How to Program a Pacemaker: Pacing mode, Rate-responsiveness, Pacing algorithm

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Nomenclature of pacemaker

• Different codes: AAI, VVI, DDD, DDDR, VDD, DDIR...

• What did the codes stand for?
## The NBG Code

<table>
<thead>
<tr>
<th>Position</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
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<tbody>
<tr>
<td>Category</td>
<td>Chamber(s) paced</td>
<td>Chamber(s) sensed</td>
<td>Response to sensing</td>
<td>Rate Modulation</td>
<td>Multisite Pacing</td>
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<tr>
<td>Letters</td>
<td>O= None</td>
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<tr>
<td></td>
<td>A=Atrium</td>
<td>A=Atrium</td>
<td>T=Triggered</td>
<td>R=Rate Modulation</td>
<td>A=Atrium</td>
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<tr>
<td></td>
<td>V=Ventricle</td>
<td>V=Ventricle</td>
<td>I=Inhibited</td>
<td>V=Ventricle</td>
<td>V=Ventricle</td>
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<td>D=Dual</td>
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<tr>
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<td>S=Single*</td>
<td>S=Single*</td>
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</tbody>
</table>

* Manufacturer’s designation only
Examples

• **VVI**: Pace ventricle
• **VVI**: Sense ventricle
• **VVI**: Inhibit pacing if sensed

• **DDDR**: Paced atrium and ventricle (dual)
• **DDD**: Sensed atrium and ventricle (dual)
• **DDD**: Able to trigger and inhibit when sensed
• **DDDR**: Rate modulation
VOO Mode
VVI Mode
DDD
Mode Selection

• The patient’s underlying rhythm and overall cardiac condition
• The likelihood of disease progression (e.g. AV block)
• Benefits of 1:1 AV synchrony for the patient
• Patient’s overall condition and life expectancy
• Cost, implant difficulty
VVI pacemaker

- The VVI mode offers certain advantages
  - Ease of implant (one lead)
  - ‘Cost-effective’ therapy
  - For those who has unreliable or non-functioning atria (AF, silent atria)
  - Those do not have vasculature to accommodate a dual-chamber system

- Problem: AV dys-synchrony
Negative Effects of Atrioventricular Desynchronization

- Decreased ventricular filling
- High atrial pressures
- Atrial contraction against closed valves
- Valvular regurgitation
- Reduced stroke volume, cardiac output and exercise capacity

➔ ‘Pacemaker Syndrome’
Dual-Chamber Pacing

• Maintains 1:1 AV synchrony
  – Every atrial beat has a corresponding ventricular beat
  – Allows for “atrial kick” to contribute to ventricular filling
  – Mimics the behavior of the healthy heart
  – May prevent “pacemaker syndrome”

• Preferred pacing mode for patient in sinus rhythm.

• Drawbacks
  – Need to implant two leads
  – Cost
Rate Responsive Pacing
Why Rate Response?

• Rate response is the pacemaker’s ability to increase the pacing rate in response to physical activity or metabolic demand

• Rate response mimics the healthy heart’s response to work
HR Response to Work

Heart Rate (HR Reserve)

$O_2$ Consumption (Work) (Metabolic Reserve)
Heart-Rate Response in the Healthy Heart

- Basal Rate
- Rapid Rise
- Stable Rate
- Slow Return To Baseline
- End of Activity
- Onset of Activity

Benditt, David G., Rate Adaptive Pacing; Blackwell Publishing 1993. p.57, fig 4.10
Rate Responsive Pacing

• Cardiac output (CO) is determined by the combination of stroke volume (SV) and heart rate (HR)
  • SV X HR = CO
  • Changes in cardiac output depend on the ability of the HR and SV to respond to metabolic requirements
Rate Responsive Pacing

• SV reserves can account for increases in cardiac output of up to 50%
• HR reserves can nearly triple total cardiac output in response to metabolic demands
Who Needs Rate Responsive Pacing?
Chronotropic Incompetence (CI) Is a Significant Problem

- 58% incidence of CI in pacemaker patients
- 30% of patients with Sick-Sinus Syndrome (SSS) had sinus function deterioration over 2.5 to 4-year follow-up
- CI can be precipitated or exacerbated by beta-blockers or calcium channel blockers
Figure 2.5 Types of chronotropic incompetence (CI) during progressive maximum exercise. Chronotropic incompetence may manifest as failure to achieve the maximum rate or only achieving this rate with a delay. Other patterns of chronotropic incompetence may include inadequate submaximum heart rate, post-exercise pauses, or rate instability during exercise.

Lau CP. *Rate Adaptive Cardiac Pacing*, 1993
Indications for Rate Responsive Pacing

• Patients who are chronotropically incompetent

• Patients with CHB who receive a ventricular only pacemaker (VVIR)
Sensors

- Rate-responsive pacemakers rely on sensor(s) to detect patient activity
- The ideal sensor should mimic sinus node
  - Physiologic
  - Quick to respond
  - Able to increase the rate proportionally to the patient’s need
  - Able to work compatibly with the rest of the pacemaker
  - Able to work well with minimum energy demands or current drain
  - Easy to program and adjust
Types of Sensors

• Activity sensors
  – Vibration sensors (piezoelectric sensors)
  – Accelerometers

• Physiologic sensors
  – Minute ventilation
  – Temperature
  – Evoked response
  – QT interval
  – Closed loop system (CLS)
Activity Sensor/Vibration

- Responds rapidly
- No special pacing leads required
- Easy to manufacture and program
- Can be “fooled” by pressure on the can or footfalls (like walking downstairs)
Activity/ Accelerometer

- Responds rapidly
- No special pacing leads required
- Easy to manufacture and program
- Cannot be “fooled” by pressure on the can
- Con: low specificity
Minute Ventilation
Minute Ventilation

• Uses low-level electrical signals to measure resistance across the chest ("transthoracic impedance")
• Requires no special sensor
• Requires bipolar pacing leads
• Reflect metabolic activity of the body

• Pro: high specificity
• Con: slow response
Temperature

• A thermistor is mounted in the lead (not the can)
• Requires a special pacing lead
• Reflect metabolic need
• Response time can be slow
QT Interval

• Measures the interval between the pacing spike and the evoked T-wave
• Theory: This interval shortens with exercise
• Requires no special pacing lead
• Works only when the device is pacing
Closed Loop System (CLS)

- Measures changes in cardiac contractility (inotropy)
- Requires a bipolar pacing lead
- May be affected by changes in posture
- Works only when the device is pacing
Rate-Responsive Parameters to Program

- Maximum sensor driven rate
- Threshold
- Slope
- Reaction time
- Recovery time
Maximum sensor driven rate:
Max pacing rate induced by the sensor

Maximum Sensor Rate (MSR) = (220 - Age) x 0.9

Heart Rate vs. Workload graph
Threshold:
Minimum workload / activity at which sensor driven pacing rate increases above the lower rate limit
**Slope:**
How fast the sensor driven pacing rate increases in response to the increasing workload
Reaction Time:
Reaction Time parameter regulates how quickly rate response is delivered.
Recovery Time:
determines the minimum time from the maximum sensor rate to go back down to the programmed based rate
Unwanted responses of sensor

- Sensors of body motion may be interfered by environmental factors:
  1. Sitting in a car on bad road
  2. Riding horse
  3. Convulsion
Unwanted responses of sensor

- Sensors of minute ventilation maybe activated by hyperventilation, cough or tachypnoea from chest infection or congestive heart failure

(contraindicated in COPD patients)
Pacing Algorithm to Avoid RV Pacing
Dual Chamber Pacing – DDD/DDDR

• Provides AV Synchrony
• Should be more physiologic than VVI pacing

• However, major clinical trials unable to demonstrate a clear benefit of dual chamber pacing over single chamber pacing.

• Why?
DAVID Trial

506 patients, study stopped before end-point met
DAVID substudy: problem of high % of Vp

A. D. Sharma et al, Heart Rhythm 2005
Mode Selection Trial (MOST): Effect of Ventricular Pacing on Heart Failure

- As % pacing increases, % of patients with heart failure increases

Sweeney et al, Circulation 2003
MOST

DDDR + Higher %VP = More AF

Sweeney et al, Circulation 2003
MOST Sub-study: RV Pacing and Heart Failure Hospitalization (HFH)

- V-pacing is > 40%
  - HFH risk is constant

- V-pacing is < 40%
  - For each 10% reduction in V-pacing there is a 54% relative reduction in risk for HFH
  - 2% when pacing was minimized to < 10%

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Sweeney et al, Circulation 2003
Strategies for Reducing/Minimizing Unnecessary RV Pacing

• AAI pacing

• DDD/DDDR pacing
  – Programming Long AV Delays
  – Search AV Hysteresis
  – Special algorithm
Potential Problems with AAI Pacing

• Development of AV block requiring ventricular pacing

• Development of chronic atrial fibrillation with bradycardia requiring ventricular pacing
Long AV Delays During Dual Chamber Pacing: An Incomplete Solution

• Long AV delays may reduce unnecessary ventricular pacing

• Long AV delays may impose limitations on optimal DDDR operation:
  – Reduced 2:1 block point due to increased TARP
  – Abandonment of mode-switching or significantly delayed AF recognition
  – Susceptibility to endless loop tachycardia
Question

VVI / 60

A) Undersensing  
B) Oversensing  
C) Fail to capture  
D) Normal pacemaker function
Hysteresis

• Allows the rate to fall below the programmed lower rate following an intrinsic beat

Lower Rate Interval-60 ppm

Hysteresis Rate-50 ppm
Special algorithm to minimize RV pacing

• Search AV+ / Managed Ventricular Pacing (MVP) – Medtronic

• AutoIntrinsic Conduction Search (AICS) and Ventricular Intrinsic Preference pacing (VIP) – St Jude Medical

• AV Search Hysteresis / AV Search+ and RYTHMIQ – Boston Scientific
Search AV Hysteresis Algorithms to reduce unnecessary RV pacing

SEARCH AV (+)

- Automatically adjust AV delay so that
  - AV Delay > Patient’s intrinsic PR interval
  - Preserve normal ventricular depolarization if intrinsic conduction exists
  - optimal AV delay when Vpacing required
SEARCH AV +

Adaptation occurs on the basis of every 16 AV sequences
Search AV(+)

VSP area: VS for 110ms

AS/AP

too early

on time

too late

55ms
15ms

“Scheduled VP”
Search AV(+)

- It monitors most recent 16 AV
- If 8/16 VS are “too early”
  - Reduces scheduled AV by -8ms
- If 8/16 VS are “too late” (or are VP)
  - Extends scheduled AV by
    - + 31ms - Search AV
    - + 62ms – Adapta Family, EnPulse
  - and search continues until 8/16 end with VS “on-time”
Search AV(+)

• AV searches:
  – If Max Offset is reached and 8/16 sequences don't find conduction (VP) AV returns to programmed values
  – New searches will happen:
    • 15min, 30min, 1h, 2h, 4h, 8h, 16h.
    • SAV : it will continue searching e/ 16h
    • SAV+: disabled if 10 failures at 16h (time/date stamp)
Managed Ventricular Pacing

MVP Mode

AAI(R)
Primary mode
CONTINUOUS AUTOMATIC CONDUCTION CHECKS

DDD(R)
Loss of AV conduction
Switching from DDD(R) to AAI(R)

AV Conduction Check (1 beat)
- Scheduled every 1, 2, 4, 8 min... Up to 16 hrs after a transition to DDD(R) has occurred
MVP Operating Details

Criteria to switch to DDD(R): 2 out of 4 most recent A-A intervals with no conducted VS event.
MVP Study Results: Reduction in %VP without Loss of Atrial Support

The Save Pace Trial: reduction in AF with minimized ventricular pacing

1065 SND patients randomized – DDDR pacing versus DDDR Minimal Ventricular Pacing

Minimising RV pacing led to 40% reduction in relative risk of developing persistent AF

Reduction in persistent AF resulted in fewer invasive ablations and fewer heart failure hospitalisations

Primary Endpoint: Persistent AF

Time to Cardioversion, AVN Ablation or PVI for AF by Treatment Group

Hazard Ratio=0.60
95% Confidence Interval=0.41-0.88
p=0.009

Hazard Ratio=0.62
95% Confidence Interval=0.37-1.63
p=0.06
AutoIntrinsic Conduction Search (AICS)

- Searches for intrinsic conduction by prolonging the AV delay interval regularly every five minutes
- If intrinsic ventricular activity is found during the extended AV delay, the pacemaker adjusts the AV delay settings (paced and sensed) to accommodate this intrinsic activity
- If no more intrinsic ventricular is sensed, the AV delays resume their previously programmed values
- Do not allow non-conducted beat
AV Search Hysteresis Algorithm

- Allows intrinsic AV conduction beyond programmed AV Delay interval
- During search, AV Delay lengthened by a fixed interval or by a fixed percentage of 10-100% of the programmed AV Delay for up to 8 cardiac cycles
- Frequency of Search is programmable to 32-1024 cycles
AV Search Hysteresis Example

- Search initiated after programmed number of **consecutive paced** cycles (nominal = 32)
- Search concluded after a **single** ventricular paced cycle during extension period
RYTHMIQ™

Operation

**RYTHMIQ** operates in AAI(R) pacing mode with VVI backup during times of normal conduction, switching to DDD(R) mode when a conduction block is detected.
During normal conduction, RYTHMIQ operates like two pacemakers running concurrently – one in AAI(R) mode and one in VVI mode.

- The device provides AAI(R) at the LRL and/or sensor indicated rate with backup VVI pacing at a rate of 15 bpm slower than the LRL
- When there is good conduction, ventricular pacing does not occur as the VVI backup mode runs in the background
The device monitors for loss of AV synchrony to determine when to switch to DDD(R) mode.

- If 3 slow ventricular beats are detected in a window of 11 beats, then the device automatically switches to DDD(R) mode.
- A slow beat for RYTHMIQ is defined as a ventricular pace or ventricular sensed event that is at least 150 ms slower than the AAI(R) pacing rate.
The device uses AV Search+ to periodically check for a return of intrinsic conduction and determine when to mode switch back to AAI(R) with VVI backup.

If AV Search+ remains in AV hysteresis for at least 25 cardiac cycles, and less than 2 of the last 10 cycles are ventricular paced, then the device automatically switches the pacing mode back to AAI (R) with VVI backup.
Conclusion

• Rate response features allow pacing at a faster rate to meet one’s metabolic demand.
• The amount of RV pacing can be minimized to by special pacing algorithm.
• The algorithm of each device company is unique, and becoming more complex.
• Always seek help from the representative from device company if needed.