Essential Concepts of Electrophysiology and Pacing through Case Studies
Dedication

To Mark E. Josephson, MD, our friend and mentor whose life and work has been a constant source of inspiration and encouragement and who continues to challenge us to advance the science of arrhythmias.

In memory of Mark A. Wood, MD, my friend and colleague whose life will always be remembered.

—Kenneth A. Ellenbogen, MD
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About the Contributors

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One of the most essential skills in electrophysiology is the ability to analyze tracings. The scope of our practice has changed dramatically, and the tracings can range from the surface electrocardiogram, to pacemaker/ICD recordings, and finally, to complex intracardiac tracings. We have tried to cover a sampling of tracings that cover the range of these experiences with a collection of basic, intermediate and challenging cases from all these areas. By doing this, we have created a volume that is useful to electrophysiology technicians, electrophysiology and pacing nurses, pacemaker and ablation field representatives and engineers, and especially electrophysiology fellows and physicians.

Each case includes relevant references that allow the reader to review the initial description of a particular pacing maneuver or the concept illustrated by the tracing(s). We have tried to focus on some of the fundamental concepts that underlie electrophysiology and pacing to provide an opportunity to review these important lessons.

We have enjoyed selecting and annotating these cases, and we hope that this book will prove useful to students and professionals preparing for the wide range of examinations that cover these areas as well as an educational and challenging learning experience.

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# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABP</td>
<td>atrial blanking period</td>
</tr>
<tr>
<td>ATP</td>
<td>antitachycardia pacing</td>
</tr>
<tr>
<td>AV</td>
<td>atrioventricular</td>
</tr>
<tr>
<td>AVNRT</td>
<td>atrioventricular nodal reentrant tachycardia</td>
</tr>
<tr>
<td>BBR</td>
<td>bundle branch reentry</td>
</tr>
<tr>
<td>CHF</td>
<td>congestive heart failure</td>
</tr>
<tr>
<td>CL</td>
<td>cycle length</td>
</tr>
<tr>
<td>CS</td>
<td>coronary sinus</td>
</tr>
<tr>
<td>DFT</td>
<td>defibrillation threshold</td>
</tr>
<tr>
<td>ECG</td>
<td>electrocardiogram</td>
</tr>
<tr>
<td>EF</td>
<td>ejection fraction</td>
</tr>
<tr>
<td>EGM</td>
<td>electrogram</td>
</tr>
<tr>
<td>EMI</td>
<td>electromagnetic interference</td>
</tr>
<tr>
<td>FFRW</td>
<td>far-field R wave</td>
</tr>
<tr>
<td>ICD</td>
<td>implantable cardiac defibrillator</td>
</tr>
<tr>
<td>ILR</td>
<td>implantable loop recorder</td>
</tr>
<tr>
<td>JT</td>
<td>junctional tachycardia</td>
</tr>
<tr>
<td>LBBB</td>
<td>left bundle branch block</td>
</tr>
<tr>
<td>LCC</td>
<td>left coronary cusp</td>
</tr>
<tr>
<td>LRI</td>
<td>lower rate interval</td>
</tr>
<tr>
<td>LV</td>
<td>left ventricle or left ventricular</td>
</tr>
<tr>
<td>MI</td>
<td>myocardial infarction</td>
</tr>
<tr>
<td>MTR</td>
<td>maximal tracking rate</td>
</tr>
<tr>
<td>MVP</td>
<td>managed ventricular pacing</td>
</tr>
<tr>
<td>NICM</td>
<td>nonischemic cardiomyopathy</td>
</tr>
<tr>
<td>NSVT</td>
<td>nonsustained ventricular tachycardia</td>
</tr>
<tr>
<td>PAC</td>
<td>premature atrial contraction</td>
</tr>
<tr>
<td>PMT</td>
<td>pacemaker-mediated tachycardia</td>
</tr>
<tr>
<td>PPI</td>
<td>postpacing interval</td>
</tr>
<tr>
<td>PV</td>
<td>pulmonary vein</td>
</tr>
<tr>
<td>PVARP</td>
<td>postventricular atrial refractory period</td>
</tr>
<tr>
<td>PVC</td>
<td>premature ventricular contraction</td>
</tr>
<tr>
<td>RBBB</td>
<td>right bundle branch block</td>
</tr>
<tr>
<td>RCC</td>
<td>right coronary cusp</td>
</tr>
<tr>
<td>RV</td>
<td>right ventricle or right ventricular</td>
</tr>
<tr>
<td>SICD</td>
<td>subcutaneous implantable cardiac defibrillator</td>
</tr>
<tr>
<td>SVT</td>
<td>supraventricular tachycardia</td>
</tr>
<tr>
<td>TCL</td>
<td>tachycardia cycle length</td>
</tr>
<tr>
<td>VA</td>
<td>ventricular arrhythmia</td>
</tr>
<tr>
<td>VF</td>
<td>ventricular fibrillation</td>
</tr>
<tr>
<td>VP</td>
<td>ventricular pacing</td>
</tr>
<tr>
<td>VSP</td>
<td>ventricular safety pacing</td>
</tr>
<tr>
<td>VT</td>
<td>ventricular tachycardia</td>
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</table>
Part 1

ECG
Case 1.A

Question

Where is the site of origin of this PVC in a 72-year-old man presenting with palpitations?

A) Anterolateral papillary muscle
B) Left posterior fascicle
C) Epicardial crux
D) Posteromedial papillary muscle
Figure 1.A.1
Figure 1.A.2

AL PAP

LPF

PM PAP

QRS: 170ms

QRS: 130ms

QRS: 185ms
Answer

The correct answer is D. This PVC originated from the postero-medial papillary muscle with history of infarction.

All of these sites of left ventricular origin have right bundle branch block left superior axis except the anterolateral papillary muscle, which has a right bundle branch block right inferior axis morphology. Crux of the heart sites of origin near the proximal CS have a characteristic sudden R wave from V₁ to V₂.

Differentiating posterior fascicular origin from posteromedial papillary muscle can be difficult. Due to proximity to the conduction system, left posterior fascicular QRS width is narrower (130 ms) than papillary muscle VT (185 ms), which has been shown to be the most reliable predictor. While ablation sites on papillary muscles may have Purkinje potentials (distal with later timing), the majority of fascicular target sites exhibit Purkinje potentials.

References


Part 2

Electrophysiology Concepts
Case 2.A

Question

What does this entrainment response demonstrate?

A) Failure to capture
B) Pacing just outside of an isthmus
C) Concealed intracardiac fusion
D) Pacing too fast within an isthmus
Answer

The correct answer is D. This demonstrates entrainment of typical atrial flutter within the cavotricuspid isthmus.

The postpacing interval exceeds the tachycardia cycle length (TCL) by over 100 ms, suggesting pacing from a site outside of the circuit. The drive train is 70 ms faster than the TCL, and therefore local conduction delay, or decrement, can prolong the postpacing interval when within a critical isthmus. Deeper penetration of the antidromic wavefront (dashed line) is seen due to faster pacing with collision into DD 7,8, and therefore, intracardiac fusion is present.

The postpacing interval is nearly identical to the TCL when entrainment is performed 20 ms faster than the TCL at the exact same site.

Reference

Part

Intracardiac Tracings

Case 3.A

Question

What does this entrainment response demonstrate?

A) Inner loop
B) Outer loop
C) Isthmus
D) Dead-end bystander
Figure 3.A.1

I
aVF
V1
V6
Abl d
Abl p
RV
Figure 3.A.2
PART 3: Intracardiac Tracings  •  Case 3.A

Figure 3.A.3

I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
Answer

The correct answer is C. Demonstration of an isthmus is shown.

Three criteria must be fulfilled at an isthmus site: (1) post-pacing interval (PPI) within 30 ms of the tachycardia cycle length; (2) concealed fusion (antidromic collision within a protected site with orthodromic exit identical to VT); and (3) stimulus to QRS (S-QRS) equal to EGM-QRS interval.

Concealed fusion is seen during entrainment with a 12/12 match with the VT. Outer loop sites and remote bystanders exhibit manifest fusion. Dead-end bystander and inner loop sites have long S-QRS and EGM-QRS intervals. Dead-end bystander sites that are attached to the circuit show concealed fusion but have a long PPI response. As the PPI is nearly identical to the TCL, and the S-QRS and EGM-QRS intervals are the same in this case, an isthmus site (distal close to exit, EGM-QRS <30% of TCL) is demonstrated. Ablation at this site resulted in abrupt termination of ventricular tachycardia.

References


Part 4

Device Tracings
Case 4.A

Background
A 48-year-old male with a past medical history of nonischemic cardiomyopathy, EF 20%, hypertension, paroxysmal atrial fibrillation, and NYHA Class II CHF is evaluated for a shock. The Cameron Subcutaneous ICD was implanted for secondary prevention (spontaneous sustained ventricular tachycardia and structural heart disease). The patient's medical history is also significant for morbid obesity, weighing 508 lbs.

Table 4.A.1  Programmed Parameters

<table>
<thead>
<tr>
<th>Shock Zone</th>
<th>200 bpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditional Zone</td>
<td>170 bpm</td>
</tr>
<tr>
<td>Therapy</td>
<td>80 J Reversed</td>
</tr>
<tr>
<td>Sensing Configuration</td>
<td>Alternate Vector</td>
</tr>
<tr>
<td>Postshock Pacing</td>
<td>On</td>
</tr>
</tbody>
</table>

The following episode was stored by the SICD while the patient remained hospitalized (Figure 4.A.1).

Question
Which of the following best describes the SICD therapy for this patient?
A) Undersensing VF
B) Oversensing
C) Double detection algorithm
D) Appropriate time to therapy
E) All of the above
Figure 4.A.1

Stored EGM, part 1.

Device Settings
Therapy: ON
Shock Zone: 200 bpm
Conditional Shock Zone: 170 bpm
Post Shock Pacing: ON

Gain Setting: 1X
Sensing Configuration: Alternate

S = Sense
P = Pace
N = Noise
T = Tachy Detection
C = Charge Start
= Discard
↑ = Shock
= Episode End

Implant Date: 03/07/2011

Gain Setting: 1X
Sensing Configuration: Alternate

S = Sense
P = Pace
N = Noise
T = Tachy Detection
C = Charge Start
= Discard
↑ = Shock
= Episode End

TREATED EPISODE 001: 03/12/11 11:28:37 AM
SHOCK IMPEDANCE = 66 ohms
FINAL SHOCK POLARITY = REV

SHOCK IMPEDANCE = 66 ohms
FINAL SHOCK POLARITY = REV

Answer

The correct answer is **E, all of the above.**

In the certification phase, the SICD uses three algorithms to minimize oversensing. These include a template-matching, wide-complex and alternating interval algorithms. These assist with appropriately sensing cardiac events and prevent inappropriate detection due to oversensing T waves and double detection from wide-complex tachycardias. When an interval is discarded due to double detection, the interval is noted with a “.” marker, as noted on this stored episode. If a double detection interval is noted, the device will decrement the X/Y counter.

The SICD utilizes the X/Y detection criteria. Once 18 of 24 fast intervals are noted, initial criteria are met. **Persistence** is then used to ensure that the patient remains in a sustained tachycardia prior to charge; the nominal value is two intervals. If two additional tachycardia, “T,” events are noted, tachycardia detection is met and initiates an 80-joule charge. An 80-joule charge occurs within 10 seconds at beginning of life. After the capacitor charge is complete, **shock confirmation** (three fast intervals and sustained tachycardia) ensures the arrhythmia is sustained and appropriate to treat. An average time to therapy with the SICD is 15±3 seconds.

On this stored episode, the entire arrhythmia lasts 17.5 seconds. Sensing the arrhythmia and tachyarrhythmia detection occur in 9.5 seconds. The 80-joule charge is 8 seconds. Reconfirmation occurs, therapy is delivered, and the arrhythmia is converted. This is an appropriate time to therapy for the SICD.

During the detection phase, the SICD detects cardiac signals and adjusts sensitivity on a beat-to-beat basis. This allows appropriate sensing of sinus rhythm and increasing sensitivity to detect fine ventricular fibrillation. Additionally, the device uses filtering to prevent artifact or noise to be detected as a tachyarrhythmia. The SICD calculates the estimated peak of the R wave based on the average of the two previous peak values. The benefit is that a single event will not affect the detection profile. However, at the onset of an arrhythmia, a rapid decrease in the peak R-wave amplitude may require several R-R intervals in order for the estimated peak values to be averaged. R-wave undersensing (or dropout) may be seen early in the episode until peak averages are maximized with increased sensitivity, resulting in consistent sensing and tachyarrhythmia detection.

This phenomenon is noted at the beginning of this stored episode. Here, seven beats of the tachycardia occur before
consistent R-wave sensing is marked. In addition, the SICD uses an average of four R-R intervals. The first “T” or tachycardia sensed marker is the fifth tachycardia event sensed by the SICD. Although initial arrhythmia dropout occurs briefly on the strip, this does not significantly delay detection.

While this patient’s arrhythmia is detected in the shock zone, the SICD utilizes discriminators in the conditional (VT) zone. The device utilizes three criteria for VT versus SVT analysis. First, the device compares the waveform of the tachyarrhythmia event to a stored template. If >50% correlated, this suggests an SVT. If <50%, the SICD compares the current beat to the previous beat. If the two events are dissimilar, a polymorphic arrhythmia is suspected and therapy decision tree initiates. If the two events are similar, a VT is suspected and further analysis occurs. Last, the device compares the QRS width of the current tachyarrhythmia event to the stored template. If it is wide, VT is suspected; if narrow, an atrial arrhythmia is suspected.
Figure 4.A.2
Stored EGM, part 2.

Shock Zone: 200 bpm
Conditional Shock Zone: 170 bpm
Post Shock Pacing: ON

TREATED EPISODE 001: 03/12/2-11 11:28:37 AM 25 mm/sec 2.5 mm/mV
SHOCK IMPEDANCE = 66 ohms FINAL SHOCK POLARITY = REV

Double Counting or Oversensing

Double detection Algorithm
Figure 4.A.3
Cameron x-ray with annotations.
Figure 4.A.4
Conditional zone markers.

SHOCK ZONE
Heart rate within Shock Zone?

INSIGHT DISCRIMINATION
Heart rate within Conditional Shock Zone?

STATIC MORPHOLOGY
Compare morphology & width to NSR Template

DYNAMIC MORPHOLOGY
Compare beat-to-beat morphology

QRS WIDTH
Compare QRS Width with NSR Template

Figure 37: Decision Phase arrhythmia analysis

Source: Used with permission from Boston Scientific.
Reference
