Management of the Patient With an Implantable Cardioverter-Defibrillator in the Third Millennium

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Implantable cardioverter-defibrillator (ICD) devices were originally developed for prevention of sudden cardiac death (SCD). They are now widely regarded as the primary therapy for this condition. Clinical trials have led to a progressive expansion in indications for their use. Recent clinical reports show effectiveness of these devices in patients with recurrent syncope, in the prevention of SCD in high-risk patients with coronary disease, and in the treatment of atrial fibrillation. Refinements in ICD technology have improved functionality and enhanced safety. Optimal patient management requires intimate knowledge of these complex devices and of the diverse arrhythmias that may be treatable by a single multifaceted ICD device.

Case Study
A 75-year-old man presented with near-syncope and ventricular arrhythmias. He had a past history of dilated cardiomyopathy, old cerebrovascular accident, symptomatic atrial flutter/ fibrillation, and heart failure. He had been treated with anticoagulation and antiarrhythmic drugs, but it was noted on admission that he was in atrial flutter with a ventricular rate of 110 bpm. Electrophysiological evaluation revealed isthmus- (common or typical) and nonisthmus- (atypical) dependent atrial flutter and inducible hypotensive monomorphic sustained ventricular tachycardia. A linear ablation of the tricuspid valve-inferior vena cava isthmus interrupted common flutter, but atypical flutter persisted. The following day, a dual chamber ICD capable of defibrillation and antitachycardia, as well as standard demand pacing in both chambers, was inserted. An additional coronary sinus lead was placed to permit dual site right atrial pacing for prevention of atrial flutter and fibrillation (Figure 1A). The patient was given a handheld activator for termination of atrial fibrillation (AF) and flutter.

Advances in ICD Technology
Over two decades, ICDs have evolved into multifunctional therapeutic and monitoring devices. Currently available devices can provide atrial pacing, rate-responsive pacing, and atrial antitachycardia pacing and defibrillation. New algorithms provide reliable discrimination of supraventricular and ventricular tachyarrhythmias and prevent arrhythmias. Diagnostic and monitoring capabilities enable the ICD to evaluate its own component functions and permit automated testing functions for system performance, record of arrhythmic events, and delivered interventional therapies. It can store information relative to patient or arrhythmia status. ICD generator longevity has now improved so that most devices are rated for 4 or more years, depending on the electrical current drain for activated features.

Single Chamber Ventricular ICD Technology
In its simplest iteration, the ICD device is capable of detecting and treating ventricular tachyarrhythmias and permitting ventricular pacing and monitoring of ventricular rhythm. Ventricular rhythm detection in these systems is based on ventricular electrogram rate, regularity, morphology, and patterns of electrogram interval changes. In general, a minimum of two-zone programming is usually performed for discrimination of a monomorphic ventricular tachycardia from ventricular fibrillation. In some instances, when prophylaxis from ventricular fibrillation alone is needed, as in patients with long QT syndrome, a single zone may suffice. When empirical programming is sought in patients with VT or cardiac arrest, we prefer to estab-
lish three zones for “slow” ventricular tachycardia, “fast” monomorphic ventricular tachyarrhythmias, and ventricular fibrillation. Such discrimination is useful for clinical and therapeutic purposes. The slowest zone is usually associated with nonsyncopal rhythms, and these are often responsive to antitachycardia pacing. Antitachycardia pacing is most effective in termination of monomorphic ventricular tachycardia, especially with rates below 180 bpm, and has efficacy rates of >80%. The second zone is often associated with significant symptoms, but early cardioversion with a rapid change time and a lower energy shock may abort syncope. For cardioversion of fast ventricular tachycardia, a 5-joule biphasic waveform shock can achieve approximately 80% success. Ventricular fibrillation produces syncope in many patients and requires a highly effective shock. Initial defibrillation energy programming is based on the defibrillation threshold. Repeated efficacy of the lowest successful energy is needed to place the shock near the threshold, with three successive or repeated successful terminations being needed for this level of efficacy (Figure 1B). An increasing trend to limit device testing may compromise confidence in the ICD’s ability to defibrillate when new drugs, heart failure, or ischemia potentially raise defibrillation thresholds.

Electrogram morphology is now available to differentiate supraventricular and ventricular tachyarrhythmias. In the absence of intraventricular conduction abnormalities, supraventricular rhythms can often be identified by matching their ventricular electrogram

Figure 1. A, Lateral radiograph of the chest showing the first dual chamber atrioventricular defibrillator inserted in patient with refractory atrial fibrillation. Note the distinct atrial and ventricular pacing and defibrillation leads. An additional coronary sinus pacing lead is placed outside the ostium for dual site right atrial pacing. B, Noninvasive electrophysiological stimulation to evaluate ventricular defibrillation efficacy in a dual chamber ICD. The top trace shows atrial electrograms, the middle trace shows current application, and the lower trace shows ventricular electrograms. P and R markers are annotations of the two electrograms and intervals are shown in ms. A DC current is applied during sinus rhythm and initiates both atrial and ventricular fibrillation. Both rapid rhythms are detected and correctly diagnosed with AV dissociation. Ventricular defibrillation is performed with a 541 V leading edge voltage shock that terminates both rhythms. C, Programmer screen shows measured data on atrial and ventricular lead function in dual chamber ICD. D, Arrhythmia logbook showing episodes of ventricular fibrillation with time-date stamp and access to stored electrograms in a dual chamber ICD.
morphology to a sinus rhythm template. Monitoring and testing functions provide for more automated device-based testing, with expanded capabilities that include continuous arrhythmia detection and noninvasive electrophysiological testing (Figure 1C and Movie). An additional feature specific to defibrillators is the capacitor charge time to maximal shock delivery. This used to be a key manual test performed at follow-up but now can be automatically initiated by the device at prespecified intervals of time. Charge times in excess of 12 seconds merit close attention and frequent follow-up, and those in excess of 15 seconds merit generator replacement. During follow-up, the patient’s arrhythmia history is readily available. Tachyarrhythmic events are logged, their durations are recorded, and in most devices, recorded ventricular electrograms are available for a segment of the event (Figure 1D). These monitoring capabilities also contribute to substantial electrical current drain and can limit longevity if used indiscriminately.

**Dual Chamber Ventricular ICD Technology**

Dual chamber ICDs require the insertion of an additional bipolar lead in the right atrium. Tachycardia discrimination in these devices uses rate-based detection algorithms overlaid with pattern analysis of atrial and ventricular electrogram relationships. Difficulties remain when AV relationships are fixed and the rates are identical. Rules for discrimination have been established in device logic and are highly individualized for each device. Thus, inappropriate atrial lead placement can seriously impair tachyarrhythmia detection. Rate response is based on an activity sensor, and multisensor devices are still awaited.

Contemporary indications for dual chamber ICD insertion in patients with ventricular arrhythmias include the standard indications for dual chamber pacing. Dual chamber ICDs are also preferred in patients with coexisting atrial and ventricular tachyarrhythmias, as they enable discrimination of the two types of rhythm disturbances.

**Dual Chamber Atrioventricular ICD Technology**

Dual chamber atrioventricular ICD technology is the latest arrival on the ICD technology scene. Individualized atrial and ventricular antitachycardia therapies can be delivered, thus expanding the potential ICD population of patients who may benefit from an ICD. Initial studies have been conducted in patients with atrial fibrillation who may or may not have coexisting lethal ventricular tachyarrhythmias. Because the pool of patients with atrial fibrillation is very large and atrial cardioversion is a commonly used procedure, the future of this technology in a “hybrid” therapy format, as used in this patient, is quite bright.

The atrial channel permits classification of and zone-based therapy for atrial tachyarrhythmias. It requires insertion of an additional atrial defibrillation electrode. Atrial tachyarrhythmia detection is based on a two-zone stratification, with a monomorphic tachycardia zone for atrial tachycardias and flutter and an AF zone. Anti-tachycardia pacing is available in the tachycardia zone using burst, ramp, or 50 Hz trains. Such 50 Hz trains have been demonstrated to be effective in previously pacing-resistant atypical flutter, with efficacy rates up to 60%. Backup shock therapy is used if pacing therapies are ineffective. In the AF zone, 50 Hz pacing and shock therapy alone are available (Figure 2). Rapid atrial flutter may be classified and pace-terminated, but established AF rarely responds to this modality. Atrial defibrillation shocks have similar principles of efficacy to ventricular defibrillation. A sigmoid defibrillation efficacy curve exists, and thresholds vary widely with lead configuration. In clinical studies, reliable atrial defibrillation has been obtained with shock energies up to 27 joules. Newer iterations of these devices include pacing prevention algorithms such as continuous atrial pacing for AF prevention. Finally, a handheld patient activator is available for delivery of therapy on demand by the patient or physician. Dual chamber atrioventricular defibrillators have been approved for use in patients with drug-refractory and symptomatic atrial fibrillation and in patients with coexisting symptomatic atrial and ventricular tachyarrhythmias.

**Multisite Pacing ICDs**

The latest development is the inclusion of multisite atrial or ventricular pacing in dual chamber ICDs. In the above-mentioned patient, an additional coronary sinus ostial pacing lead was inserted. Dual site right atrial pacing is used to prevent of symptomatic AF and flutter. Dual site right atrial pacing reduces intra-atrial conduction delay, abbreviates P wave duration, prolongs the time to recurrent AF in patients on class 1 or 3 antiarrhythmic drug therapy 2, reduces AF burden, and improves left atrial filling fraction and A wave velocity on echocardiography. Programming to avoid oversensing in the ventricle and atrium is important for optimal device function. This mode can reduce the need for cardioversion and improve efficacy of “hybrid” therapy.

Similarly, biventricular pacing has been used for ventricular resynchronization in patients with left bundle branch block, first degree AV block, and refractory class 2 or 3 congestive heart failure. In this system, a coronary sinus pacing lead is inserted into the posterolateral left ventricular vein or, as far as clinically feasible, into the distal coronary sinus or its tributaries (Figure 3). Simultaneous pacing at the venous site and the right ventricular apex can abbreviate QRS duration in patients with moderate and severe left bundle branch block (QRS duration >140 ms) and improve left ventricular hemodynamics and exercise capacity. These ICDs achieve both sudden death risk reduction and improved hemodynamics.

**Updated Indications for ICD Therapy**

American College of Cardiology/American Heart Association guidelines for the use of the ICD in ven-
ular tachyarrhythmias were published in 1998. New indications for ICD therapy in 2002 may now include asymptomatic patients at high-risk for lethal ventricular arrhythmias and drug-refractory symptomatic atrial tachyarrhythmias.

Implantable Defibrillators for Primary Prevention of Ventricular Arrhythmias

Subgroups of the patients with the following findings have been or are being actively evaluated for primary prevention of malignant ventricular tachyarrhythmias.

1. Nonsustained Ventricular Tachycardia With Coronary Artery Disease and Left Ventricular Dysfunction. This patient group is the first primary prevention category evaluated in the Multicenter Automatic Defibrillator Implantation Trial-1 (MADIT-1) study. This category of patients has long been recognized to have a high propensity for sudden death. The MADIT-1 study demonstrated a 54% reduction in relative risk of death in these patients as compared with drug therapy. It has been estimated that approximately 3% to 7% of acute myocardial infarction survivors will eventually be stratified into this subgroup.

2. Familial Syndromes With High Risk of Sudden Death. The guidelines recognized several important but small patient groups that have familial or acquired diseases that predispose them to sudden death. In most of these categories, small clinical series or pilot data and expert consensus led to adoption of the indication. This includes high-risk patients with congenital long QT or Brugada syndromes, hypertrophic cardiomyopathy, and arrhythmogenic right ventricular dysplasia. A family history of sudden death is a key element in selection of the ICD as a primary prevention therapy.

3. Refractory Heart Failure Necessitating Cardiac Transplantation. Data from cardiac transplant centers has documented an inordinately high risk of sudden death in individuals awaiting cardiac transplantation. In these individuals, pilot data has shown appropriate ICD prevention of malignant ventricular tachycardias.

4. Coronary Artery Disease With Left Ventricular Dysfunction and Left Ventricular Ejection Fraction of <31%. The role of left ventricular dysfunction as an important determinant of survival benefit with defibrillator therapy has been highlighted. The MADIT-2 study evaluated the hypothesis that patients with coronary disease and myocardial infarction who had an LV ejection fraction <31% would have improved survival with defibrillator insertion. The trial demonstrated a 30% reduction in relative risk, which was estimated to decline from a projected 19% two-year mortality to an actual 14% mortality with defibrillator insertion. Important analyses are in progress to identify the subgroup(s) that derive the most benefit. Initial analyses suggest that these subgroups could include electrophysiological markers, as well as other clinical markers.

Conclusions

New, increasingly complex and rapidly evolving ICD technology has widened indications and clinical application of these devices. Management of
the present day ICD patient requires intimate knowledge of new device technology and well-organized programs with facilities for the ICD patient and device surveillance.

References

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