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Perioperative Electrophysiology: *Perioperative Management of Pacemakers*

Pacemaker Modes

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I have no conflict of Interest

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Introduction

- Need to understand all clinically relevant pacing modes
- Start with 5-Letter Code
- Discuss each mode
- Summarize

379

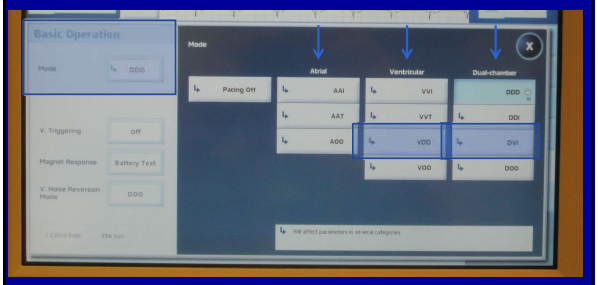
Goals of the Lecture

380

Examples of Mode Options

381

St Jude Programmer Mode Options



382

Medtronic

383

Bos Scientific

384

Pacemaker Nomenclature

Table 2 NASPE/BPEG generic pacemaker code (NBG) [Revised 2002]

Position I	Position II	Position III	Position IV	Position V
Chambers paced O = None A = Atrium V = Ventricle D = Dual (A+V)	Chambers sensed O = None A = Atrium V = Ventricle D = Dual (A+V)	Response to sensing O = None I = Inhibited T = Triggered D = Dual (T+I)	Programmability O = None R = Rate Modulation	Multisite pacing O = None A = Atrium V = Ventricle D = Dual (A+V)

NASPE, North American Society of Pacing and Electrophysiology; BPEG, British Pacing and Electrophysiology Group.

1. Paced
2. Sensed
3. Activity
4. Rate Response Mode
5. Multisite pacing

Ellenbogen Clinical Cardiac Pacing 2nd Ed p. 329

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Inhibition

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Trigger

- Triggered Mode—a type of pacemaker response in which the pacemaker will fire when a beat is sensed.
  - Can pace in the same chamber (VVT)
  - Can pace in the other chamber (VAT)

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1. Paced
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5. Multisite pacing

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How to discuss any given Mode?

- What the pacer does based on the 5-letter code
- Programmed intervals
- Derived intervals
- Sensing risks
- Risk mitigation

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Analysis of Modes Format

Description

Prog. Intervals

Der. Intervals

Sensing Risks

Risk Mitigation

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AOO

Description	Atrial Pacing No sensing
Prog. Intervals	Lower Rate interval
Der. Intervals	None
Sensing Risks	None
Risk Mitigation	NA

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AOO

- Asynchronous atrial pacing at LRL
  - No sensing
  - Each atrial paced beat LRI msecs apart
  - Automatic interval starts with each paced beat

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AOO

- Advantages
  - Good for pacer dependent patients exposed to noise (EMI)
  - Avoids oversensing and asystole
- Disadvantages
  - Pacing occurs regardless of intrinsic events
  - Potential risk of atrial arrhythmia induction

395

VOO

Description	Ventricular Pacing No sensing
Prog. Intervals	Lower Rate interval
Der. Intervals	None
Sensing Risks	None
Risk Mitigation	NA

396

VOO

- Asynchronous ventricular pacing at LRL
  - No sensing
  - Each ventricular paced beat LRI msecs apart
  - Automatic interval starts with each paced beat

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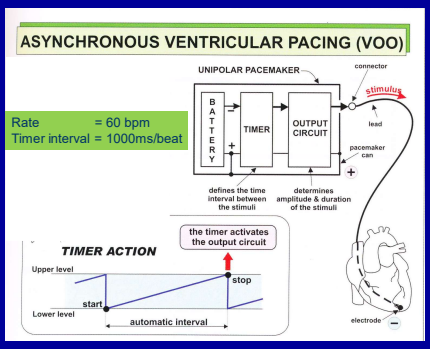
Pacemaker Modes: VOO



Cardiac Pacemakers, SS Barold et al

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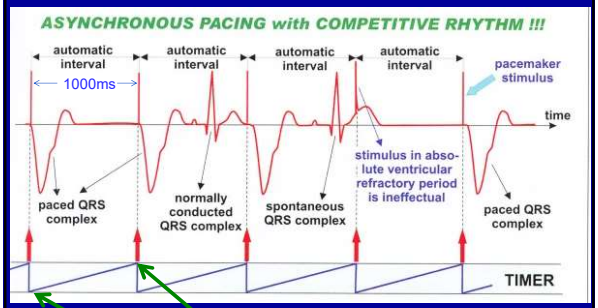
VOO: Rate=60



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VOO

- Advantages
  - Good for pacer dependent patients exposed to noise (EMI)
  - Avoids oversensing and asystole
- Disadvantages
  - Lose A-V synchrony
  - Pacing occurs regardless of intrinsic events
  - Potential risk of vent. arrhythmia induction

400

DOO

Description	A and V pacing No sensing
Prog. Intervals	Lower rate interval AV interval
Der. Intervals	Atrial escape interval
Sensing Risks	none
Risk Mitigation	NA

401

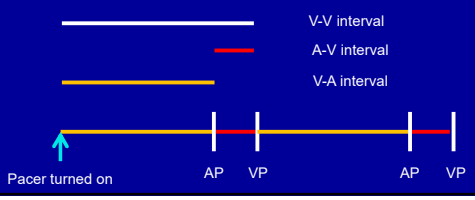
DOO

- Asynchronous, A-V sequential pacing
  - No sensing
  - An atrial pacing output is followed by a pAV interval and then a ventricular paced output
  - AEI starts after VP and cycle continues

402

DOO

- Set Ventricular Rate (V-V interval)
- Set AVI interval (AVI)
- Derived VA interval (VAI) = VV – AVI



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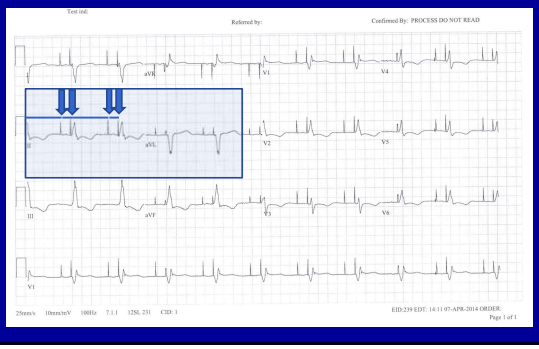
DOO



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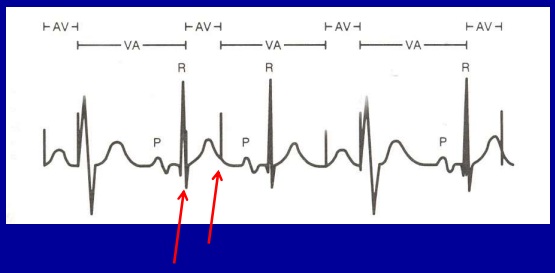
DOO pacing: Interpret this



Pseudopseudofusion beat = atrial pacing spike within a native QRS

Ellenbogen, Cardiac Pacing 1st Ed p. 267

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DOO

- Advantages
  - Good for pacer dependent patients exposed to noise (EMI)
  - Avoids oversensing and asystole
- Disadvantages
  - Pacing occurs regardless of intrinsic events
  - Potential risk of atrial or vent. arrhythmia induction

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AAI

Description	A-pacing A-sensing Inhibition of pacing upon sensing
Prog. Intervals	Lower rate interval
Der. Intervals	None
Sensing Risks	Atrial pace, evoked potential, atrial repol. Far-field QRS
Risk Mitigation	Atrial BP, Atrial RP

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AAI

- Paces atrium at set rate unless underlying atrial depolarization inhibits output
- No awareness of ventricular activity
- No tracking ability
- AKA Atrial Demand Pacing

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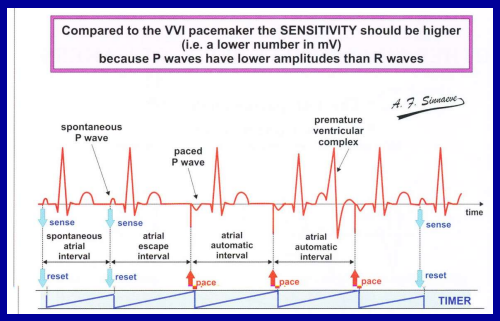
AAI



Barold, Cardiac Pacing and Resynch. p.84

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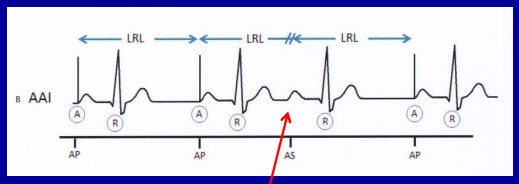
AAI



Timing cycle interrupted by intrinsic atrial activation
Timing cycle (escape interval) restarts
The ventricular R-wave does not affect the timing cycle

Ellenbogen Cardiac Pacing and ICDs, p.216

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Atrial Blanking and Refractory Periods

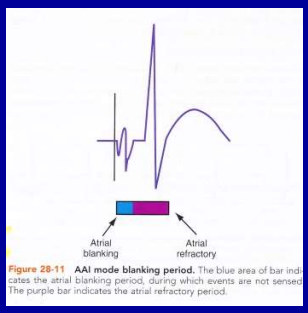

Figure 28-11 **AAI mode blanking period.** The blue area of bar indicates the atrial blanking period, during which events are not sensed. The purple bar indicates the atrial refractory period.

Ellenbogen, Clinical Cardiac Pacing, Defib and RST, p.816

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AAI Mode

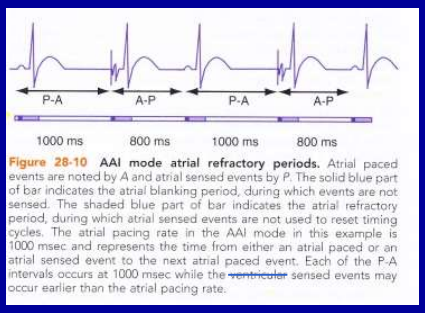

Figure 28-10 **AAI mode atrial refractory periods.** Atrial paced events are noted by *A* and atrial sensed events by *P*. The solid blue part of bar indicates the atrial blanking period, during which events are not sensed. The shaded blue part of bar indicates the atrial refractory period, during which atrial sensed events are not used to reset timing cycles. The atrial pacing rate in the AAI mode in this example is 1000 msec and represents the time from either an atrial paced or an atrial sensed event to the next atrial paced event. Each of the P-A intervals occurs at 1000 msec while the ~~ventricular~~ sensed events may occur earlier than the atrial pacing rate.

Ellenbogen, Clinical Cardiac Pacing, Defib and RST, p.816

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AAI Oversensing

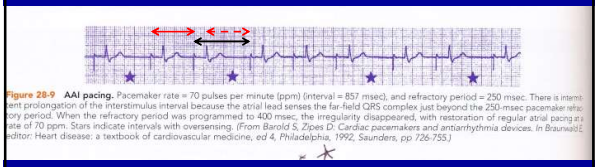

Figure 28-9 **AAI pacing.** Pacemaker rate = 70 pulses per minute (ppm) (interval = 857 msec), and refractory period = 250 msec. There is intermittent prolongation of the interstimulus interval because the atrial lead senses the far-field QRS complex just beyond the 250-msec pacemaker refractory period. When the refractory period was programmed to 400 msec, the irregularity disappeared, with restoration of regular atrial pacing at a rate of 70 ppm. Stars indicate intervals with oversensing. *(From Barold S, Zipes D: Cardiac pacemakers and antiarrhythmia devices. In Braunwald E, editor: Heart disease: a textbook of cardiovascular medicine, ed 4, Philadelphia, 1992, Saunders, pp 726-735.)*

LRI=857 msec
Prolonged interval due to far-field QRS sensing
LRI of 857 msec restarted by falsely sensed QRS

Ellenbogen, Clinical Cardiac Pacing, Defib and RST, p.816

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AAI

- Advantages
  - Ideal for patients with sinus node dysfunction but acceptable A-V conduction
  - Uses only one lead and therefore preserves battery
- Disadvantages
  - AAI lacks ventricular pacing in the event of intermittent A-V block

414

VVI

Description	Ventricular pacing Ventricular sensing Inhibition of pacing upon sensing
Prog. Intervals	Lower rate interval
Der. Intervals	none
Sensing Risks	Vent pacing output, evoked potential, T-wave Far-field P-wave
Risk Mitigation	Vent BP, Vent RP

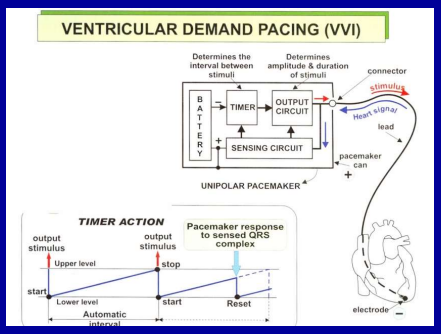
415

VVI

- Pacer set to pace the ventricle at the LRL, but a sensed event before the timing cycle elapses will inhibit the pacing pulse and restart the timing cycle
- AKA Ventricular Demand Pacing

416

VVI



Cardiac Pacemakers, SS Barold et al

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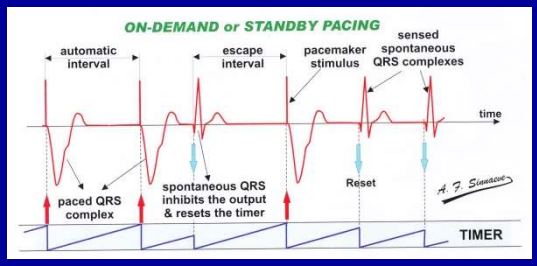
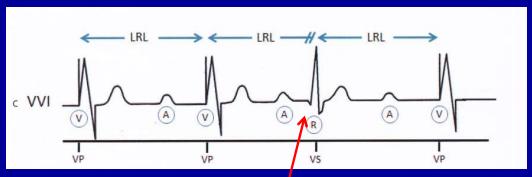
VVI pacing



Escape interval is slightly shorter than the Automatic interval

418

VVI



Timing cycle interrupted by intrinsic ventricular activation
Timing cycle (escape interval) restarts
The atrial P-wave does not affect the timing cycle—AV Diss.

Ellenbogen Cardiac Pacing and ICDs, p.216

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VVI

- Advantages
  - Safer than VOO in patients with an underlying ventricular rhythm
  - Ideal for patients in Atrial Fibrillation
  - Useful for short term pacing after a ICD shock
  - Less battery than a dual chamber device
- Disadvantages
  - In the presence of any organized atrial rhythm, VVI would result in AV asynchrony
  - Associated with a higher rate of Atrial arryhthmias

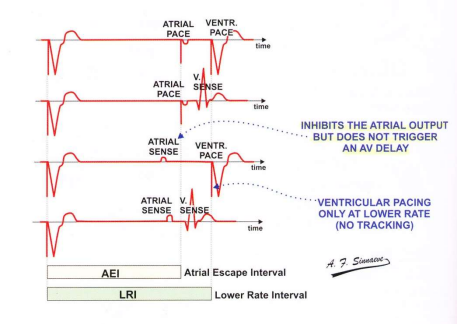
420

DDI

Description	A and V pacing A and V sensing Inhibition only, no tracking
Prog. Intervals	Lower rate interval AV interval
Der. Intervals	AEI
Sensing Risks	noise can inhibit atrial or ventricular pacing
Risk Mitigation	

421

DDI



Barold, Cardiac Pacemakers and Resynch. p. 144

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Description

Prog. Intervals

Der. Intervals

Sensing Risks

Risk Mitigation

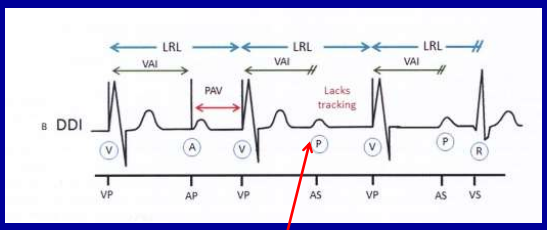
423

DDI

- AV sequential pacing with dual chamber sensing and inhibition without P-synchronous pacing
  - Functions as two separate pacemakers (AAI and VVI)
  - Does not track intrinsic atrial P-waves
- Program the LRL and AVI
- The ventricular paced rate is never greater than the programmed LRL regardless of the atrial rate

425

DDI



Intrinsic P-waves inhibit atrial pacing, but do not get tracked

Ellenbogen Cardiac Pacing and ICDs, p.216

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DDI Again

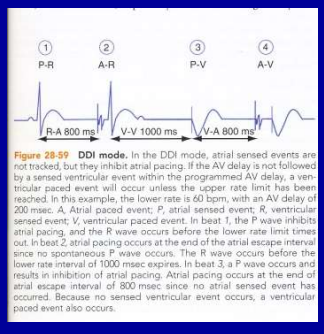


Figure 28-59 **DDI mode.** In the DDI mode, atrial sensed events are not tracked, but they inhibit atrial pacing. If the AV delay is not followed by a sensed ventricular event within the programmed AV delay, a ventricular paced event will occur unless the upper rate limit has been reached. In this example, the lower rate is 60 bpm, with an AV delay of 200 msec. *A*, Atrial paced event; *P*, atrial sensed event; *R*, ventricular sensed event; *V*, ventricular paced event. In beat 1, the *P* wave inhibits atrial pacing, and the *R* wave occurs before the lower rate limit times out. In beat 2, atrial pacing occurs at the end of the atrial escape interval since no spontaneous *P* wave occurs. The *R* wave occurs before the lower rate interval of 1000 msec expires. In beat 3, a *P* wave occurs and results in inhibition of atrial pacing. Atrial pacing occurs at the end of atrial escape interval of 800 msec since no atrial sensed event has occurred. Because no sensed ventricular event occurs, a ventricular paced event also occurs.

Ellenbogen Clinical Cardiac Pacing p.836

427

DDI

- Advantages
  - Good mode for patients in A-Fib/Flutter
- Disadvantages
  - Possible AV dyssynchrony due to lack of atrial tracking

428

4. Single Chamber Tracking Modes

- VVT, AAT, VAT*
- Track a sensed event with either an immediate same chamber pacing impulse (VVT, AAT) or a delayed (after the AVI) ventricular pacing impulse (VAT)
- Programming intervals: LRL, AVI, MTR

*not truly a single chamber pacing system

429

AAT

- Atrial triggered mode
  - Atrial pacing, atrial sensing, trigger response
- If no underlying rhythm, the pacer will A-pace at the LRL
- Delivers an atrial pacing output every time a native atrial event is sensed or the LRL is reached
- Program LRL, MTR

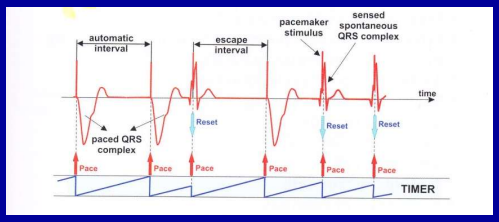
430

VVT

- Ventricular triggered mode
  - Ventricular pacing, ventricular sensing, triggered response
- Delivers a ventricular pacing output every time a native R-wave is sensed or the LRL interval is reached
- Must program a LRL and a MTR

431

VVT



1. If no underlying rhythm the pacemaker will V-pace at the LRL
2. If there is an intrinsic R-wave, the pacer will V-pace and the reset the timer

Barold, Cardiac Pacemakers and Resynch. p. 84

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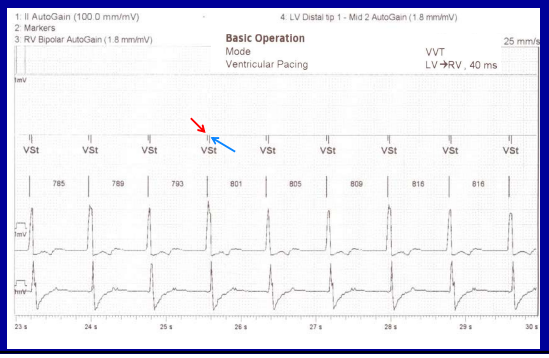
VVT Pacing in a CRT-D



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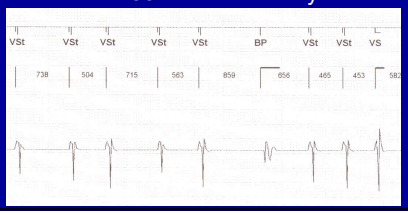
Another Example of VVT in a St Jude CRT device

- VVTR pacer with LRL 70 and UTR 130
  - When HR < 70: BiV Pacing
  - When HR 71-130: VSt with BiV tracking
  - When HR > 130: VS only



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VAT

- Ventricular pacing, Atrial sensing, Triggered mode
- Atrial sensing triggers ventricular pacing
  - Ventricular pacing is performed blindly—intrinsic ventricular activation cannot be seen
- Program LRL, AVI, MTR
- Could work for a patient with complete heart block but a normal SA node and chronotropic response

435

5. Dual Chamber with Inhibition and Tracking

- DDD, VDD
- Program LRL, AVI, MTR
- Ideal systems for safe and efficient pacing

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DDD

- Most common pacing mode
- Paces both chambers
- Senses both chambers
- Inhibits and Triggers
  - Atrial sensing inhibits atrial output and triggers A-V interval→ventricular output
  - Ventricular sensing inhibits ventricular output

437

DDD

- Programmer must set a lower rate limit, 2 AV intervals, and an upper rate limit
  - Atrial sensing can allow pacer to track intrinsic atrial beats (pace the ventricle after an appropriate AV interval)

438

4 Basic DDD Timing Cycles

• Lower Rate Limit (LRL)	60 bpm
▪ V-V interval (VVI)	1000 ms
• A-V Interval (PAVI)	250 ms*
• V-A interval (VAI)	
▪ VAI = VVI – AVI	750 ms
• Upper Rate Limit (URL)	120 bpm

*SAVI might be set at 220 ms

441

DDD

Description	A and V pacing A and V sensing Inhibition and tracking
Prog. Intervals	Lower rate interval AV interval URL interval**
Der. Intervals	AEI TARP
Sensing Risks	Atrial pacing stimulus, Atrial evoked potential Vent. pacing stimulus, Vent. evoked potential Far-field noise
Risk Mitigation	Atrial BP, ARP, PVAB, PVARP Vent. BP, VRP, PAVB, CDW

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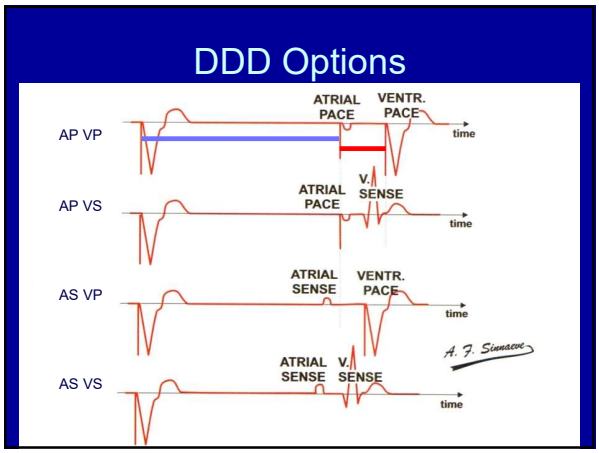

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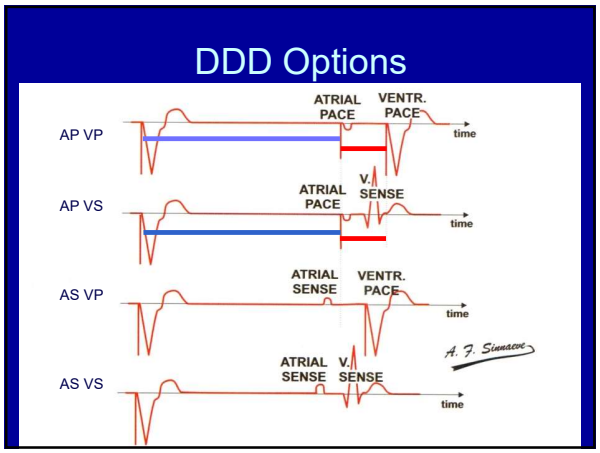

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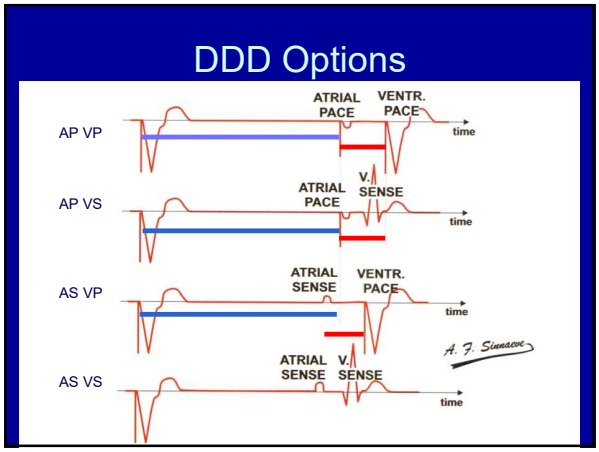

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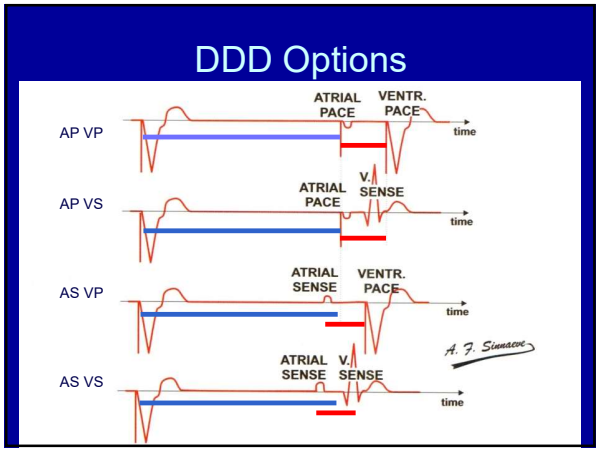

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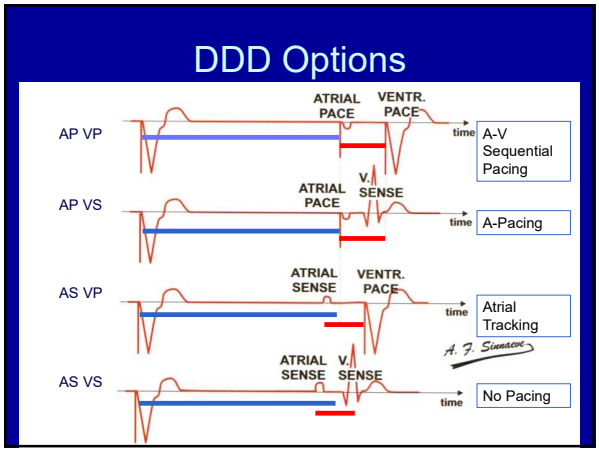

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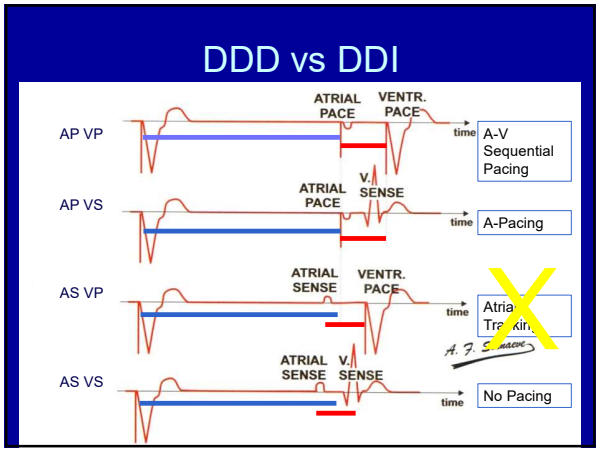

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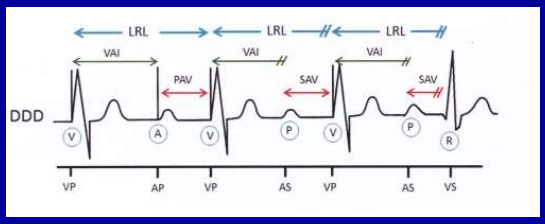
DDD



A-V sequential Atrial Tracking No pacing

Ellenbogen Cardiac Pacing and ICDs, p.216

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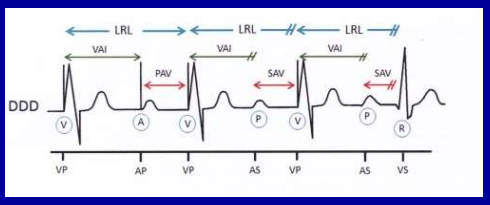
DDD—Slow Motion is Easier



V-pacing impulse initiates the VAI
VAI elapses→A-Pace pulse delivered→PAV initiated
PAV elapses→V-Pace pulse delivered→new VAI initiated
Spontaneous P-wave halts the VAI→SAV initiated
SAI elapses→V-Pace pulse delivered→new VAI initiated
Spontaneous P-wave halts the VAI→SAV initiated
Spontaneous R-wave halts the SAV

Ellenbogen Cardiac Pacing and ICDs, p.216

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DDD

- Advantages
  - Preserves AV synchrony
  - Low incidence of arrhythmias
  - Improved hemodynamics
- Disadvantages
  - Will track atrial dysrhythmias to the MTR
  - Shorter battery longevity

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Other Pacing Modes

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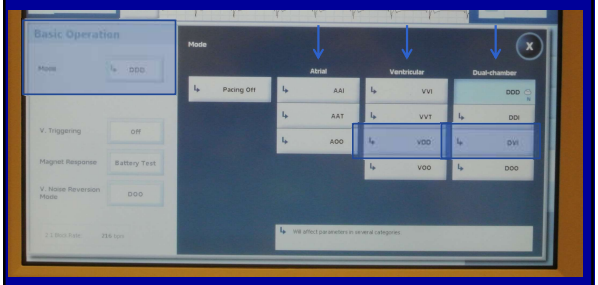
St Jude Programmer Mode Options



455

VDD

- Ventricular pacing, dual chamber sensing and P-synchronous ventricular pacing and inhibition
- Typically used in devices with a single pass lead which integrates an atrial sensing electrode with a ventricular sense/pace electrode

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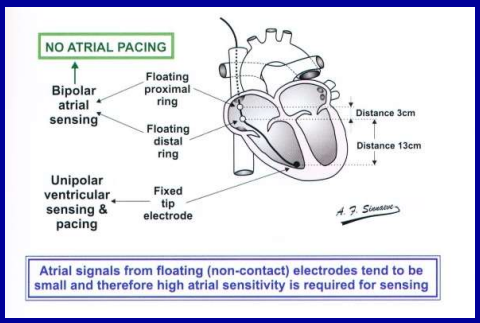
VDD Pacing Lead



Atrial signals from floating (non-contact) electrodes tend to be small and therefore high atrial sensitivity is required for sensing

p.147

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VDD

- Useful for patients with intact sinus node but A-V conduction disease or those needing biventricular pacing
- Must program LRL, sAVI, and MTR
- Is there an effective AEI (VAI)?
- Why no pAVI?

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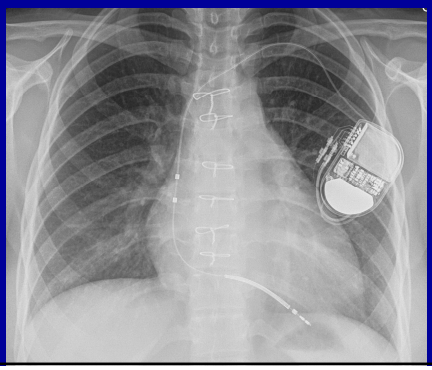
Biotronik ICD Lead



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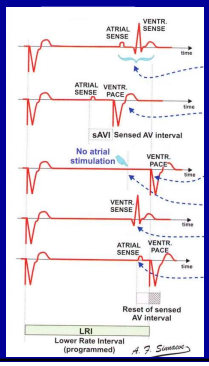
VDD Mode



1. Senses a P-wave, an AVI is started, R waves inhibits VP
2. Senses a P-wave and the AVI elapses, it V-paces
3. Without any P-wave, the pacer becomes VVI at LRL
4. Same as #3, but R inhibits VP before the LRLI elapses
5. The P-wave is sensed but because it occurs relatively late, it is not tracked, V-pacing occurs at LRL

VDD is essentially VVI with the added benefit of atrial tracking

Barold, Cardiac Pacemakers and Resynch. p.145

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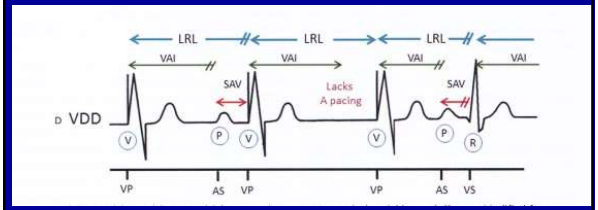
VDD



Atrial Tracking VVI Spont. rhythm

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VDD Summary

- V-pace, Atrial and Ventricular sense, trigger and inhibit
- Typically associated with a special lead
- Must program the LRL, sAVI, MTR
- Can pace at LRL or higher, depending on the intrinsic atrial rate, up to the MTR
- Good for patients with intact SA node but suboptimal A-V conduction

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DVI

- Similar to DDI, but no sensing in the atrium
- If the intrinsic rate is less than the LRL, A-V pacing occurs at the LRL with programmed AVI
- If the intrinsic atrial rate exceeds the LRL, competitive atrial pacing will occur
  - The ventricle will still pace at the LRL without any atrial synchrony

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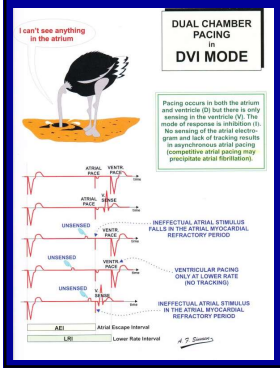
DVI



1. After a sensed or paced ventricular QRS, the AEI begins—at the end of that interval A-pacing occurs
2. If no intrinsic R-wave before LRI elapses→V-pace (1)
3. If intrinsic R-wave→LRI/AEI begin again (2)
4. Asynchronous Atrial pacing may not capture if the atrium is refractory from a prior spontaneous depolarization (3)
5. Intrinsic P-wave not sensed, A-Pace not effective, intrinsic QRS and inhibited V-pace (5)

p.143

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DVI

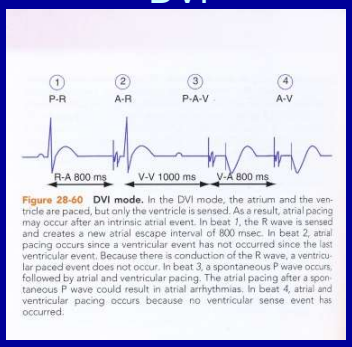

Figure 28-60 **DVI mode.** In the DVI mode, the atrium and the ventricle are paced, but only the ventricle is sensed. As a result, atrial pacing may occur after an intrinsic atrial event. In beat 1, the R wave is sensed and creates a new atrial escape interval of 800 msec. In beat 2, atrial pacing occurs since a ventricular event has not occurred since the last ventricular event. Because there is conduction of the R wave, a ventricular paced event does not occur. In beat 3, a spontaneous P wave occurs, followed by atrial and ventricular pacing. The atrial pacing after a spontaneous P wave could result in atrial arrhythmias. In beat 4, atrial and ventricular pacing occurs because no ventricular sense event has occurred.

Ellenbogen Clinical Cardiac Pacing p.836

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VDI

- VVI pacing while sensing both chambers
- Good for patients who go into A Fib
  - Does not track but does provide some addl information about the atrial rate
  - No concern for asynchronous atrial or ventricular pacing

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ADI

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Rate Response Modes

- Used when patients do not have sufficient P-wave response to exercise:
  - Atrial Fibrillation
  - SA node disease
- Rate Response makes up for "chronotropic incompetence" by increasing the LRL with increased activity
- Signified by the addition of an "R" in the 4th position

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Common Rate Response Modes

- Pacing Modes without Tracking Function
  - DDIR
  - VVIR
  - AAIR
- Pacing Modes with Tracking Function
  - DDDR

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DDIR

- DDI pacing with a rate response mode
- Frequently used as the mode switch response to A Fib or Flutter
- Rate response allows the base HR (LRL) to increase with activity
- Must program the LRL, AVI, and Max Sensor Rate (no need to program MTR)

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DDDR

- DDD pacing with a rate response mode
- Must define a Max Sensor Rate as well as the LRL, MTR, and AVI
- Useful for patients with intermittent sinus node incompetence who are physically active

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Bi-Ventricular Pacing Modes

- DDDOV
- DDDRV
- Two ventricular pacing electrodes
  - Typically RV and Cor Sinus
  - Could be RV and LV epicardial
  - Could be Bi-atrial

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DDDOV

- DDD with biventricular pacing
  - Typically the extra lead is in the coronary sinus
  - Used in patients with intraventricular conduction defects and poor LV systolic function
  - Must program LRL, AVI, MTR, and MSR

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DDDRV

- DDD with Bi-ventricular pacing and a rate response mode
  - Useful for patients with chronotropic incompetence

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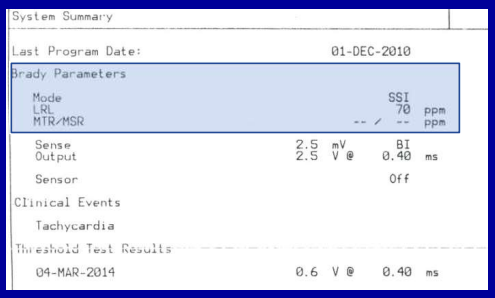
What is this Mode?



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Enter another SSI example

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How to Analyze the Pacing Mode?

1. Describe what the pacing mode does
   - VVI: V-pace, V-sense, inhibit
   - DDD: A-V pace, A-V sense, Track and Inhibit

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How to Analyze the Pacing Mode?

2. What will the pacer do under 4 conditions
   a. No intrinsic rhythm
   b. P-wave only
   c. R-wave only
   d. P and R waves

   VVI
   a. V-pace at LRL
   b. V-pace at LRL, disregards P-waves
   c. Inhibits V-pacing unless intrinsic rate < LRL
   d. Inhibits V-pacing unless intrinsic rate < LRL

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How to Analyze the Pacing Mode?

2. What will the pacer do under 4 conditions?
   a. No intrinsic rhythm
   b. P-wave only
   c. R-wave only
   d. P and R waves

   DDD:
   a. AP, VP at LRL with PAVI
   b. AS then AP inhibit, and initiate SAVI followed by VP
   c. AEI elapses so AP, PAVI started, VS so VP inhibited
   d. AS inhibits AP, SAVI started, VS inhibits VP—no pacing

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Summary of Modes

- More common modes you will see:
  - DDD(R)
  - DDI(R)
  - DDD(R)V
  - VVI(R)
  - AAI(R)
  - DOO

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Key Take Home Message

- Think about each letter individually when you try to determine the possible response of the pacemaker in the OR setting
  - DDD
    - Cautery could inhibit atrial pacing
    - Cautery could initiate Ventricular tracking
    - Cautery could inhibit Ventricular pacing
    - Weak (far-field) cautery could inhibit atrial pacing, but not ventricular pacing and therefore track the cautery
      - **Cautery sensed by atrium triggers inappropriate V-pacing**

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Table 5. Characteristics of commonly used pacing modes.

Characteristics	VVI	VVIR	AAI	AAIR	DDD	DDI	DDDR	DDIR
Simplicity	+++	+++	++	++	+	+	—	—
AV synchrony	—	—	+	+	+	+[a]	+	+[a]
Potential for pacemaker syndrome	+	+	—	—	—	—	—	—
Normal LV activation	—	—	+	+	—[b]	—[b]	—[b]	—[b]
Propensity to ELT	—	—	—	—	+	+[c]	+	+[c]
Tracking of SVT	—	—	—	—	+	—	+	—
Contraindicated in AV block	—	—	+	+	—	—	—	—
Increase of pacing rate in atrial chronotropic incompetence	—	+	—	+	—[d]	—	+	+
Cost	—	+	—	+	++	++	+++	+++

[a] In the DDI mode if normal sinus rhythm is faster than the programmed rate, and in the DDIR mode if normal sinus rhythm is faster than the sensor-driven rate, AV dissociation with hemodynamic disadvantage is frequent in patients with AV block.
[b] Unless AV delay is prolonged to allow for normal anterograde conduction.
[c] Endless loop without tachycardia at the lower rate or at the sensor-driven rate.
[d] Ventricular pacing rate does not increase if the sinus rate does not increase on exercise.

Barold, Cardiac Pacemakers and Resynch., p. 375

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Section Summary

- Memorize the 5-Letter Code
- T or D in the 3rd position indicates the presence of tracking
  - Good for maximizing cardiac output
  - Bad for Atrial dysrhythmias
  - May be bad for cautery
- DDD is the most versatile mode
- An "R" in the 4th position means the pacer has a rate-response mode
- A "V" in the 5th position indicates biventricular pacing

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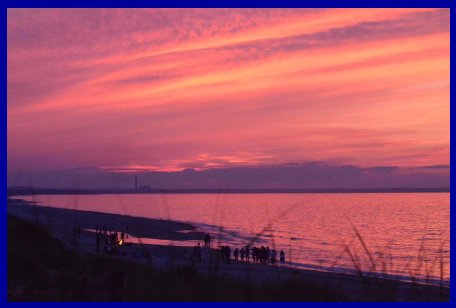
End of Part 3 of 4



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