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Implantable Cardioverter-Defibrillators and the Pathologist: Comment and Cautionary Notes

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ABSTRACT: This paper briefly reviews the components of, the clinical uses of, the techniques to place, and the complications related to implantable cardioverter-defibrillators (ICDs). Information useful in the specific identification of ICDs is presented. A series of recommendations for the autopsy examination or postmortem explantation of ICDs by the pathologist is given. Because of the serious risk of injury to the pathologist possible with postmortem discharges of ICDs which have not been deactivated, and because of the risk of device explosion if the ICD is incinerated, a number of cautionary notes are provided. A brief case with occurrence of accidental postmortem discharge of an active ICD is also presented.

KEYWORDS: forensic science, forensic pathology, sudden death, heart, arrhythmias, pathology, defibrillators, pacemakers, prevention, treatment

Implantable cardioverter-defibrillators (ICDs) have undergone significant design changes, becoming increasingly sophisticated and more commonly used over the past decade. Most pathologists are aware of the appropriate autopsy investigation of patients with permanent pacemakers, and of the dangers of cremating bodies if such pacemakers are left in situ; the investigation of, and safety precautions relevant to, patients with ICDs may be less well known. The case report here and the literature review provided address these issues.

Case Report

This 56-year-old male patient was a smoker with systemic arterial hypertension and borderline hypercholesteremia. He had a long history of coronary artery atherosclerosis, with at least two myocardial infarcts, 14 and 6 years previously. The patient had undergone coronary artery bypass grafting 16 years, and regrafting 6 years, prior to his death. He suffered from severe left ventricular dysfunction. The patient experienced refractory ventricular arrhythmias, and had an ICD placed 8 months prior to his death. This defibrillator was a Ventak Mini™ 1743 (Cardiac Pacemakers, Inc., St. Paul, MN) coupled with a single ventricular lead.

In the weeks prior to his death, this patient received 21 defibrillator shocks, occasionally with episodes of associated syncope. The patient was seen in the pacemaker clinic the day prior to his death, having experienced accelerated need for defibrillation, with 5 shocks in the week previous. On the day prior to his death the patient's low dose Metoprolol was changed to low dose Sotalol 80 mg twice daily. On the morning of his death, the patient's ICD (which was set to discharge at rates of greater than 170 beats/min with intervals # 353 MS, and with a 29 J biphasic shock) discharged when it sensed a ventricular tachycardia with a rate of approximately 200 beats/min. Over the subsequent minute or so, the ICD discharged five more times at intervals of 13 to 15 s but failed to terminate the arrhythmia, and the patient died.

A full autopsy revealed a mildly obese male with moderate left ventricular hypertrophy (heart weight 800 g). There were large areas of old transmural myocardial infarct in the inferior wall of the left ventricle, with subendocardial involvement of the lateral and anterolateral walls and the septum, and associated with marked scarring of the posterior papillary muscle, and moderate scarring of the anterior one. Changes of heart failure with dilatation and hypertrophy of all cardiac chambers, and with pulmonary edema and visceral congestion were also noted.

The ICD was explanted at autopsy. Its battery/control pack had been placed in the subcutaneous tissue over the patient's left upper anterior chest. The defibrillator was removed in continuity with its lead (Fig. 1), which had been placed via the left innominate vein and the superior vena cava, with tip in right ventricle. Where the lead tip had been in contact with right ventricular endocardium, and where it had delivered its shocks, small patches of endocardial and underlying myocardial fibrous scar were evident.

When the defibrillator was removed it was partially cleaned of tissue and placed on a stainless steel autopsy table. Subsequently, the ICD spontaneously discharged; a loud ''snap'' was heard and, where the ICD lead tip was in contact with the table, a small crater was created, approximately 0.2 cm in diameter. A short time later while it was being further cleaned the ICD again was seen to discharge, while sitting on a moist towel; a small ''puff'' of blue smoke or steam was seen when this happened. The same day the ICD was transferred to the hospital's pacemaker clinic. When the defibrillator's memory was interrogated it became clear that the ICD had discharged 11 times after the patient's death.

Discussion

Implantable cardioverter-defibrillators (ICDs) are pacemaker-like devices that are being used in increasing numbers for patients who have had aborted sudden death, sustained ventricular tachycardia (VT), syncope due to VT, or arrhythmias that are not optimally managed or amenable to ablation or surgery (1–5).

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An ICD consists of two components, a pulse generator and a lead (or leads). The pulse generator is an electrical device containing miniaturized electrical circuitry and battery power cells; it is capable of analyzing the electrical rhythm of the heart and delivering therapeutic anti-tachycardia pacing or countershock impulses to the heart as necessary. Current devices also provide anti-bradycardia pacing. The pulse generator keeps an electronic record of its function; it can be interrogated for that record, and can be reprogrammed, transcutaneously. The pulse generator is inserted surgically, generally subcutaneously over the pectoral muscles (6,7); much less commonly it is placed over the upper abdomen. Currently, a single right venticular lead is most common, placed transvenously at the time of the pulse generator insertion (Fig. 2). Alternatively, multiple transvenous leads in the right ventricle, superior vena cava, or coronary sinus, and even transcutaneous patch or epicardial patch leads (with combinations) are possible.

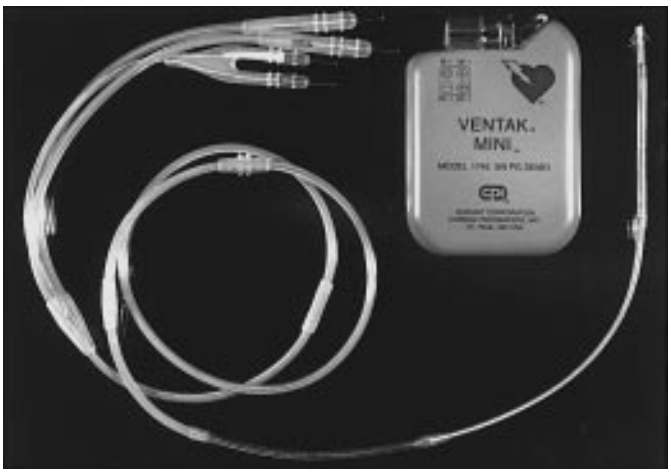

FIG. 1—*This gross photograph is of the ICD of the patient described, and has been removed in continuity with its lead.*

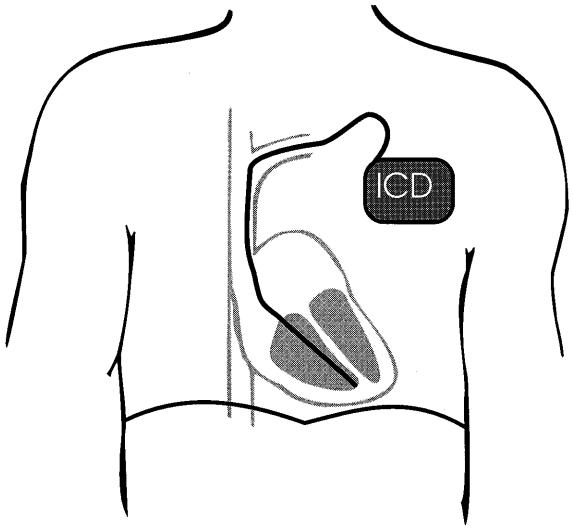

FIG. 2—*This diagram represents the most common ICD configuration, with the pulse generator placed subcutaneously over the left upper anterior chest, and a single transvenous lead via the cephalic and inominate veins and superior vena cava, with its tip in the right ventricular apex.*

Each ICD is described by a NASPE/BPEG Defibrillator (NBD) Code (8) (Table 1). Most current devices have only ventricular lead systems (Fig. 2), but devices with both atrial and ventricular leads are becoming more common. A frequently used configuration is an ICD with the ventricle (V) as the chamber that receives the shock, the ventricle (V) as the chamber that receives anti-tachycardia pacing, that has electrogram (E) anti-tachycardia detection, and that has the ventricle (V) as the chamber that receives anti-bradycardia pacing—referred to, using the scheme in Table 1, as a VVEV ICD.

There are currently many different models of ICDs manufactured. Each patient should carry an identification card detailing the manufacturer, model and programmed features of his/her particular device. If this information is not available, the device can be identified by a code, identified on radiographs of the generator. Information on the types and models of many common ICDs are listed in Table 2, with manufacturer's technical support contact telephone numbers. Each manufacturer produces a variety of models, and can be contacted 24 hours a day for information specific to each device.

Clinicians, as well as anaesthetists and radiologists, must be aware of the functions and hazards of ICDs (9,10). So too must pathologists (11), as examination of an ICD may be an important element of an autopsy. In other cases the pathologist may be asked to aid the family or funeral director by explanting an ICD when a full autopsy is not being performed. Generic recommendations for handling ICD devices applicable to all cases are detailed below, but two overriding cautions should be emphasized. First, before any explantation of the ICD, the device must be deactivated before it can be safely handled. Secondly, whether or not an autopsy is being performed, an ICD pulse generator must never be incinerated (i.e., never accompany a body being cremated), as the pulse generator contains a sealed chemical power cell and capacitors and will explode with incineration.

Generic Recommendations Applicable to the Autopsy Examination or Postmortem Explantation of an ICD

- Obtain permission to remove an ICD. The controlling permission, generally, is with the family of the deceased or the deceased's power-of-attorney (will vary with jurisdiction).
- Verify the manufacturer and model of the ICD through patient

TABLE 1—*Guide to the NASPE/BPEG* Defibrillator (NBD) Code.*

Position of code	I	II	III	IV
Function or site referred to	shock chamber	anti-tachycardia pacing chamber	method of tachycardia detection	anti-bradycardia pacing chamber
Meaning of symbols used	O = None A = Atrium V = Ventricle D = Dual (A + V)	O = None A = Atrium V = Ventricle D = Dual (A + V)	E = Electrogram H = Hemodynamic	O = None A = Atrium V = Ventricle D = Dual (A + V)

* North American Society of Pacing and Electrophysiology/British Pacing and Electrophysiology Group.

TABLE 2—*Common models of ICDs and their important features.*

Model No.	Model Name	Code	Defibrillating Waveform	X-ray ID
	Cardiac Pacemakers Inc. (CPI)/Guidant (Phone number: 1-800-227-3422)			
1400	AID-B	VOEO	Mono	B
1410	AID-B	VOEO	Mono	B
1420	AID-BR	VOEO	Mono	BR
1500	VENTAK 1500	VOEO	Mono	CPI 1500
1510	VENTAK 1510	VOEO	Mono	CPI 1510
1520	VENTAK 1520	VOEO	Mono	CPI 1520
1550	VENTAK 1550	VOEO	Mono	CPI 1550
1555	VENTAK 1555	VOEO	Mono	CPI 1555
1600	VENTAK P	VOEO	Mono	CPI 1600
1620	VENTAK P2	VOEV	Mono/Biphasic	CPI 1620
1625	VENTAK P2*	VOEV	Mono/Biphasic	CPI 1625
1635	VENTAK P3	VOEV	Mono/Biphasic	CPI 1635
1640	VENTAK MINI + HC/S	VVEV	Mono/Biphasic	CPI 1640
1645	VENTAK MINI + S	VVEV	Mono/Biphasic	CPI 1645
1700	VENTAK PRx	VVEV	Mono	CPI 1700
1705	VENTAK PRx	VVEV	Mono	CPI 1705
1710	VENTAK PRx II	VVEV	Mono/Biphasic	CPI 1710
1715	VENTAK PRx II*	VVEV	Mono/Biphasic	CPI 1715
1720	VENTAK PRx III	VVEV	Mono/Biphasic	CPI 1720
1721	VENTAK Prx III HC	VVEV	Mono/Biphasic	CPI 1721
1725	VENTAK PRx III	VVEV	Mono/Biphasic	CPI 1725
1740	VENTAK MINI	VVEV	Mono/Biphasic	CPI 1740
1741	VENTAK MINI +	VVEV	Mono/Biphasic	CPI 1741
1742	VENTAK MINI HC	VVEV	Mono/Biphasic	CPI 1742
1743	VENTAK MINI + HC	VVEV	Mono/Biphasic	CPI 1743
1745	VENTAK MINI	VVEV	Mono/Biphasic	CPI 1745
1746	VENTAK MINI +	VVEV	Mono/Biphasic	CPI 1746
1752	VENTAK MINI II HC	VVEV	Mono/Biphasic	CPI 1752
1753	VENTAK MINI II + HC	VVEV	Mono/Biphasic	CPI 1753
1762	VENTAK MINI II	VVEV	Mono/Biphasic	CPI 1762
1763	VENTAK MINI II + HC	VVEV	Mono/Biphasic	CPI 1763
1810	VENTAK AV	VVED	Mono/Biphasic	CPI 1810
1815	VENTAK AV	VVED	Mono/Biphasic	CPI 1815
	Venitrex (now St. Jude Medical) Inc. (Phone number: 1-800-733-3455)			
V-100	Cadence	VVEV	Mono/Biphasic	V-100
V-100B	Cadence	VVEV	Mono/Biphasic	V-100
V-100C	Cadence	VVEV	Mono/Biphasic	V-100
V-100D	Cadence	VVEV	Mono/Biphasic	V-100
V-105	Cadet LT	VOEV	Mono/Biphasic	V-105
V-105B	Cadet LT	VOEV	Mono/Biphasic	V-105
V-105C	Cadet LT	VOEV	Mono/Biphasic	V-105
V-105D	Cadet LT	VOEV	Mono/Biphasic	V-105
V-110	Cadence	VVEV	Mono/Biphasic	V-110
V-110B	Cadence	VVEV	Mono/Biphasic	V-110
V-110C	Cadence	VVEV	Mono/Biphasic	V-110
V-110D	Cadence	VVEV	Mono/Biphasic	V-110
V-110E	Cadence	VVEV	Mono/Biphasic	V-110
V-112	Cadence	VVEV	Mono/Biphasic	V-112
V-112B	Cadence	VVEV	Mono/Biphasic	V-112
V-112C	Cadence	VVEV	Mono/Biphasic	V-112
V-112D	Cadence	VVEV	Mono/Biphasic	V-112
V-112E	Cadence	VVEV	Mono/Biphasic	V-112
V-115	Cadet	VVEV	Mono/Biphasic	V-115
V-115AC	Cadet	VVEV	Mono/Biphasic	V-115
V-115B	Cadet	VVEV	Mono/Biphasic	V-115
V-115C	Cadet	VVEV	Mono/Biphasic	V-115
V-115D	Cadet	VVEV	Mono/Biphasic	V-115
V-135AC	Contour Lt	VVEV	Mono/Biphasic	V-135
V-135C	Contour Lt	VVEV	Mono/Biphasic	V-135
V-135D	Contour Lt	VVEV	Mono/Biphasic	V-135
V-145AC	Contour	VVEV	Mono/Biphasic	V-145
V-145C	Contour	VVEV	Mono/Biphasic	V-145
V-145D	Contour	VVEV	Mono/Biphasic	V-145

TABLE 2—*Continued*

Model No.	Model Name	Code	Defibrillating Waveform	X-ray ID
		Medtronic Inc. (Phone number: 1-800-328-2518)		
7201B	CD	VOEV	Mono	9J
7201D	CD	VOEV	Mono	TBK
7202C	Jewel CD	VOEV	Mono/Biphasic	TBN
7202D	Jewel CD	VOEV	Mono/Biphasic	TBP
7202E	Jewel CD	VOEV	Mono/Biphasic	PCH
7216A	PCD	VVEV	Mono	SS
7217B	PCD	VVEV	Mono	ZB
7217D	PCD	VVEV	Mono	TBJ
7217IB	PCD	VVEV	Mono	3N
7218B		VVEV	Mono/Biphasic	PCD
7218C		VVEV	Mono/Biphasic	PBT
7218D		VVEV	Mono/Biphasic	PBU
7219B	Jewel PCD	VVEV	Mono/Biphasic	PCB
7219C	Jewel PCD	VVEV	Mono/Biphasic	TBL
7219D	Jewel PCD	VVEV	Mono/Biphasic	PAE
7219E	Jewel PCD	VVEV	Mono/Biphasic	PCE
7220B	Jewel Plus	VVEV	Mono/Biphasic	PCV
7220C	Jewel Plus	VVEV	Mono/Biphasic	PCW
7220D	Jewel Plus	VVEV	Mono/Biphasic	PCY
7220E	Jewel Plus	VVEV	Mono/Biphasic	PDA
7221B	Micro Jewel	VVEV	Mono/Biphasic	PFL
7221Cx	Micro Jewel	VVEV	Mono/Biphasic	PFK
7221E	Micro Jewel	VVEV	Mono/Biphasic	PFM
7223Cx	MicroJewel II	VVEV	Mono?biphasic	PFR
		Telectronics Pacing Systems (Phone number: 1-800-525-7042)		
4202	GUARDIAN ATP	VVEV	Mono	TAJ
4203	GUARDIAN ATP	VVEV	Mono	TPW
4204	GUARDIAN II	VVEV	Mono	TQW
4210	GUARDIAN ATP II	VVEV	Mono	TWV
4211	GUARDIAN ATP III	VVEV	Mono/Biphasic	tIZ
4215	GUARDIAN ATP III	VVEV	Mono/Biphasic	tWW
4310HC	SENTRY	VVEV	Mono/Biphasic	tCL
4310	SENTRYHC	VVEV	Mono/Biphasic	TEJ
		Intermedics, Inc. (Phone number: 1-800-231-2330)		
101-01	Res-Q	VVEV	Biphasic	IEC
101-01R	Res-Q	VVEV	Biphasic	IFC
101-09	Res-Q Micron	VVEV	Biphasic	GN or I-XXX
		Angeion Corporation (Phone Number: 1-800-264-3466)		
2000	Sentinel	VVEV	Mono/Biphasic	AN 2000
2010	Sentinel	VVEV	Mono/Biphasic	AN 2020
2011	Sentinel	VVEV	Mono/Biphasic	AN 2011
2012	Sentinel	VVEV	Mono/Biphasic	AN 2012

history, device identification card, and/or device radiographic markers.

- Interrogate the ICD with the manufacturer's programmer (an electronic device used to query the ICD's memory function and change its function settings; if a programmer is not available, call the manufacturer's representative to assist in the explantation of the device) and print out all diagnostics and electrograms. If this step is not followed valuable information contained in the device's memory, and potentially relevant to determining the cause of the patient's death, may be lost.
- Turn the ICD off (program to ''All Functions Off'') to prevent unwanted and potentially dangerous shocks, i.e., deactivate the pulse generator before post-mortem examination or explantation. This is done with the manufacturer's programmer. If a device must be removed without a programmer available, it should not deliver a shock if a doughnut-shaped magnet (Fig. 3) is placed directly over the pulse generator.
- Remove the ICD starting with an incision over the generator implant site. The ICD is externalized and the lead(s) disconnected

FIG. 3—*This gross photograph is of a typical doughnut-shaped magnet (obtainable from ICD manufacturers) which may be used in urgent situations to deactivate an ICD.*

from the ICD. The ICD lead(s) has a metal connector and can easily be disconnected with the appropriate tool (the leads are connected to the ICD by small setscrews; small Allen wrenches are used to remove the setscrews that are concealed beneath a silicone rubber seal in the connector portion of the ICD. The disconnected lead(s) can be drawn through the chest wall and removed in continuity with the heart and great vessels for further examination (to ensure there are no lead-related complications present). Alternatively, if the generator cannot be disconnected from the lead(s), the pulse generator can be removed in continuity with the leads and tissues by passing it through an incision in the chest wall. Less desirable, but occasionally necessary, is cutting of the lead(s) from the pulse generator.

- Fill out a manufacturer's explant report, if available.
- Clean and disinfect the device. Wash, but do not submerge, the pulse generator and the leads to remove body fluids and debris using a disinfectant solution. Do not allow fluids to enter the pulse generator's lead ports, and do not submerge the device in fluid.
- Return the ICD along with the Explant Report to the manufacturer. Do not remove, clean, or ship the pulse generator unless it has been disabled. Request a detailed report of the device's function from the manufacturer.

There is a variety of complications of ICD implantation (1–4,7). Early clinical complications may relate to progression of the preoperative or comorbid conditions, or to complications of the operative procedure. The latter are markedly lower, and therefore overall survival rates improved, when endocardial lead systems are used (3,7). Subsequent complications may relate to device-related problems. These may be pulse generator-related, including: generator failure; oversensing, or inappropriate discharge or other function; interrogation of the device should demonstrate these. Other complications may be lead- or lead-connector related, including inappropriate lead positioning, cardiac perforation by the lead, lead coiling, lead migration, lead deterioration, and/or lead breaks; careful examination of the lead system in situ, and later by the manufacturer will identify these. A careful autopsy examination should reveal infection of the device or its lead(s), hematomas formed around the pulse generator, or intravascular leads which are complicated by thrombosis. The pathologist may be an invaluable contributor to identifying these important complications, but must remember to approach such devices cautiously and with a considered and thorough approach.

References

1. Nunain SO, Roelke M, Osswald S, et al. Limitations and late complications of third-generation automatic cardioverter-defibrillators. Circulation 1995;91:2204–13.
2. Porterfield JG, Porterfield LM, Smith BA, et al. Experience with three different third-generation cardioverter-defibrillators in patients with coronary artery disease or cardiomyopathy. Am J Cardiol 1993;72:301–4.
3. The PCD Investigator Group. Clinical outcome of patients with malignant ventricular tachyarrhythmias and a multiprogrammable implantable cardioverter-defibrillator implanted with or without thoractotomy: an international multicenter study. J Am Coll Cardiol 1994;23:1521–30.
4. Bardy GH, Hofer B, Johnson G, et al. Implantable transvenous cardioverter-defibrillators. Circulation 1993;87:1152–68.
5. Ashtar M, Jazayeri M, Sra J, et al. Implantable cardioverter defibrillator for prevention of sudden cardiac death in patients with ventricular tachycardia and ventricular fibrillation: ICD therapy in sudden cardiac death. PACE 1993;16:511–8.
6. Hammel D, Block M, Geiger A, et al. Single-incision implantation of cardioverter defibrillators using nonthoracotomy lead systems. Ann Thorac Surg 1994;58:1614–6.
7. Lawton JS, Ellenbogen KA, Wood MA, et al. Clinical experience with nonthoracotomy cardioverter defibrillators. Ann Thorac Surg 1995;59:1092–9.
8. Bernstein AD, Camm AJ, Fisher JD, et al. NASPE policy statement: the NASPE/BPEG defibrillator code. PACE 1993;16:1776–80.
9. Bourke ME. The patient with a pacemaker or related device. Can J Anaesth 1996;43:R24–R32.
10. Davidson T, Harper P, Wenk A. Implantable cardioverter defibrillators: a guide for clinicians. Heart Lung 1994;23:205–15.
11. Prahlow JA, Guileyardo JM, Barnard JJ. The implantable cardioverter-defibrillator: a potential hazard for autopsy pathologists. Arch Pathol Lab Med 1997;121:1076–80.

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