



Implantable Cardioverter Defibrillators (ICDs) Fundamentals Overview



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Objectives

- Review History of the ICD
- Discuss Indications
- Describe ICD Sensing & Detection
- Provide Basics of ICD Therapies & Diagnostics
- Present ICD Electrograms
- Review ICD Therapy Case Studies



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ICD System Historical Milestones

- 1966 Conception
- 1969 First experimental model
- 1969 First transvenous defibrillation
- 1975 First animal implant
- 1980 First human implant
- 1982 Addition of cardioverting capability
- 1985 FDA approval
- 1988 First programmable ICD implanted

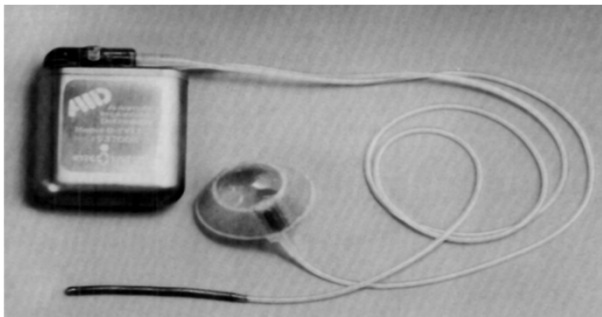


Dr. Michel Mirowski
1924 - 1990

Mirowski M, Mower M, Staewen W, Tabatznick B, Mendeloff A, (1970), Standby automatic defibrillator. An approach to prevention of sudden coronary death. Arch Intern Med 126:158 - 161



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1980

The original ICD device (Intec) had two electrodes:

- One, a spring, was placed in the Vena Cava
- The other, a cup, designed to conform to the cardiac apex



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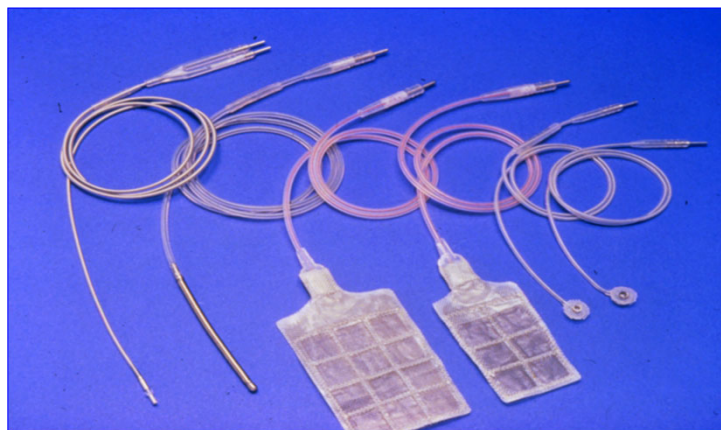
1988

Teletronics developed the first ICD with an "on board" VVI pacemaker



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ICD Lead History

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ICD Evolution 1989 - 2000



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Today's ICD

- Bradycardia Pacing** • Dual chamber and CRT
- Antitachycardia Pacing** • Multiple algorithms

- Low-Energy Cardioversion** • Widely programmable
- High-Energy Cardioversion** • Fast charge times
- Energy waveforms

- Improved Algorithms** • AV discrimination
- Dual chamber sensing
- Detection enhancements
- Hemodynamic monitoring

- CIED Diagnostics** • Stored electrograms
- Device integrity
- Remote monitoring

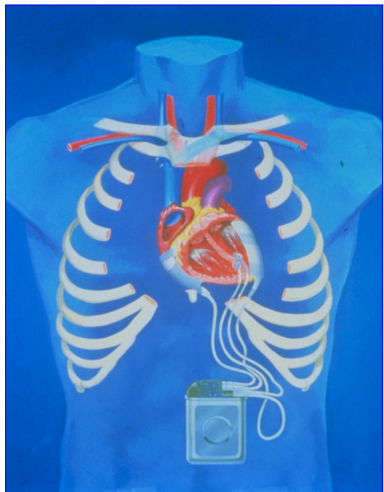


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The ICD Procedure – In the beginning

The patient admitted AFTER surviving Sudden Cardiac Death...

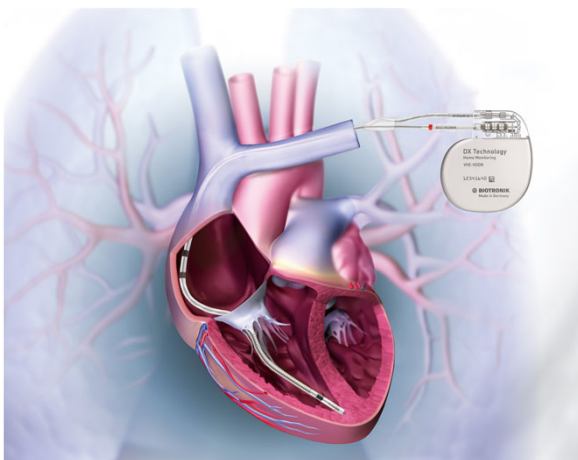


- EP testing required
- DFT testing routine
- Sternal thoracotomy
- Average 18 months battery longevity

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The ICD Procedure - Now

Patient at high risk for SCD:



- Admitted as an outpatient majority of the time
- Discharged the same or next day
- DFTs only performed in select patients
- 8+ years battery longevity common

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ICD Indications: Primary

Primary Prevention Guidelines:

- ICD therapy is recommended to reduce total mortality by a reduction in SCD in patients who have ischemic heart disease and whose MI was greater than 40 days ago, with EF less than 30%, NYHA II or III symptoms and optimal medical therapy
- ICD therapy is recommended to reduce total mortality by a reduction in SCD in patients with non-ischemic cardiomyopathy, EF less than 30%, NYHA II or III symptoms with optimal medical therapy

2017 AHA/ACC/HRS Guideline for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death
A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society
Sana M. Al-Khatib, Michael J. Ackerman, William J. Bryant, David J. Callans, Anne B. Curtis, Barbara J. Deal, Timm Dickfeld, Michael E. Field, Gregg C. Fonarow, Anne M. Gillis, Christopher B. Granger, Stephen C. Hammill, Mark A. Hlatky, José A. Joglar, G. Neal Kay, Daniel D. Matlock, Robert J. Myerburg and Richard L. Page
Originally published 1 Aug 2018 <https://doi.org/10.1161/CIR.0000000000000549> Circulation. 2018;138:e272–e391



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ICD Indications: Secondary

- Cardiac arrest due to VF or VT not due to a transient or reversible cause
- Nonsustained VT with CAD, previous MI, left ventricular dysfunction, and inducible VF or sustained VT at EP study not suppressible by Class I antiarrhythmic drug
- Spontaneous sustained VT in a normal heart when alternative therapies have failed
- Syncope of undetermined origin with clinically relevant, hemodynamically significant sustained VT or VF induced at EP study when drug therapy is ineffective, not tolerated or not preferred

2017 AHA/ACC/HRS Guideline for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death
A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society
Sana M. Al-Khatib, Michael J. Ackerman, William J. Bryant, David J. Callans, Anne B. Curtis, Barbara J. Deal, Timm Dickfeld, Michael E. Field, Gregg C. Fonarow, Anne M. Gillis, Christopher B. Granger, Stephen C. Hammill, Mark A. Hlatky, José A. Joglar, G. Neal Kay, Daniel D. Matlock, Robert J. Myerburg and Richard L. Page
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Common Diagnosis/Indications for ICD, CRT-Defibrillator Implant

Why did the patient receive the implant?

- Cardiac arrest
- Ventricular tachycardia (VT)
- Ventricular fibrillation (VF)
- Ischemic cardiomyopathy
- Non-ischemic cardiomyopathy
- Left ventricular (LV) dysfunction due to prior myocardial infarction (MI), minimum 40 days post-MI, LV ejection fraction (EF) < 30% with New York Heart Association (NYHA) functional class I heart failure (HF)
- Hypertrophic cardiomyopathy
- Brugada syndrome
- Catecholaminergic polymorphic VT (CPVT) with syncope
- Cardiac sarcoidosis
- Arrhythmogenic right ventricular dysplasia (ARVD)
- Long QT syndrome

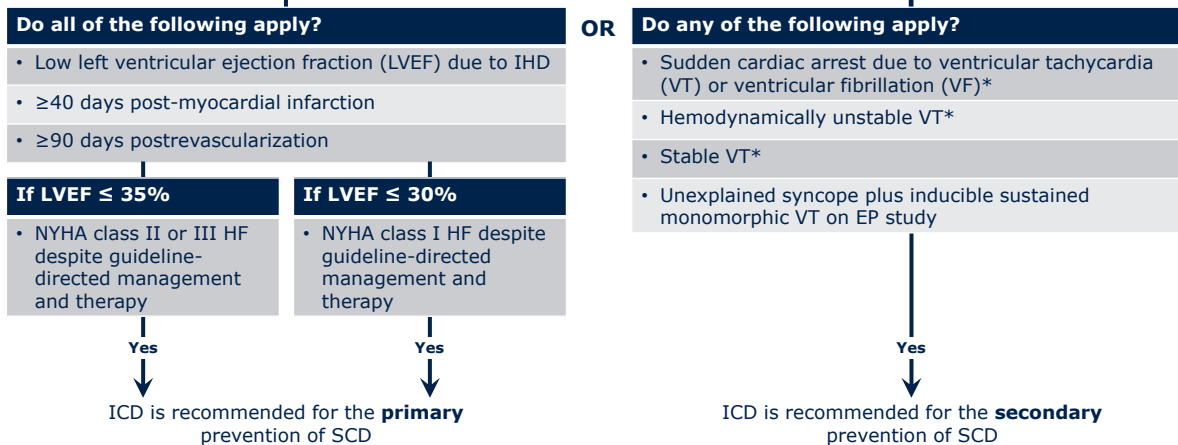
Courtesy of Amy Tucker, MSN, RN, CCDS Sanger Heart & Vascular Institute



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Indications for Implantable Cardioverter-Defibrillator (ICD) in Patients with Ischemic Heart Disease (IHD) to Prevent Sudden Cardiac Death (SCD)

Patient with ischemic heart disease (IHD) with a meaningful survival > 1 year expected



*Not due to reversible causes. Al-Khatib, S.M., et al. J Am Coll Cardiol. 10.1016/j.jacc.2017.10.052



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Sensing: Two Important Definitions

SENSITIVITY

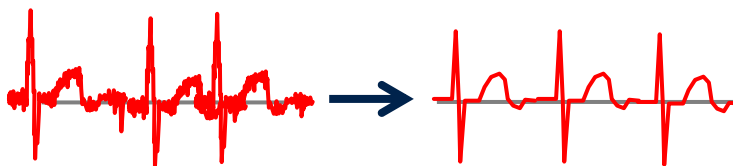
The ability of the ICD to detect VT 100% of the time for fast arrhythmias

SPECIFICITY

The ability of the ICD to discriminate between VTs and SVTs

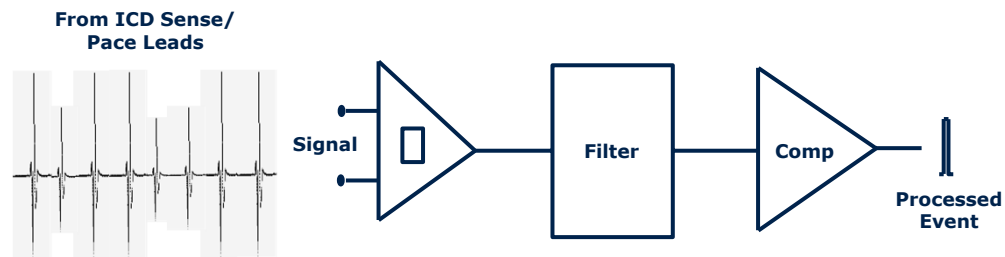
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Sensing



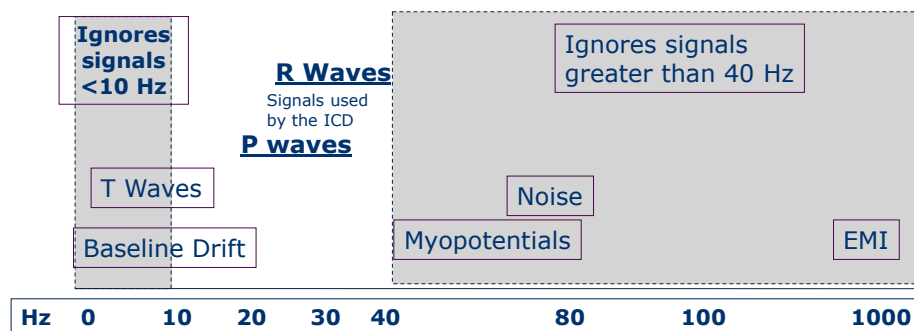
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Sensing



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High and Low Bandpass Filters



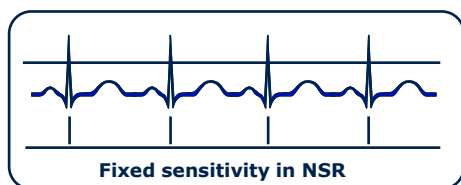
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ICD Signal Processing Summary

- The intra-cardiac signal is sensed and converted into an electronic signal
- The intervals between the electronic signals can then be processed by the device
- Due to the varying amplitudes of tachyarrhythmia signals, an automatic sensing system is needed

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Sensing: A Review



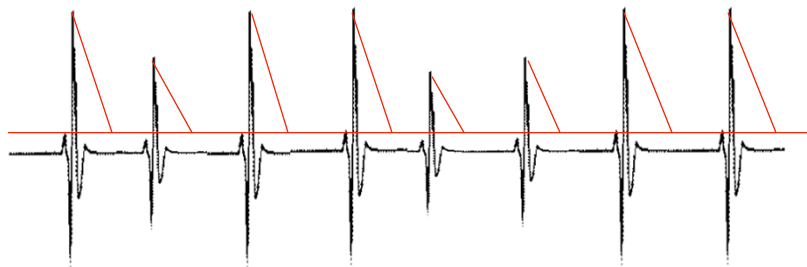
Pacemaker sensitivity

A fixed sensitivity setting cannot be used with an ICD

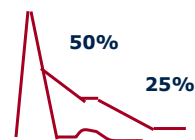


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Automatic Sensing

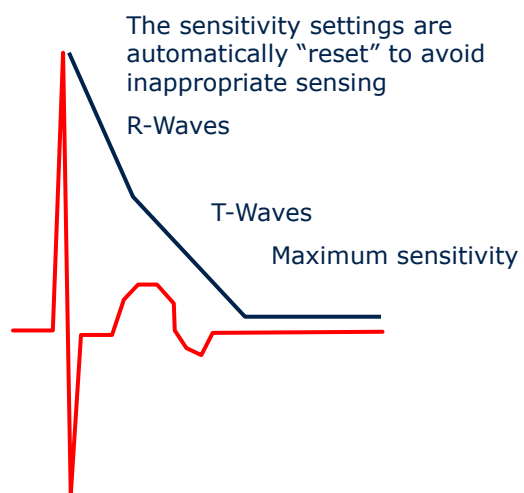


A system of **automatically adapting sensitivity** settings is used in ICDs



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Automatic Sensing



The sensitivity settings are automatically "reset" to avoid inappropriate sensing

R-Waves

T-Waves

Maximum sensitivity

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Detection Criteria for Fast Arrhythmias:

Rate

- Programmed rate to begin detection

Specificity Discrimination

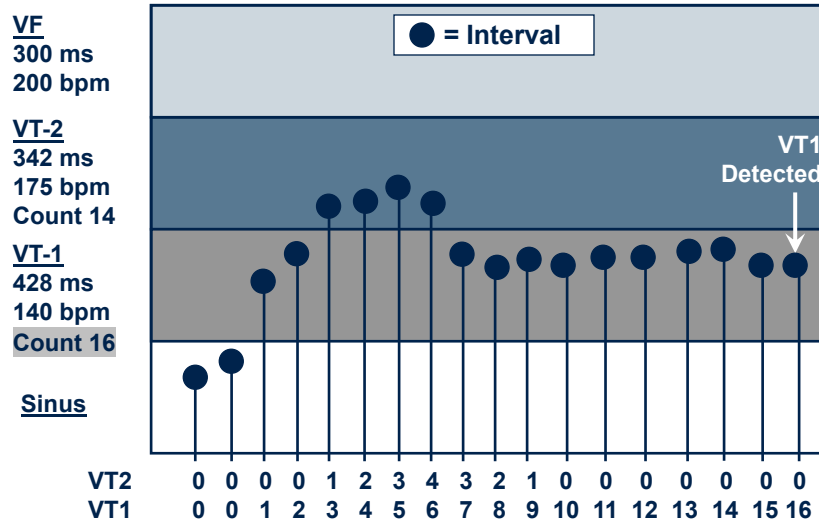
- Onset detector
- Stability detector
- Morphology comparison

Fibrillation Detection

- Quick delivery of defibrillation therapy

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Single Chamber VT Detection



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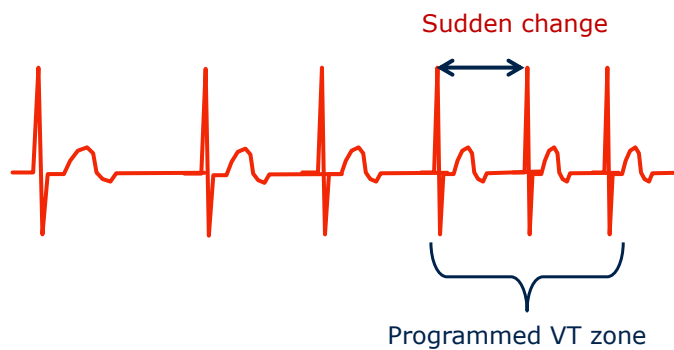
Onset: A Hallmark of VT

- **Sudden Onset** is used to differentiate sinus tachycardias (normally a slow onset), from VTs which have a rapid onset
- With Onset ON, Onset AND the Detection Counter must be satisfied before Detection is met and therapy will be delivered

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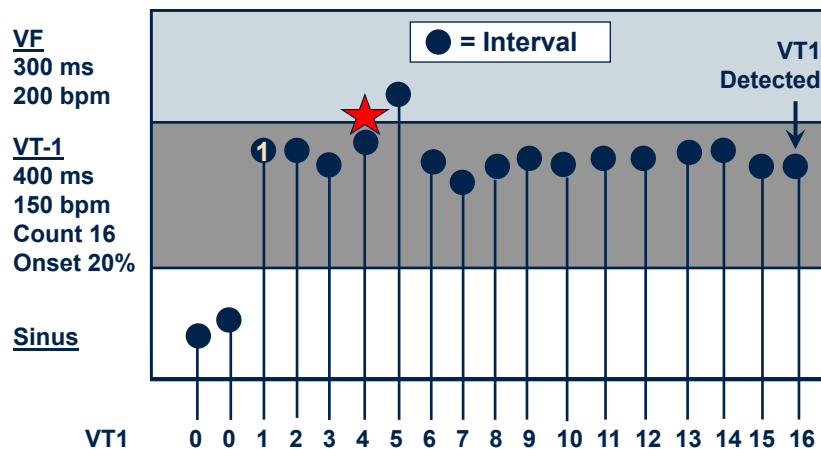
Onset

- The increase in rate from previous average of four beats to new average of four beats is greater than the programmed Onset
- The most recent interval falls into VT or VF zone



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VT Detection with Onset



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Stability: Inhibit or Treat?

Stability is used to differentiate SVTs that conduct irregularly to the ventricles (atrial fibrillation) from monomorphic VTs which are stable

- Atrial fibrillation (with high ventricular rate response) is the most common reason for inappropriate shock

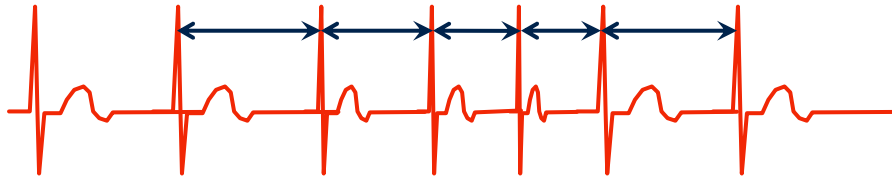
With Stability ON, Stability AND the Detection Counter must be satisfied before Detection is met

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Stability: Inhibit or Treat?

Stability delays detection in the presence of an unstable R-R interval

- Unstable R-R decrements VT counter by 20



Inappropriate ICD shocks were attributed to atrial fibrillation (44%), supraventricular tachycardia (36%), and abnormal sensing (20%). (What is the rate of inappropriate shocks from implantable cardioverter-defibrillators (ICDs)? Updated: Oct 11, 2019 Author: Daniel M Beyerbach, MD, PhD; Chief Editor: Jeffrey N Rottman). <https://emedicine.medscape.com/article/> Visited March 18, 2024.

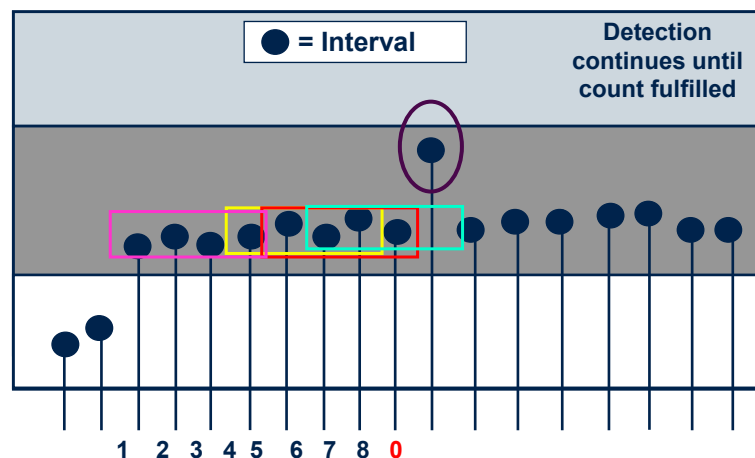
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Stability

VF
300 ms
200 bpm

VT-1
400 ms
150 bpm
Count 16
Stability
24ms

Sinus



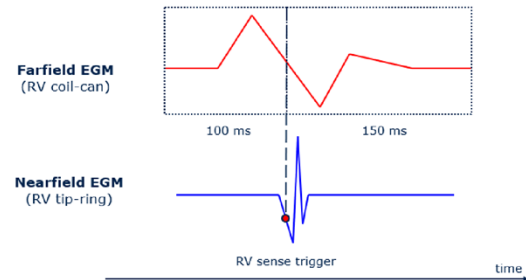
The interval falling outside of the stability range results in the VT counter being set back to 0

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Morphology Discriminator

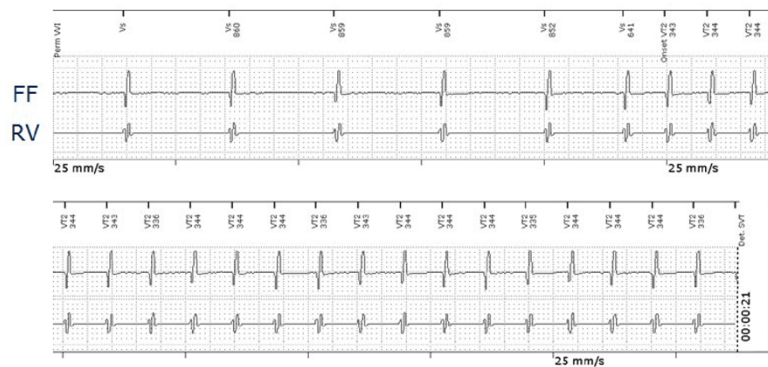
Compares the QRS morphology of the intrinsic ventricular beats (normal) with those in a fast arrhythmia

- **MorphMatch (BIOTRONIK specific)** compares far-field signals obtained during sinus rhythm to those occurring in the VT zone(s)
- The reference QRS is updated on a beat-by-beat basis for sinus rhythm
- Once the morphology reference is created, the device can then compare the reference QRS to the current or actual QRS
- MorphMatch is programmable OFF, ON or Monitoring



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Example



Recordings - Details		Episode: 53
Detection		
Zone		SVT
Measured Onset in V [%]	(fulfilled)	57
Measured stability in V [ms]		4

Remark
SVT (MorphMatch)

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Tiered Therapy

Fib Zone Rate →	Fib Zone	Shock Therapy
Tachy Zone Rate →	Tachy Zone	ATP, CV & Shock Therapy
Bradycardia Pacing Rate →	No Therapy Zone	No Therapy
	Bradycardia Zone	Pacing Therapy

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Pain-Free Therapy – ATP (Anti-Tachycardia Pacing)

- ATP is rapid pacing at a cycle length shorter than VT
- ATP can terminate reentrant VT by penetrating the circuit and depolarizing the excitable gap which will block reentry
- Mostly effective treating monomorphic VTs
- ATP can reduce painful shocks, improve quality of life, and lengthen pulse generator life
- "Successful termination of VT by ATP was 89% in the Pacing Fast Ventricular Tachycardia Reduces [Shock Therapies](#) (PainFREE Rx) study,¹⁹ 81% in the PainFREE Rx II study,²⁰ 91% in the EMPIRIC study,²¹ 88% in the Automated Antitachycardia Pacing study,²² and 74% in the Nippon Storm Study.²³"

Laurence D. Sterns, Angelo Auricchio, Edward J. Schloss, Dan Lexcen, Luke Jacobsen, Paul DeGroot, Amy Molan, Takashi Kurita,
Antitachycardia pacing success in implantable cardioverter-defibrillators by p atient, device, and programming characteristics, Heart Rhythm, Volume 20, Issue 2,2023,Pages 190-197,ISSN 1547-5271,https://doi.org/10.1016/j.hrthm.2022.10.015.

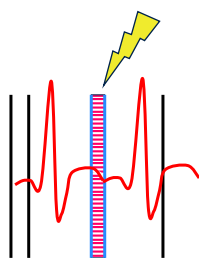
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Theory of ATP



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Programming ATP therapies



VT Re-entry circuit



ATP must hit outside the absolute refractory period of the VT to be successful

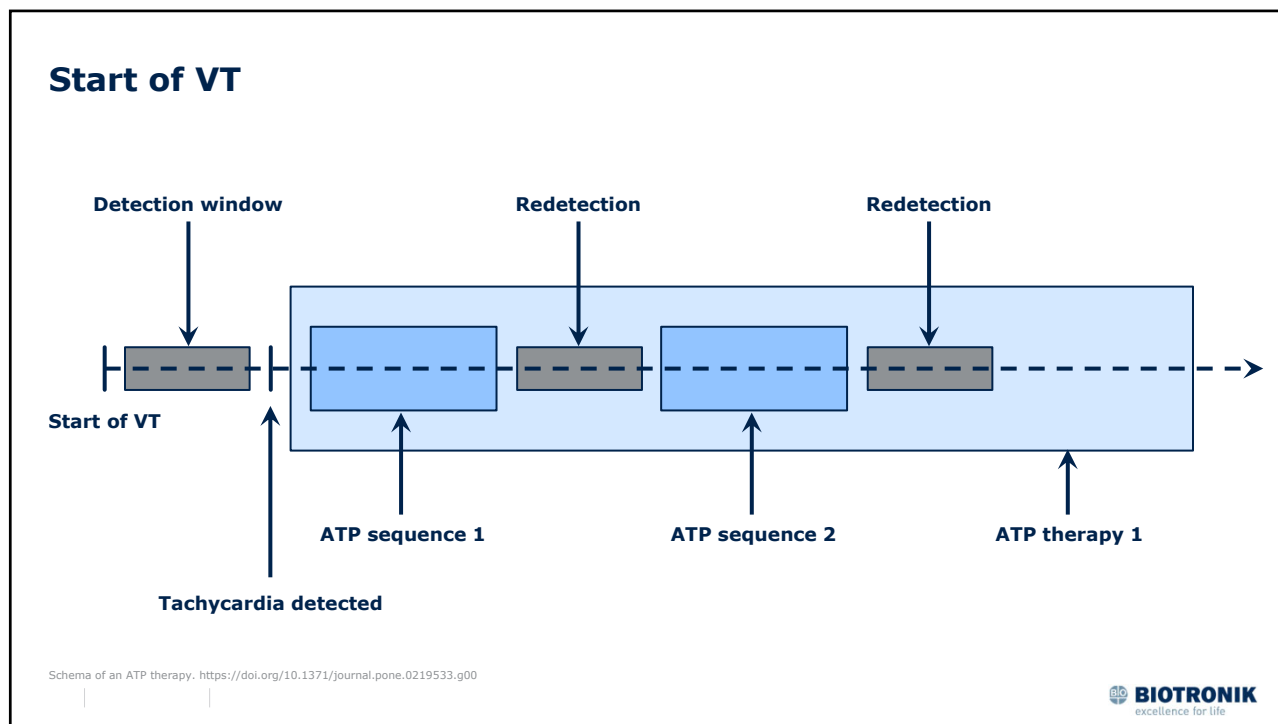
ATP Schemes:

- **Burst** – Number of paced beats at a set rate
- **Ramp** – Programmed paced beats will get shorter at a set interval

Enhancements:

- Add one more scheme
- Scan decrement

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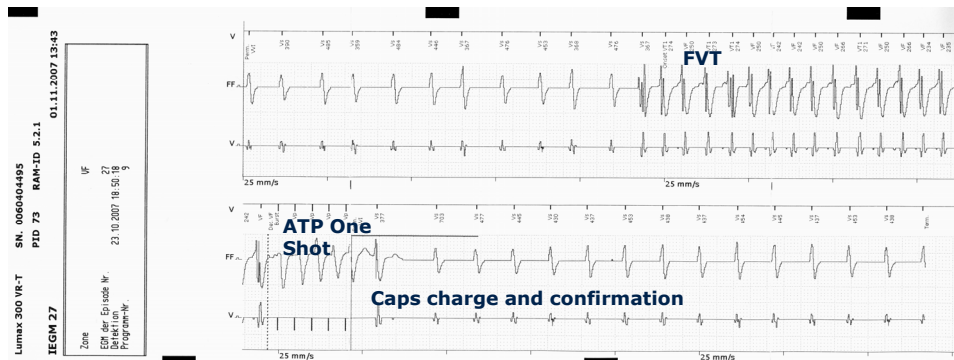
ATP One Shot®

- Allows the programming of **one train of ATP** to treat stable, **fast VT** occurring in the VF zone
- Delivery: Initial detection criterion met and meets **stability criterion** of +/-12% (nonprogrammable)
- ATP is delivered **immediately** before charging of the shock capacitors
- Pulse amplitude of **7.5 V with pulse width of 1.5 ms**, and in a VOO mode
- **Shock confirmation** occurs to confirm efficacy of ATP
- Capacitors bleed off the energy if confirmation criterion of $\frac{3}{4}$ slow intervals is met

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ATP One Shot®



Key Points

- In the presence of true VF shock delivery is immediate
- Battery longevity is not compromised due to Confirmation during charge

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VF Detection

- Single VF zone set in an ICD
- VF Detection: Based on the VF Heart Rate/Interval limit and an X out of Y criterion (Ex: 8/12)
- X/Y detection compensates for undersensing of fine VF

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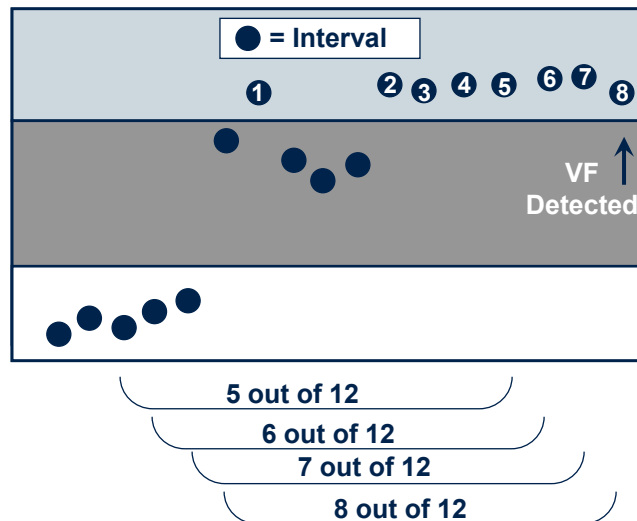
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VF Detection

VF
300 ms
200 bpm
8 in 12
VT-1
400 ms
150 bpm
Count 16

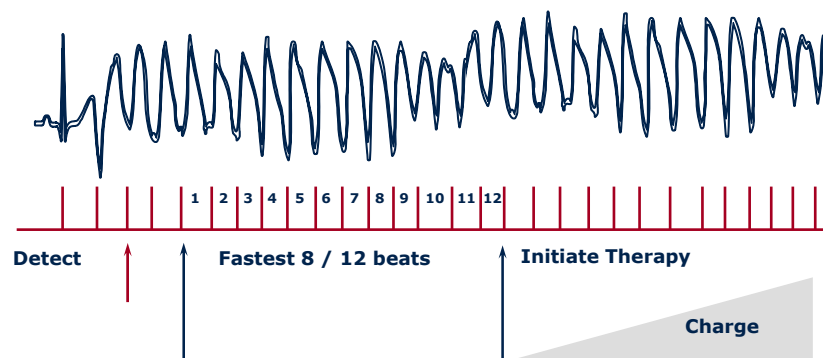
Sinus



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VF Detection

Fib Zone



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ICD Diagnostics

A few added diagnostic features for ICD optimization

- Statistics
- Stored IEGMs
- Event counters (interval plots)
- Shock times
- Capacitor reformation (charge time)



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A clinical magnet placed on an ICD:

SUSPENDS tachyarrhythmia detection & therapies (for BIOTRONIK this is up to 8 hours while the magnet remains positioned over the ICD)

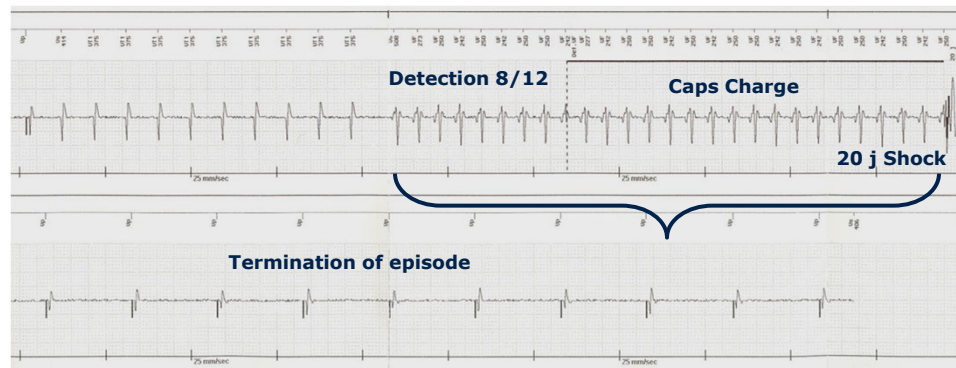
A magnet placed on an **ICD** will *not* affect pacing response

Device manufacturer specific - so always contact tech support to be sure of the effect of clinical magnet placement on your patient's device.



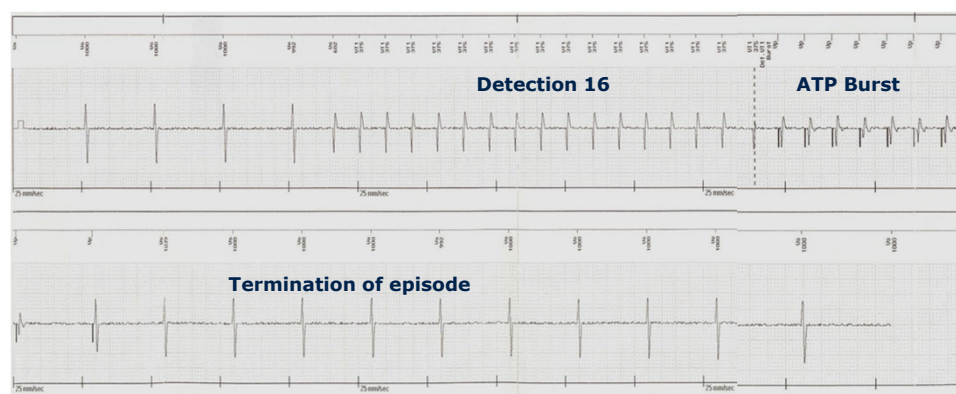
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Example 1: VF Detection with Shock



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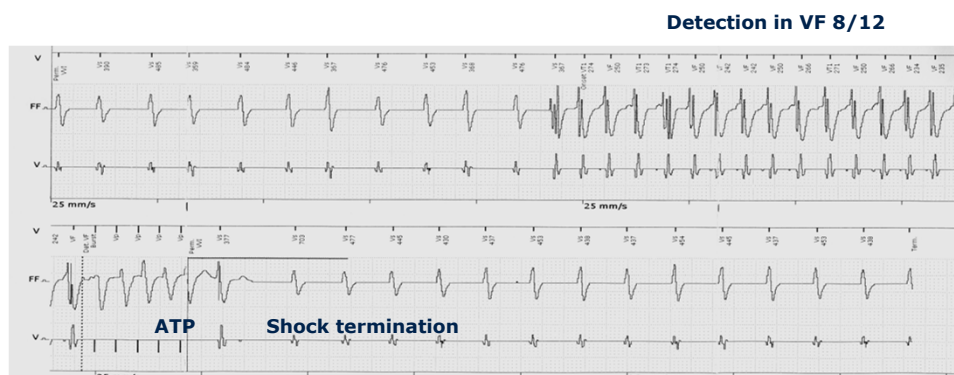
Example 2: VT Detection with successful ATP



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Example 3: ATP During VF

ATP may be very effective for FVT in the VF zone



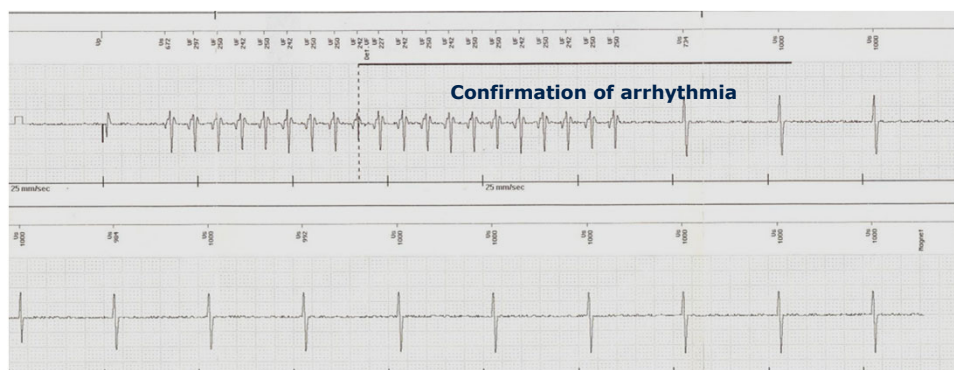
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Example 4: Aborted Shocks

Confirmation during charge: Another way to optimize ICD therapy



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ICDs and Patient Education

Continuous Patient Education = Patient Engagement

- Why did they have an ICD implant?
(with a pacemaker)
- Detection heart rates/therapy parameters
- ATP vs a Shock
- Shock Plan
- ERI

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Questions?

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