ICD Troubleshooting

- Evaluating patients with shocks
- Evaluating ineffective or absent treatment
- Preventative programming
ICD Troubleshooting

When assessing an episode of shock, why happened, we look for:

- Stored & clinical data
  - Tachyarrhythmia
    - SVT (inappropriate detection)
    - VT/VF (appropriate detection)
  - No tachyarrhythmia (oversensing)
    - Intracardiac signals
    - Extracardiac signals
Evaluating Appropriateness of Delivered Therapy

ICD Troubleshooting

The first step is to determine if therapy was delivered in response to oversensing or a true tachycardia.
Oversensing

Inappropriate therapy occurs in the absence of tachycardias because nonphysiological or nonarrhythmic, physiological signals are oversensed and detected as arrhythmias.
Nonphysiological signals usually are extracardiac.

Physiological signals may be intracardiac (P, R, or T waves) or extracardiac (myopotentials).

Oversensing presents characteristic patterns of stored electrograms and associated markers.
Intracardiac Signals

Ventricular oversensing of physiologic intracardiac signals results in two detected ventricular electrograms for each cardiac cycle, which may result in inappropriate detection of VT or VF.
**T-Wave Oversensing**

Oversensing of spontaneous T waves may cause inappropriate detection of either VT or VF, depending on the sensed RT interval and programmed VF detection interval.

T-wave oversensing is identified by alternating electrogram morphologies. RR intervals usually alternate, but the magnitude of alternation may be small.
T wave oversensing

Ventricular couplets with T wave oversensing as T wave exceeds the voltage threshold for sensing
R-wave Double Counting

It occurs if the duration of the sensing electrogram exceeds the ventricular blanking period of 120ms. It may be exacerbated by sodium-channel-blocking drugs, particularly at high heart rates, which increase use-dependent sodium-channel blockade.
Double counting of R waves results in alternation of ventricular cycle lengths with an isoelectric interval between sensed events, producing a characteristic “railroad track” pattern of ventricular intervals on interval plots.
Trend report of an event with far field oversensing with rapidly alternating VV interval (railroad track appearance) with inappropriate shock for NSVT.
**P-wave oversensing**

- *It may occur if the distal coil of an integrated bipolar lead is close to the tricuspid valve, and the sensed PR interval exceeds the ventricular blanking period.*

- *It is rare in adults with defibrillation leads near the RV apex, but may occur in children or in adults if the RV electrode dislodges or is positioned in the proximal septum or inflow portion of the RV.*
**Far-field R-wave oversensing**

On the atrial channel, it is the analog of P-wave oversensing on the ventricular channel, it shows a pattern of alternating atrial cycle lengths with one sense marker timed close to the ventricular electrogram. If rate and duration criteria for VT are fulfilled, far-field R wave oversensing may confound SVT-VT discrimination. But it does not cause inappropriate detection of VT if the ventricular rate is in the sinus zone.
**Extracardiac Signals**

The distinctive feature of oversensing extracardiac signals is replacement of the isoelectric baseline with high-frequency noise that does not have a constant relationship to the cardiac cycle.
External electromagnetic interference

Signal amplitude is greater on the high-voltage electrogram recorded from widely spaced electrodes than on the sensing electrogram recorded from closely spaced electrodes. The interference signal may be continuous.
Lead/Connector Problems

Oversensing due to lead or connector problems is intermittent. Usually it occurs only during a small fraction (\(<10\%)\) of the cardiac cycle. It may be limited to the sensing electrogram and may be associated with postural changes.

Often, the pacing-lead impedance is abnormal, indicating complete or partial interruption of the pace-sense circuit. However, abnormal impedance measurements may be intermittent.
**Myopotential oversensing**

It may persist for variable fractions of the cardiac cycle. **Diaphragmatic myopotentials** are most prominent on the sensing electrogram.

Oversensing usually occurs after long diastolic intervals or after ventricular paced events when amplifier sensitivity or gain is maximal. It often ends with a sensed R wave, which abruptly reduces sensitivity.
In pacemaker-dependent patients, diaphragmatic oversensing causes inhibition of pacing, resulting in persistent oversensing and inappropriate detection of VF.

Clinically this may present as syncope from inhibition of pacing followed by an inappropriate shock.
Diaphragmatic myopotentials oversensing leading to inappropriate VF detection, pacing is withheld during detection leading to asystole with persistent noise on near-field electrogram.
Pectoral myopotentials are more prominent on a far-field electrogram rather than the near-field electrogram; because ICDs do not use this electrogram for rate-counting, oversensing of pectoral myopotentials does not usually cause inappropriate detection.
VT versus SVT: Analysis of Stored Electrograms

If therapy is delivered in response to a tachycardia, the second step is to determine if the initial rhythm detected as VT or VF is true VT/VF or SVT.
Analysis of stored electrograms in dual and single chamber ICDs

A Dual Chamber

- Analyze atrial and ventricular rates
  - A > V
    - Ventricular morphology
    - Ventricular interval stability
    - AV association
    - Conducted AFib/AFib
  - VT + AFib/AFib
  - 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

B Single Chamber

- Ventricular electrogram morphology
  - Uniform and identical to sinus morphology
    - SVT
  - Variable or minimal difference from sinus morphology
    - Abrupt onset → VT*
    - Irregularly irregular → AFib
  - Uniform and distinctly different from sinus morphology
    - VT
Single-chamber SVT-VT discrimination

Analysis of Single-Chamber Electrograms

• Morphology
• Abruptness of onset
• Regularity of ventricular electrograms
Analysis of Dual-Chamber Electrograms

- Atrial and ventricular rates
- Atrio-ventricular (AV) relationships

If the ventricular rate exceeds the atrial rate, the diagnosis is VT.

If the atrial rate exceeds the ventricular rate, rapidly conducted AF or AFL must be distinguished from VT during atrial arrhythmia.
Tachycardias with 1:1 AV Relationship

In tachycardias with 1:1 AV association, transient AV block permits the diagnosis of SVT; transient VA block permits the diagnosis of VT.

The vast majority of tachycardias with 1:1 AV relationship are SVT, primarily sinus tachycardia. VT with 1:1 VA conduction accounts for less than 10% of VTs detected by ICDs in most studies.
The principal differentiating features between SVT and VT with 1:1 AV relationship include:

- Morphology of the ventricular electrogram
- Chamber of onset
- Response to ventricular ATP

Atrial tachycardia usually begins with a short PP interval followed by a short RR interval whereas VT usually begins with a short RR interval.

In sinus tachycardia, the atrial rhythm accelerates gradually with an approximately stable PR interval.
Tachycardias with Atrial Rate > Ventricular Rate:
Once far-field R waves are differentiated from atrial electrograms, conducted AF or AFL must be distinguished from VT during atrial arrhythmia.

Most VT during paroxysmal atrial fibrillation is fast enough to be classified in the VF zone. The single-chamber criteria of abnormal ventricular morphology and regular ventricular rate are most helpful for diagnosing VT during atrial fibrillation.
Trend report showing an abrupt non sustained tachycardia episode. Sudden onset excludes sinus tachycardia but does not differentiate VT from SVT.
Stored EGM of the same episode show that after the onset of tachycardia, P waves are lost but the morphology is unchanged .......AF
Stored electrogram of WCT episode

Atrial EGM shows continuing AFL and ventricular EGM shows regular WCT ........ Conducted AFL vs. Concomitant VT
Real time recording of the same patient during SR showing similarity between far-field EGM during SR and morphology during the episode …….. Conducted AFL
VT Vs. SVT

Onset of VT with abrupt onset of V. rate and change in electrogram morphology without change in A. rate

VT ..VT with 1:1 VA conduction
Programming to Reduce Shocks

Four principal programming goals aim to reduce inappropriate shocks:

1. Optimize SVT-VT discrimination
2. Prevent oversensing
3. Prevent detection of nonsustained VT.
4. Treat VT with ATP to reduce unnecessary shocks, whether appropriate or inappropriate
Additional Programming to Reduce Shocks

Programming to Prevent Oversensing

Consistent *oversensing of spontaneous P waves* often requires lead revision.

One strategy is to force atrial pacing using DDDR or Dynamic Overdrive modes. This shortens the ventricular CL to prevent ventricular sensitivity from reaching its minimum value and introduces cross-chamber ventricular blanking after each atrial event to prevent oversensing of P waves.
R-wave double counting may be overcome by increasing the ventricular blanking period from the nominal value of 125–150ms.

Oversensing of diaphragmatic myopotentials may be corrected by reducing ventricular sensitivity if VF sensing and detection are reliable at the reduced level of sensitivity.
**T-wave oversensing** by ICDs is an unwanted result of the requirement to sense VF electrograms reliably, which may have low amplitudes and slow rates.

To minimize the likelihood of T-wave oversensing, ICDs automatically adjust sensitivity in relation to the amplitude of the preceding R wave.
Programming to Prevent Shocks For Nonsustained SVT or VT

An ICD may deliver inappropriate shocks for self-terminating VT or SVT if the arrhythmia terminates during the time required to charge the high-voltage capacitor, which reduces ICD longevity.
Shocks delivered for self-terminating arrhythmias occur for one of two reasons:

• The “confirmation” process between capacitor charging and delivery of a first, noncommitted shock fails

• The shock is committed.
In all ICDs, the confirmation algorithm delivers the stored shock if a few intervals immediately following charge completion are shorter than the programmed VT interval (St. Jude and Guidant) or $60 \text{ ms} > \text{VT interval (Medtronic)}$. This hidden interaction effectively commits the first VF shock if the VT interval is programmed to a long cycle length.
So, all nominal values of confirmation process should be increased in patients who have long episodes of nonsustained device-detected VF.
Non committed shock

NSVT which terminates during capacitor charge and shock is withheld. After detection and capacitor charging, the device confirms if there is ongoing tachyarrhythmia before delivery of shock.
Nominal programming of the number of intervals for initial detection of VF (18 of 24) substantially reduces inappropriate therapies without significantly delaying detection compared with 12 of 16 intervals, which is a commonly used setting.
Inappropriate therapy for nonsustained VT or SVT may also be delivered after application or inappropriate ATP or shocks. Increasing the duration for redetection may prevent inappropriate redetection of delayed termination of VT or post shock nonsustained VT.

However, excessive delays in detection or redetection may result in syncope or an increase in DFT.
Programming ATP to Reduce Shocks

Painless ATP terminates 80–95% of spontaneous VT with cycle length >300–320 ms with a low risk of acceleration (1–5%).

Recent studies have demonstrated that a single trial of ATP (8-pulse burst train at 88% of the VT cycle length) can terminate 75–85% of fast VT (cycle length 240–320 ms) with low rates of acceleration and syncope.
Thus ATP reduces both unnecessary, appropriate shocks for fast VT and inappropriate shocks for SVT. It improves quality of life and should be programmed “on” empirically in most patients,
If therapy is not programmed “on” for slow VT, the slowest rate zone may be programmed as a “monitor-only” zone with detection “on” and therapies “off.”

However, interactions between the counters in the monitor-only zone and the next zone may restrict use of SVT-VT discriminators or decrease the number of intervals required for detection in the therapy zone.
Unanticipated Therapy In Monitor-Only Zones

Current ICDs provide independent monitor-only zones and events in the “monitor” zone do not increment the “combined count” counter, and tachycardias in the monitor-only zone do not accelerate therapy if a few intervals cross into the slowest therapy zone.
Failure to Deliver Therapy or Delay of Therapy

Absent or delayed therapy may be caused by
- Programmed values (including human error),
- ICD system performance, or
- Combination of the two.

The most common causes are ICD inactivation, VT slower than the programmed detection interval, SVT-VT discriminators and undersensing.
Failure to Deliver Therapy or Delay of Therapy

ICD Inactivation

If detection is programmed OFF for surgery using electrocautery, reprogramming must be performed at the end of the procedure, a fact easily forgotten, especially in outpatient surgery.

SVT-VT Discriminators

SVT-VT discriminators may prevent or delay therapy if they misclassify VT or VF as SVT and most of dual chamber algorithms reevaluate the rhythm during ongoing tachycardia to risk of VT underdetection.
In most ICD patients, VT with cycle lengths $>400–450$ ms \textit{are tolerated well}. However, slow VT may be catastrophic in patients with severe LV dysfunction or ischemia... To prevent underdetection of irregular VT, the VT detection interval should be set at least 50 ms longer than the slowest predicted VT. A long VT detection interval is important in patients with advanced heart failure, in whom slow VT may be catastrophic.
ICD troubleshooting should be performed in a structured manner following interrogation of the device and examining the patient. Important issues include:

- Device activity: arrhythmia related to malfunction of device, or lead (or both) or related to an external source?
- Device activity: caused by SVT or VT?
- Device activity: appropriate or inappropriate?
- Device activity: adjustment of settings necessary?
Rapidly conducted atrial tachycardia with changes in AA interval precede changes in VV interval with unchanged far-field morphology. AT is detected as VF Inappropriate SHOCK
After SHOCK ... nine AT complexes are conducted with wide QRS followed by SR and despite wide QRS, the AA interval drive the VV intervals which confirms SVT
Subsequent development of VT with V. rate > A. rate and morphology of near field and far field EGM is different from sinus morphology …….. VT  

Appropriate SHOCK
After successful SHOCK... first 4 complexes are sinus tachycardia with aberrant QRS.... VT recurs that could be differentiated from aberrantly conducted sinus tachycardia.