ICD Discrimination Algorithms
How Do They Work?

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EGM of A.Fib with fast ventricular response

Case 1
EGM of Sinus Tachycardia

Case 2

THERAPY SEQUENCE (continued)

<table>
<thead>
<tr>
<th>Therapy</th>
<th>Energy (J)</th>
<th>Charge Time (sec)</th>
<th>Waveform</th>
<th>Pathway</th>
<th>Delivered Energy (J)</th>
<th>Impedance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT Rx 2: CV</td>
<td>0.1 - 10.0</td>
<td>1.95</td>
<td>BIPHASIC</td>
<td>AX:B</td>
<td>9.9</td>
<td>62</td>
</tr>
<tr>
<td>VT Rx 3: CV</td>
<td>0.3 - 36.0</td>
<td>7.11</td>
<td>BIPHASIC</td>
<td>AX:B</td>
<td>28.8</td>
<td>54</td>
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<tr>
<td>VT Rx 4: CV</td>
<td>1.1 - 36.0</td>
<td>6.63</td>
<td>BIPHASIC</td>
<td>D:A:AX</td>
<td>29.6</td>
<td>59</td>
</tr>
<tr>
<td>VT Rx 5: CV</td>
<td>1.1 - 30.0</td>
<td>6.61</td>
<td>BIPHASIC</td>
<td>AX:B</td>
<td>29.5</td>
<td>59</td>
</tr>
<tr>
<td>VT Rx 6: CV</td>
<td>1.1 - 30.0</td>
<td>6.72</td>
<td>BIPHASIC</td>
<td>D:A:AX</td>
<td>29.5</td>
<td>59</td>
</tr>
</tbody>
</table>
Introduction

**Inappropriate therapy**

- Incidence: 20 to 40%
- Psychological adverse effect
- Longevity
- Atrial fibrillation, Supraventricular tachycardia including Sinus tachycardia and abnormal sensing

<table>
<thead>
<tr>
<th>Trial</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCD-HeFT</td>
<td>32%</td>
</tr>
<tr>
<td>MADIT II</td>
<td>36.4%</td>
</tr>
<tr>
<td>AVID</td>
<td>21% of patients</td>
</tr>
</tbody>
</table>
## Inappropriate therapy

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial Fibrillation</td>
<td>44%</td>
</tr>
<tr>
<td>Other SVT</td>
<td>36%</td>
</tr>
<tr>
<td>Abnormal Sensing</td>
<td>20%</td>
</tr>
</tbody>
</table>
Incidence of Inappropriate ICD therapy

SVT discrimination

- Prevent detection of tachyarrhythmias caused by the presence of an SVT
- Prevent inappropriate, unnecessary therapy due to rapid SVT conduction
SVT discrimination

- RR Interval
- Regularity/Stability
- Onset
- VEGM morphology
- PR patterns/relationships
- PR dissociation

* VEGM: ventricular electrocardiogram
RR Interval

- **Purpose**
  -- Identify high ventricular rates

- **Detection Zone**

<table>
<thead>
<tr>
<th></th>
<th>VF Detection Zone</th>
<th>FVT Detection Zone</th>
<th>VT Detection Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enable</strong></td>
<td>VF On</td>
<td>FVT via VF</td>
<td>VT On</td>
</tr>
<tr>
<td><strong>Initial</strong></td>
<td>18/24</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td><strong>Redetect</strong></td>
<td>9/12</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td><strong>V Interval [Rate]</strong></td>
<td>320 ms (188 bpm)</td>
<td>260 ms (231 bpm)</td>
<td>400 ms (150 bpm)</td>
</tr>
</tbody>
</table>
The minimum ventricular intervals at which the device applies SVT discrimination
Regularity/Stability

- **Purpose**
  -- Discrimination of monomorphic VT (regular cycle lengths) from rapid AF (irregular cycle lengths)

- **Potential weakness**
  -- Atrial flutter has regular RR intervals
  -- Underdetection of VT with irregular RR intervals
Stability

Activated when the VT counter = 3

Stability 50ms

Varies >50 ms from previous 3

480ms - 440ms = 40ms
450ms - 440ms = 10ms
510ms - 440ms = 60ms

60ms > Stability 50ms

Unstable, A.Fib

Current Interval

In Medtronic devices
Regularity in PR Logic

- **Ventricular Cycle Length (Irregular)**
  - Calculates the percentage of how often the two most frequent intervals occur

\[
\frac{8}{18} = 44\%
\]

For Atrial Fib must be \(< 50\%\); For Other 1:1 SVT must be \(> 25\%\)

In Medtronic devices
Regularity in PR Logic

- Ventricular Cycle Length (Regular)

For VT $\geq 75\%$

$\frac{14}{18} = 77\%$

In Medtronic devices
Interval Stability

- 700ms: 2nd longest
- 402ms: 2nd shortest

700ms - 402ms = 298ms

298ms > Stability 80ms

Unstable, A.Fib

In St. Jude Medical devices
Interval Stability

- 387ms: 2nd longest
- 370ms: 2nd shortest

387ms − 370ms = 17ms

17ms < Stability 80ms

Stable, VT

In St. Jude Medical devices
Interval Stability (w/AVA)

Atrial Ventricular Association Delta

AVA Setting: 40ms

160ms – 150ms = 10ms

10ms < AVA 40ms

160: 2nd longest AV Interval
150: 2nd shortest AV Interval

Association, SVT

In St.Jude Medical dual chamber devices
**Interval Stability (w/ SIH)**

- **Count sinus intervals** in ‘Interval Stability Window’
- **SVT = Sinus intervals > SIH delta(1~8)**

In St. Jude Medical single chamber devices
A.Fib rate threshold: 200 bpm

A Rate > 200 bpm AND V rate Stability (> 20ms)

No → VT

Yes → SVT (AF)
**Stability**

Sensitivity & Specificity values for different stability values

- **Purpose:**
  - Identify sudden ventricular rate changes

- **Potential weakness**
  - May miss VT arising during sinus tachycardia
  - Sudden onset A.Fib, AT, PSVT

![Graph showing ventricular tachycardia and sinus tachycardia with time and rate axes]
Onset

- Average of previous 4 beats $\times$ programmed Onset %
- ? Averages of 4 Tachycardia beats of
- VT if Tachy average is less than 430ms in this example

In Medtronic devices

Onset:

- 81%

530ms $\times$ 81% = 430ms

430ms $\neq$ or $\geq$ 460ms

$\Rightarrow$ Not sudden Onset
**Sudden Onset**

Compared to previous interval as soon as get in VT zone.

**How suddenly** did the rate change?

In St. Jude Medical devices.
Sudden Onset

Any of intervals (322ms) > Onset 200ms

Sudden onset, VT

In St. Jude Medical devices
Onset

VEGM morphology

- **Purpose:**
  -- Abnormal ventricular EGM morphology against template may indicate ventricular tachyarrhythmias

- **Potential weakness**
  -- Confounded by conduction aberrancy or changes in normal VEGM morphology

VEGM: ventricular electrocardiogram
Vector Timing and Correlation

NSR or SVT

VT

Rate

Shock

NSR

VT

Align Peaks

In Guidant devices

NSR: normal sinus rhythm
Morphology Discrimination

- Sequence of Peaks
- Number of Peaks
- Area Under Peaks
- Polarity
- Signal Amplitude

In St. Jude Medical devices
**Morphology Discrimination**

\[ X = \text{Non Match with Template} \]
\[ \checkmark = \text{Match with Template} \]

Too many “non-matches” = VT

In St.Jude Medical devices
Wavelet

- Stores a template of a normal QRS wave
- Detect VT if 6 out of 8 do not match

% difference compared against:
Match Threshold Value

In Medtronic devices
VEGM morphology

- Inaccurate Template
- Correlation patient position
- Correlation post shock delivery
- Correlation pharmacology changes
- Rate-Related Aberrancy
- Inappropriate Classification of VT as SVT
**Purpose:**
-- Consistent AV pattern/relationship usually indicates SVT

**Potential weakness**
-- Atrioventricular reentrant tachycardia and VT with 1:1 retrograde conduction

A: atrial, V: ventricular
PR patterns/relationships

- Defining a rhythm
  -- Series of V-V Patterns
- Atrial event classification
- 19 Pattern Codes (A~Z)

In Medtronic devices

VS
Junctional Retrograde Antegrade

AFib/AFlutter
On
Sinus Tach
On
Other 1:1 SVTs
On
PR dissociation

- **Purpose:**
  -- AV dissociation may indicate VT

- **Potential weakness**
  -- VT with 1:1 retrograde conduction
AV Interval

- The rhythm is classified into the Sinus Tach rate branch.
- Same algorithm as AVA

2nd longest - 2nd shortest AV interval

\[ \geq AV \text{ interval Value}(40\text{ms}) \]

\[ \Rightarrow VT \]

In St. Jude Medical devices
A:V Dissociation

- Provides evidence that sensed atrial events are not related to sensed ventricular events

Does any criterion satisfy > 4/8 VV interval?

- VV interval has no atrial sensed events
- OR
- Current AV interval differs from the average of the previous 8 by more than 40 msec

No
AV Associated

Yes
AV Dissociated

Identify Rhythm as AV Dissociated

In Medtronic devices
SVT discrimination in Redetection

Purpose

- For SVT after appropriate therapy of VT
- To classify SVT correctly after inappropriate therapy
SVT discrimination in Redetection

Each Manufacturer

- Biotronik and ELA
  - Equivalent initial detection and redetection
  - Except onset
- Guidant
  - Permit stability after shocks, but not after ATP
- Medtronic
  - Only single chamber stability applies
- St. Jude Medical
  - Do not apply any discriminator
Dual chamber SVT discrimination

Dual Chamber

A > V
- Ventricular morphology
- Ventricular interval stability
- AV association

Conducted AFib/AFlu

VT + AFib/AFlu

A = V
- Ventricular morphology
- AV interval
- Chamber of onset
- Response to ATP*

SVT (1:1 AV conduction)

VT (1:1 VA conduction)

V > A

VT

Analyze atrial and ventricular rates

<table>
<thead>
<tr>
<th>The name of Discrimination</th>
<th>Rate Branch (St. Jude Medical)</th>
<th>PR Logic (Medtronic)</th>
<th>Rhythm ID (Guidant)</th>
<th>PARAD+ (ELA)</th>
<th>SMART (Biotronik)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR stability</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>XX</td>
<td>X</td>
</tr>
<tr>
<td>Sudden onset</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>VEGM morphology</td>
<td>XX</td>
<td></td>
<td>XX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A rate vs V rate</td>
<td>XX</td>
<td>X</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>PR patterns</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR association</td>
<td>XX</td>
<td>XX</td>
<td></td>
<td>XX</td>
<td>XX</td>
</tr>
</tbody>
</table>

x = algorithm uses this discrimination  
X : A rate > V rate  
X : A rate = V rate
Summary

- An ideally programmed device should provide
  - Detection and treatment for true VT (sensitivity) as well as discern SVT and inhibit inappropriate therapies (specificity)