (mV)
- Pace in Volts (V)
- Higher the number/wall (sensitivity) the less the pacemaker will see

To correct:
Programming a lower number increases the sensitivity of the device, causing more signals to be sensed (seen).

“Lower the wall”
(Or reprogram sensing polarity)

Remember Under-sensing = Over-pacing
Troubleshooting: Oversensing

Definition:
The sensing of events other than P or R-waves by the pacemaker circuitry

- Sense in milliVolts (mV)
- Pace in Volts (V)
- Higher the number/wall (sensitivity) the less the pacemaker will see
- Remember Over-sensing = Under-pacing

To correct:
Programming a higher number decreases the sensitivity of the device, causing less signals to be sensed (seen).

“Raise the wall”

Or increase refractory periods
Troubleshooting: Oversensing

Remember over-sensing = under-pacing

CAUSES:

T wave oversensing / Far field sensing

Lead failure (insulation break/lead fracture)

Poor connection at connector block

Exposure to interference electro-magnetic interference or Myopotentials
Troubleshooting: Oversensing

T Wave Oversensing

- Sensing of myocardial repolarisation
- Vs marker coincides with T wave
- May be intermittent
  - Drugs
  - Electrolyte disturbance
- **Solution**: Alter V sensitivity or lengthen V refractory period so T wave in refractory period

Far Field Sensing

- Sensing in one chamber events in the other.
- **Sense in milliVolts (mV)**
- **Pace in Volts (V)**
- Typically atrial lead senses ventricular depolarisation (R wave)
  - Far field R wave sensing
  - May inhibit atrial pacing
- **Solution**: Extend PVARP
Troubleshooting: Loss of Capture

Definition:
The emitted pacemaker stimulus does not cause depolarization and resultant cardiac contraction

CAUSES:
Lead dislodgment, maturation, failure
Low output, Battery depletion
Poor connection at connector block
Twiddler’s syndrome
Electrolyte abnormalities, e.g. ↓K⁺
Myocardial infarction
Drug therapy

“High Threshold”
Troubleshooting: Loss Of Capture

Atrial displacement

Twiddler
Troubleshooting: Loss Of Capture

Possible solutions

- Program Voltage higher
- Program Pulse Width longer
- Reposition or replace pacing electrode
Psuedomalfuncon: Magnet Operation

Paces at a **fixed rate**
- Asynchronous, AOO, VOO, DOO
- Ignores underlying intrinsic rhythm
- Pacing spikes at regular intervals

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<td>PHK</td>
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Note: (VVI) = Ventricular Vagal Inhibition
Psuedomalfinction: Fusion

- **Definition:**
  - The combination of an intrinsic beat and a paced beat
- The morphology varies; a fusion beat doesn’t really look like a paced beat or an intrinsic beat
- Fusion beats contribute to the contraction of the chamber being paced but waste energy
Psuedomalfunction: Pseudofusion

• Definition:
  – A pacing pulse falls on an intrinsic beat. The pacing pulse is ineffective and the intrinsic complex is not altered.
  – Waste energy
Introduction To Cardiac Device Function And Trouble Shooting

Covered
• Sensing
• Capture
  – Threshold tests
• Pacing Modes
• Single Chamber Timing Cycles
• Dual chamber timing cycles
  – Introduction

Troubleshooting
• Undersensing
• Oversensing
• Loss of capture
• Pseudomalfunction
  – Magnet mode
  – Fusion and pseudofusion