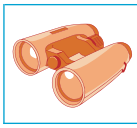

My Defibrillator Fired: What to Do?

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The management of a patient whose implantable cardioverter-defibrillator (ICD) has just fired has become a common problem for the non-electrophysiologist. The ICD patient who has just received device therapy is often frightened and his cardiologist may feel unprepared to deal with this type of patient. Management of the ICD patient requires a basic knowledge of indications for ICDs, function of ICDs, diagnostic approach to the patient whose ICD has fired and specific treatment guidelines for common triggers of ICD therapy.

This review will focus on the latter two points outlined above. The reader is directed to the American Heart Association/American College of Cardiology guidelines for ICD indications and to several recent comprehensive reviews about ICDs for further information provided in the Suggested Reading section.

The Function of ICDs

The ICD system is composed of a pulse generator and one or more leads or patches capable of sensing, pacing and defibrillation. The generator is comprised of a battery, high-voltage capacitors and electronic circuitry responsible for tachyarrhythmia detection, therapy delivery, bradyarrhythmia pacing, diagnostics and telemetry. The lead and/or patch system can either be epicardial with ventricular sensing/pacing leads and defibrillation patches or an integrated transvenous, endocardial defibrillation, sensing/pacing lead system. Earlier ICDs were quite large, requiring implantation of the pulse generator in the patient's abdomen either above or below the rectus muscle. In the past decade, ICDs have evolved to encompass a transvenous single or dual coil sensing/defibrillation lead placed via a central vein (e.g., cephalic, axillary or subclavian vein) in conjunction with a small pectorally implanted pulse generator (<40 cm^3, <80 g). Other recent additions to the capabilities of ICDs include advanced dual chamber bradycardia pacing, therapies for atrial tachyarrhythmias, and biventricular pacing, which may have a beneficial effect in heart failure patients.

The primary detection parameter for ventricular tachycardia (VT) or ventricular fibrillation (VF) is the ventricular rate. Many ICDs have a VT zone (typically 150–200 bpm) and a VF zone (typically >200 bpm). A programmable minimum number of ventricular intervals faster than the rate cutoff must be exceeded to trigger therapy. In the VT zone, algorithms to discriminate supraventricular tachycardia (SVT) from VT may be activated. Even with the inclusion of atrial intracardiac electrograms in SVT discrimination algorithms, 20% or more of ICD therapies are inappropriate (Figure 1). ICDs also incorporate sophisticated information storage and diagnostic capabilities, which may be noninvasively accessed using an ICD programmer and are immensely helpful in the work-up and treatment of an ICD patient who has had a shock. For example, stored intracardiac electrograms and event logs allow the physician to determine the type of arrhythmia precipitating device therapy. Diagnostic data may give clues to the presence of a conductor fracture or insulation failure, which could lead to inappropriate therapy.

Diagnostic Approach to the ICD Patient Who Has Had a Shock

The approach to the ICD patient who has had therapy should include a directed history and physical, a diagnostic evaluation, and device interrogation. A systematic approach will help the physician to rapidly triage the patient and initiate treatment if necessary.

History and Physical

Initial questioning of the patient should cover the points included in Table 1. Multiple episodes of ICD therapy in a short period of time should be viewed as a medical emergency and the patient should be rapidly transferred to the hospital emergency department for immediate electrocardiographic monitoring to document arrhythmias and further work-up. Multiple ICD discharges may be the result of a fractured lead or recurrent VT/VF (electrical storm). If the patient had only an isolated shock and otherwise feels well, semielective follow-up can be arranged. If the patient had chest pain, shortness of breath or syncope associated with one or more shocks, he should be urgently evaluated since an unstable acute cardiac syndrome may be present. Drug history is important, since some medications may be proarrhythmic, or the discontinuation of antiarrhythmic medications may predispose the patient to arrhythmias such as atrial fibrillation or VT. A history of trauma to the ICD system should be elicited, since a lead fracture may be causing inappropriate noise and triggering therapy. Multiple firings of a recently implanted ICD system may be caused by lead dislodgement.

The initial physical exam should be directed to the cardiovascular and respiratory systems, looking for triggers of SVT or VT/VF including cardiac ischemia, congestive heart failure or hypotension. Infection or pulmonary disease exacerbation are other important triggers of tachyarrhythmias. The ICD site should be carefully examined for evidence of trauma. If lead fracture is suspected, further examination (preferably done when the ICD is inactivated and intracardiac electrograms can be monitored) may include flexion/extension of the arm ipsilateral to the side of

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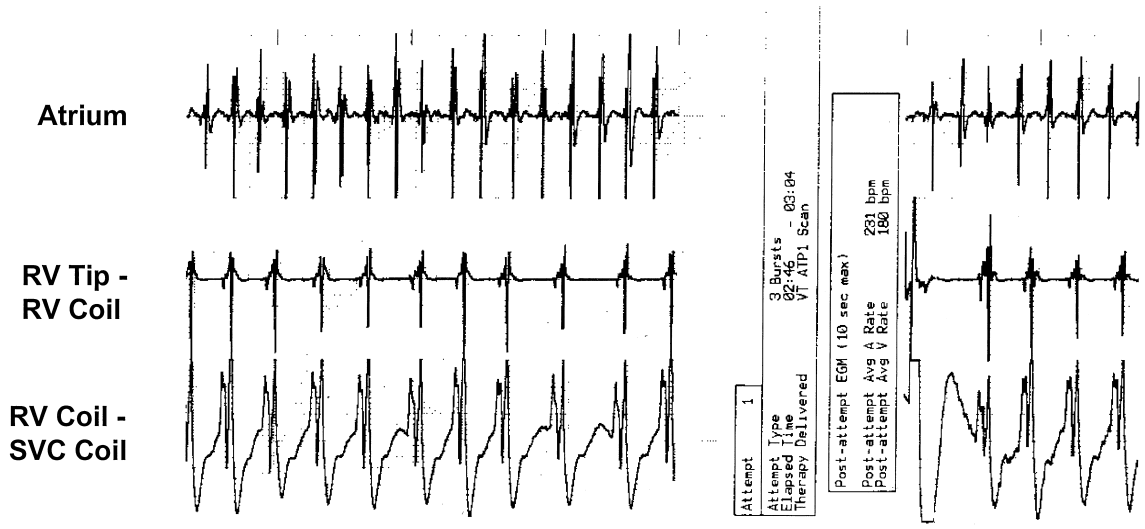

Figure 1. Atrial fibrillation with a rapid ventricular response leading to inappropriate therapy, as recorded by a dual chamber pacing, ventricular defibrillator. The stored atrial electrogram (top tracing) shows atrial fibrillation. The corresponding stored ventricular electrogram as recorded by the tip to the defibrillation coil of the ventricular lead which is in the right ventricle (RV Tip - RV Coil, middle tracing) and by the right ventricular coil to superior vena cava coil of the ventricular lead (RV Coil - SVC Coil, lower tracing) demonstrates a rapid ventricular response. Programmed SVT discriminators initially suppressed therapy but eventually a sustained high ventricular rate duration was exceeded leading to inappropriate therapy.

the ICD implant, isometric pushing or pulling of the arms, Valsalva maneuvers and bending.

Diagnostic Testing

The underlying cardiac rhythm should be documented. Supraventricular tachycardias including atrial fibrillation are common triggers of inappropriate ICD therapy. Nonsustained ventricular ectopy may suggest recurrent ventricular arrhythmias causing appropriate discharge.

Initial blood work should include serum potassium and magnesium levels since hypokalemia and hypomagnesemia are important triggers of SVT and VT. Other blood work should be directed to underlying diseases (i.e., hypoglycemia in a diabetic patient or anemia in a patient with a recent blood loss may trigger sinus tachycardia). If an acute cardiac syndrome is suspected, markers of myocardial infarction should be determined.

A chest radiograph should be obtained if lead fracture or lead dislodgment is suspected. Other imaging should be based on concurrent pathological processes.

ICD Interrogation

Present ICDs store a wealth of diagnostic information including cardiac electrograms at the time of ICD discharge. Early ICD interrogation is indicated so that the triggering arrhythmia can be determined. Other diagnostic information can help determine if a lead fracture is present. This information can be printed and faxed to a clinical cardiac electrophysiologist who can provide initial telephone guidance to the treating physician. All ICD companies in the United States maintain a technical workforce of experts who are available to help with interrogation and interpretation of ICD information.

Treatment of the Patient with ICD Shocks

Single Shocks

If the patient has received only an isolated shock and has no residual symptoms, telephonic assessment and reassurance is often all that is needed. The patient can be followed up at his next ICD clinic visit when the ICD can be interrogated. The patient should be advised to seek earlier medical evaluation if he has additional shocks. Obviously, if the patient has lingering symptoms as mentioned previously, he should seek urgent medical attention.

Multiple Shocks

The patient who presents with multiple ICD shocks should be treated as a medical emergency. Multiple shocks are painful and frightening to the patient and may cause significant psychological dysfunction. To decrease anxiety, the ICD patient who has received multiple shocks should be sedated appropriately.

In the case of multiple shocks, the ICD should be promptly inactivated. Concurrently, the patient should be monitored on telemetry and external defibrillation should be readily available. Ideally, the ICD should be inactivated using a programmer. Often, this cannot be done because a programmer may not be readily available, the manufacturer and model of ICD may be unknown, or the health care provider caring for the patient may be unfamiliar with the programmer. For most ICDs, tachyarrhythmia therapies may be temporarily inactivated by taping a doughnut-shaped magnet in place over the ICD. This is dependent on whether the ICD has been programmed to ignore magnet application (feature in CPI/Guidant, Intermedics and Ventritex/St. Jude ICDs). Application of a magnet to some ICDs

Table 1. Pertinent Clinical Information Concerning ICD Firing

Palpitations?
Irregular (atrial fibrillation)
Regular (SVT vs. VT)
Preceding symptoms?
Shortness of breath (CHF exacerbation)
Chest pain (cardiac ischemia)
Dizziness or loss of consciousness (hemodynamically destabilizing arrhythmia)
Recent changes in medications?
Addition of diuretic (hypokalemia precipitating AFIB or SVT)
Addition of antiarrhythmic or other agent (proarrhythmia)
Discontinuation of a beta-blocker or other negative chronotropic agent (sinus tachycardia)
Recent reprogramming of ICD
Lowering of VT rate threshold (inappropriate detection of SVT)
Change in SVT discriminators (inappropriate detection of SVT)
Activity When ICD Fired
Physical activity (sinus tachycardia trigger)
Upper extremity movement (lead fracture)
Exposure to electromagnetic interference (electrocautery, alternators, anti-theft devices, etc.)
Frequency of ICD Firing
Multiple episodes in previous 24 hours (lead fracture, SVT, electrical storm)
Infrequent episodes with symptoms similar to past occasions (isolated VT/VF with therapy)
Other Diseases
Congestive heart failure (exacerbation could lead to VT or SVT)
Coronary artery disease (recent ischemia could precipitate VT or SVT)
Hypertension (changes in diuretic could lead to hypokalemia and VT or SVT)

Abbreviations: AFIB, atrial fibrillation; CHF, congestive heart failure; ICD, implantable cardioverter-defibrillator; SVT, supraventricular tachycardia; VF, ventricular fibrillation; VT, ventricular tachycardia.

(CPI/Guidant) may cause reprogramming of tachyarrhythmia therapies. In general, bradyarrhythmia functions are not affected by magnet application to ICDs. Specific ICD responses to magnet application for various manufacturers are noted in Table 2. If an attempt is made to inactivate an ICD with a magnet, the patient should **not** be released until the status of the ICD is formally checked with a programmer.

After initial patient stabilization, the ICD should be promptly interrogated. A flow diagram for evaluating and treating ICD discharges based on the ICD interrogation is shown in Figure 2.

Electrical Storm

In the case of electrical storm (multiple episodes of VT/VF causing device therapy), standard Advanced Cardiac Life Saving (ACLS) protocols should be followed for cardiovascular and respiratory support. Since recent studies have documented the efficacy of beta-blockers in electrical storm and the superiority of intravenous amiodarone over lidocaine in the treatment of refractory, unstable VT/VF, these agents should be first line therapy for suppression of VT or VF. Other precipitating causes of VT/VF should be treated, including hypokalemia and hypomagnesemia, cardiac ischemia, hypoxia, congestive heart failure or cardiogenic shock.

Chronic antiarrhythmic therapy for suppression of VT/VF may include amiodarone, or sotalol, both of which decrease the frequency of ICD discharges. Other therapies which suppress sudden cardiac death including beta-blockers, angiotensin converting enzyme inhibitors, lipid lowering agents and spironolactone should be included when appropriate. Coronary artery revascularization may be indicated if the patient has significant cardiac ischemia. If the patient has recurrent VT that is <200 bpm, aggressive overdrive pacing therapies may be efficacious and less painful than shocks. Finally, percutaneous radiofrequency ablation may decrease the incidence of VT in selected patients.

Inappropriate Shocks

If the patient with multiple shocks has minimal symptoms, inappropriate shocks should be considered. A differential diagnosis is included in Table 3. Stored intracardiac electrograms and datalogs from the ICD are invaluable in determining the cause of inappropriate shocks.

Table 2. ICD Response to Continuous Application of a Magnet

Manufacturer	Magnet Response?	Tones Heard When Magnet Placed?	Tachycardia Therapy Response to Magnet?	Bradycardia Therapy Response to Magnet?
CPI (Guidant)	May not respond	None—device set to ignore magnet; tone synchronized with QRS—tachycardia therapies active; continuous—tachycardia therapies off	Tone synchronized with QRS changing to continuous tone—device off; continuous tone changing to tone synchronized with QRS—device active; no tone—device programmed to ignore magnet	Unaffected
Biotronik	Yes	None	Inhibited	Unaffected
ELA	Yes	None	Inhibited	Magnet rate (77–96 bpm)
Intermedics (Guidant)	May not respond	None—device set to ignore magnet; beeping—tachycardia therapies off	If beeps heard, inhibited	Unaffected
Medtronic	Yes	Possible	Inhibited	Unaffected
Telectronics (St. Jude)	Yes	None	Inhibited	Unaffected
Ventritex (St. Jude)	May not respond	None	If programmed to respond, inhibited	Unaffected

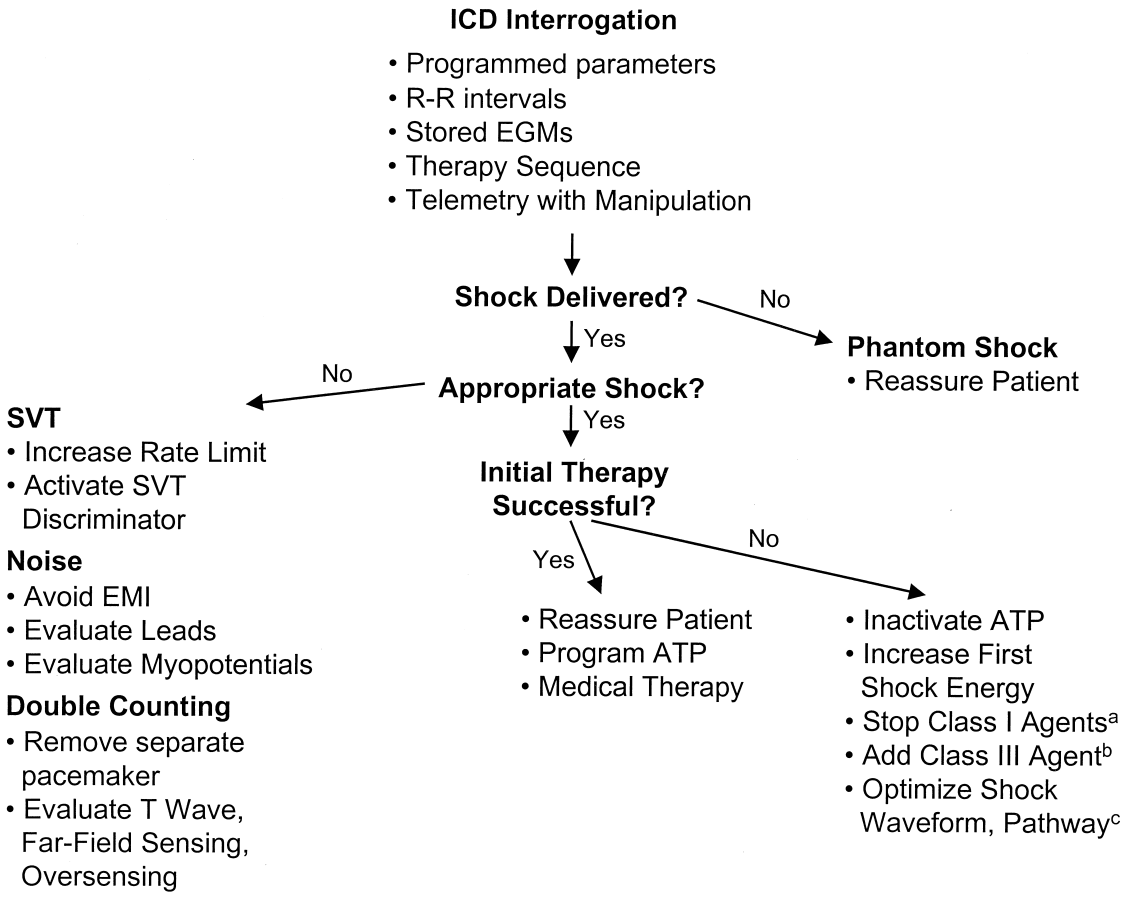

Figure 2. Flow diagram for evaluation and treatment of the ICD patient who has received therapy. Abbreviations: ATP, antitachycardia pacing; EGM, electrocardiograms; EMI, electromagnetic interference; SVT, supraventricular tachycardia. Notes: a-class I antiarrhythmics include quinidine, disopyramide, procainamide, mexiletine, propafenone and flecainide; b-class III agents include sotalol and dofetilide; c-not programmable on all devices. Adapted with permission from ref. 2.

The most common cause of inappropriate shocks is SVT. Ventricular rate control should be immediately obtained with intravenous agents that may include beta-blockers, diltiazem, digoxin or amiodarone, all of which may be converted to oral form if needed on a chronic basis. In some cases, definitive ventricular rate control can be achieved only by ablation of the atrioventricular node to induce complete heart block. Maintenance of sinus rhythm can be achieved with antiarrhythmics, cardioversion or radiofrequency ablation. Reprogramming of the ICD may also reduce inappropriate shocks. For example, an increase in the VT detection rate may prevent a sinus tachycardia from triggering the device or addition of SVT discrimination algorithms may suppress therapy in the presence of atrial fibrillation with a rapid ventricular response. Other SVT discrimination parameters may be programmed as outlined in Table 4. Any reprogramming in ICD parameters should be carefully reviewed to make sure that VT and VF detection is not adversely affected.

Table 3. Differential Diagnosis of Inappropriate Shocks

Supraventricular tachycardias
Atrial fibrillation
Atrial flutter
Sinus tachycardia
Atrial tachycardia
Reentrant supraventricular tachycardia
Oversensing
T wave
Diaphragmatic/chest wall
Other devices
Lead dislodgment/double counting of atrium and ventricle
Noise
External electromagnetic noise (alternators/welding/cautery/lithotripsy)
Loose set screw/extendable lead screw
Lead fracture
Phantom shocks

Oversensing causing double counting and inappropriate therapy may be caused by T wave or diaphragmatic oversensing or counting of atrial and ventricular signals due to ventricular lead dislodgment or a separate bradycardia pacing system. These can often be treated by reprogramming the ICD. If lead dislodgment is found, repositioning of the lead will be necessary. If a pacemaker causes double counting, removal of the pacemaker and upgrading of the ICD system to incorporate bradyarrhythmia therapies should be done.

Electromagnetic noise recorded on the sensing lead can

Table 4. Detection Enhancements for Differentiation of SVT from VT

Parameter	What It Does	Useful For	Problems With
Stability	Suppresses therapy for tachyarrhythmias with variable V rate	Atrial fibrillation	Underdetection of VT with irregular rate; failure to suppress therapy or SVTs with regular V response
Onset	Suppresses therapy for tachyarrhythmias that slowly accelerate	Sinus tachycardia	Underdetection of gradually accelerating VT or VT onset during sinus tachycardia; failure to suppress therapy for sudden onset SVTs
QRS width	Suppresses therapy for tachyarrhythmias with V EGM morphology similar to that in sinus rhythm	Potentially useful for differentiation of narrow complex SVT from VT	Limited specificity with bundle branch block; may prevent therapy for narrow complex VT
QRS morphology	Suppresses therapy for tachyarrhythmias with ventricular EGM morphology similar to that in sinus rhythm	Potentially useful for differentiation of SVT from VT	Limited specificity with bundle branch block
A rate-V rate relationship	Suppresses therapy for tachyarrhythmias where A rate $\geq$V rate	Atrial flutter and other SVTs with regular ventricular response	May delay therapy for VT with retrograde A activation
A and V pattern recognition	Certain patterns of A and V timing associated with SVT suppress therapy	Most SVTs	A activity falling in refractory period or farfield R waves detected on A channel can confound algorithm
Sustained rate duration	Therapy for tachyarrhythmias finally delivered after this period of time, even if SVT discriminators are still met	Prevents indefinite inhibition of therapy for VT misdiagnosed as SVT	Therapy will be eventually delivered if the SVT continues after sustained high rate duration expires

Note: some detection enhancements are available only in certain models of ICD. Abbreviations: A, atrial; EGM, electrogram; SVT, supraventricular tachycardia; V, ventricular; VT, ventricular tachycardia.

cause inappropriate therapy. The most common cause of this is a lead fracture which should be remedied by removal/replacement of the fractured lead. Occasionally external noise (e.g., high frequency electromagnetic signals from electric motors, alternators, electrocautery, lithotripsy, and welding equipment) may trigger ICD therapy. Rarely, magnets (typically found in theft detectors, motors, generators, and audio speakers) can temporarily inhibit ICD therapies for tachyarrhythmias. If an ICD patient is inadvertently exposed to high levels of electromagnetic interference, the status of the ICD should be formally checked with a programmer.

Conclusion

The ICD patient who has received an isolated shock frequently can initially be assessed by his/her cardiologist and then followed up electively in an outpatient ICD clinic by an cardiac electrophysiologist. If the ICD patient has received multiple shocks, urgent medical attention should be obtained and the ICD should be interrogated as soon as possible.

Suggested Reading

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