The automatic implantable cardioverter-defibrillator (AICD) effectively prevents death due to ventricular tachycardia or ventricular fibrillation. Some patients who need an AICD also require cardiac pacing to treat symptomatic bradycardia, bradycardia after defibrillation, or to provide a rate floor to reduce the frequency of bradycardia-related ventricular arrhythmias. Some patients also can benefit from antitachycardia pacing. A mapping technique to implant a pacemaker and AICD sensing leads is presented. For patients with a pacemaker who later need an AICD, the left ventricle is mapped with use of the AICD rate-sensing electrodes to identify a site at which the minimal pacemaker stimulus and maximal ventricular electrogram amplitudes are recorded. An external cardioverter-defibrillator that has amplifiers similar to those in the AICD is used to monitor the rate-sensing electrogram. For patients with an implanted AICD, pacemaker implantation is undertaken by mapping the right ventricle with the pacemaker lead while the AICD is in standby mode; the AICD beep monitor is then used to determine a site where pacemaker stimulus detection by the AICD does not occur. Eight patients underwent implantation of a combined AICD-pacemaker system (four ventricular antitachycardia pacemakers, three ventricular demand pacemakers and one atrial demand pacemaker). Neither inhibition of AICD arrhythmia detection nor double counting occurred. Satisfactory AICD-pacemaker function was shown in all patients postoperatively, and no pacemaker malfunction was observed. Thus, with currently available technology, a combined AICD-pacemaker system can be implanted with satisfactory function of both devices and without adverse device-device interactions. (J Am Coll Cardiol 1989;13:121-31)

The automatic implantable cardioverter-defibrillator (AICD, Cardiac Pacemakers, Inc.) effectively prevents death due to ventricular tachycardia or ventricular fibrillation (1-3). Some patients who need an AICD also require cardiac pacing to treat underlying symptomatic bradycardia, severe bradycardia after defibrillation, or to provide a rate floor to reduce the frequency of bradycardia-related ventricular arrhythmias (4-8). Some patients also have hemodynamically well tolerated ventricular tachycardia and remain alert during their arrhythmia. The discomfort of electrical cardioversion therefore makes the use of the AICD as the sole antiarrhythmic therapy for these individuals difficult. Although antitachycardia pacemakers can terminate many episodes of these slower ventricular tachycardias (8-10), the possibility of rate acceleration has led to interest in combining the capabilities of antitachycardia pacing, cardioversion and defibrillation into a single device (6,11,12). The currently available AICD does not incorporate pacemaker capability. Although future implantable defibrillators will have pacing capabilities, at present when both an AICD and a pacemaker are needed, the leads and pulse generator for each device must be implanted separately. However, implantation of the devices in combination has been problematic (13-16). Although interactions between the AICD and pacemakers have been described (2,17-24), there are only isolated detailed reports of combined AICD and pacemaker implantation (7,25,26). This communication describes techniques for the implantation of a combined AICD-pacemaker system in patients with life-threatening ventricular arrhythmias who require either pacing for bradycardia or antitachycardia pacing for ventricular tachycardia.
Table 1. Summary of Eight Patients With Combined AICD and Pacemaker Implantation

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>Patient 2</th>
<th>Patient 3</th>
<th>Patient 4</th>
<th>Patient 5</th>
<th>Patient 6</th>
<th>Patient 7</th>
<th>Patient 8</th>
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<tr>
<td>Age/gender</td>
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<td>56/M</td>
<td>54/M</td>
<td>67/M</td>
<td>56/M</td>
<td>73/F</td>
<td>62/M</td>
</tr>
<tr>
<td>Underlying disease</td>
<td>CAD</td>
<td>CAD</td>
<td>CAD</td>
<td>CAD</td>
<td>IDC</td>
<td>CAD</td>
<td>CAD</td>
</tr>
<tr>
<td>Clinical rhythms</td>
<td>VT</td>
<td>VT</td>
<td>VT</td>
<td>VT/IVF</td>
<td>VT/IVF</td>
<td>VT/IVF</td>
<td>SB</td>
</tr>
<tr>
<td>EF</td>
<td>0.13</td>
<td>0.21</td>
<td>0.17</td>
<td>0.29</td>
<td>0.28</td>
<td>0.33</td>
<td>0.20</td>
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<tr>
<td>AICD Model</td>
<td>1520</td>
<td>1520</td>
<td>1520</td>
<td>1520</td>
<td>AID-B</td>
<td>1520</td>
<td>1520</td>
</tr>
<tr>
<td>Rate (beats/min)</td>
<td>202</td>
<td>204</td>
<td>204</td>
<td>162</td>
<td>203</td>
<td>174</td>
<td>176</td>
</tr>
<tr>
<td>PDF</td>
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<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>Energy (J)*</td>
<td>31131</td>
<td>31133</td>
<td>31131</td>
<td>31131</td>
<td>30130</td>
<td>26130</td>
<td>30130</td>
</tr>
<tr>
<td>Pacemaker model</td>
<td>Telelectronics PASAR 4171</td>
<td>Telelectronics PASAR 4171</td>
<td>Intermedics 262-14</td>
<td>Intermedics 262-14</td>
<td>Medtronic Activitrax</td>
<td>Medtronic Activitrax</td>
<td>Medtronic Teletronics</td>
</tr>
<tr>
<td>Pacemaker order</td>
<td>P=AICD</td>
<td>P=AICD</td>
<td>P=AICD</td>
<td>P=AICD</td>
<td>P=AICD</td>
<td>P=AICD</td>
<td>P=AICD</td>
</tr>
<tr>
<td>No. of drugs failed</td>
<td>9</td>
<td>10</td>
<td>5</td>
<td>6</td>
<td>N1</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

*Energy delivered for first and subsequent shocks. Afl = atrial flutter; AICD = automatic implantable cardioverter-defibrillator; CAD = coronary artery disease; EF = ejection fraction; F = female; HV = HV interval; IDC = idiopathic dilated cardiomyopathy; M = male; N1 = noninducible; P = pacemaker; PDF = probability density function; QT = QT interval; SB = sinus bradycardia; SSS = sick sinus syndrome; VR = ventricular response; VF = ventricular fibrillation; VT = ventricular tachycardia.

Methods

Patients. Between September 12, 1984 and April 7, 1988 at the University of Alabama at Birmingham, 65 automatic implantable cardioverter-defibrillators (AICD) were implanted in 46 patients. Eight of these patients also required a pacemaker and constitute the study group (Table 1). Four patients had hemodynamically well tolerated ventricular tachycardia effectively terminated by antitachycardia pacing. The AICD was implanted as backup for treating possible tachycardia acceleration precipitated by pacing. One of these four patients also required ventricular demand pacing for high degree atrioventricular block (Patient 2) and another had sinus bradycardia with a long HV interval (Patient 3). The other four patients had both hemodynamically unstable ventricular tachyarrhythmias and important bradycardias requiring demand pacing. One of these patients had a demand pacemaker implanted because pacing had been shown to markedly decrease the frequency of episodes of polymorphic ventricular tachycardia.

Preoperative evaluation. Before AICD implantation, each patient was evaluated with electrocardiography, ambulatory monitoring, echocardiography, radionuclide ventriculography, coronary angiography, left ventriculography and electrophysiologic study. A treadmill exercise test was also performed whenever possible to determine the maximal ventricular rate during exercise and to assess if there was overlap in the rates of the supraventricular rhythms and ventricular tachycardia. Before implantation of an antitachycardia pacemaker, ≥50 and preferably 100 successful conversions of the stable ventricular tachycardia by pacing were required. Antitachycardia pacemaker implantation was performed with Institutional Review Board approval after the patients had given fully informed consent.

Devices. The AICD was used in all patients. One patient underwent implantation of an AID-B device; the other seven had a Ventek model 1520 device implanted.

Six different pacemakers were used. A Telelectronics PASAR model 4171 antitachycardia pulse generator was implanted in two patients. This device automatically detects and responds to the presence of a tachycardia when ≥5 consecutive RR intervals occur at a rate faster than a preprogrammed tachycardia detection rate. Two patients underwent implantation of an Intermedics Intertach model 262-14 pulse generator. For tachycardia recognition, this device has the capability of assessing rate, cycle length stability, change in cycle length at tachycardia onset and the number of tachycardia cycles at a particular cycle length.

One patient each underwent implantation of an Optimax MPT and Spectrax (Medtronic, Inc.) model 8412 and 8420 ventricular pulse generators. These devices are capable of sensing and tracking the sinus node and pacing at a rate faster than a preprogrammed sinus detection rate. The seventh and eighth patients had a Medtronic model 8420 ventricular demand pulse generator and a Teletronics model 5282A atrial demand pulse generator implanted, respectively.

Potential device interactions investigated. Detection inhibition (13). Ventricular demand pacemakers may fail to sense ventricular tachycardia or ventricular fibrillation. Therefore, pacing stimuli may be delivered asynchronously during these arrhythmias. If compared with the R waves of
the tachycardia the pacemaker stimuli in the AICD rate-sensing electrogram are large, the AICD automatic gain control may filter the lower amplitude signals of the tachycardia and cause the AICD to interpret the pacemaker stimuli as a nontachycardia rhythm, thereby leading to failure of the AICD to detect the arrhythmia. Prior investigators have emphasized that this problem may be greater with unipolar ventricular pacemakers. Nevertheless, detection inhibition may also occur when bipolar pacemaker stimuli are large (23).

Double counting (13). If the interval between the pacemaker stimulus and the R wave in the bipolar AICD sensing electrogram is greater than the 150 to 160 ms refractory period of the AICD, both signals may be interpreted as ventricular depolarizations. If these signals occur together at a combined rate greater than the AICD tachycardia detection rate, the AICD rate detection criterion will be satisfied. A charging cycle will be initiated and a shock will be delivered even though the underlying cardiac rhythm was neither ventricular tachycardia nor ventricular fibrillation.

AICD discharge precipitated by pacing above the AICD tachycardia detection rate. Even in the absence of double counting, pacing at a rate and duration that satisfy the AICD rate-sensing criterion may initiate an AICD charging cycle and subsequent discharge although the underlying rhythm would not result in a discharge.

AICD-induced pacemaker malfunction (13,17,18,22). Pacemakers may be reprogrammed or damaged by AICD discharges. In addition, if during or after an episode of ventricular tachycardia or ventricular fibrillation the pacing threshold increases, ineffective pacing may occur if the pacemaker stimulus becomes subthreshold.

Operative Procedures

The AICD and the pacemaker were implanted at separate procedures in all patients. The pacemakers were implanted in the prepectoral region and the AICD in the anterior left upper quadrant of the abdomen to maximize the distance between the devices and thereby avoid magnet and programmer interaction between the devices.

Implantation of an AICD in patients with a previously implanted pacemaker. Four surface electrocardiographic (ECG) leads (I, II, III and aVR) and electrograms between the defibrillating leads and the bipolar epicardial sensing leads were recorded on an Electronics-for-Medicine VR-16 switched beam oscilloscopic recorder. Two patch electrodes (model L67 or A67, Cardiac Pacemakers, Inc.) were always used because defibrillation thresholds are usually lower than those when a right atrial-superior vena cava spring electrode (model C10, Cardiac Pacemakers) is used (23). The external cardioverter defibrillator (ECD, Intec Systems, Inc.) was used to monitor the cardiac electrograms from the AICD sensing and defibrillating leads. The patients were positioned to allow access with both a magnet and programmer head away from the sterile operative field. So as to mimic a “worst case scenario,” the pacemaker was programmed to its highest stimulus amplitude and duration to maximize the size of the pacemaker stimulus and increase the possibility of sensing by the AICD. The same techniques were used when implanting an AICD in the presence of either an atrial or a ventricular pacemaker.

After the cardiac electrogram signals were calibrated, mapping of the left ventricle was performed to locate a site at which the pacemaker stimulus artifact size was as small as possible in the rate-sensing electrogram of the AICD. The bipolar epicardial sensing electrodes of the AICD (model KS4, Cardiac Pacemakers, Inc.) were left in their carriers and held by the surgeon with the electrode tips within 1 cm of each other (Fig. 1). The electrodes were thereafter moved to various sites over the left ventricular epicardium during high output pacing to identify a site where the amplitude of the pacemaker stimulus was as small as possible both in absolute amplitude and relative to the native and paced R waves. The R wave amplitudes optimally exceeded 7 mV. A pacemaker stimulus and paced R wave “map” was thereby constructed (Fig. 2A). If a long stimulus to R wave interval was observed, the bipolar leads were moved closer to the pacemaker electrode. Mapping was performed before the patch leads were implanted to avoid placing the patches over the optimal bipolar sensing site.

When a site was located where the pacemaker stimulus amplitude was minimal and the R wave amplitude was large in both ventricular paced and sinus rhythm, one of the epicardial screw-in leads was implanted. The second epicardial screw-in electrode was then moved circumferentially within 1 cm around the implanted leads to identify the site where the smallest pacing stimulus was recorded. However, because the sensing vector may change as the screw-in electrode enters the myocardium, the amplitudes of the pacemaker stimulus artifact and R wave may also change. Thus, the amplitude of the pacemaker stimulus and R wave during pacing and sinus rhythm were always remeasured after the second screw-in electrode was implanted (Fig. 2B and 2C). When the patient was discharged from the hospital, the pacemaker was reprogrammed to a lower output as clinically indicated, resulting in pacemaker stimuli of smaller amplitude (Fig. 2B).

After the bipolar leads were implanted, the patch electrodes were implanted followed by cardioversion and defibrillation threshold testing in the usual fashion (14–16, 23). Special attention was paid to the behavior of the implanted pacemaker during both ventricular tachycardia (Fig. 3A) and ventricular fibrillation (Fig. 3B and 3C) to determine whether pacing occurred during these arrhythmias and whether the pacemaker stimulus artifact was visible in the electrogram recorded with use of the AICD bipolar sensing electrodes.

When satisfactory cardioversion and defibrillation...
thresholds were established, the AICD was implanted. To assess the actual sensing performance of the AICD, the magnet was left over the AICD after activation so that the AICD functioned in the standby ("EP") mode. If during ventricular pacing double beeping was heard (one beep for the pacemaker artifact and one for the QRS response), then double counting was considered to be present. In addition, the pacemaker was also programmed to >50% of the AICD detection rate to observe whether an AICD charging cycle was initiated that suggested the occurrence of double counting.

The performance of the AICD and the pacemaker were then tested during both ventricular tachycardia and ventricular fibrillation to observe whether the pacing occurred during ventricular tachycardia (Fig. 4A) or ventricular fibrillation (Fig. 4B) and whether the AICD accurately detected these arrhythmias. For those individuals with an antitachycardia pacemaker, conversion of ventricular tachycardia was also tested in the operating room (Fig. 4C).

Implantation of a pacemaker when an AICD is already implanted. For pacemaker implantation, the AICD was placed in the standby ("EP") mode and the pacemaker lead was advanced to the right ventricle. A pacing system analyzer (Medtronic model 5311) programmed to maximal output and pulse width was used for pacing. The lead was then positioned to find a site that had acceptable pacing and sensing characteristics and avoided AICD sensing of the pacing stimulus, as detected by listening for double beeping from the AICD. Use of an active fixation lead facilitated positioning at a site satisfying these criteria. The lead and pacemaker were then implanted.

Postoperative evaluation. In patients with a combined AICD and pacemaker system, a postoperative electrophysiologic study was performed before the patient was discharged from the hospital. At this study, the pacemaker was again programmed to its maximal stimulus amplitude and duration. For patients with ventricular tachycardia, this rhythm was always induced whether or not an antitachycardia pacemaker was implanted. For individuals with a combined antitachycardia pacemaker and AICD system, ventricular tachycardia was induced and terminated multiple times. Finally, regardless of whether a patient had experienced ventricular fibrillation clinically, this arrhythmia was always induced and tested. Special attention was paid to the following questions: What tachycardias and rates were observed? Did the AICD discharge reprogram or injure the pacemaker? Did the pacemaker cause AICD oversensing, double counting or detection inhibition? Did antitachycardia pacing accelerate the tachycardia?

Results

Postoperative electrophysiologic studies. Seven of the eight patients underwent postoperative electrophysiologic study. The eighth patient had multiple successful conversions of arrhythmia after implantation. Each patient tested had ventricular fibrillation induced that was successfully terminated in each case (Fig. 5 and 6).

Patient 8 with an atrial demand pacemaker had a defibrillation threshold of 25 J in the operating room. At postoperative electrophysiologic study (Fig. 6), ventricular fibrillation was induced by rapid ventricular pacing. These recordings demonstrated continued atrial pacing during ventricular fibrillation. The AICD not only sensed the arrhythmia and delivered an appropriate discharge but also was able
Figure 2. A and B. Recordings from Patient 5 with a Medtronic Activitrax II activity-sensing, rate-adaptive pacemaker at automatic implantable cardioverter-defibrillator (AICD) implantation. Shown are surface ECG leads I, II, III, aVR and the electrogram recorded from the AICD bipolar epicardial leads (Bi). The gain for all recordings is identical. A, Epicardial recordings from one right ventricular (RV) and three left ventricular (LV) sites are shown during pacing at high stimulus amplitude (8 V) and duration (2 ms). The pacemaker stimulus artifact is extremely large close to the apex of the right ventricle and at left ventricular sites 1 and 2. Left ventricular site 3 is the location where the AICD bipolar sensing electrodes were implanted because the pacemaker stimulus artifact at this rate has a modest amplitude and is relatively small compared with that of the paced R wave. B, The AICD sensing leads are implanted. The R wave during sinus rhythm is 8.7 mV (left column). During bipolar pacing (middle columns) the pacemaker stimulus amplitude and pulse width are shown below the stimulus artifacts. As the programmed pacemaker stimulus amplitude is decreased, the stimulus artifact similarly decreases as recorded in the AICD bipolar sensing lead (Bi). During unipolar pacing (right column) when the pacing stimulus amplitude is only 2.5 V, the stimulus artifact amplitude is larger than that at any bipolar pacing output. C, Recordings from Patient 8 with a Telectronics (model 5282A) atrial demand pacemaker demonstrate virtually no identifiable pacemaker stimulus artifacts (asterisks) in the AICD bipolar sensing electrogram (Bi) after the bipolar leads were implanted. The R wave in the bipolar electrogram measures 15.7 mV.

Figure 3. Recordings during defibrillation threshold testing at automatic implantable cardioverter-defibrillator (AICD) implantation. Shown are surface ECG leads I, II, III and aVR, the electrogram recorded from the two AICD patch electrodes (P-P) and the AICD bipolar rate-sensing electrogram (Bi). A and B illustrate antitachycardia pacing during a nonclinical and rapid ventricular tachycardia (A) and ventricular fibrillation (B) in Patient 2 with a previously implanted Telectronics PASAR antitachycardia pacemaker. There is virtually no pacemaker stimulus artifact detectable in the bipolar rate-sensing electrogram (Bi) (asterisks) during pacing (arrows). B, The fourth through sixth impulses delivered during ventricular fibrillation are delivered from the antitachycardia function in the ventricular demand mode. C, Similar recordings during defibrillation threshold testing are shown for Patient 8, who has a Telectronics (model 5282A) atrial demand pacemaker. Virtually no pacemaker stimulus artifact is visible in the bipolar rate-sensing electrogram (Bi) (asterisks) during pacing (arrows).

to recycle and rescue the patient with a second discharge when the first proved ineffective.

In those patients with ventricular tachycardia, arrhythmia conversion was also tested by either the AICD or the antitachycardia pacemaker (Fig. 7) as indicated. No inhibition of AICD function by the pacemaker was observed. At postoperative electrophysiologic study. Patient 3 with an
Figure 4. A, An intraoperative automatic implantable cardioverter-defibrillator (AICD) defibrillation test for Patient 5, who has a combined Medtronic Activitrex II activity-sensing, rate-adaptive pacemaker and AICD system, when the pacemaker was programmed to its highest output (8 V) and pulse width (2 ms). Pacing occurred during this ventricular tachycardia, but the first AICD discharge successfully sensed and terminated the arrhythmia (sensing time of 9.5 s, charging time of 7.2 s) without detection inhibition. Ventricular demand pacing followed the shock. B, With the AICD in the standby mode, ramp pacing induced ventricular fibrillation in Patient 2 who has a combined Teletronic PASAR antitachycardia pacemaker and AICD. After 17.0 s [standby time 4 s, sensing time (sense) 5.7 s, charging time (charge) 6.1 s and lag time after capacitor charging 1.2 s], the AICD successfully terminated the arrhythmia. The antitachycardia pacemaker supported the cardiac rhythm after successful defibrillation but did not pace during the arrhythmia. C, Patient 2. Termination of ventricular tachycardia by an antitachycardia pacemaker is demonstrated. With the AICD in the standby mode and the antitachycardia pacemaker inactivated, programmed stimulation by way of the AICD bipolar leads (Bi) induced the patient's clinical stable monomorphic ventricular tachycardia. Then both the antitachycardia pacemaker and the AICD were placed in their active modes. The first antitachycardia pacing burst (initial delay 380 ms, coupled delay 250 ms) terminated the ventricular tachycardia and its first pacing sequence. The AICD did not initiate a charging cycle because this tachycardia had a rate of only 115 beats/min and the AICD rate cutoff was 204 beats/min. Recordings are labeled as in previous figures.

Intermedics Intertach pacemaker implanted for ventricular tachycardia was found to have had a change in his arrhythmia substrate. Whereas ventricular tachycardia had been easily inducible and hemodynamically well tolerated before AICD implantation, no ventricular tachycardia was induced postoperatively despite programmed stimulation with up to four extrastimuli. However, burst pacing induced ventricular flutter. Although the antitachycardia pacemaker correctly recognized this arrhythmia as exceeding its detection rate and attempted to pace and terminate the arrhythmia, polymorphic ventricular tachycardia was precipitated. Furthermore, when the AICD discharged during a burst of pacemaker pulses, ventricular fibrillation was precipitated, thereby initiating a cycle of termination of ventricular fibrillation by the AICD with reinitiation by the antitachycardia pacemaker. Similar arrhythmia acceleration by the devices in this patient had also been demonstrated intraoperatively (Fig. 8). Because the AICD can only deliver four pulses for one arrhythmia episode, an unsalvageable arrhythmia could have been precipitated. For this reason the patient was discharged from the hospital with the Intertach in the ventricular demand (VVI) mode.
Figure 5. Tracings recorded at postoperative electrophysiologic study in Patient 6, who has a Medtronic Activitrax activity-sensing, rate-adaptive pacemaker. Surface ECG leads I, II, III and V<sub>1</sub> are shown with the right ventricular apex (RVA) electrogram from a temporary electrode catheter advanced to the right ventricle for programmed stimulation. The automatic implantable cardioverter-defibrillator (AICD) was placed in the standby mode and ventricular fibrillation was induced. The AICD was then activated and despite ventricular demand pacing (arrows) during ventricular fibrillation, the AICD correctly identified and converted the arrhythmia. Note that the patient is pacemaker dependent after AICD discharge.

**Follow-up.** The two patients with a PASAR antitachycardia device have reported self-terminating episodes of palpitation that are presumably due to ventricular tachycardia successfully treated by antitachycardia pacing. Patient 2 has also had AICD discharges. Immediately before one defibrillation, transtelephonic monitoring documented ventricular tachycardia that was not terminated by the antitachycardia pacemaker. Patient 3 has had 11 AICD discharges, the first one occurring 2 months after implantation. Syncope and ventricular tachycardia were documented. Patient 4 has been followed up for 3 months after implantation without any reported clinical event. However, interrogation of his Intercard pacemaker revealed that a tachycardia with a cycle length of 492 ms had been detected and terminated on 3 occasions. The sensed events were unlikely to have been sinus tachycardia because the maximal heart rate achieved during treadmill exercise testing was 83 beats/min. The two patients (Patients 5 and 6) with an activity-sensing, rate-adaptive pacemaker remain well 10 and 11 months, respectively, after implantation. Patient 6 with idiopathic dilated cardiomyopathy has used her AICD since pacemaker implantation. Patient 7 with a ventricular demand pacemaker experienced 17 appropriate discharges before he died later from pulmonary embolism. Patient 8 has also received an appropriate AICD discharge preceded by premonitory dizziness. Thus, five of the eight study patients have used their AICD successfully in the presence of their pacemaker.

Figure 6. Recordings from the postoperative electrophysiologic study in Patient 8 with an automatic implantable cardioverter-defibrillator (AICD) and a Telectronics (model 5282A) atrial demand pacemaker. Channels I to 4 show surface ECG leads I, II, III and V<sub>1</sub>. RA and RVA are endocardial electrograms recorded from a temporary electrode catheter from which the two proximal poles record the intracavitary right atrial (RA) electrogram and the distal poles record the right ventricular apical (RVA) electrogram. Ventricular fibrillation was induced by rapid ventricular pacing with the AICD in the standby mode. At the asterisk, the AICD was placed in the active mode. In the lower panel, the first AICD shock was delivered but ventricular fibrillation persisted. A second rescue shock terminated the arrhythmia. In the right atrial electrogram continued atrial demand pacing is shown during ventricular fibrillation. The AICD recognition of ventricular fibrillation was not affected. Recordings labeled as in previous figures.
Figure 7. Surface electrocardiographic leads and electrogram from a catheter inserted percutaneously at the right ventricular apex (RVA) in Patient I with a Telectronics PASAR antitachycardia pacemaker and an automatic implantable cardioverter-defibrillator (AICD) undergoing postoperative electrophysiologic study. Triple extrastimuli delivered during sinus rhythm (S3,S3,S3) induced the patient's clinical right bundle/right superior axis ventricular tachycardia (rate 150 beats/min). The AICD was in the active mode during programmed stimulation, and 5 beats after the antitachycardia pacemaker was activated (asterisk) 7 pulses (S) were delivered and successfully restored sinus rhythm. Recordings labeled as in previous figures.

Discussion

Combined automatic implantable cardioverter-defibrillator (AICD) and pacemaker implantation provides a substrate for potential adverse interactions between the two devices (2,13-23). Although successful implantation of combined AICD and pacemaker systems has been reported (2,7,25,26), we are not aware of a detailed description of the operative techniques. This report extends prior observations by describing an operative approach to combined AICD and pacemaker implantation. In the present study, no adverse device interactions occurred that could not be remedied by reprogramming the ventricular pacemaker.

Order of AICD and pacemaker implantation. Our mapping techniques allow localization of sites in the right ventricle for pacemaker lead implantation in patients with a previously implanted AICD pulse generator. Conversely, we have also successfully implanted an AICD pulse generator in patients with a previously implanted pacemaker. However, the pacemaker should be implanted first, if possible, for two reasons: 1) Regardless of which device is implanted first, the pacemaker lead and the AICD sensing lead or leads must be positioned so that the pacemaker stimulus artifact is small and not sensed by the AICD. It is potentially more difficult to identify a satisfactory right ventricular site for pacemaker lead implantation in a patient who already has an AICD implanted than it is to identify a satisfactory left ventricular site for AICD sensing lead implantation in a patient who already has a pacemaker. For a patient with an AICD that uses either a transvenous rate-counting electrode or an epicardial rate-counting lead system implanted near the right ventricle, locating a satisfactory right ventricular pacing site...
may be impossible, necessitating a thoracotomy or sternotomy for pacemaker lead implantation. 2) When the pacemaker is implanted first in a separate procedure, stable fixation of the endocardial lead is possible before AICD implantation which requires manipulation of the heart.

**Implantation of the AICD rate-sensing and defibrillating electrodes.** Most adverse interactions can be avoided by implanting the AICD rate-sensing electrodes at a location that minimizes the amplitude of the pacemaker artifact. The external cardioverter-defibrillator is used to record the electrograms because its filtering system closely resembles that in the AICD, and the implanting physician is able to observe the electrograms as viewed by the AICD monitoring circuit itself. (The external cardioverter-defibrillator does not have an automatic gain control as does the AICD.) Optimal AICD sensing electrode position is demonstrated in Figures 2, 3 and 4 because the pacemaker stimulus artifact is virtually invisible in the electrogram of the AICD bipolar sensing lead. Special attention must be given to assure not only that the **absolute** amplitude of the pacing stimulus is minimal, but also that its **relative** amplitude to the R wave is minimal because relatively large pacing stimuli in relation to the R wave can cause inhibition of arrhythmia detection and double counting. Neither complication was observed with our technique.

Because there is always the possibility that a pacemaker may become necessary in a patient after AICD implantation, we have abandoned using the transvenous bipolar sensing electrode (model BT10, Cardiac Pacemakers, Inc.) and now routinely implant the bipolar sensing electrodes epicardially high on the lateral left ventricle 0.5 to 1 in. (1.27 to 2.54 cm) below the atrioventricular groove. By doing so, the possibility of finding a satisfactory right ventricular pacing site is maximized in the event that a permanent pacemaker is required after AICD implantation. If the AICD sensing lead or leads were to be implanted endocardially in the right ventricular or epicardially over the right ventricle, it would be particularly difficult to find a satisfactory site in the right ventricle where a permanent pacemaker could be implanted without causing double counting and adverse interaction with the AICD.

**Importance of bipolar pacing.** Unipolar pacing contraindicates AICD implantation (13-16,21,23). Figure 2B demonstrates the difference between unipolar and bipolar pacing as recorded at a single AICD bipolar recording site. Although the vector orientations of the unipolar and bipolar paced signals were different in relation to the AICD rate-sensing electrodes, the amplitudes of the pacemaker stimulus artifacts were consistently larger during unipolar than during bipolar pacing. Nevertheless, even bipolar stimulus artifacts can be large (Fig. 2A) and if they are similar in amplitude to the amplitude of the R wave during ventricular tachycardia or ventricular fibrillation, then it may be necessary to move the bipolar sensing electrodes to avoid detection inhibition by the pacemaker.

Despite concerns about double counting and detection inhibition, we found implantation of the AICD rate-sensing electrodes quite simple in our patient with a bipolar atrial demand pacemaker, probably because the atrial pacing site was far removed from the ventricle.

**Risk of arrhythmia acceleration and importance of postoperative electrophysiologic study.** Several precautionary measures can protect the patient against the repetitive reinitiation of hemodynamically unstable ventricular tachycardia or fibrillation by antitachycardia pacing as was observed in Patient 3 (Fig. 8). First, the slowest and shortest effective antitachycardia pacing bursts should be employed because faster and longer bursts may increase the likelihood of both tachycardia acceleration and AICD activation due to pacing. Second, because the AICD can deliver only four shocks for one sensed arrhythmia, consideration may be given to delivery of two or at most three antitachycardia pacing bursts so that at least one or two AICD shocks are available for delivery in the absence of antitachycardia pacing.

**Pacemaker function and follow-up.** Satisfactory pacing occurred in our patients after AICD discharge (Fig. 4 to 6). Although there have been reports of injury to implanted pacemakers by AICD shocks (17,18), this was not observed in our experience.

Because **asynchronous ventricular (VOO)** pacing may initiate ventricular tachycardia, and, in fact, did so in one of our patients, we are now reluctant to allow patients with easily inducible ventricular tachycardia to have pacemaker checks at home. Asynchronous ventricular pacing can also result in AICD discharges when asynchronous pacemaker stimulus artifacts are counted in addition to the native underlying R waves (24). Certainly, if the AICD is deactivated during pacemaker checks as has been advocated by others (24), this should not be done at home. Finally, if magnet pacemaker checks are done at home, they should not be done by the patient but rather by another individual because magnet movement across the abdomen may initiate an AICD charging cycle.

**Device limitations and future directions.** In view of the various AICD-pacemaker interaction discussions and because the current AICD is not programmable, the choice of the appropriate pacemaker to implant with an AICD and its programming are complex. Antitachycardia pacemakers are rapidly becoming more sophisticated, having greater versatility in both tachycardia detection and pacing. New generation AICDs will similarly have greater versatility in providing the capability of not only programmability but also antitachycardia and ventricular demand pacing. Many of the problems that exist today will become obsolete when a combined AICD-antitachycardia pacemaker-ventricular demand pacemaker becomes available. These new devices should have a blanking period during pacing for the cardio-
future transvenous pacemaker electrode implantation in the thresholds during periods of threshold rise, whether they dial sensing electrodes over the right ventricle because the lateral left ventricle as far from the right ventricular apex as possible. We advise against implantation of AICD epicardial and subcutaneous lead systems are being developed such that cardioversion and defibrillation can be accomplished without the need for epicardial patch placement. With these latter systems, both pacing and rate sensing can be accomplished by way of the transvenous lead itself. Finally, it is hoped that a combined device will have greater capability for high pacing output to overcome increased thresholds during periods of threshold rise, whether they occur acutely after implantation, during ischemia, during ventricular tachycardia or after a shock (18–20,22).

Recommendations. 1) With the devices currently available, only a bipolar pacemaker should be implanted in conjunction with an AICD.

2) When an AICD is implanted alone, it should always be anticipated that antitachycardia or ventricular demand pacing may be needed in the future. For this reason, the bipolar rate-sensing electrodes should be placed epicardially and on the lateral left ventricle as far from the right ventricular apex as possible. We advise against implantation of AICD epicardial sensing electrodes over the right ventricle because future transvenous pacemaker electrode implantation in the right ventricle may be particularly difficult.

3) When an AICD is implanted in a patient with a pacemaker, the left ventricle should always be mapped to find a site for AICD sensing lead implantation where the amplitude of the pacemaker stimulus is minimal even when the pacemaker is programmed to its highest output.

4) Because locating such a site is possible only when the pacemaker is implanted before the AICD, pacemaker implantation should precede AICD implantation whenever possible.

5) When combined AICD-pacemaker systems are implanted, postoperative electrophysiologic study should always be performed before patients are dismissed from the hospital to assure successful function of both devices and lack of adverse device interaction. Ventricular fibrillation should always be tested and ventricular tachycardia should also be tested when present. Electrophysiologic study is also important because arrhythmia substrates may change postoperatively.

6) Whenever drug therapy is altered in patients with combined systems, repeat electrophysiologic study should be performed to assure satisfactory function of both devices (27–30). Antiarrhythmic drugs can alter pacing thresholds, defibrillation thresholds and tachycardia rates, rendering antitachycardia pacing more difficult and AICD recognition of the tachycardia perhaps impossible if the tachycardia rate declines below the rate cutoff of the AICD itself.

The roles of pacing therapy and automatic cardioversion and defibrillation with the AICD are clearly established. The implantation of both a pacemaker and an AICD in one individual is significantly more complex than is that of either device alone. Nevertheless, with meticulous attention to detail and full understanding of potential interactions between the devices, successful combined implantation can be performed.

Addendum
Since acceptance of this article, we have subsequently implanted an AICD in a patient with a Pacemaker model 2010-T bipolar dual chamber (DDD) pacemaker demonstrating the applicability of our techniques to not only single chamber but also dual chamber pacemakers implanted in conjunction with AICDs.

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References


