Electrical Management of Cardiac Rhythm Disorders

For Cardiology Fellows

December 5-8
Austin, Texas

Single and Dual Chamber Pacing

Single Chamber Timing Cycles
Single Chamber Timing

- Sensing and Pacemaker Inhibition
- Capture
- Fusion and Pseudofusion
- Single-chamber Timing Cycles
- Rate Hysteresis

Asynchronous Pacing

- Pacing without sensing
- Oldest mode of pacing
- Magnet mode for most pacemakers
  - Magnet application turns off pacemaker sensing thus forcing it to pace
  - Magnet uses:
    - Assess pacer function during inhibition
    - Troubleshooting
    - Evaluate ERI (elective replacement indicator) and EOL (end of service life)
VOO

Paces: Ventricle
Senses: None
Response: None

AOO

Paces: Atrium
Senses: None
Response: None
Demand Pacing

- Pacing with sensing
- Pacing pulse is inhibited by intrinsic “P-” or “R-waves”
- Sensed events reset the pacing interval

Sensing

- When programming sensitivity, as you lower the number you make the pacemaker more sensitive, (allow it “see” more).
• When programming sensitivity, as you lower the number you make the pacemaker more sensitive, (allow it “see” more).
Surface ECG

IEGM
(Intra-cardiac Electrogram)
Ventricular Sensing / Inhibition

- Sensed R-waves re-start the pacing interval
- Appropriate ventricular sensing

Capture

- Definition:
  - The depolarization and resultant contraction of the atria or ventricles in response to a pacemaker stimulus.
  - One-to-one capture occurs when each pacemaker stimulus causes a corresponding depolarization and resultant cardiac contraction
Atrial Capture

• Paced atrial events re-start the pacing interval

Ventricular Capture

• Ventricular capture (paced ventricular beats look like PVCs or LBBB)

• Paced ventricular events re-start the pacing interval
Fusion Beat

• 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

Ventricular Fusion
Pseudofusion Beat

• Definition:
  – A pacing pulse falls on an intrinsic beat. The pacing pulse is ineffective and the intrinsic complex is not altered

Ventricular Pseudofusion
Fusion and Pseudofusion

Clinical Significance

- **Fusion**
  - Contributes to the contraction
  - Can use to determine capture

- **Pseudofusion**
  - Does not confirm capture
  - Output pulse ineffective

- To confirm capture in both situations increase the pacing rate.

- Once capture confirmed, consider decreasing programmed rate
Pacing Interval / Pacing Rate

• The rate at which the pacemaker will pace if the patient does not have their own rhythm
  – Expressed in either PPM or ms

• Your pacing Interval is your programmed base rate
  – (Also known as pacing rate, lower rate limit)

![Base Rate](60 bpm)

Pacing Intervals

- Automatic Interval
- Escape Interval
- Refractory Period
- Alert Period
Rate Hysteresis

- By lowering the pacing rate, allows for intrinsic rate to drop to below the hysteresis rate before pacing will occur.
- On the surface ECG, looks like a separate rate for pacing and sensing.
- The purpose of hysteresis is to promote intrinsic conduction.

Hysteresis

Pacing Interval

Hysteresis Interval
• Refractory period
  – A programmable (changeable) period of time that starts with pacing or sensing
  – This period of time has two components:
    • Absolute refractory period
    • Relative or noise sampling period

• Absolute refractory period
  – The pacemaker cannot see during this time
  – The sense amplifier is totally shut off

= Absolute Refractory Period
Relative Refractory Period

- The device sees electrical activity but doesn't respond

Clinical Application of Refractory Periods

Programmer
- AAI mode
  - “A. refractory” (nominal 275 ms)
    - Used to blank far-field event in DDD mode
  - Atrial absolute refractory period is programmable in AAI/R and AAT/R modes only

- VVI mode
  - “Ventricular refractory” (nominal 250 ms)
  - Used to prevent oversensing of T-waves
Alert Period

- **Definition:**
  - The portion of the timing cycle where the device senses electrical activity (e.g., cardiac) and responds in a preset or programmed manner.

- The period of time after the refractory period.
- The pacemaker can see and will respond in the programmed manner.

- Relative or Noise Sampling Period
- Alert Period
Ventricular Refractory plus Alert
Equal the Pacing Interval (Rate)

Example with BR 60, V-Ref of 250
1000-250 = 750ms Alert Period

Oversensing

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

• Oversensing leads to underpacing
Ventricular Oversensing

T-wave Oversensing

How can this be fixed?
Oversensing Causes

- Insulation break
- Intermittent lead fracture
- Myopotentials
- EMI
- Concealed extrasystoles

Rib-Clavicle Crush-Conductor Fracture

Dotted line identifies lower edge of clavicle
Undersensing

• Definition:
  – Failure of the pacemaker circuitry to sense intrinsic P- or R-waves
• Undersensing may cause the pacemaker to emit
  inappropriately-timed, asynchronous, or competitive
  output pulses
• Undersensing leads to overpacing

Ventricular Undersensing
**Under-sensing Causes**

- Inadequate cardiac signal
- Dislodged lead
- Insulation break

**Possible Solutions**

- Program the sensitivity to a lower number
- Reprogram polarity
Loss of Capture

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

• Loss of capture occurs when the pacemaker’s programmed energy is less than the stimulation threshold

Ventricular Loss of Capture
Loss of Capture Causes

- Dislodged lead
- Twiddler’s syndrome
- Insulation break
- Perforation
- Exit block
- Threshold higher than programmed output

Loss of Output

- Definition:
  - The pacemaker does not emit a stimulus
Ventricular loss of output

Pacemaker should have paced

Loss of Output Causes

- Cause for the pause
  - Loose set screw
  - Lead fracture
  - Pacemaker Inhibition
  - Concealed stimulus on ECG
  - Battery exhaustion
Single Chamber Troubleshooting

Intrinsic Refractory Period
Captured QRS Complex
Intrinsic Refractory Period
Refractory Period Alert Period
Capture
Refractory Period Alert Period

Dual-Chamber Timing Cycles
• Dual Chamber Pacing
  – What is it why do we need it?

• Dual-chamber Timing Cycles
  – Atrial and Ventricular Timing Cycles

• Atrial- vs. Ventricular-based Timing

VVI Mode

VVI Pacing - Loss of A-V Synchrony
• Pacemaker Syndrome
  • Symptoms
    – Due to loss of AV synchrony
    – May include
      • Syncope
      • Dizziness
      • Decreased blood pressure
      • Distended neck veins
      • Shortness of breath
      • Fatigue
      • Palpitations
    – May be alleviated by restoring AV synchrony!

Ventricular Diastole – Atrial Contribution

• In the beginning we all had atrial contraction followed by ventricular contraction (AV synchrony)

Atrial Kick = 20 – 30%
Dual-Chamber Pacing Systems

- Two leads
  - Atrial lead
  - Ventricular lead
- One pulse generator with two pacing circuits
  - Circuit 1 for atrial pacing and sensing
  - Circuit 2 for ventricular pacing and sensing

Dual-Chamber Pacing is:

- Pace and sense in the atrium and ventricle
- Try to mimic the normal contraction sequence of the heart (Put in the beat that is MISSING!)
For Identity® and above devices, St. Jude Medical uses the following markers to identify pacemaker operation:

- **AS** = Atrial Sense (P-Wave)
- **VS** = Ventricular Sense (R-Wave)
- **AP** = Atrial Pacing
- **VP** = Ventricular Pacing

**DDD Mode “P Tracking”**

- Sensing A and V
- Pacing A and V
- Track (or trigger) & Inhibit - Atrium
- Inhibit - Ventricle
Four States Of Dual-Chamber Pacing

Patient’s Rhythm: Sinus Brady with Complete Heart Block

What will the pacer do? AV Pace
Patient’s Rhythm: Complete Heart Block with a Functioning SA Node

What will the pacer do? P wave (AS) followed by V pacing

Patient’s Rhythm: Sinus Bradycardia

What will the pacer do? Atrial pacing followed by R-waves (VS)
Base Rate

• The base rate is the slowest rate the pacemaker will pace
• You will only see atrial pacing at the base rate if the patient doesn’t have a p-wave
Dual-Chamber Timing Cycles

Atrial Timing Cycles

- Paced AV Delay
- Sensed AV Delay
- Post Ventricular Atrial Refractory Period (PVARP)
  - Post Ventricular Atrial Blanking (PVAB)
- Total Atrial Refractory Period (TARP)
- Atrial Alert Period
**Paced AV Delay**
- Time from an atrial pacing spike (AP) to a ventricular pacing spike (VP)
- Mimics the PR interval
- Expressed in milliseconds (ms)

**Uses:**
- Optimize ventricular filling
- Optimize cardiac output
- Provide ventricular back-up
- Allow intrinsic conduction

**Sensed AV Delay**
- Time from a P-wave (AS) to a ventricular pacing spike (VP)
- Mimics the PR interval
- Expressed in milliseconds (ms)

**Uses:**
- Optimize ventricular filling
- Optimize cardiac output
- Provide ventricular back-up
- Allow intrinsic conduction
Sensed and Paced AV Delay

Paced and sensed AV delay completed with pacing in the ventricle
Paced and Sensed AV Delay

Sensed and paced AV delay interrupted by an intrinsic R-wave
Atrial Timing Cycles

- Paced AV delay
- Sensed AV delay
- Post-ventricular atrial refractory period (PVARP)
  - Post ventricular atrial blanking (PVAB)
- Total atrial refractory period (TARP)
- Atrial alert period

Post-Ventricular Atrial Refractory Period

- Timeframe the atrial channel is refractory, initiated when there is a ventricular pacer spike or sensed R wave
- Expressed in milliseconds (ms)
- Nominal 275 ms
Post-Ventricular Atrial Refractory Period (PVARP)

- Prevents the atrial channel from sensing retrograde P-waves
- RVAC can vary in the same patient
  - Day to day
  - With positional changes
  - With exercise
- RVAC at rest is typically ~230 ms hence PVARP nominally 275ms
Why Do We Care About Retrograde Conduction?

- AV synchrony is lost
- Can occur via normal conduction pathways or via accessory pathways (i.e. Wolff-Parkinson-White syndrome)

AV synchrony

AV synchrony lost

Retrograde P-waves

How to Check for VA Conduction

1. IEGM Atip-Case (Identity® also turn on V Sense Amp)
2. Mode VVI
3. Paper speed 50 sec
4. Change base rate to 20 ppm above pts intrinsic rate
5. Check at low, medium and high rate (80,100,120)
6. Look for "marriage"
7. If VA conduction add
8. 40-50 ms to PVARP
Retrograde Conduction

Practice Strips

Is retrograde conduction present? If so, what will you reprogram?

<table>
<thead>
<tr>
<th>ECG Controls</th>
<th>Programmed Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Surface ECG</td>
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<tr>
<td>Gain</td>
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<tr>
<td>Filter</td>
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<td>Paper Speed</td>
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<td>ECG Display</td>
<td>On/Off</td>
</tr>
<tr>
<td>Position</td>
<td>3/4</td>
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<tr>
<td>Gain</td>
<td>On</td>
</tr>
<tr>
<td>Configuration</td>
<td>Atp-Arming / V Sense Amp</td>
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<td>Sensitivity</td>
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<td>GFR Filter</td>
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<tr>
<td>1.0 Second</td>
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</tbody>
</table>

Is retrograde conduction present? If so, what will you reprogram?

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Post-Ventricular Atrial Blanking (PVAB)

- Timeframe the atrial channel is blanked
- The first portion of PVARP
- Initiated with a ventricular pacer spike or a sensed R-wave
- Programmable in all devices, nominal values vary per device family
PVAB Used to Fix Far-Field R-Wave Sensing

A far-field R-wave (FFRW) is a true ventricular signal which is detected on the atrial channel in PVARP.

A far-field R-wave (FFRW) is a true ventricular signal which is detected on the atrial channel in PVARP.
Consequences of FFRW Detection

• DDD / DDDR pacing
  — Triggering AMS episodes
  — Activation of high atrial rate EGM trigger

Each time we paced in the ventricle, we sensed it in the atrium

How to Measure Far-Field R-Wave Sensing

• PVAB
  — Prevent the atrial channel from sensing far-field ventricular signals

1. Best to examine on atrial sense amp IEGM
2. Freeze and change sweep speed to 50 mm/s
3. Measure V to far-field R-wave
4. Program PVAB 40 ms greater than V to far-field R
PVAB and PVARP

- Uses of PVARP
  - Prevents the atrial channel from sensing retrograde P-waves

- Uses of PVAB
  - Prevents the atrial channel from sensing far-field ventricular events

Atrial Timing Cycles

- Paced AV delay
- Sensed AV delay
- Post Ventricular Atrial Refractory Period (PVARP)
  - Post Ventricular Atrial Blanking (PVAB)
- Total Atrial Refractory Period (TARP)
- Atrial alert period
Total Atrial Refractory Period (TARP)

- Sensed AV delay + PVARP = TARP
- Total time the pacemaker is committed to timing cycles

Why We Need TARP

- TARP aids in upper rate limits
- TARP is used to calculate the 2:1 block rate
  - (TARP divided by 60,000)
Atrial Timing Cycles

- Paced AV delay
- Sensed AV delay
- Post-ventricular atrial refractory period (PVARP)
  - Post-Ventricular Atrial Blanking (PVAB)
- Total atrial refractory period (TARP)
- Atrial alert period

Atrial Alert Period

Timeframe after PVARP when the sense amplifier is open and can see P-waves
**Atrial Timing Cycle Review**

- Alert Period
- PVARP
- Paced AV Delay
- Sensed AV Delay

**Ventricular Timing Cycles**

- Ventricular timing cycles
  - Ventricular Blanking
    - Ventricular Safety Standby
    - Auto Blanking
  - Ventricular refractory period
  - Ventricular alert period
Ventricular Blanking

- Timeframe the ventricular channel is blanked in response to atrial pacemaker spike
- Only initiated when an atrial pacer spike is delivered
- Nominal: 12 ms

Why do we need ventricular blanking?

- Clinical significance: To keep the ventricular sensing circuit from seeing the atrial pacemaker spike
- Prevents crosstalk

1. The atrial lead delivers 3.0 Volts (3,000 mV) to the atrium
2. The ventricular pacing lead senses in millivolts
3. This large current (3,000 mv) is sensed by the ventricular lead and will inhibit the ventricular output spike
What happens if the ventricular channel senses an atrial spike?

Crosstalk - Results in Ventricular Inhibition

Refractories & Blanking

<table>
<thead>
<tr>
<th>PVARP</th>
<th>256 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricle Refractory</td>
<td>258 ms</td>
</tr>
<tr>
<td>Rate Responsive PVARP/IVR</td>
<td>Medium</td>
</tr>
<tr>
<td>Shortest PVARP/IVR</td>
<td>206 ms</td>
</tr>
</tbody>
</table>

- Post Ventricle Atrial Blanking: 100 ms
- Ventricle Blanking: 12 ms
- Ventricle Safety Standby: 0 s

PVC Options
- PVC as PVC

PMT Options
- 18 Beats + PMT

PMT Detection Rate: 190 bpm

@ St. Jude Medical
Ventricular Timing Cycles

- Ventricular timing cycles
  - Ventricular Blanking
    - Ventricular Safety Standby
    - Auto Blanking
  - Ventricular refractory period
  - Ventricular alert period

Ventricular Refractory Period

- Definition: The programmable timeframe after either a ventricular spike or a sensed R-wave when the sensing amplifiers are effectively disabled.
  - Used to prevent double counting due to oversensing the T-waves or wide QRS complexes
Ventricular Refractory Period

Nominal = 250 ms

Ventricular Timing Cycles

- Ventricular timing cycles
  - Ventricular Blanking
    - Ventricular Safety Standby
    - Auto Blanking
  - Ventricular Refractory
  - Ventricular alert period
Ventricular Alert Period

Period of time when the device may sense and respond to ventricular events

Ventricular Timing Cycles

- Ventricular Blanking Period
- Ventricular Refractory Period
- Ventricular Alert Period
Atrial and Ventricular Timing Cycles

- Alert Period
- PVARP
- Paced AV Delay
- Sensed AV Delay
- V Refractory
- V Blanking
- V Alert

More Timing
There are two types of timing:

- **Atrial-based timing**
  - The rate clock starts with pacing or sensing in the atrium
    - A to A interval

- **Ventricular-based timing**
  - The rate clock starts with pacing or sensing in the ventricle
    - V to A interval or atrial escape interval
    - V to A interval = programmed rate minus the programmed paced AV Delay

**Atrial Based Timing**

- Minimum rate (atrial based timing)
  - The A to A interval
Ventricular Based Timing (Trilogy® DR+)

- **Base rate**
  - The paced AV delay plus the V to A interval
    - V to A interval = programmed rate minus programmed AV delay
    - V to A interval is sometimes called the Atrial Escape Interval (AEI)

**Calculation of V-A Interval**

- V-A Interval = base rate (in ms) minus programmed paced AV delay

Base Rate: 60 ppm (1000 ms)
Paced AV Delay: 200 ms
V-A Interval: 800 ms
Atrial vs. Ventricular Based Timing

Programmed: Base Rate: 60 ppm  Paced AV delay: 200 ms

Atrial Based:
A to A

\[ AA = 1000 \text{ ms} \]

Ventricular Based:
Paced AV delay + VA

\[ 200 + VA = 1000 \text{ms} \]

The only time you see a real difference is if there is an intrinsic R-wave
If there is a R-wave ventricular based timing will always be faster
A vs. V Based Timing with Intrinsic R-wave

Programmed: Base Rate: 60 ppm, Paced AV Delay: 200 ms

Atrial-Based Timing

- AA Interval = 1000 ms
- Rate = 60 ppm

Ventricular-Based Timing

- AV delay is shorter
- VA (AEI) = 800 ms
- Rate = 63 ppm (AV+VA)

Intrinsic Conduction

Atrial based

<table>
<thead>
<tr>
<th>Surface ECG</th>
<th>ECG / IGM freeze</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mV/cm</td>
<td>Filter: Off</td>
</tr>
<tr>
<td>Sweep Speed 50 mm/s</td>
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</tr>
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</table>

Base Rate: 60 ppm, AV delay: 200 ms

Ventricular based

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<td></td>
</tr>
</tbody>
</table>

60 ppm | 64 ppm | 60 ppm | 64 ppm | 64 ppm | 64 ppm
Transition to AV-Block

- Base Rate: 60 ppm, AV Delay: 200 ms

Trilogy® DR+
Affinity® DR

Transition to AV-Block

Atrial Based Timing
Ventricular Based Timing
Modified Atrial-Based Timing
- Since Affinity® - St. Jude Medical
  - Modified atrial based timing
    - (PVC ventricular-based timing)
  - Will use atrial-based timing as long as AV synchrony is occurring. Once a PVC occurs, timing is changed to ventricular based timing.
Modified Atrial-Based Timing

Atrial based

- Surface ECG 2 mV/cm
- Filter: Off
- Sweep Speed 50 mm/s

Ventricular based

- Surface ECG 2 mV/cm
- Filter: Off
- Sweep Speed 50 mm/s

Programmed: Rate: 80 ppm, AV Delay: 120 ms, No PVC Response

Wrap it Up

- AV paced vs. AV sensed delay
- Clinical uses of PVARP
- Clinical uses of PVAB
- Timing cycle to prevent crosstalk
- Atrial- vs. ventricular-based timing