Automatic Methods for Detection of Tachyarrhythmias by Antitachycardia Devices

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Electrical devices play an increasingly important role in the control of tachyarrhythmias. Antitachycardia pacing and automatic defibrillation have been severely limited by the poor specificity of tachycardia discrimination in commercially available devices. Although absolute heart rate has been the principal means of automatic diagnosis, several new detection algorithms and methods are being investigated. Multiple electrode timing comparison, signal processing and pattern recognition are employed in these newer techniques. Although each offers some improvement over present technology, none is capable of identifying all arrhythmias.

The methods employing comparison of atrial and ventricular rates, without additional criteria, are unable to detect ventricular tachycardia in the presence of 1:1 retrograde conduction. Electrographic analysis techniques require very stable electrodes and may not tolerate normal morphologic variations. A combination of two or more approaches may ultimately be required. All techniques will require that certain critical variables be programmable to allow for individualization in each clinical situation. Software-controllable devices and those capable of sensing from both the atria and the ventricles will provide the sophistication necessary for the implementation of complex tachycardia detection algorithms. This report reviews automatic tachycardia detection techniques in current use and under investigation.

The treatment of patients with recurrent ventricular or supraventricular tachycardia involves the use of antiarhythmic drugs, electrical stimulation, surgery or a combination of these techniques (1-4). Although the choice of approach depends on a variety of factors, antitachycardia pacing is often not used partly because of the lack of a universally applicable and reliable arrhythmia recognition capability for these devices (4,5). Early devices used recognition systems that depended on absolute heart rate or the first derivative of heart rate (6). Such criteria have proved to be nonspecific in many different clinical situations, including some episodes of sinus tachycardia and paroxysmal atrial fibrillation with rapid ventricular response. Because the automatic diagnosis of tachycardia is so important, more sophisticated detection techniques are under investigation.

Some of the techniques to be described are at the experimental stage; others have been implemented as computer algorithms and still others are in clinical use. An understanding of the methods used to test and develop the experimental techniques is essential to assess the progress of research. Because criteria for detection and test data (electrograms) differ among these studies, a description of the investigations involving the newer approaches is included in the following discussions.

Detection Techniques for Automatic Diagnosis of Tachycardia

Manual Activation

Externally controlled rapid pacemakers, such as the Medtronic 5998 R transmitter and receiver (7), or external stimulators that can trigger an implanted synchronous pacemaker with a programmable refractory period have been used in the recent past (8,9). Such methods are useful when the patient can recognize the tachycardia and remains conscious and is able to use an external triggering device or to seek help at a medical facility.

Several semiautomatic devices in current use also utilize manual tachyarrhythmia detection. When a patient with a...
device such as a 262-01 Cybertrach (Intermedics) (10) programmed to the VVI (ventricular-inhibited) mode experiences symptoms of tachycardia, a physician can confirm the arrhythmia by electrocardiogram (ECG) and program the pacemaker to the antitachycardia mode. Once activated, the device will perform its antitachycardia function only after sensing a heart rate that is higher than its programmed rate criterion. This system also requires that the patient remain conscious and that the appropriate pacemaker programmer be available at a nearby facility.

Heart Rate

The simplest automatic method of tachycardia recognition is measurement of heart rate only. The antitachycardia response is elicited whenever the pacemaker counts a specific number of consecutive electrographic complexes or events having an interval (cycle length) shorter than a preset limit. In the 262-01 Cybertrach (10), for example, eight complexes above the rate criterion must be counted in order to trigger the device. A similar criterion has been used in other commercially available devices (11,12) (Table 1).

Devices that depend on rate alone can be triggered by myopotentials or other electromagnetic interference, although this problem is reduced by use of bipolar sensing. The rate-only method is the inverse of bradycardia sensing used in VVI pacemakers. The chief drawback of rate-only detection is its inability to discriminate between sinus tachycardia caused by emotion or exercise and pathologic arrhythmias; it also cannot recognize a slow tachycardia as pathologic.

Rate-Related Criteria

Rate acceleration and sudden onset. In addition to measurement of heart rate alone, several antitachycardia pacemakers also calculate rate acceleration by comparing successive RR intervals. Rapid onset is usually associated with pathologic tachycardias and gradual acceleration characterizes sinus tachycardia (13). In one device, if the sudden onset criterion is not met by comparison of two successive intervals, the preceding interval is also compared with the latest interval before the detection system is reset (14).

This detection scheme is also not completely specific. Abnormal tachycardias can be preceded by premature complexes followed by a compensatory pause, and thus there can be, in effect, a gradual onset of ventricular tachycardia as detected and interpreted by the pacemaker. A compensatory pause during a period of otherwise high sinus rate, such as a premature ventricular complex occurring during exercise, can cause both rate and onset criteria to be satisfied during sinus rhythm, classifying the normal activity as abnormal.

Stability of tachycardia. Another rate-related criterion is stability of the tachycardia. Electrically terminable rapid rhythms are often stable in rate, and this rate stability can be used along with absolute heart rate and suddenness of onset. The Intermedics 262-12 Interach allows programming of all these variables in various combinations (15) (Table 1).

Activation Sequence

Atrioventricular. Techniques that employ two sensing electrodes to detect atrioventricular (AV) synchrony and timing are being investigated. One algorithm continually stores the 36 most recent consecutive atrial and ventricular events (16,17). On detecting a rate that is higher than a preset limit, an analysis of the AA, AV and AV intervals is performed (Fig. 1). The rhythm is then classified as sinus tachycardia, supraventricular tachycardia, ventricular tachycardia, atrial fibrillation or ventricular fibrillation. Using bipolar electrograms recorded on magnetic tape, this algorithm was capable of correctly identifying tachyarrhythmias in 21 of 22 cases. The system was designed to operate in real time. A microprocessor is used to perform calculations, but operates only during a 4 ms period after a sensed event to minimize current drain, The microprocessor is not used for the entire detection system, thereby increasing processing speed. The key factor in the analysis is the ratio of atrial to ventricular events in a given period of time. This ratio, combined with a sustained high rate criterion, is used to classify the rhythm. This system still depends on suddenness of onset to discriminate between sinus tachycardia and ventricular tachycardia with 1:1 retrograde conduction (18).

To improve specificity in the detection of abnormal tachycardias in which the atria and ventricles beat synchronously, an addition to this algorithm has been proposed (19). Premature atrial extrastimuli are delivered during the tachycardia, and the ventricular responses occurring after the atrial extrastimuli are measured. If the tachycardia is of atrial origin, the extrastimuli will perturb the ventricular rhythm; there will be no effect on ventricular tachycardia. In a test of this method, atrial extrastimuli that were premature by 80 to 100 ms induced premature ventricular responses in 14 of 15 patients. During 1:1 tachycardias in 13 of 13 patients, the premature atrial stimuli failed to produce a ventricular response that was premature by more than 10 ms. This technique was capable of distinguishing sinus tachycardia from AV node reentrant tachycardia, circus movement tachycardia and ventricular tachycardia with 1:1 ventriculoatrial conduction.

Multiple ventricular electrodes. The altered pattern of ventricular depolarization that occurs with ventricular tachycardia can be used as a detection tool. One technique under active investigation (20) involves the use of multiple electrodes to detect differences in AV association and ventricular activation sequence between normal sinus beats and
ectopic beats. In a pilot study, simultaneous recordings from two ventricular sites were obtained in eight patients during normal sinus rhythm and during premature ventricular complexes or ventricular tachycardia. Leads were placed transvenously at the right ventricular apex and outflow tract in five patients, and at the right ventricular apex and inflow tract in one patient; epicardial leads were placed on the left ventricle in two patients. Intervals between the intrinsic deflections of the two ventricular electrograms were measured manually. These intervals in sinus rhythm differed

Table 1. Commercially Manufactured Automatic Antitachycardia Devices

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Rate Criteria (beats/min)</th>
<th>No. of Beats Counted</th>
<th>Other Criteria</th>
<th>Device Status</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medronic</td>
<td>2404</td>
<td>(See Remarks)</td>
<td>None</td>
<td>Discontinued 1980</td>
<td>Rate and no. of beats individually specified; manuf to custom order by prescription</td>
<td></td>
</tr>
<tr>
<td>Medronic</td>
<td>Symbios 7005</td>
<td>100 to 175</td>
<td>5</td>
<td>None</td>
<td>In clinical evaluation</td>
<td>Programmable rate (= upper rate limit)</td>
</tr>
<tr>
<td>Medronic</td>
<td>7210</td>
<td>110 to 297</td>
<td>2 to 32</td>
<td>Sudden onset (on/off)</td>
<td>In clinical evaluation</td>
<td>Programmable</td>
</tr>
<tr>
<td>Cordis</td>
<td>BK series</td>
<td>(See remarks)</td>
<td>None</td>
<td>Discontinued 1973</td>
<td>Rate and no. of beats individually specified; manuf to custom order by prescription</td>
<td></td>
</tr>
<tr>
<td>Cordis</td>
<td>Orthocor II-284A</td>
<td>100 to 220</td>
<td>4 to 25</td>
<td>None</td>
<td>In clinical evaluation</td>
<td>Rate and no. of beats programmable</td>
</tr>
<tr>
<td>Intermedics</td>
<td>Cybertrach-262-01</td>
<td>120 or 160; 137 or 180</td>
<td>8</td>
<td>None</td>
<td>Released</td>
<td>Two units available, each having two programmable rate minimums</td>
</tr>
<tr>
<td>Intermedics</td>
<td>Intertrach-262-12 262-14</td>
<td>94 to 226</td>
<td>5 to 99</td>
<td>1) 20 to 252 ms sudden onset time; 2) Rate stability (15 to 149 ms deviation); over 8 to 250 intervals; 3) Sustained high rate (over 6 to 250 intervals required)</td>
<td>262-12; approved for atrial use; 262 to 14; in clinical evaluation for ventricular use</td>
<td>All criteria stages programmable; criteria can be combined by programming; 262-12, 262-14 have the same specifications</td>
</tr>
<tr>
<td>Biotronik</td>
<td>Phylax</td>
<td>150</td>
<td>4</td>
<td>None</td>
<td>Not evaluated in USA</td>
<td>Others available on order</td>
</tr>
<tr>
<td>Teletronics</td>
<td>Passar 4151</td>
<td>130 to 225</td>
<td>5</td>
<td>None</td>
<td>Discontinued 1985</td>
<td>Scanning response output</td>
</tr>
<tr>
<td>Siemens</td>
<td>Tachyline 651B</td>
<td>95 to 250</td>
<td>4 (average)</td>
<td>Interval change (onset) averaged over 8 intervals</td>
<td>Not evaluated in USA</td>
<td>Programmable rate</td>
</tr>
<tr>
<td>Siemens</td>
<td>6608D</td>
<td>137</td>
<td>(1 interval)</td>
<td>None</td>
<td>Approved for general pacing</td>
<td>Programmable rate; depends on programmed tachy rate at 436 ms refractory period</td>
</tr>
<tr>
<td>INTEC</td>
<td>AID</td>
<td>(approx. 250)</td>
<td>(10 to 30 s from arrhythmia onset to output pulse)</td>
<td>PDF</td>
<td>Approved for VF; discontinued 1982</td>
<td>Rate counting only as part of PDF implementation for VF detection</td>
</tr>
<tr>
<td>CPI/INTEC</td>
<td>AID-BR</td>
<td>155</td>
<td>(10 to 30 s from arrhythmia onset to output pulse)</td>
<td>None</td>
<td>Approved for VT</td>
<td>Other rates available</td>
</tr>
<tr>
<td>CPI</td>
<td>AID-B (AICD)</td>
<td>155</td>
<td>(10 to 30 s from arrhythmia onset to output pulse)</td>
<td>PDF</td>
<td>Approved for VF/VF, discontinued 1986</td>
<td>Other rates available, autogain used for both criteria</td>
</tr>
<tr>
<td>CPI</td>
<td>Vestak (AICD)</td>
<td>155</td>
<td>(10 to 30 s from arrhythmia onset to output pulse)</td>
<td>PDF</td>
<td>Approved for VF/VF</td>
<td>Same as AID-B (AICD), but has hybrid electronics</td>
</tr>
</tbody>
</table>

Approx = approximately; manuf = manufactured; max = maximal; PDF = probability density function; tachy = tachycardia; VF = ventricular fibrillation; VT = ventricular tachycardia.
of Irk! 'to ventricular rate determines whether tachycardia (Tachlc) is of ventricular origin. In cases where the ratio is very nearly equal to 1, the additional use of tachycardia onset time or a premature atrial stimulus has been proposed (see text). From Anbaecher et al. (16), with permission. AF = atrial fibrillation; AFI = atrial flutter; AT = atrial tachycardia; VT = ventricular tachycardia; w = with.

from those of ectopic beats by >20 ms in 14 of 15 cases (Fig. 2A and B). Such differences in timing are easily detectable by electronic devices. Such an analysis is analogous to "mapping" the patient's sequence of activation on a beat to beat basis. Combined with an atrial sensing lead, ventricular activation sequence can be employed in an algorithm to add specificity to the detection of ventricular tachyarrhythmias that do not result in AV dissociation.

Detection using four ventricular electrodes (left and right ventricular apex, left and right ventricular septum) in each of 10 patients was reported (21) to be successful in detecting ventricular tachycardia and ventricular fibrillation. Ventricular tachycardia was simulated using right ventricular outflow tract pacing at cycle lengths of 500, 400 and 333 ms, and ventricular fibrillation was induced by alternating current. During sinus rhythm and right ventricular outflow tract pacing, cycle lengths varied from 460 to 930 ms and electrograms from the four sites were synchronized but with different activation sequences in eight patients. In all 10 patients, the time interval from first to last depolarization increased from 40 to 90 ms (mean 65) with right ventricular outflow tract pacing. Varying the pacing cycle length did not affect synchrony or activation sequence. Ventricular fibrillation caused rapid irregular polymorphous localized intrinsic activity to be seen at all four sites, with a cycle length of 130 to 240 ms and an electrographic amplitude of 0.4 to greater than 5 times the amplitude during sinus rhythm.

These are preliminary studies; requirements for implementation and the practical problems of employing three or four electrodes have not been addressed. Tachycardias that demonstrate rate-related bundle branch block may trick the system by altering ventricular activation sequence. The stability of the measured timing under varying conditions (for example, changes in medications or electrolyte balance) needs to be evaluated.

Characteristics of Electrograms

Frequency domain analysis. Frequency analysis of tachycardia electrograms as a means of differentiating ventricular from supraventricular tachyarrhythmias also has been proposed (22,23). Although electrograms are commonly displayed as a plot of voltage versus time, such signals can also be displayed as voltage versus frequency in a frequency domain plot (24). An efficient algorithm, called the fast Fourier transform, can convert time variant signals such as electrograms into their frequency domain representation.

Figure 1. Atrioventricular (two-electrode) algorithm. Flow chart of the computer analysis program used for two-electrode atrioventricular timing detection. This program is activated upon detection of a preset minimal atrial (A) or ventricular (V) rate. The ratio of atrial to ventricular rate determines whether the tachycardia (Tach) is of ventricular origin. In cases where this ratio is very nearly equal to 1, the additional use of tachycardia onset time or a premature atrial stimulus has been proposed (see text). From: Arzbaecher et al. (16), with permission. AF = atrial fibrillation; AFI = atrial flutter; AT = atrial tachycardia; VT = ventricular tachycardia; w = with.

Figure 2. Intracardiac electrograms recorded from two electrodes 1 mm apart on the left ventricle (LV, and LV,), and surface electrocardiogram (lead II) from the same patient during (A) normal sinus rhythm (NSR) and (B) ventricular tachycardia (VT). ID indicates the intrinsic deflection of the electrogram when the wave of depolarization passes under the electrode. The point on the intrinsic deflection with maximal rate of voltage change (dV/dt) is used for timing. The vertical time lines are 200 ms apart in each tracing. A 1 mV amplitude calibration for the electrograms in both A and B is shown in B (arrows). In A (normal sinus rhythm), the time elapsed between the intrinsic deflections at ventricular electrodes LV, and LV, is 90 ms. In B (ventricular tachycardia), the time elapsed between the intrinsic deflections at ventricular electrodes LV, and LV, is only 15 ms, a decrease of 75 ms from the value during normal sinus rhythm. This difference in arrival of depolarization at the two ventricular electrodes could be used as a criterion for automatic detection of ventricular tachycardia.
Because the frequency spectrum of normal beats differs from that of ectopic ventricular beats, the fast Fourier transform potentially can be used in an algorithm that detects this difference. Comparing the frequency spectrum of a normal sinus rhythm electrogram to the frequency spectrum of a patient's other complexes would be a pattern recognition problem, requiring the same computation time as time domain recognition (as described later). The advantage of frequency analysis is that it allows one to identify frequency ranges over which a sinus rhythm electrogram has a concentration of high amplitudes and the ventricular tachycardia electrogram low amplitudes. Comparisons could then be made only at those specific frequencies. The frequency range of difference can be selected by an appropriate filter.

Thus, fast Fourier transform analysis can be efficiently used to determine the specifications of filters that could be included in implantable devices. These would discriminate between sinus rhythm and ventricular tachycardia by selectively altering the amplitude of the tachycardia electrogram as a result of filtering. This is less complex than making use of configurational differences in the time domain. If a universal range of difference in frequency between normal sinus rhythm and ventricular tachycardia electrograms could be found, a fixed frequency filter could be used. Otherwise, the filters must be tuned in each patient in the same way that other variables are programmed in a pacemaker.

Measurements of the individual electrophysiological frequency spectra during normal sinus rhythm and tachycardia have yielded varied results. One study (22) analyzed 12 bipolar recordings of ventricular tachycardia and sinus rhythm using both endocardial and epicardial electrodes. The center frequency of the major peak in amplitude for normal sinus rhythm was found to be 27 ± 9 Hz (endocardial) and 26 ± 4 Hz (epicardial); for ventricular tachycardia, the corresponding frequencies were 16 ± 9 Hz and 18 ± 6 Hz. This study considered the range of difference in normal sinus rhythm versus ventricular tachycardia frequency spectra to be potentially useful as a detection tool. Another study (26), however, examined the frequency spectra of normal sinus rhythm versus ventricular tachycardia in seven patients and found no significant difference. A third study (23) analyzed 22 bipolar paired normal sinus rhythm and ventricular tachycardia recordings from 22 patients. The mean difference in peak frequency between individual normal sinus rhythm and ventricular tachycardia electrograms was found to be 8 ± 7 Hz. The mean difference in bandwidth (point at which the amplitude is 3 db below the peak) was 18 ± 18 Hz for the 22 cases. These differences were considered useful for detection. Because of the variation in frequency spectra from patient to patient, the filters utilized in this system would require programmable frequency specifications.

**Time domain analysis: gradient pattern detection.** Gradient pattern detection makes use of the different order and magnitudes of the slopes ("gradients") of the normal sinus rhythm and ventricular tachycardia electrograms (27). The electrogram is processed to provide a signal that resembles its first derivative. The first deflection above a preset amplitude threshold triggers the analysis program. The turning points (points at which the slope changes direction from positive to negative or negative to positive) that are above the preset reference are used in the analysis in order to avoid noise artifacts. Gradient pattern detection was reported to identify 10 of 11 cases of ventricular tachycardia recorded from 10 patients. Bipolar recordings from the right ventricular apex were used for analysis.

**Intrinsic deflection timing.** Intrinsic deflection timing is a technique reported (26) to be effective in the identification of ventricular tachycardia in 10 of 11 recordings from 10 patients. Using electrograms recorded from the right ventricular apex, the time interval from the first significant deflection (departure from baseline) to the intrinsic deflec-
The automatic implantable defibrillator (AICD) uses the probability density function principle for detection of ventricular fibrillation. This is an indicator of the percentage of time an electrogram is at each amplitude (voltage) level, and it is similar to a histogram of discrete amplitude levels. A, Normal sinus rhythm and its corresponding probability density function. Note the presence of a significant percentage of time near baseline (zero voltage on horizontal axis). B, Ventricular fibrillation and its corresponding probability density function. Note the virtual absence of time spent at baseline. It may be possible to also use the probability density function for detection of ventricular tachycardias having a configuration similar to that of ventricular fibrillation. From: Reid W, with permission. Also, Flores BT, Hildebrandt NO. The automatic implantable defibrillator. Heart and Lung, 1984; 13:609; used with permission.

A variety of pattern recognition techniques can be employed to detect differences that may exist between two waveforms (28). Pattern recognition systems that employ template matching have been frequently utilized. In its simplest form, the two waveforms to be compared are digitized and stored in a computer. One of the waveforms is usually used as a reference. The comparison can take the form of arithmetic point by point subtraction to yield number and size of differences. The accuracy depends upon the number of points in the digitized waveforms, which in turn depends on the speed of the analog to digital converter and the amount of memory available for storage. Comparison algorithms require relatively large amounts of computation time, increasing with the number of points in the digitized waveforms. In arrhythmia monitoring units that employ automated body surface ECG analysis systems, large mainframe computers or minicomputers store reference templates for normal and ectopic beats for each patient. These templates are created through interactive training sessions in which an operator classifies ECG complexes for a patient as normal or abnormal and indicates to the computer the nature of the beat. The computer will then place future ECG complexes from that patient into the categories in which they most closely fit (within a preset tolerance) (29–31). Although the same technique theoretically could be used in an implantable system, it is currently not feasible to implant a device with such large computational and memory requirements.

One investigation (32) of intracardiac electrogram template pattern recognition for ventricular tachycardia used bipolar recordings from the right ventricular apex in seven patients. These were recorded with a passband of 0.04 to 500 Hz and digitized at a rate of 1,000 samples per second. A sample window of 40 ms before and after the point of maximal dV/dt (rate of change of voltage) was used. A template was formed by averaging five normal sinus rhythm electrograms. The area of the differences between this template and subsequent electrograms was measured in seven patients during normal sinus rhythm and ventricular tachycardia. The smallest area of difference for a normal sinus rhythm electrogram was 4.9 times the largest area of difference for a ventricular tachycardia electrogram. Even though there was a small beat-to-beat variation, all ventricular tachycardia electrograms could be identified.

A more feasible approach to the problem is the use of a probability density function. Electrocardiogram configuration is analyzed using a different approach in the automatic implantable cardioverter/defibrillator (AICD) (33,34). The computation of the percentage of time the electrogram spends away from baseline has been termed the probability density function. The normal electrogram spends a relatively large proportion of time at or near baseline (Fig. 4A), whereas the electrogram of ventricular fibrillation spends very little time at baseline (Fig. 4B). Automatic gain control is used to adjust the sensitivity to allow for sensing of fibrillation signals as small as 0.1 mV in amplitude. Because there is great variability in ventricular fibrillation amplitudes, automatic gain control is essential. The original device, the AICD (automatic implantable defibrillator), relied chiefly on probability density function calculation and was virtually rate insensitive. This would not allow the unit to detect tachycardias unless they possessed a configuration similar to that of ventricular fibrillation. The possibility of false positive diagnoses was
also present. In the AID-B model, a rate criterion was added, and both criteria—rate and probability density function—must be satisfied for the electrogram to be classified as revealing ventricular fibrillation. This device is now referred to as the AICD (automatic implantable cardioverter/defibrillator). These criteria may both be met for ventricular tachycardia as well. The AID-BR is a rate-only model (without probability density function) that classifies any rhythm above a certain factory-set rate (usually approximately 155 beats/min) as tachycardia or ventricular fibrillation (35). This model, of course, possesses all the attendant drawbacks of any rate-only device.

In the AICD, the probability density function is implemented by filtering the electrogram through a high pass filter to produce an approximation of the first derivative. A detector then outputs a signal during periods that the electrogram spends at high slope. This output is averaged to provide the time spent at high slope (36). Abnormal rhythm is defined by a high percentage of high slope and thus little time spent at low slope and baseline.

In the AID-B, both the factory-set minimal rate criterion and the probability density function must be satisfied for the rhythm to be classified as ventricular fibrillation or ventricular tachycardia. In the original model (AID), both rate and probability density function were detected through the same electrodes, one of which was also one of the shocking electrodes. In the present model of the AICD (AID-B), rate sensing is performed through a pair of ventricular epicardial electrodes or a transvenous electrode and the probability density function detection is performed through the shock electrodes. It must be noted that classification of a rhythm as requiring termination initiates charging of the output capacitor to full energy. Once charged, the device is committed to produce a shock whether or not the abnormal rhythm has self-terminated. The AICD has on occasion been triggered by rhythms other than ventricular fibrillation (37), including atrial fibrillation during exercise (Fig. 5).

**Impedance**

Impedance measured between proximal and distal right ventricular electrodes has been proposed as an indicator of ventricular tachycardia or ventricular fibrillation (38). During a hemodynamically significant tachyarrhythmia, decreased cardiac output presumably results in a change of impedance between the two electrodes. This variable was measured using a 4.5 µA current at a frequency of 4 kHz with Medtronic 10240 catheters. Changes in impedance, mean arterial pressure and surface ECG were recorded before, during and after ventricular tachycardia or ventricular fibrillation. Ventricular tachycardia and ventricular fibrillation showed a mean decrease of 44 ± 16% in impedance and mean arterial pressure showed a mean decrease of 45 ± 20%. The change in impedance was especially marked during ventricular fibrillation, showing a 61 to 87% decrease. This technique is especially appealing because it detects the hemodynamic effect of a tachyarrhythmia. The utility of this technique for differentiating between ventricular tachycardia and ventricular fibrillation and its response during supraventricular or sinus tachycardia have yet to be evaluated.

**Discussion**

Single versus multiple electrode techniques. Algorithms that make use of characteristics of the electrogram (configuration, frequency spectrum, duration) can be implemented using a single pacemaker electrode. This does not require that special leads be developed and does not modify the implantation technique. A single ventricular electrode technique cannot distinguish between sinus rhythm and supraventricular tachycardia. The optimal detection system may be one that combines a timing technique with some electrographic measurement, or an approach requiring three or four electrodes that can be independently placed. The accuracy of configurational methods is dependent on the stability of the electrode and has relatively low tolerance for beat-to-beat variability. In order to program detection variables after implantation, high resolution telemetry would be needed and the programming in general would be considerably more complex than that now performed for any pacemakers.

Timing algorithms, such as the atrial-ventricular two electrode system and the dual ventricular method, would present a much simpler postimplantation programming task. Because electrographic characteristics can change over time (39), it is advantageous to use detection schemes that are independent of these characteristics, and thus would not require readjustment of sensing. Postimplantation programming would require telemetry of only marker pulses rather than transmission of the electrogram itself. Timing methods
in general would result in less of an increase in electronic complexity over present designs than would those methods using characteristics of the electrogram. These approaches would require that multiple electrode leads be developed that can be placed at various sites, tested intraoperatively and perhaps relocated during the procedure before permanent placement. This requires several leads that can be placed independently or the availability of various multielectrode leads providing a choice of electrode spacing.

Epicardial electrodes can be attached at various sites either individually or in fixed arrays, which would be similar to the patch electrode for the AICD. However, the thoracotomy required for this technique is probably not warranted for antitachycardia pacing alone. The feasibility of endocardial electrode arrays should be investigated. Timing algorithms that use only two electrodes cannot identify all arrhythmias. Implantation of dual chamber pacemakers with the attendant placement of atrial and ventricular leads is routine now, and development of lead systems with three or four electrodes would allow implementation of even the most complex algorithms. If multiple electrode and lead systems, possibly having several actively fixed electrodes, are to be used, it is essential that they do not exacerbate the problem of lead removal should exploitation become necessary.

The proper choice of available detection criteria (such as onset and stability) for the arrhythmia being treated is important. Too specific a combination of criteria may fail to recognize some tachyarrhythmias. Although most patients apparently tolerate unnecessary bursts of rapid pacing, the effect of an arrhythmia that is not terminated by the implanted device is at least discomforting.

Accuracy and reliability of tachycardia detection techniques. Although the accuracy of tachycardia detection may be improved by some of the techniques described, no method is completely reliable. Use of a detection method that does not provide complete accuracy in automatic detection of tachycardia can place a patient at risk of receiving unnecessary antitachycardia pacing or defibrillation. A simple rate criterion is accurate in the majority of patients and should be a part of any detection algorithm. The more sophisticated methods can be added to improve specificity of diagnosis. Advances made in basic pacemaker technology, such as reliable lead systems for sensing and device programmability, have paved the way for the new sophisticated detection algorithms presented in this study. Unfortunately, it is not possible to directly compare the various techniques because reported success rates are based on dissimilar test data. Eventually, comparisons can be made by testing each method against the same set of recorded electrograms.

Future status. Antitachycardia pacing and defibrillation using implantable devices will continue to be an important treatment modality for patients with recurrent life-threatening tachyarrhythmias. Hybrid devices that employ both antitachycardia pacing functions and automatic defibrillation as backup are under investigation and should be available for clinical use in the near future. Although electrical devices will probably not be useful in treating all patients with tachyarrhythmias, any increase over the present limited use of such devices would justify development of the more sophisticated sensing algorithms.

References