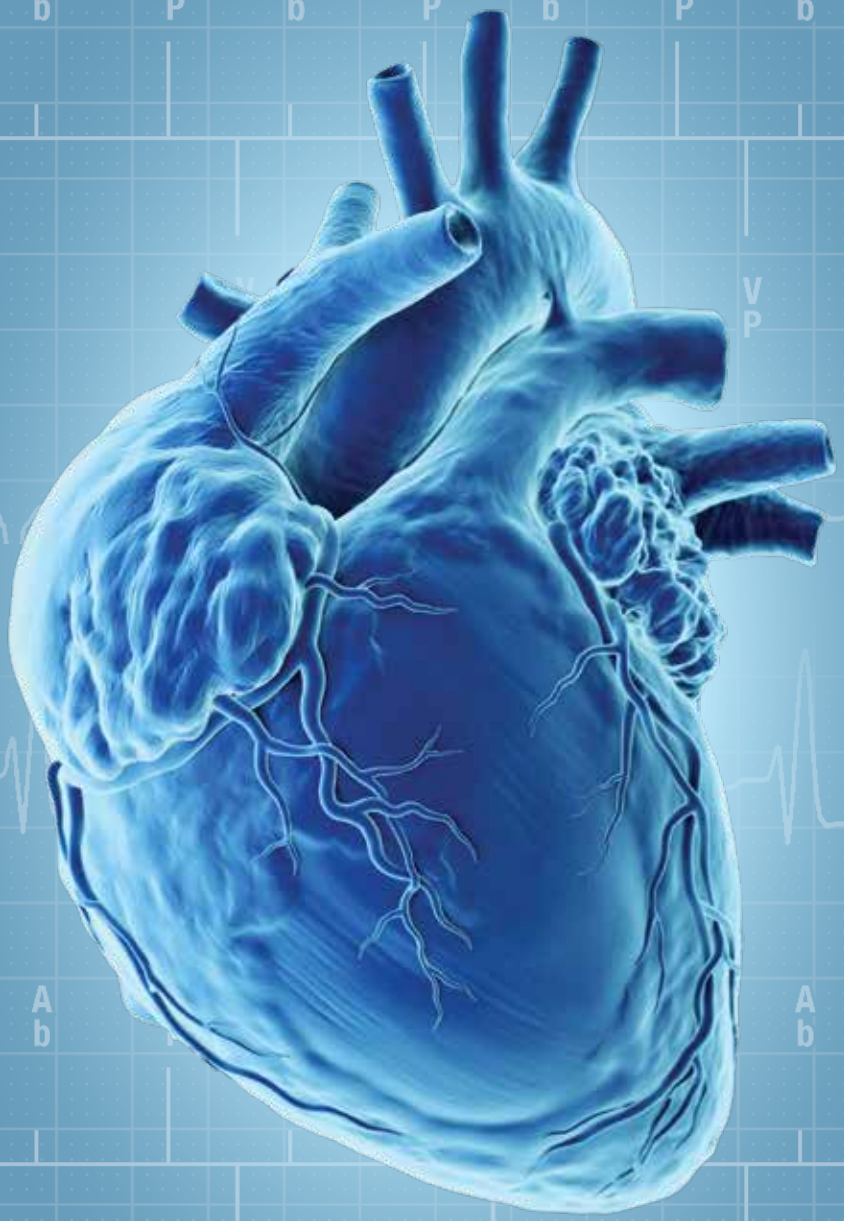
Workbook of Diagnostics for
CARDIAC IMPLANTABLE DEVICES



David L. Hayes, MD
James D. Ryan, RN
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info@cardiotextpublishing.com

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Contents

*St. Jude Medical is now Abbott.

Contributors

David L. Hayes, MD

Consultant, Department of Cardiovascular Medicine, Mayo Clinic, Rochester, Minnesota; Professor of Medicine, Mayo Clinic College of Medicine and Science

James D. Ryan, RN

Registered Nurse, Department of Nursing, Cardiology Division, Heart Rhythm Services, Mayo Clinic, Rochester, Minnesota

Siva K. Mulpuru, MD

Consultant, Department of Cardiovascular Medicine, Mayo Clinic, Rochester, Minnesota; Associate Professor of Medicine, Mayo Clinic College of Medicine and Science

Nora E. Olson, RN

Registered Nurse, Department of Nursing, Cardiology Division, Heart Rhythm Services, Mayo Clinic, Rochester, Minnesota

Tracy L. Webster, RN

Registered Nurse, Department of Nursing, Cardiology Division, Heart Rhythm Services, Mayo Clinic, Rochester, Minnesota

Yong-Mei Cha, MD

Consultant, Department of Cardiovascular Medicine, Mayo Clinic, Rochester, Minnesota; Professor of Medicine, Mayo Clinic College of Medicine and Science

Mark J. Henrich, RN

Registered Nurse, Department of Nursing, Cardiology Division, Heart Rhythm Services, Mayo Clinic, Rochester, Minnesota; Instructor in Nursing, Mayo Clinic College of Medicine and Science

Jon M. Meyer, RN

Registered Nurse, Department of Nursing, Cardiology Division, Heart Rhythm Services, Mayo Clinic, Rochester, Minnesota

Michael J. Hillestad, RN

Registered Nurse, Department of Nursing, Cardiology Division, Heart Rhythm Services, Mayo Clinic, Rochester, Minnesota

Preface

"The world is the true classroom. The most rewarding and important type of learning is through experience, seeing something with our own eyes."

—Jack Hanna

In order to understand cardiac implantable electronic device (CIED) management, the clinician requires a foundation of information regarding CIED purpose, design, and function, as well as experience in interpreting CIED output, i.e., electrical assessment of the system, programmed parameters, electrograms, and markers. In addition, one must be able to correlate and interpret the accompanying electrocardiographic tracing with the patient's clinical presentation.

As I've encountered students of CIED management, be they beginners in the field or more advanced students of CIED, there is always an appreciation for case studies, i.e., real-world examples of managing a specific device-related issue.

In our practice, we see opportunities every day for teaching CIED management, coming from the clinic, the bedside, and remote transmissions. These are rich examples that range from very simple and straightforward clinical management issues to more complex issues that may be related to a specific device algorithm.

The Heart Rhythm Service practice at the Mayo Clinic is supported by a talented group of RN Device Specialists who are trained "on the job." The RN Device Specialists manage the vast majority of our day-to-day CIED patient encounters. They are involved in device implantation, pre-and postoperative management, patient education, in-clinic and bedside programming, and troubleshooting, as well as initial interpretation of all remote transmissions.

This text has been prepared by six of our talented RN Device Specialists and three physicians involved in our Heart Rhythm Services. (Some cases were contributed by Dean Engle, RN, Katherine Lukkason, RN, and Francisco [Kit] Gatcheco, RN.)

We have collected examples from pacemakers, ICDs, and CRT devices, illustrating interpretation, and management of a variety of device behaviors, some with abnormal function that requires diagnosis and management approach, and others that display appropriate behavior of a specific device algorithm that may be confusing for the CIED student. We have attempted to organize the cases from basic concepts to more complex device issues.

We have adapted a successful format from friends and colleagues in France who have developed a large series of device management cases (cardiocases.com, a data bank of theoretical teaching and practical clinical training, StimuPrat Ed., FR).

Our cases follow a specific format:

- Title describing the topic of the case
- Type of device, manufacturer, and model
- Brief patient/scenario description
- Presentation of the EGM and other pertinent tracings or programmed parameters
  - Figures include numerical notations, e.g., [111], that correspond to a specific finding that is important in terms of understanding the case
  - The same notations then correlate with the explanatory text that follows
- EGM analysis that includes individual teaching points/explanations, and included within the text are corresponding numerical references, e.g., [2] correlates with [111] on the EGM
- Clinical response—a brief explanation of what management was required as a result of the issue described

We have learned a great deal as we developed and reviewed the clinical cases included in this book. Despite a detailed and sequenced review process with each case being scrutinized by multiple authors, there are no doubt cases where readers may have a difference of opinion or see some nuance or other teaching point that was included in the description. We welcome your feedback on the cases as we hope to make this a dynamic process and continue to add cases to our collections. We also welcome any cases you may wish to share for inclusion in a subsequent edition that would be credited appropriately. Please contact us at cases@cardiotextpublishing.com.

—David L. Hayes, MD, and the contributors

1 Variation in Paced QRS Morphology

DEVICE: St. Jude Medical* Accent DR 2110 DC PM

PATIENT: An 82-year-old patient with a history of chronic atrial fibrillation receives a single-chamber pacemaker for symptomatic bradycardia. At a routine in-clinic follow-up, the EGM tracing (**Figure 1**) was obtained.

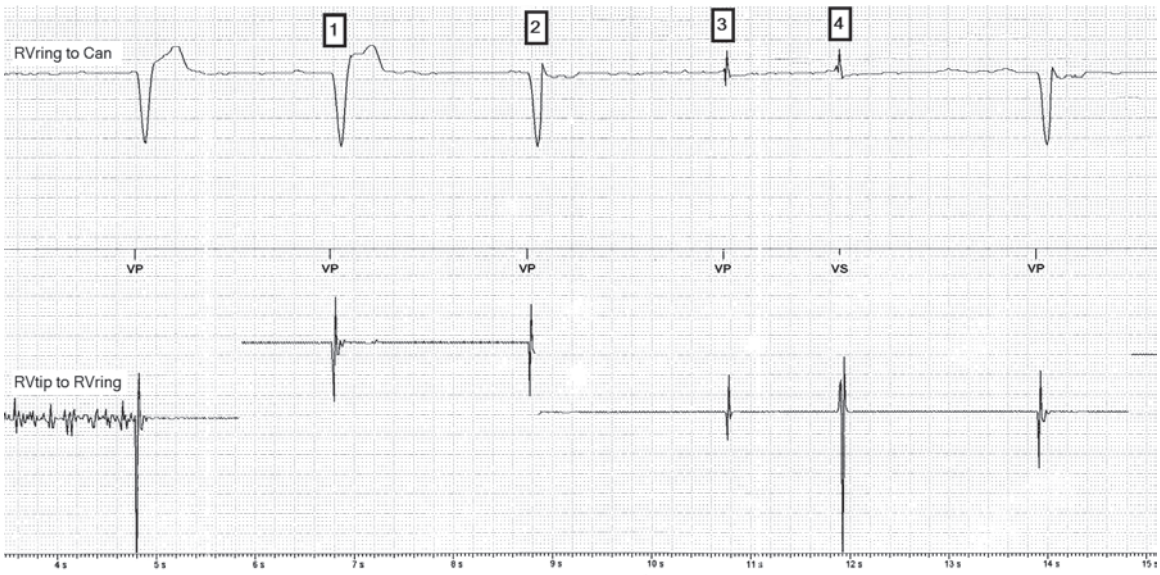

Figure 1.

ANALYSIS

1. The first two QRS complexes share the same wide QRS morphology and represent a true ventricular paced beat.

2. The third complex is not the same as the first two QRS complexes, i.e., the QRS is narrower, but significantly different than the single ventricular sensed beat seen later in the tracing [4]. This represents a ventricular fusion beat (fusion of paced and conducted wavefronts).

*St. Jude Medical is now Abbott.

3. The QRS complex labeled [3] appears identical to the QRS complex that follows [4] but is a paced ventricular beat as evidenced by the "marker" below, and indeed a pacing artifact can be seen on the narrow QRS complex. This represents a pseudofusion ventricular beat. Pseudofusion occurs when the local ventricular activation near the pacing lead occurs late in the inscribed QRS. The timing cycle expires, resulting in ventricular pacing. However, the ventricular pacing may capture the local myocardium and does not contribute much to change the QRS complex and is therefore identified as a pseudofusion beat. It takes about 20% of the ventricular myocardial activation from a wavefront to appreciate fusion on surface ECG.

4. This QRS complex is the only sensed ventricular beat in the tracing (VS) and represents a true intrinsic beat.

CLINICAL RESPONSE

This tracing represents entirely normal function. It is important to be able to recognize the difference between intrinsic and wholly paced beats from fusion and pseudofusion complexes.

2 Ventricular Undersensing in a Dual-Chamber Pacemaker

DEVICE: Medtronic Advisa DR MRI A2DR01 DC PM

PATIENT: An 80-year-old male had a dual-chamber pacemaker implanted for intermittent, symptomatic second-degree heart block two years ago. The EGM tracing in **Figure 2a** was obtained during routine in-clinic pacemaker interrogation. Pertinent programmed parameters are shown in **Figure 2b**. What is the problem in this tracing?

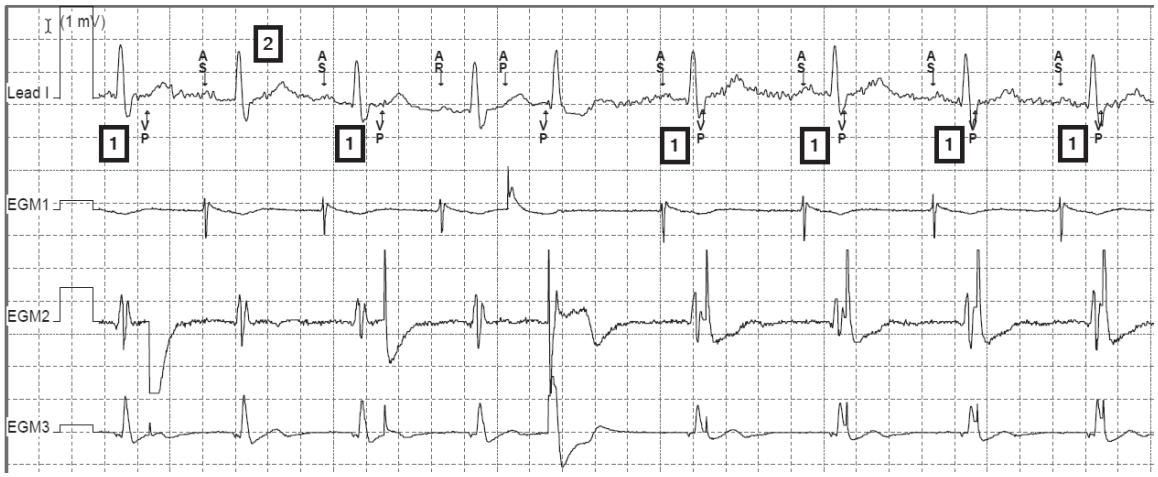

Figure 2a.

Parameter Summary

Mode	2 AAI↔DDD	Lower Rate	60 bpm	Paced AV	250 ms
Mode Switch	171 bpm	Upper Track	130 bpm	Sensed AV	250 ms
		Upper Sensor	130 bpm		

Figure 2b.

ANALYSIS

1. The surface lead, lead I, shows an intrinsic QRS that is not sensed, as indicated by the lack of a VS event marker. The QRS is then followed by a VP. The ventricular lead was programmed pace/sense bipolar. Bipolar R wave measured 0.5 mV to 1.2 mV during interrogation and RV sensitivity was set to nominal bipolar value of 0.9 mV.

2. Medtronic's MVP algorithm is in effect, which changed pacing mode to DDDR with programmed A-V delay of 250 ms. Please refer to Medtronic's manual for complete algorithm functionality.

CLINICAL RESPONSE

The patient denied any symptoms that could be related to heart rate or rhythm. The R wave had shown slight, gradual decrease in amplitude since implant. The RV impedance and threshold have appeared to remained stable since implant. The R-wave unipolar measured 5.0 mV. RV thresholds both unipolar and bipolar were the same and no extracardiac stimulation noted when pacing unipolar at max outputs. Provocative maneuvers to elicit oversensing of myopotentials were seen at RV sensitivity of 2.0 mV, but not at the nominal unipolar sensitivity of 2.8 mV. Due to this, and the patient's lack of pacemaker dependency, the RV was left as pace bipolar and sensing was changed to unipolar with a sensitivity of 2.8 mV. The patient will require close follow-up via CareLink remote transmission or clinic checks to identify future lead issues.

Atrial and ventricular leads are programmed to bipolar pace/sense. The measured R wave ranged from 0.5 mV to 1.2 mV bipolar and the device was programmed with RV sensitivity at the nominal bipolar value of 0.9 mV. This resulted in frequent undersensing and inappropriate or "overpacing" of the RV as seen above. Other lead trends were stable.

3 Atrial Pacing with a Competing Junctional Rhythm

DEVICE: Medtronic Adapta ADDR01 DC PM

PATIENT: A 75-year-old male with a history of paroxysmal atrial fibrillation had a dual-chamber pacemaker implanted for junctional bradycardia following mitral valve replacement and a maze procedure. One year later, after developing significant tricuspid valve regurgitation, the RV lead was explanted and the device was programmed to AAI mode at 80 bpm with an atrial amplitude of 5.0 V with a pulse width of 0.4 ms. The pacemaker nurse specialist was called to interrogate the device due to concerns for loss of atrial capture as evidenced by a change in rhythm on the monitor and a heart rate frequently below the programmed lower rate limit of 80 bpm. The bedside nurse noted that the monitor showed irregular conduction of atrial pacing impulses, which represented a change from what was previously seen on the monitor when atrial pacing at 80 bpm with 1:1 conduction was consistently seen. Presenting rhythm (**Figure 3a**), underlying rhythm (**Figure 3b**), atrial threshold testing (**Figure 3c**), and atrial pacing at 100 bpm (**Figure 3d**) are shown.

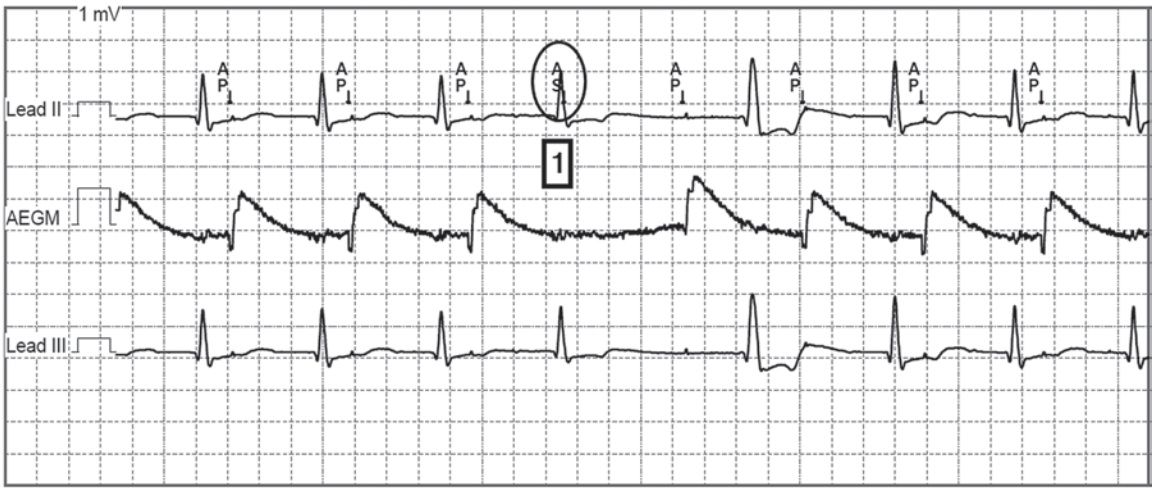

Figure 3a.

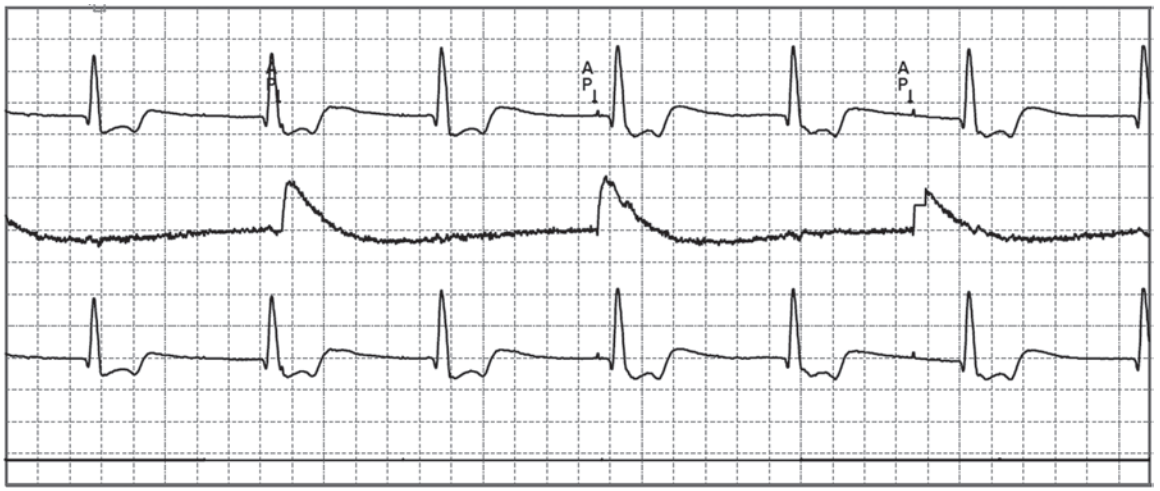

Figure 3b.

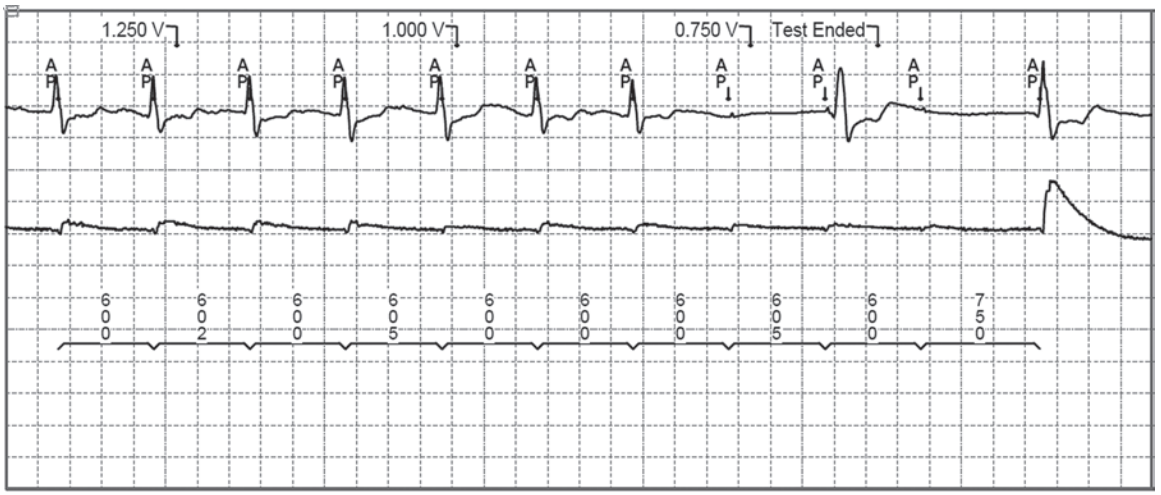

Figure 3c.

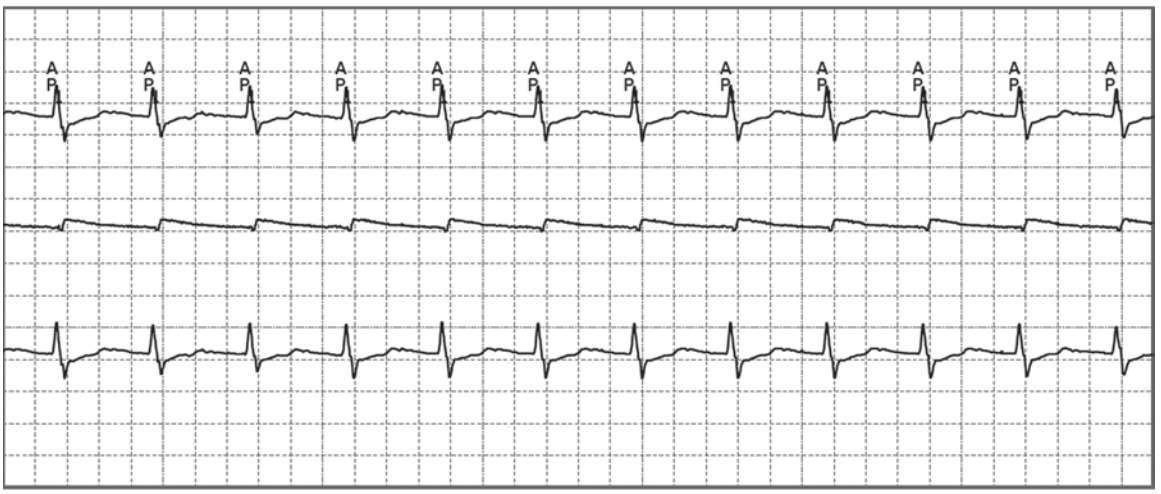

Figure 3d.

ANALYSIS

1. In Figure 3a, the presenting EGM shows atrial pacing at 80 bpm with a variable ventricular rate ranging from 50 to 80 bpm. This variable rate occurs when the far-field R wave (FFRW), sensed by the atrial lead, inhibits atrial pacing [1]. Inspecting the tracing in a vertical fashion demonstrates that the QRS complex is noted on the atrial EGM as a sensed atrial (AS) event. After pacing stimulus, polarization is seen on the sensing electrode, and it decays with time. When the decay point is more than the set sensitivity or when far-field signals exceed the threshold, atrial events are declared and pacing is withheld.

2. In Figure 3b, device was programmed AAI at 30 bpm for a P-wave amplitude test revealing no sensed P waves, atrial pacing at 30 bpm, and a junctional escape rhythm at a rate of 56 bpm.

3. To confirm atrial capture, an atrial threshold test was conducted with AAI pacing at 100 bpm, revealing a threshold of 1.0 V at 0.4 ms (see Figure 3c).

4. Programming the device AAI at 100 bpm showed 1:1 conduction with an AP interval of 600 ms, as seen in Figure 3d. However, given the short AP interval, pacing at this rate or higher is likely to produce occasional dropped beats and potential activity intolerance for the patient. The FFRW oversensing seen in Figure 3a can occur at any rate and will likely produce the irregular ventricular rate seen by the bedside nurse.

CLINICAL RESPONSE

In an attempt to reduce FFRW oversensing, the atrial sensitivity was reduced from 0.18 mV to 0.25 mV. The atrial output was adjusted based on the threshold testing. The patient was discharged from the hospital with a 30-day monitor to determine the need for ventricular pacing and a potential upgrade to a biventricular (BiV) device.

4 Loss of AV Synchrony

DEVICE: Medtronic Evera XT DR DDBB1D4 DC ICD

PATIENT: A 39-year-old patient with a history of dilated cardiomyopathy and ventricular tachycardia is a heart transplant candidate with an ejection fraction of 18%, and a dual-chamber ICD has been implanted for primary prevention due to severe LV dysfunction. Patient complains of an "odd feeling" when relaxing before going to bed or when lying in bed before sleep. The presenting EGM from the patient's most recent routine remote transmission is shown in **Figure 4**. The patient's atrial lead is known to have persistent failure to capture; atrial sensing is appropriate.

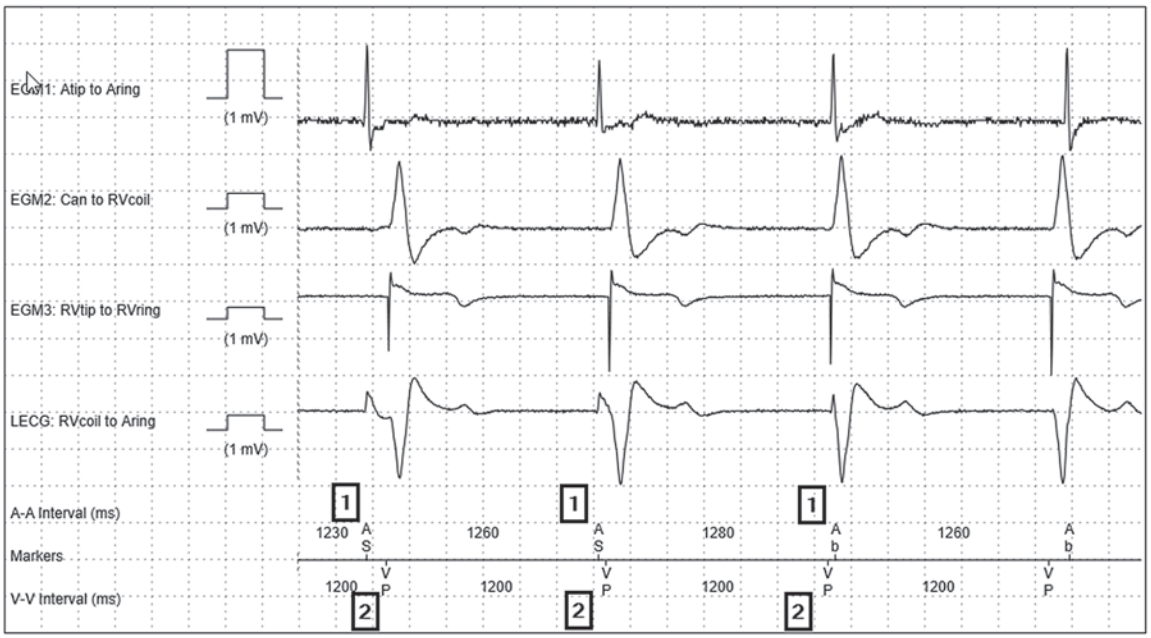

Figure 4.

ANALYSIS

1. The atrial sensed events [1] are not synchronized with the ventricular paced events [2].
2. The pacing mode is currently programmed VVI at 50 bpm. The device is functioning as programmed with ventricular pacing at 50 bpm (1200 ms). The patient's intrinsic atrial rate [1] is slower at approximately 47 bpm. This results in loss of AV synchrony. The patient is experiencing pacemaker syndrome from the loss of AV synchrony.

CLINICAL RESPONSE

The single-chamber pacing mode of VVI at 50 bpm was chosen due to the atrial lead malfunction, which caused the failure to capture. This was acceptable while the patient's clinical condition did not warrant atrial pacing. AV synchrony could be restored by reprogramming the lower rate to 40 bpm. This type of programming is common in patients with single-chamber ICDs who do not require pacing support for bradycardia. Programming a different nighttime rate or turning rate hysteresis on are other potential options. Unfortunately, this leaves the patient at risk for decompensation and worsening heart failure. As a result, atrial lead revision was advised.

Appendix B: Cases by Manufacturer

*St. Jude Medical is now Abbott.