Detection of Atrial Fibrillation and Flutter by a Dual-Chamber Implantable Cardioverter-Defibrillator

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Background—To distinguish prolonged episodes of atrial fibrillation (AF) that require cardioversion from self-terminating episodes that do not, an atrial implantable cardioverter-defibrillator (ICD) must be able to detect AF continuously for extended periods. The ICD should discriminate between atrial tachycardia/flutter (AT), which may be terminated by antitachycardia pacing, and AF, which requires cardioversion.

Methods and Results—We studied 80 patients with AT/AF and ventricular arrhythmias who were treated with a new atrial/dual-chamber ICD. During a follow-up period lasting 6±2 months, we validated spontaneous, device-defined AT/AF episodes by stored electrograms in all patients. In 58 patients, we performed 80 Holter recordings with telemetered atrial electrograms, both to validate the continuous detection of AT/AF and to determine the sensitivity of the detection of AT/AF. Detection was appropriate in 98% of 132 AF episodes and 88% of 190 AT episodes (98% of 128 AT episodes with an atrial cycle length <300 ms). Intermittent sensing of far-field R waves during sinus tachycardia caused 27 inappropriate AT/AF detections; these detections lasted 2.6±2.0 minutes. AT/AF was detected continuously in 27 of 28 patients who had spontaneous episodes of AT/AF (96%). The device memory recorded 90 appropriate AT/AF episodes lasting >1 hour, for a total of 2697 hours of continuous detection of AT/AF. During Holter monitoring, the sensitivity of the detection of AT/AF (116 hours) was 100%; the specificity of the detection of non-AT/AF rhythms (1290 hours) was 99.99%. Of 166 appropriate episodes detected as AT, 45% were terminated by antitachycardia pacing.

Conclusions—A new ICD detects AT/AF accurately and continuously. Therapy may be programmed for long-duration AT/AF, with a low risk of underdetection. Discrimination of AT from AF permits successful pacing therapy for a significant fraction of AT. (Circulation. 2000;101:878-885.)

Key Words: atrial fibrillation - defibrillators, implantable - arrhythmia - atrial flutter

Sensing and detection requirements for implantable cardioverter-defibrillators (ICDs) that treat atrial fibrillation (AF) and atrial tachycardia/flutter (AT) differ from those for ventricular ICDs and dual-chamber pacemakers. Because AF is usually hemodynamically stable and frequently terminates spontaneously, it may be desirable to delay painful and potentially proarrhythmic atrial defibrillation shocks for periods ≥24 hours. To achieve this goal, an ICD must sense low and varying-amplitude AF electrograms and detect AF continuously. It must distinguish continuous AF, which may require shocks, from termination and subsequent reinitiation of AF, for which shocks should be withheld. However, atrial sensing of far-field R waves should not cause inappropriate detection of AT/AF. Further, an atrial ICD should discriminate between AT, which may be terminated by antitachycardia pacing, and AF, which requires cardioversion.

A new dual-chamber ICD (Medtronic Jewel AF 7250) detects specific atrial and ventricular tachyarrhythmias; has independently programmable therapy for AT, AF, ventricular tachycardia (VT), and ventricular fibrillation (VF); and functions as a DDD pacemaker. We studied patients treated with this ICD to determine if the device could detect AT/AF accurately and continuously and discriminate AT from AF.

Methods

Patients—We studied 80 consecutive patients treated with this ICD in 19 medical centers (Appendix). Patients had both a clinical indication for the implantation of a ventricular ICD and ≥2 episodes of AF and/or AT in the 3 months before implantation. All patients gave written, informed consent according to a protocol approved by the Human Subjects Committee of the institution at which the devices were implanted.
Far-field R-wave Discrimination

The detection algorithm discriminates far-field R waves. The detection algorithm discriminates far-field R waves from AT/AF using the following 3 criteria: exactly 2 atrial events in each RR interval, a stable and short interval between the R wave on the ventricular channel and the far-field R wave on the atrial channel, and stable alternation in atrial intervals. If all 3 criteria are met, the atrial electrogram after the R wave is classified as a far-field R wave and excluded from the AT/AF evidence count (Figure 3).

AT/AF Autodiscrimination

AF and AT detection zones may overlap. If the atrial cycle length is in this overlap zone, the atrial rhythm is classified as AT if it is regular and AF if it is not. After each sensed atrial event, atrial detection is blanked for 100 ms. AT/AF autodiscrimination zone extends from this value to programmable AF detection interval (AFDI). AT/AF autodiscrimination zone extends from AFDI to AFDI.

Implant Procedure

The ICD pulse generator and electrodes were inserted through a single left pectoral incision. A closely spaced (9.1 or 9.5 mm) right atrial bipolar was used for atrial sensing. The P-wave amplitude in sinus rhythm was measured. A 2-lead defibrillation system (right atrium and right ventricle) was used in 74 patients, and a 3-lead system (including a coronary sinus electrode) was used in 6 patients. The electrode system was selected by investigator preference.

Detection of AT/AF

AT/AF was detected by a combination of median atrial cycle length and an AT/AF evidence counter that uses the number of sensed atrial electrograms in consecutive RR intervals. This counter provides high specificity for detecting AT with N:1 atrioventricular conduction (Figure 1A). The counter operates in 2 different modes for preliminary and sustained detection. Preliminary detection occurs when the count reaches 32 and the median cycle length for the last 12 PP intervals is less than the programmable AT or AF detection interval.

Termination of Device-Defined AT/AF Episodes

A device-defined atrial arrhythmia episode ends with the detection of 5 consecutive beats of sinus- or atrial-paced rhythm or 3 minutes of unclassified atrial rhythm. Sinus rhythm is defined by a previously described dual-chamber algorithm (PR Logic). This algorithm is also used to discriminate between rapidly conducted AT/AF and VT/VF for the purpose of withholding ventricular therapy. Accuracy of this discrimination was not analyzed in the present study. The AT/AF detection algorithm studied in this report was used only for delivering or withholding AT/AF therapy, not to discriminate AT/AF from VT/VF.

Far-Field R-Wave Discrimination

To ensure the accurate sensing of atrial rate and rhythm, the ICD has minimal postventricular atrial blanking. Minimal blanking and auto-adjusting atrial sensitivity may result in inappropriate atrial sensing of far-field R waves. The detection algorithm discriminates far-field R waves from AT/AF using the following 3 criteria: exactly 2 atrial events in each RR interval, a stable and short interval between the R wave on the ventricular channel and the far-field R wave on the atrial channel, and stable alternation in atrial intervals. If all 3 criteria are met, the atrial electrogram after the R wave is classified as a far-field R wave and excluded from the AT/AF evidence count (Figure 3).

AT/AF Autodiscrimination

AF and AT detection zones may overlap. If the atrial cycle length is in this overlap zone, the atrial rhythm is classified as AT if it is regular and AF if it is not.

ICD Programming

Automatic therapies for AT/AF were programmed using a randomized, crossover design: on or off for the first 3 months and the opposite setting for the next 3 months. Thus, not all episodes of spontaneous AT/AF were treated.

Holer Recordings

Digital Holter recordings were performed in 59 patients. Recordings included 1 ECG lead, a telemetered atrial electrogram, and atrioventricular pace/sense markers. In 14 patients, Holter recordings were used to mark the time for the initial detection of AF in a postoperative electrophysiologic study. In 58 patients, a total of 80 Holter recordings were performed during follow-up both to validate the continuous detection of spontaneous AF and to determine the sensitivity of the detection algorithm for AT/AF. Patients who had frequent AT/AF, AF in progress, or inappropriate detection of AT/AF were selected for multiple recordings.

Follow-Up

Patients were followed for a total of 491 patient-months from the date of implant until the date of study closure or patient death. Five patients died during follow-up, 4 from heart failure and 1 from cancer. The mean duration of follow-up was 6±2 months (median, 6 months; range, 1 to 11 months). ICDs were interrogated at 1 month and 3 months, every 3 months thereafter, and whenever patients reported shocks or palpitations.

Data Analysis

Appropriate versus inappropriate detection of spontaneous AT/AF was determined from electrograms and intervals stored before therapy. Because the ICD does not store electrograms or intervals for untreated AT/AF episodes, only treated episodes were analyzed for the group as a whole.

Continuous versus intermittent detection of ongoing, sustained AT/AF was determined from intervals stored before the termination of device-defined episodes. Termination was judged appropriate when the P:R pattern showed sinus rhythm or DDI pacing. Inappropriate episode termination caused by atrial undersensing was suspected if ≥50% of intervals before episode termination were shorter than the detection interval corresponding to that episode (AT or AF). A pattern of repetitive detections and terminations was used to identify inappropriate episode termination. Device-defined sustained AT/AF was classified as continuous if episode termination was appropriate and as intermittent if episode termination was inappropriate.

Data are presented as means±1SD. P<0.05 was used to reject the null hypothesis. Basic comparisons were made using the paired r-test, unpaired r-test, Mann-Whitney U test, or chi-squared test.

Results

Patient characteristics are summarized in Table 1. The acute, sinus-rhythm P-wave amplitude at implantation was 3.9±1.9 mV. The programmed minimum value of the autoadjusted atrial sensitivity was 0.35±0.14 mV (nominal, 0.3 mV). It was 0.15 mV in 2 patients, 0.3 mV in 63 patients, 0.45 mV in...
7 patients, 0.6 mV in 5 patients, and 0.9 mV in 3 patients. The programmed atrial cycle length below which arrhythmias were classified as AT or AF were 336 ± 64 ms and 265 ± 29 ms, respectively.

Initial Detection of AF
The initial detection of AF was analyzed during an electrophysiologic study in 14 patients for 129 induced and 36 spontaneous episodes of AF (Figure 2). The time for initial detection was 18 ± 4 ms. The median PP interval was 192 ± 42 ms.

Spontaneous AT/AF
During follow-up, 31 patients had episodes of spontaneous AT/AF that were detected and treated: AF only occurred in 13 patients, AT only in 8 patients, and both in 10 patients. Twenty-eight patients had only appropriate detections, 3 had only inappropriate detections, and 2 patients had both. Detection was appropriate in 88% of 190 AT episodes, and 98% of 132 AF episodes. The longest inappropriate episode lasted 9.5 minutes. The 27 inappropriate AT/AF detections resulted in 29 antitachycardia pacing therapies; 28 were asymptomatic, and 1 induced AF, which was terminated by atrial defibrillation.

Figure 4 shows a histogram of the median atrial cycle length for treated AT and AF episodes. The median cycle length was 240 ms in 84% of appropriate AF episodes, but it was 250 ms for all 3 inappropriate AF episodes (P < 0.01). Of the 128 AT episodes with a median cycle length ≥ 300 ms, 98% were appropriate. However, 22 of 24 inappropriate AT episodes (92%) had a median cycle length ≥ 300 ms. Overall, the median cycle length was longer for inappropriately detected episodes than for appropriately detected episodes (AT, 336 ± 52 versus 246 ± 57 ms, P < 0.001; AF, 267 ± 17 versus 203 ± 37 ms, P < 0.01).

Inappropriate Detection of AT/AF
Misclassification of far-field R waves caused all inappropriate detections. These occurred most commonly because of conducted premature atrial complexes that changed the pattern of the stable alternation of PP intervals (n = 19, 2 patients;
Figure 5A). A second cause was DDI pacing, which resulted in unstable PR intervals (n=6, 1 patient; Figure 5B). Other causes included variations in the intervals between the right ventricular electrogram and the far-field R-wave electrogram (n=1) and first-degree atrioventricular block in sinus tachycardia, resulting in equal PR and R to far-field R intervals (n=1). In all cases, the short duration of inappropriate detection was due to rapid redetection of the sinusrhythm pattern or correct classification of far-field R waves.

Inappropriate detection of far-field R waves was corrected in 3 patients by decreasing atrial sensitivity. No parameters were reprogrammed in 2 patients who had no subsequent inappropriate detections.

**Detection of Ongoing AT/AF**

Of the 295 appropriate episodes of spontaneous AT/AF, 294 (99.7%) were detected continuously (Figure 6). One episode was detected continuously for 10 days. There were 90 AT/AF episodes >1 hour in 19 patients, with a total duration of 2697 hours. One episode of asymptomatic AF was undersensed and intermittently underdetected because the atrial sensitivity had been set to 0.9 mV to prevent oversensing of far-field R waves. Undersensing was corrected by reprogramming atrial sensitivity. No patient had symptomatic, undetected AT/AF.

**Holter Recordings**

Of the 80 Holter recordings made during follow-up, 1406 hours had a suitable quality of both telemetered atrial electrograms and surface ECG for analysis (18±7 hours of recording). Tables 3 through 5 summarize all Holter-recorded episodes of AT/AF that satisfied the minimum duration corresponding to the initial detection criterion (32 RR intervals). All 120 AT and 26 AF episodes that satisfied the programmed atrial rate criterion were detected continuously, for a total of 116 hours. Three episodes of AT lasting a total of 3 minutes were not detected because the AT cycle length exceeded the programmed detection interval. Holter-recorded AF electrograms had a wide variation in slew rate and amplitude, as shown in Figures 2, 5, and 6.

![Figure 3. Holter recording shows correct classification of far-field R waves. ECG, atrial electrogram (AEGM), marker, median PP interval, and AT/AF evidence counter are shown, as in Figure 2. Additional far-field R line identifies RR intervals in which counter does not create increments because atrial electrogram is classified as a far-field R wave (FR). TF on atrial marker channel denotes intervals shorter than programmed AT detection interval of 270 ms. Other abbreviations as in Figure 2. TF intervals are classified correctly as far-field R waves because of stable PR interval, stable RP interval, and stable alternation of PP intervals with short intervals, including R wave.](http://circ.ahajournals.org/)}
A total of 1290 hours of Holter recordings were made during which the atrial rhythm was sinus- or atrial-paced. In this period, 6 inappropriate detections of AT/AF occurred, lasting a total of 7 minutes. Expressed in terms of duration of ICD-classified rhythms, sensitivity for the detection of AT/AF that satisfied detection criteria according to Holter analysis was 100%, whereas specificity for the detection of rhythms other than AT/AF was 99.99%.

**AT/AF Discrimination**

Of the 166 spontaneous, appropriate, and treated AT episodes, 116 (70%) had a cycle length in the AT/AF overlap zone (214±22 ms), and 50 (30%) had a cycle length more than the AF detection interval (321±39 ms) (Figure 7). No significant difference existed between the success rate of antitachycardia pacing in the overlap zone (49 of 116 episodes, 42%) and the success rate in the slower AT zone (26 of 50 episodes, 52%; P=0.34).

**Discussion**

This study demonstrates that a new dual-chamber ICD provides both rapid and continuous detection of AT/AF and discriminates accurately between AF and AT.

**Goals of AT/AF Detection**

Antiarrhythmic devices detect AT/AF to perform 3 functions: mode switching to prevent inappropriate tracking of AT/AF, withholding inappropriate ventricular therapy, and delivery of atrial therapy. The dual-chamber ICD evaluated in the present study performs all 3 functions. It is the first ICD that permits therapy for long-duration AT/AF while withholding therapy from self-terminating AT/AF. It is, thus, the first ICD that must detect low and varying fibrillation electrograms continuously for extended periods. It also discriminates between AT and AF to deliver antitachycardia pacing for AT; thus, it must determine the atrial rate and rhythm accurately.

**AT/AF Detection in Other Devices**

Dual-chamber pacemakers and some ICDs do not require accurate determination of atrial rate and rhythm. They have postventricular atrial blanking and refractory periods that prevent atrial oversensing of far-field R waves but result in undersensing of AT/AF, particularly during high ventricular rates and AT with 2:1 atrioventricular conduction.

An atrial ICD detects AF intermittently. Thus, continuous AF cannot be distinguished from sequential, self-terminating episodes. Atrial electrograms are analyzed only during the electrocardiographic ST segment, so the precise rate and
regularity of the atrial rhythm cannot be determined. AT is not detected, AF is not detected during ventricular-paced rhythm, and a coronary sinus electrode is required for sensing. Wellens et al reported that the sensitivity for the detection of AF was 92%.

AT/AF Detection and Discrimination in the Jewel AF

Several features combined to permit continuous detection of AF for extended periods. A closely spaced, atrial sensing bipole, autoadjusting sensitivity with a short time constant, and minimal atrial blanking all minimize atrial undersensing. The detection algorithm continues to detect AF, despite some undersensing and brief periods of unclassified atrial rhythm.

Determining the atrial rate and rhythm accurately requires that postventricular, atrial blanking be minimized to a value insufficient to blank far-field R waves. Thus, the detection algorithm must prevent the sensing of far-field R waves from causing inappropriate detection of AT/AF.

Accuracy of AT/AF Detection

The present study describes the initial, multicenter experience with this ICD, during which the importance of minimizing far-field R waves was not recognized uniformly. Nevertheless, the true-positive detection rate was 98% for AF and 98% for AT, with a detection interval ≤300 ms. All inappropriate detections with a median atrial cycle length ≤320 ms lasted ≤5 minutes. However, an AT detection interval >300 ms facilitates inappropriate detection by increasing the probability that inappropriately classified far-field R-wave intervals will reduce the measured atrial cycle length below the AT detection interval.

All sustained episodes of AF were detected continuously when atrial sensitivity was ≤0.6 mV. Holter monitoring with telemetered atrial electrograms confirmed the 100% sensitiv-
TABLE 4. Inappropriately-Detected AT/AF: Individual Episodes

<table>
<thead>
<tr>
<th>Holter Recording</th>
<th>Rhythm</th>
<th>Median PP Interval, ms</th>
<th>Duration, min:s</th>
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</thead>
<tbody>
<tr>
<td>55100a</td>
<td>AT</td>
<td>310</td>
<td>0:31</td>
</tr>
<tr>
<td>5512a</td>
<td>AT</td>
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</table>

Clinical Implications

This study clarifies several principles for the optimal application of atrial ICDs that have minimal atrial blanking periods. (1) The atrial electrode should be positioned to minimize far-field R waves. (2) The AT/AF detection interval should be set slightly greater than the anticipated AT/AF interval. In contrast, optimal programming for DDD pacemakers or dual-chamber ICDs requires setting the mode-switch or AT/AF rate threshold slightly above the maximum sinus rate to compensate for atrial blanking and refractory periods. (3) The AT detection interval should be ≥300 ms to minimize inappropriate detection due to far-field R waves. It may be ≥300 ms only if no atrial sensing of far-field R waves occurs. (4) Inappropriate detection of AT/AF caused by atrial oversensing of far-field R waves is transient, and it need not result in inappropriate therapy. Restricting therapy to episodes >10 minutes prevents inappropriate AT/AF therapy and does not delay VT/VF therapy. Attention to the first 3 principles should minimize inappropriate detection, whereas attention to the fourth should minimize inappropriate AT/AF therapy in the event of inappropriate detection.

Conclusions

AT/AF can be detected rapidly and continuously by a dual-chamber, atrial ICD. Thus, shocks may be programmed for long-duration AT/AF without the risk of inappropriate episode termination due to atrial undersensing. Discrimination of AT versus AF on the basis of the regularity of the atrial rhythm permits successful, painless antitachycardia pacing for some rhythms that would otherwise require painful cardioversion.

Appendix

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Acknowledgment
We wish to thank Lucy Gonzales for manuscript preparation.

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*Circulation*. 2000;101:878-885
doi: 10.1161/01.CIR.101.8.878

*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:

http://circ.ahajournals.org/content/101/8/878

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