

Recent Advances in Dual-Chamber ICD Therapy

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Summary

This article provides historical data regarding the development of the implantable cardioverter-defibrillator (ICD). The advantages and disadvantages of single- and dual-chamber ICDs are discussed in view of the treatment of ventricular tachycardia. Recently, dual-chamber ICDs have been developed to provide DDDR pacing and sensing information from the atrium, with the hopes of improving diagnostic specificity for supraventricular arrhythmias, without sacrificing the sensitivity of detection of ventricular tachycardia and ventricular fibrillation.

Key Words

Implantable cardioverter-defibrillator (ICD), arrhythmia detection, single-chamber ICD, dual-chamber ICD

Introduction

Sudden cardiac arrhythmic death is a common problem usually resulting from ventricular fibrillation (VF) that is sometimes preceded by monomorphic or polymorphic ventricular tachycardia (VT). For several years, empirically tailored antiarrhythmic drug therapy was the only method of treatment. In the early 1980s, an electrophysiological examination was the method to evaluate and control the use of these drugs, particularly through serial drug testing or a parallel study.

This was followed by the introduction of non-pharmacologic therapies including the use of an implantable cardioverter-defibrillator (ICD), ablative surgery, transcatheter ablation, and, in selected individuals, cardiac transplantation to treat those patients. ICDs represent a category of medical devices that have revolutionized the treatment of patients at risk for sudden death. The antiarrhythmic capabilities, implant methods, and clinical indications for these devices have increased rapidly since Mirowski implanted the first automatic defibrillator in man [1,2]. Early ICDs were primitive by current standards. The generators were bulky, nonprogrammable, and without cardioversion capability. A thoracotomy was required to position at least one defibrillation patch epicardially. The subsequent generations of ICDs made it possible to program the rate and duration for arrhythmia detection, as well as the initial shock energy.

In the early 1990s, the advent of transvenous-subcutaneous defibrillation leads obviated the need for thoracotomy [3]. The adoption of biphasic shock waveforms improved defibrillation efficiency, and the addition of extensive telemetric and diagnostic capabilities refined patient follow-up. Current tiered-therapy ICDs deliver not only high-energy defibrillation shocks, but also low-energy shocks and antitachycardia pacing for VT, and back-up pacing for bradyarrhythmias. The ICDs are < 60 ml in size and are implanted transvenously with techniques similar to those used in standard pacemakers. These advances, coupled with improved understanding of the limitations of antiarrhythmic drugs, have resulted in an exponential increase in the number of ICDs implanted worldwide, mainly in a group of patients that is at an increasingly greater risk. However, the widespread use of ICDs also brought complications and device interactions that were never dealt with before. The need for frequent replacements, infections, and access-related problems demanded development of systems that could incorporate all functions needed to treat ailing cardiac patients using a single device. It was clear that up to 40 % of patients received inappropriate shocks for supraventricular tachycardias (SVTs) [4]. Programming strategies to decrease the incidence of inappropriate device intervention were developed, but they could not entirely solve the problem, even

though they decreased the frequency. Undersensing and oversensing was also an issue, especially in those who also had permanent pacemakers implanted.

So the emergence of a single device with DDDR pacing capabilities and ventricular antitachycardia therapies was very attractive. These devices can also use the atrial channel for sensing, making possible the development of strategies to better discriminate between SVT and VT; as a result, inappropriate shocks were avoided and dangerous ventricular arrhythmias did not go undetected. Other advantages of these devices are the sparing of access sites for future replacements, no interference between ICD and pacemaker functions, smaller number of implanted leads, and easier handling and device programming. Patients with severe ventricular dysfunction also can benefit from maintaining atrioventricular (AV) synchrony and maybe a decreased incidence of atrial fibrillation (AF) episodes. Electrophysiologists also can learn a great deal of information about the mechanisms of sudden death and arrhythmogenesis, and tailor therapy accordingly.

Single-Chamber ICD Arrhythmia Detection

The basic principle of ICD arrhythmia detection is to maximize sensitivity for ventricular arrhythmias, even though at the same time specificity is inevitably lost. In other words, the ICD cannot miss a potentially fatal, fast ventricular rate (VT or VF); the price to pay is that sometimes therapies are applied for non-life-threatening SVTs. Over the past few years, algorithms have been developed to recognize all ventricular rhythms and, at the same time, avoid unnecessary therapies [5]. The heart rate criterion is the most important for detecting a tachycardia, and determines whether or not the patient has a tachycardia that should be treated. However, it does not differentiate SVT from VT. After it has been established that a fast ventricular rate is ongoing, the device has to define its origin to apply the best therapy. Different zones of tachycardias can be programmed so that specific therapies can be delivered to each of them. In this way, extremely fast ventricular rates are dealt with as if they are always ventricular in origin, with therapy being very aggressive – antitachycardia pacing or shocks. This is because very fast rates are likely to cause hemodynamic deterioration, even if they are supraventricular. In order to avoid sudden death, it is better to have an inappropriate therapy for SVT than not initiate therapy for a VT.

Slower ventricular rates can be more thoroughly analyzed and less aggressive therapies can be applied only after certain other criteria of ventricular origin are met. Therefore, even when a VT is present, its slower rate is probably better-tolerated, giving the chance for a better analysis. A shock can then be avoided or delayed. Antitachycardia pacing can be all that is required; this form of therapy is much better tolerated and spares battery energy. It is important to note that these zones are arbitrarily defined and have to be tailored to the individual patient. It has to take into account the clinical tachycardias present, the tolerability and characteristics of inducible tachycardias, the degree of ventricular dysfunction, and associated atrial arrhythmias.

When tiered-therapy ICDs detect VT only by rate criteria, inappropriate therapy for SVT occurs in up to 40 % of treated patients. This is an even greater problem than it was with earlier ICDs because the probability of rate overlap between the target VT and SVT is greater. Pacing therapies delivered during SVT may induce VT; and cardioversion can induce AF, which may in turn be sensed as VT and treated with pacing, thereby reinitiating VT. For these reasons, tiered-therapy ICDs include detection-enhancement algorithms to discriminate VT from SVT [6,7]. Onset and stability, and ventricular morphology are the most common parameters that have been used to differentiate SVT from ventricular arrhythmias.

Interval-stability algorithms attempt to discriminate VT from AF by rejecting irregular arrhythmias that fulfill the rate criteria. The active algorithms vary, depending upon the manufacturers. Basically, the device withholds therapy if a predetermined degree of cycle length variation is met. The ICD continues to analyze stability as long as the rate criterion is satisfied. Therapy is delivered as soon as the cycle length variance is less than the programmed value; otherwise, therapy is inhibited.

Onset algorithms attempt to discriminate sinus tachycardia from VT by rejecting tachycardias in which the rate increases gradually. A sudden onset is compatible with VT, and thus therapy is not inhibited. As for stability criteria, each manufacturer uses different algorithms. Usually, if an average of 9 to 34 % difference is exceeded during the first tachycardia beats, the sudden onset criteria is met.

Optimal programming of onset and stability criteria can reduce inappropriate therapy of SVT by more than 80 % with less than 1 % underdetection of hemodynamically stable VT. In the absence of antiarrhythmic

drugs, stability algorithms are highly specific for rejecting AF with ventricular rates of less than 170 beats/min while producing minimal delays in detection of monomorphic VT. Antiarrhythmic drugs may decrease the stability of monomorphic VT. Appropriately programmed stability algorithms delay, but almost never prevent, detection of monomorphic VT because stability is evaluated continuously.

In contrast, onset algorithms prevent detection of VT if the rhythm is not classified correctly by the initial evaluation. This occurs under the following conditions:

- VT occurs during sinus tachycardia without abrupt onset;
- It occurs with abrupt onset, but during sinus tachycardia with cycle length in the VT zone;
- The initial VT cycle length exceeds the VT detection interval followed by gradual acceleration across this detection boundary;
- Undersensing occurs at the onset of VT. For these reasons, some investigators recommend that onset algorithms be programmed in conjunction with a sustained-duration override to prevent VT underdetection.

The morphology algorithms, which discriminate VT from SVT based on electrogram morphology, provide an alternative method for discrimination that does not depend on a correct classification of one or a few intervals. They were not applied in early ICDs because the required calculations exceeded the capability of the microprocessors in these devices. They are complex algorithms. Many practical issues may limit the utility of these measurements when used to supplement rate detection algorithms. Clearly, bundle branch block or any type of aberrant conduction may confound these measurements. Electrogram amplitude and morphologies undergo a considerable change during the first few months after implantation, owing to growth of a fibrotic capsule over the electrodes and lead. Sympathetic tone, exercise, heart rate, lead maturation and other sources of variability are known to alter the amplitude and shape of intracardiac electrograms.

Recommendations for Programming Detection Enhancements

It is important to make sure that single-chamber detection enhancements should be programmed only in rate zones that correspond to hemodynamically stable VT. Onset and stability algorithms should be programmed together; the best recommended values are 40 ms and

9 %. Onset algorithms should be programmed only in conjunction with a sustained-duration algorithm, or if the patient-specific risk of failure to detect VT in the VT zone is judged acceptable. Sustained-duration algorithms make sure that if the tachycardia persists long enough (quantitatively programmed), therapy is applied even though there was an inhibitory criterion present. Consequently, a VT therapy could be delayed but not prevented.

Morphology algorithms may be programmed in patients with hemodynamically stable, monomorphic VT who are at risk for any SVT in the VT zone. They may be particularly valuable for discrimination of VT from atrial flutter, and as an alternative to onset algorithms for discrimination of sinus tachycardia from VT.

Dual-Chamber Detection of Ventricular Arrhythmias

The addition of an atrial lead to the ICD system was a great step forward in discrimination algorithms [5,8]. Besides being able to pace the atrium, this lead can more importantly register intracavitary electrograms, thus allowing the atrial activation pattern to be analyzed during an episode of tachycardia. Dual-chamber detection algorithms use atrial and ventricular timing to discriminate SVT from VT [9]. During tachycardia, detecting an AV dissociation with a ventricular rate greater than the atrial rate indicates a diagnosis for VT. In this instance, therapy can be delivered without any delays and with a high degree of accuracy. In some devices, this is a security function that will enable delivery of therapy, independent of fulfillment of other programmed criteria.

Other criteria that can provide an additional level of certainty regarding inhibition of therapy for rapidly conducted atrial arrhythmias are the AF rate threshold, usually above 200 beats/min and the ventricular rate > atrial rate. The former is an enhancement criterion used in conjunction with the stability algorithm, and is intended to permit therapy for irregular VT in the absence of evidence of AF. The ventricular rate > atrial rate uses the relationship between average atrial and ventricular rates to overrule either or both of the onset and stability inhibitors. It supersedes these inhibitors if the average ventricular rate exceeds the atrial rate by more than 10 beats/min. It is intended to permit therapy for gradual-onset VT without 1:1 ventriculoatrial conduction.

Up to one-third of patients with a slow, hemodynamically stable VT have 1:1 retrograde conduction. The occurrence of 1:1 SVT with long AV times may lead to misclassification of SVT as VT. However, pre-existing atrial arrhythmias or one that begins after the onset of VT may complicate accurate determination of the relationship between atrial and ventricular electrograms. Various algorithms have been designed to make this distinction as accurate as possible [9,10].

Algorithm for Discriminating SVT from VT in a Dual-Chamber ICD

There are several different algorithms to discriminate SVT from VT; among them are morphologic analysis, the onset algorithm, and single atrial extrastimulus. The morphologic analysis can be used to discriminate tachyarrhythmias with a 1:1 AV relationship. Correlation waveform analyses can successfully discriminate antegrade from retrograde atrial depolarization wave shapes, but the algorithms are extremely complex.

Algorithms based on a neural network morphology using a classification with a decision tree for timing analysis, and a multiway sequential hypothesis testing algorithm that calculates the likelihood of a function from PR intervals were also evaluated. Implantable cardioverter defibrillator manufacturers have developed dual-chamber detection algorithms with markedly different designs. Some systems use atrial data only to prevent onset and stability algorithms from withholding appropriate therapies, but not to improve the specificity of VT therapy. This is in contrast to systems that use dual-chamber data to discriminate SVT from VT [11]. Sudden onset criteria can discriminate between sinus tachycardia with 1:1 AV conduction rate and VT with retrograde conduction [12]. Nevertheless, a weakness of this method is that VT initiated by a SVT will be misclassified as SVT and therapy inappropriately withheld.

Another algorithm used the effect of a single atrial extrastimulus delivered with a prematurity of 80 to 120 ms to classify the tachycardia with a 1:1 AV relationship. These atrial extrastimuli failed to alter the subsequent RR intervals by more than 10 ms in VTs, but shortened the subsequent RR interval for conducted SVTs. This method however, may classify SVT as VT if the extrastimulus blocks the AV node. It may also classify VT as SVT if ventricular capture occurs. Further, atrial extrastimuli may be proarrhythmic in either the atrium or the ventricle.

Comparison of Single- and Dual-Chamber Detection

Single- and dual-chamber detection enhancements have not been compared prospectively in a large trial. Initial reports indicate that nominal programming of first-generation dual-chamber algorithms perform comparably to optimal programming of single-chamber detection enhancements. However, there are also some reports showing a similar number of inappropriate therapies when comparing the two different devices. Dual-chamber detection has several specific advantages:

- Nominal programming of dual-chamber algorithms is simpler than optimal patient-specific programming of single-chamber algorithms; these have been applied infrequently in clinical practice because of their complexity and device-specificity.
- Physicians may be more concerned about actively causing underdetection of VT by specific programming than about inherent ICD limitations of inappropriate shocks.
- Dual-chamber algorithms that analyze PP, RR, RP, and PR patterns and rates improve discrimination of atrial tachycardia from VT and correctly classify irregular VT without 1:1 ventriculoatrial conduction.
- It is likely that discrimination of sinus tachycardia will be improved.
- Dual-chamber electrograms may increase physician confidence in the analysis of stored electrograms.

At present, limitations of dual-chamber algorithms include:

- Atrial-sensing problems, e.g., far-field R-waves, leading to misclassification;
- Tradeoffs between problems of crosstalk versus under-sensing caused by cross-chamber blanking periods;
- Discrimination of VT with 1:1 retrograde conduction from sinus tachycardia or other 1:1 SVTs;
- Discrimination of simultaneous VT and SVT (double tachycardia) from rapid, regular conduction of SVTs.

It is not yet known which patients will actually benefit from dual-chamber detection algorithms to discriminate SVT from VT, taking into consideration the additional complexity, expense, and battery consumption [13]. Those who do not benefit however, are those whose sinus tachycardia or atrial arrhythmias are not conducted at cycle lengths below the VT detection zone.

Dual-Chamber Pacing

The capability of DDD pacing along with antitachycardia pacing and shock therapies was one of the greatest advantages of dual-chamber ICDs since device interactions with permanent pacemakers is a considerable problem [14]. We have learned recently that DDD pacing and enhanced appropriate therapy are not the only advantages of the dual-chamber ICD. Through research studies, a greater understanding of new mechanisms of arrhythmias through the atrial channel has been gained [15]. For instance, sinus tachycardia was shown to be the most common SVT preceding the onset of VT, despite the use of beta-blockers. Also, it was shown that patients who developed sinus tachycardia after the onset of VT could benefit significantly from beta-blocker therapy; its administration could reduce VT incidence and improve response to antitachycardia pacing shock. As a result, a new field for dual-chamber ICD research involves a greater insight into the mechanisms that contribute to ventricular arrhythmias, as well as a better interpretation of arrhythmia detection and therapy outcome. Information from the atrial chamber could allow better device programming and individualization of drug therapy.

Conclusion

Dual-chamber ICDs have been developed to provide DDDR pacing and sensing information from the atrium, with the hope of improving diagnostic specificity for supraventricular arrhythmias without sacrificing the sensitivity of VT and VF detection. A recently described advantage of these devices over single-chamber ICDs is the possibility of better device programming, and individualization of therapy for ventricular arrhythmias, along with a better understanding of arrhythmogenesis.

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