Types of Pacemakers and their Complications

By Doris J. W. Escher, M.D.

The three types of artificial cardiac pacemaker systems in common clinical use are:

1. Implantable pulse generators with endocardial or myocardial electrodes for long-term or permanent use.
2. External, miniaturized, transistorized, patient-portable, battery-powered, pulse generators with exteriorized electrodes for temporary transvenous endocardial or transthoracic myocardial pacing.
3. Console battery- or AC-powered cardioverters, defibrillators, or monitors with high-current external transcutaneous or low-current endocardial or myocardial circuits for temporary pacing in asynchronous or demand modes, with manual or triggered initiation of pacing.

Console Pacemakers

The simplest and fastest method of pacing is external transcutaneous stimulation by two electrode plates or subcutaneous needles applied to the skin of the chest. However, the high voltages required (75–150 v) to penetrate to the heart result in vigorous and painful contractions of the muscles of the chest wall, tolerable only under sedation. Capture is uncertain in the obese or emphysematous patient, and skin burns may occur as a result of insufficient electrode jelly or prolonged use. This route of pacing, therefore, is reserved for brief emergencies or where no other means are available.

The use of alternating current (AC) powered consoles for temporary endocardial or myocardial stimulation always carries the risk of malfunction with the possibility, despite safeguards, of inducing ventricular fibrillation by AC leakage into the pacing wires.

Battery-powered consoles eliminate this direct risk, but as pacemakers they are bulky, limit mobility and ambulation, and are less convenient and more expensive than miniaturized units.

External Pacemakers

External, patient portable, battery-powered pulse generators are designed to provide a wide range of choices in pacing rate, current amplitude, and mode of action. Several models are available (table 1).

Common features are that they are small in size (average 11.7 × 7.4 × 3.1 cm), are light in weight (average 3.0 g), can be strapped to the patient’s chest or limbs, are designed to accept, directly or by adapters, all or almost all electrodes likely to be utilized with them, are readily serviced for battery changes or cleaning, are capable of gas autoclaving for sterilization or contamination control, and are of increasingly dependable reliability.

These units operate in the asynchronous and R-wave inhibited modes over a wide range of rates. Their low trigger sensitivity may allow for their use in atrial as well as ventricular noncompetitive pacing. The Vitatron Triplextern offers the additional feature of ventricular synchronous pacing. This has a very useful special application in treatment of pacing failure of an implanted system operating in the fixed-rate mode with intermittent stimulus output or with regular output but intermittent capture. In these cases, where the implant emission cannot be suppressed by external stimuli and induces competition with asynchronous external pacing or suppression of R-wave inhibited external pacing, synchronous pacing locks to the timing of the implant emission and effects noncompetitive external supplemental pacing. It is not preferable to ventricular-inhibited pacing in routine use, as the stimulus artifact in the absolute refractory period deforms the electrocardiogram and may not be absolutely safe. The Triplextern also has a six-beat hysteresis in the R-wave inhibited node.

The optional rate-doubler feature of the General Electric External Standby is useful in the special case of rapid supraventricular tachycardias where it permits capture and rate reduction by overriding pacing or the disruption of a rapid tachycardia or flutter by the blocking action of brief application of very high rates. Rapid fixed rate pacing (to 400 beats/min), atrial and ventricular synchronous or stimulus-inhibited pacing, and paired and coupled pacing are otherwise available only in specialized instruments, such as Medtronic Multiple Mode Research Generator (5837) or the Cordis Synchrocor II.

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### Table 1

**External Pacemakers and their Functional Parameters**

<table>
<thead>
<tr>
<th>Model</th>
<th>Pulse rate (beats/min)</th>
<th>Current (mA)</th>
<th>Battery voltage, unipolar (V)</th>
<th>Refractory period (msec)</th>
<th>Trigger sensitivity (mv)</th>
<th>Pulse duration (msec)</th>
<th>Interference rejection or protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medtronic 5800</td>
<td>50 – 180</td>
<td>1.1 - 22</td>
<td>9.4</td>
<td></td>
<td>2.0</td>
<td>Asynchronous only</td>
<td></td>
</tr>
<tr>
<td>Cordis Chronocor II*</td>
<td>50 – 140</td>
<td>1 – 20</td>
<td>9.0</td>
<td>240 ± 20</td>
<td>1.0 ± 0.2</td>
<td>1.5 ± 0.2</td>
<td>Fixed rate over 5 Hz</td>
</tr>
<tr>
<td>Cordis Chronocor III†</td>
<td>30 – 150</td>
<td>0 – 20</td>
<td>8.4</td>
<td>240 ± 20</td>
<td>1.0 ± 0.1</td>
<td>1.5 ± 0.2</td>
<td>Over 5 Hz fixed rate at 15-20% higher than set rate</td>
</tr>
<tr>
<td>Medtronic 5840*</td>
<td>50 – 150</td>
<td>0.5 – 25</td>
<td>9.4</td>
<td></td>
<td>1.0 – 2.0</td>
<td>1.9 ± 0.3</td>
<td>60 Hz rejected; 5840B also rejects 50 Hz</td>
</tr>
<tr>
<td>Medtronic 5880A†</td>
<td>50 – 150</td>
<td>0.1 – 20</td>
<td>8.4</td>
<td>220 – 250</td>
<td>1.0 – 2.0</td>
<td>1.8 ± 0.2</td>
<td>50–60 Hz rejected; inhibition with nonrejected interference</td>
</tr>
<tr>
<td>General Electric A2071AB External standby†</td>
<td>60 – 140</td>
<td>0.1 – 12.0</td>
<td>8.4</td>
<td>100 – 150</td>
<td>1.0 – 2.5</td>
<td>2.0 ± 0.5</td>
<td>50–60 Hz filtered; if swamped, fixed rate</td>
</tr>
<tr>
<td>American Optical Mini-Pacer 210†‡</td>
<td>30 – 180</td>
<td>0.2 – 20</td>
<td>22.5</td>
<td>190 at 180 beats/min</td>
<td>1.0</td>
<td>1.9 ± 0.2</td>
<td>With 50-60 Hz to fixed rate at 10% over set rate</td>
</tr>
<tr>
<td>Hewlett-Packard 7834A†‡</td>
<td>50 – 150</td>
<td>0.1 – 20</td>
<td>8.4</td>
<td>250 ± 20</td>
<td>1.0 ± 0.25</td>
<td>1.8 ± 0.25</td>
<td>Threshold to 50 Hz is over 6.8 mv</td>
</tr>
<tr>
<td>Vitatron-Triplextern†</td>
<td>30 – 180</td>
<td>0 – 20**</td>
<td>9.0</td>
<td>38% of R-R interval</td>
<td>1.0</td>
<td>1.2</td>
<td>Electrically shielded; reverts to fixed rate if swamped</td>
</tr>
</tbody>
</table>

* Being replaced by later number model.
† Defibrillation protection to 400 w-sec; American Optical to 500 w-sec.
‡ Have systems for identifying electrode disruption and battery depletion.
§ Standard resistive load 500 ohm.
** 400-ohm load.
Any unipolar or bipolar temporary or implantable pacemaker electrode can be connected to any of these external generators. The routes and technics of application and their special utilities or problems are:

1. Percutaneous transthoracic direct myocardial puncture of the left ventricle by a needle electrode or by a temporary needle inserter through which a fine-wire or coil-spring electrode is passed to the lumen. This technic, reserved for the acute emergency, can be lifesaving. Complications are potentially grave and include the possibility of pneumothorax, damage to a coronary artery, tamponade, and, especially if used during closed-chest massage, of unstable pacing or electrode displacement.

2. Myocardial wires inserted by thoracotomy after pulmonary or cardiac surgery. In this application, an exposed segment of an otherwise insulated 0 or 00 braided-steel wire suture is stitched through the myocardium in such a fashion that a light tug can remove it without difficulty. Two wires are applied to the chamber to be paced (atrium or ventricle) for bipolar pacing. In unipolar pacing, one wire (the cathode) is applied to the myocardium, and the second "indifferent" wire (anode) is applied to the skin. Common difficulties are premature displacement of the loosely applied wires and/or marked increases in threshold to pace. Less frequently, failure to pace is caused by touching of exposed wires or their approximation in fluid pools, with short circuit of output or demand suppression of output by ectopic (wire motion or interference) signals. If the signals are rapid transients, they may not be seen on the peripheral electrocardiogram or even on the myocardial electrogram but should appear on an oscilloscope with an expanded time and amplitude scale.

3. Percutaneous transvenous endocardial catheter electrodes passed to the right ventricle or right atrium through the right or left subclavian vein by the infra- or supraclavicular route and the right or left femoral, brachial, and external or internal jugular veins. The electrodes commonly used are the United States Catheter and Instrument Corporation (5651, 5652) and the Electro-Catheter Company (Elecath 0501-2, 3501-2) 5F and 6F bipolar catheter electrodes, usually passed under direct observation by fluoroscopy, and the Cordis Corporation (370-110) and Elecath (561) semi-floating 4F bipolar electrodes, usually passed by indirect electrocardiographic control. The heavier and stiffer electrodes are more likely to stay in place if they are positioned visually as well as electrically. They are inserted in the jugular and brachial veins by direct cutdown, and similarly in the femoral veins of children. In adults, they are passed routinely by percutaneous needle in the femoral vein and occasionally in all other veins. The semifloating electrodes are almost always inserted by percutaneous needle, usually by the subclavian or brachial veins, and occasionally by any other vein. They can be monitored by electrocardiograph or X-ray.

A number of complications relate specifically to particulars of application. The brachial route is associated with an increased incidence of thrombophlebitis and of motion displacement of any electrode (especially if the arm is lifted over shoulder level) with disruption of pacing and myocardial perforation. To a lesser degree, motion displacement occurs with the femoral route when both knee and hip are flexed 90°, but disruption of pacing is much less frequent (5-7%) and accidental perforation of the artery during insertion (3%) responds promptly and benignly to 5 min of local pressure.

The subclavian route is known to allow arterial puncture (3%), pneumothorax (0.7%), and rarely an extravascular, intrapleural electrode passage. The relatively high frequency of easily corrected electrode malposition (17%) is not a function of route but of positioning by electrocardiography rather than by direct vision. Bacteremia (1%) and gross sinus infection (2%) are problems common to all percutaneous insertions but fortunately of low incidence, especially with good skin hygiene, and are promptly responsive to electrode withdrawal and antibiotic therapy.

Most of the operating complications are inherent in the situation: the external electrodes are temporarily connected; the pulse generators are subject to disruption and interference because they are exposed and mobile, with adjustable controls and short-life removable batteries; they are handled, mishandled, and serviced by various personnel or even patients. Because they are exposed, however, they can be inspected, tested, repaired, or changed with no trauma to the patient unless an electrode has to be repositioned or replaced. The major problems are an increased incidence of external damage, wetting, wire shorting, poor external electrode contact, gross electrode displacement or internal electrode malposition, battery
depletion, and the increased risk of AC interference or induced fibrillation.8

Implanted Pacemakers

Implanted pacemakers are of two basic types: (1) fully implanted; (2) radiofrequency or electromagnetically coupled semiimplants.

In the semiimplanted group, the pulse generator, with replaceable batteries and variable rate and current-amplitude controls, is carried externally. Its pacing stimulus is released through a primary-coil antenna taped to the patient's skin overlying an implanted secondary-coil receiver. The implanted unit is a subcutaneous secondary coil attached to a standard implantable myocardial or endocardial electrode.18-21 Surgery is not required for pulse generator replacement, and many threshold or rhythm problems can be handled by changes of rate or current amplitude or the use of specially tailored pulse generators.22 The very small size of the receiving capsule can be accommodated in the limited subcutaneous tissue of infants or cachectic adults eliminating the tumescence and pressure necrosis that can result in these patients even with "pediatric"-sized fully implantable pulse generators. The disadvantages are the bulk, constant presence, and psychological pressure of the need to care for the external generator and relatively fragile antennae, the risk of accidental displacement or fracture of the antennae (intrinsic to this system), and the fact that these systems operate only in the fixed-rate mode. In the United States the relatively carefree fully implanted pacemakers are preferred, and therefore the semiimplanted systems are very rarely used. Only one, the Cordis Corporation Transicor, is available by special order. In Europe, especially England, they, in are more prevalent use, even where competition could be anticipated because of their fixed-rate limitation.23-25

Fully implanted pacemakers are now manufactured in most nations with sophisticated technologies. Tables 2 and 3 list most instruments made or retailed in the United States. Established producers and new firms (e.g., in the U.S.A., Edwards Laboratories) regularly introduce new models.

Fully implanted pacemakers are categorized primarily on the basis of their pulse-generator function as asynchronous, atrial synchronous, ventricular synchronous, and ventricular inhibited. The latter three, with sensing circuits, are also known as triggered pacemakers. The ventricular synchronous and ventricular inhibited units, variously termed demand or standby pacemakers, are both noncom-petitive instruments. Implanted pacemakers are further cross categorized by whether they are unipolar or bipolar, transvenous endocardial or transthoracic myocardial systems and whether they are pacing the ventricle or the atrium.

Asynchronous Pacemakers

These are defined as "pulse generators in which the repetition rate is independent of the electrical and/or mechanical activity of the heart."26 Their stimulus repetition rate usually is set at 60-70 beats/min for adults and 80-100 beats/min for children, and they discharge at this rate regardless of the underlying rate or rhythm of the patient. They have the simplest construction and are the most stable and long lasting of all implants. Without a current-utilizing, continuously operating sensing circuit they have fewer components to fail, no nonpacing battery drain,27, 28 and little or no response to electromagnetic interference.29 They even have a somewhat lower incidence of problems with their electrodes, because they exclude those related to failure to sense or to the delivery of false signals as may occur in triggered systems.27

The major defect of asynchronous pacing is competition if there are interpolated spontaneous beats or tachyarrhythmias. Patients often find the resultant "palpitations" disquieting. Physician disquiet foresees competition-induced ventricular fibrillation. The degree of risk of this occurring is disputed but is probably low in healthy patients and increases if there is tissue anoxia or injury, electrolyte imbalance, or drug toxicity.30-32

Atrial Synchronous Pacemaker

Historically the first implantable triggered system,23 it is "a ventricular stimulating pulse generator, the repetition rate of which is directly determined by the atrial rate"26 (table 3). It senses the atrial contraction voltage and, following a simulated P-R interval, emits a ventricular stimulus. It utilizes two electrodes, atrial sensing and ventricular stimulating. These are usually sutured to the left atrium and ventricle, when implantation is by thoracotomy. The atrial potential to the sensor is 3.0-8.0 mv.34 Right-sided transvenous atrial synchronous pacing is much less reliable as atrial electrode stability is difficult to maintain and the atrial signal is only 0.5-3.0 mv.34, 35 If the atrial signal is lost, becomes subthreshold, or slows below the base rate (lower escape rate), these pacemakers are programmed to drop into asynchronous pacing at 60-70 beats/min for adults, 70-90 for children. An upper
Table 2

Technical Features of some Implantable Asynchronous Pulse Generators

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Electrodes</th>
<th>Size (cm)</th>
<th>Weight (g)</th>
<th>Output (500-ohm load)</th>
<th>Impulse duration (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medtronic</td>
<td>5870</td>
<td>B</td>
<td>7.1×2.5</td>
<td>170</td>
<td>5.5</td>
<td>0-11.0</td>
</tr>
<tr>
<td></td>
<td>5870C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5862</td>
<td>B</td>
<td>5.7×2.5</td>
<td>110</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>5862C</td>
<td>B</td>
<td>7.0×2.5</td>
<td>150</td>
<td>6.5</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>5906</td>
<td>B</td>
<td>7.0×2.5</td>
<td>180</td>
<td>5.5</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>5906E</td>
<td>B</td>
<td>7.0×2.5</td>
<td>174</td>
<td>0.75-10.0</td>
<td>1.5-20.0</td>
</tr>
<tr>
<td></td>
<td>5858</td>
<td>U</td>
<td>5.0×2.5</td>
<td>73</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>5931</td>
<td>U</td>
<td>6.3×2.3</td>
<td>160</td>
<td>5.2</td>
<td>10.4</td>
</tr>
<tr>
<td>Cordis</td>
<td>Venticor††</td>
<td>U</td>
<td>5.9×2.4</td>
<td>130</td>
<td>6.5</td>
<td>8.0-11.03</td>
</tr>
<tr>
<td>General Electric</td>
<td>A2072BA*</td>
<td>B</td>
<td>7.0×5.0×2.3</td>
<td>143</td>
<td>6.0</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>A2072AA*</td>
<td>B</td>
<td>7.0×5.0×2.3</td>
<td>143</td>
<td>6.0</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>A2073AB</td>
<td>BU</td>
<td>6.5×5.7×2.3</td>
<td>125</td>
<td>4.7</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.2</td>
<td>12.4</td>
</tr>
<tr>
<td>American Optical</td>
<td>CM7</td>
<td>U</td>
<td>6.4×5.5×2.4</td>
<td>139</td>
<td>6.0</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>CB7</td>
<td>B</td>
<td>6.4×5.5×2.4</td>
<td>138</td>
<td>6.0</td>
<td>12.0</td>
</tr>
<tr>
<td>ESB Medcor</td>
<td>RA70</td>
<td>U</td>
<td>6.8×6.2×2.2</td>
<td>150</td>
<td>4.3</td>
<td>8.6</td>
</tr>
<tr>
<td>Elema-Schonander</td>
<td>EM52B</td>
<td>U</td>
<td>6.4×2.4</td>
<td>130</td>
<td>6.5</td>
<td>13.0†</td>
</tr>
<tr>
<td>Biotronik</td>
<td>IP44</td>
<td>U</td>
<td>5.0×4.2×2.0</td>
<td>100</td>
<td>5.2</td>
<td>10.0†</td>
</tr>
<tr>
<td>Vitatron</td>
<td>MIP50IT</td>
<td>U</td>
<td>7.0×4.7×2.1</td>
<td>135</td>
<td>6.5</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>MIP151S or P</td>
<td>U</td>
<td>5.2×5.2×2.1</td>
<td>105</td>
<td>5.2</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>MIP251T</td>
<td>U</td>
<td>7.0×5.2×2.1</td>
<td>140</td>
<td>7.8</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Abbreviations: B = bipolar; U = unipolar.
*Discontinued model but may still be in patients.
†Rate set at manufacture often with small * range in specification; other rates available in most equipment.
‡High and low output range regularly available.
§Rate drop correlated to battery voltage drop.
**Conversion between unipolar and bipolar, myocardial and endocardial electrodes within or between manufacturers' products usually possible directly or by "kits."
††See last footnote to table 3.
### Technical Features of some Triggered Pulse Generators

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Electrodes</th>
<th>Output (500 ohm load)</th>
<th>Rate†</th>
<th>Impulse duration (msec)</th>
<th>Refractory period (msec)</th>
<th>Sensitivity</th>
<th>Comment††</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cordis</td>
<td>Atricor§§ U 6.5 6.0–9.0 60–120 Sr§ 70–140 Jr§</td>
<td>1.5 360 1.0, 0.5 133A6*, 133C7*, 145A, 145B§; now 145E Sr (60 beats/min), 145F Jr (70 beats/min)§</td>
<td>Atrial synchronous††,‎††,‎***,‎****</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elema-Schonander</td>
<td>EM155</td>
<td>U 5.2 10.0 50–150 1.8 400 0.9 1.5 EM156 high sensitivity (0.5 mV); no magnetic switch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotronik</td>
<td>IPV54</td>
<td>U 5.2 10.0 70–150§ 1.0 400 0.5 Metal case</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medtronic</td>
<td>5841*</td>
<td>B 5.5 11.0 70 1.5 80–120–200 1.5 RF rate control; no magnetic switch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5842 5942</td>
<td>B 5.5 11.0 70§ 0.9 300 = 50 2.5 ± 0.5 5842, 5942, 5943, 5943, magnetic rate decay erratic before April-July 1972; 5942 and 5943 titanium case; 5943 and 5943 hysteresis 10 beats</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>5843 3943</td>
<td>B 4.0 8.0 72§ 0.9 300 = 50 2.0 ± 0.5</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cordis</td>
<td>Stanicor§§ U 6.5 8.0–11.0 70§ 1.5 224 = 20 2.0 ± 5 143C*, 143F, and 143J. Specials low in ma and low in sensitivity available</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>General Electric</td>
<td>A7072DEF B 5.8 11.6 60–70–80§ 1.0 125 = 25 2.5 ± 0.5 A7072A,B,C-ma 10 = 0.4, 2-msec pulse*: rate hystereses 60–70, 70–80, 80–85; recent models limit depolarization recycling of refractory period; RF rate control</td>
<td></td>
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</tr>
<tr>
<td>American Optical</td>
<td>DB7</td>
<td>B 6.0 12.0 70 2.0 75 = 25 2.0 Senses in ventricle but passes atrium and/or ventricle on demand</td>
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<tr>
<td></td>
<td>DM7</td>
<td>U 6.0 12.0 70 2.0 75 = 25 2.0 Dual battery system, spontaneous refractory period 250 msec</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Bifocal†† B A5.8 A11.6 70 1.0 150 2.0</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ESB Medcor</td>
<td>RD70</td>
<td>U 4.3 8.6 70 1.0 325 = 25 1.5 Dual case, 1-cell loss; 10-beat drop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elema-Schonander</td>
<td>EM158</td>
<td>U 6.5 13.0 60 &amp; 70 0.8 325 = 25 3.0 With interference, fixed rate at 80 beats/min, metal case</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotronik</td>
<td>IPD44</td>
<td>U 5.2 10.00 70 1.0 320 2.0 MIP41RT with 6-beat hystereses</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Vitatron</td>
<td>MIP40-41RT U 6.5 10.0 70 1.2 325 ± 2% 1.0 MIP43RT with 6-beat hystereses</td>
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<td>MIP42-43R</td>
<td>U 5.2 10.0 70 1.2 325 ± 2% 1.0</td>
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<td>Cordis</td>
<td>Ectocor§§ U 6.5 8.0–11.0 70–140§ 1.5 490 = 20 2.0 ± 0.5 129E7*, 129L7*, 144A7*, 144B7*, 144 C7, and 144G</td>
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<td>Elema-Schonander</td>
<td>EM153B</td>
<td>U 6.5 13.0 60–120 70–150 ≥380 ≥410 10-beat rate drop for 1-cell loss</td>
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Abbreviations and symbols *, †, ‡, §, and ** same as table 2.
††Triggered pacemakers sometimes are slightly larger and heavier than asynchronous pacemakers.
†‡Atrial and ventricular electrodes.
§§With rapid rate or interference block 2:1, 3:1, 4:1, etc., never exceeding own maximum rate.
***With 50–60Hz interference block to maximum spontaneous rate.
†††With 50–60Hz interference block to escape rate; Medtronic 5942, 5943 block to escape rate over 30Hz and 5943, 5943 block to 50–55 PPM; General Electric goes to escape interval at rates over 300/min; Cordis Stanicor to fixed rate at 10‰ over escape rate.
††††Magnetic rates. Other than escape rate: Medtronic, R-R20 msec longer than escape R-R. American Optical 10‰ over escape rate.
§§§The new Omnicor series have RF-induced changes in rate (60, 65, 70, 80, 90, 103) and current (3, 4–6, 6–9, 8–11 ms).
escape limit protects the ventricle against direct stimulation in an atrial tachycardia by initiating a 2:1, 3:1, or 4:1 block. A poststimulation refractory period to sensing or pacing protects against reactivation of the pacemaker by its own electrode capacitance and against an early atrial premature contraction releasing a competitive stimulus on the T wave of the preceding QRS.

The complications of atrial synchronous pacing include the following:

1. Difficulty in positioning and maintaining transvenous atrial electrodes for stable sensing despite newly designed electrodes or special techniques for transvenous36, 37 or mediastinal insertion.38 Thoracotomy, which does provide stable positioning, is acceptable in the young, difficult for the old, and obligates repeat thoracotomy if there are intrathoracic electrode problems. With loss of atrial sensing, fixed-rate pacing supervenes, competitive if there is an underlying spontaneous rhythm. Occasionally, the sensor responds to a ventricular instead of an atrial signal, and the pacing stimulus is emitted at the end of the QRS or start of the T wave. This is probably not dangerous as long as the impulse is delivered early enough in the S-T area to avoid the vulnerable zone (fig. 1a).

2. Heart failure or angina with stimulated ventricular rates of 100-120 or 140-150 beats/min,

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**Figure 1**

(a.) Atrial synchronous pacing (S) with an asynchronous paced beat (A) and ventricular triggering (V). (b.) Atrial synchronous pacing with intruding ventricular extrasystoles. This artifact may be ventricular synchronized and triggered; if it were not sensed it would fall on the apex of the T wave asynchronously. (c.) Rate acceleration of triggered pacemakers by external interference. (d.) Ventricular synchronous pacing with late sensing (third and fifth QRS) and triplets (third and fifth beats and fifth to seventh beats), because of early unsensed extrasystoles. (e.) Bifocal pacing with atrial and ventricular stimulation with response to an extrasystole. (f.) Inadequate sensor signal. The difference between the large distal and proximal intracardiac bipolar signal (left and middle complex, respectively) is so little that the bipolar signal generated between them is barely 2 mw (right complex).
in response to the sensed rapid atrial rates of sinus tachycardias, multiple atrial extrasystoles, or atrial flutter or fibrillation with inadequate block. Digitalis does not affect the blocking mechanism in these cases, and these upper escape rates, designed to accommodate to a sinus response to exercise, are too high for the patient with a diseased myocardium, prothetic valve, or coronary narrowing. In a coarse atrial fibrillation, signals of trigger amplitude may result in irregular ventricular tachyarrhythmias interspersed with fixed-rate pacing. Here, digitalis may convert a coarse fibrillation to a finer more rapid action, less likely to elicit synchrony.

(3) Failure to sense or accommodate to ventricular extrasystoles which produce an effective ventricular tachycardia if they intrude between sinus paced beats and competition if the succeeding atrially triggered stimulus falls on the vulnerable period of their T wave (fig. 1b).

(4) Susceptibility to electrical or electromagnetic interference which in the physiologic rate range trigger simulated atrial premature contractions when the signals are discrete or drive the pulse generator to its upper limit of performance if repetitive. At supraphysiologic rates, including 50–60 cycle alternating current, the pulse generators block to asynchronous pacing usually at their lower escape rates (table 3). The risk of competition engendered is less than that of a sustained upper-limit tachycardia (fig. 1c).

Ventricular Synchronous Pacemaker

This pacemaker is one with "a ventricular stimulating pulse generator delivering its output synchronously with the natural ventricular activity and asynchronously in the absence of natural ventricular activity."26 (table 3). Ventricular synchronous pacemakers are modifications of atrial synchronous pacemakers. They have a similar upper and lower safeguard escape rate, but utilize a single ventricular electrode for sensing and stimulation, have a lower trigger sensitivity, an almost immediate response to a trigger stimulus, logic to differentiate the QRS from the P and T waves, a refractory period of about 400 msec, and a magnetic-switch asynchronous mode. They are noncompetitive with ventricular activity except in very rare instances and insensitive to nontransmitted atrial activity.30, 40

Special problems or deficits associated with their use include the following.

(1) During sustained synchronous stimulation, the threshold to pace is uncertain, and its adequacy must be checked periodically by overdrive stimulation or magnetic conversion to asynchronous pacing.

(2) Failure to sense (electrode malposition, battery depletion, or signal decrement) results in fixed-rate pacing and, if the pacing threshold is sustained, competition with spontaneous rhythms.41, 42

(3) The synchronous-pacer artifact consistently distorts the electrocardiogram even during sinus rhythm. Magnetic mode pacing allows occasional breakthrough of unpaced spontaneous beats if the rhythm is at or over the escape rate, but this engenders competition and is avoided when the need to see a true complex is the highest, i.e., during an acute coronary.

(4) Extrasystoles that come within the refractory period of a paced beat are not sensed, and the next paced beat, cycling at the escape rate from the previous paced beat, results in a tachycardic triplet. Prolongation of the refractory period enhances this effect and allows the paced "escape" beat to come uncomfortably close to the T wave of the "missed" spontaneous beat.41, 42 These mixtures of spontaneous and ectopic beats, with synchronous and paced beats, are difficult to interpret and often alarming to the uninitiated (fig. 1d).

(5) A wide variety of transient "interference" currents, including those produced by the magnetic or radiofrequency tripping of the magnetic switch, wire breaks, faulty connections, short circuits, whipping catheter motions, and tall T waves, are equated with QRS signals by the sensor circuit.44 This results in an erratic, frequently competitive, pacing output. With repetitive stimuli, however, the response rate cannot exceed the top design output of the pacemaker (a fail-safe feature) (fig. 1c).44 A positive effect of this interference sensitivity is that these pulse generators may be externally triggered to overdrive rates (to their upper escape limits), which is useful in the treatment of postimplantation multifocal extrasystoles or intermittent tachyarrhythmias.

(6) Late synchronization occasionally occurs with the stimulus late in the QRS. Rarely, it reaches the vulnerable zone and initiates early or repetitive contractions.44 In right-sided transvenous pacing, it has been ascribed to origination of the contraction on the left with delayed conduction to the right (RBBB). There may also be a specific latency, with either ventricle, particularly in recent infarction (fig. 1d).

(7) Impulses driven into the "absolute refractory" period may sensitize to lesser, later impulses.
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This suggests reexamination of the use of the ventricular synchronous mode and may be a source of problem in competition.3, 46

(8) The ventricular synchronous pacemaker has the shortest mean longevity of battery life due to constant pacing, often above the escape rate, and the additional current drain of the sensing circuit.47

Ventricular-Inhibited Pulse Generator

This is “a ventricular stimulating pulse generator which suppresses its output in response to natural ventricular activity, and produces an output asynchronously in the absence of natural ventricular activity”26 (table 3). It is a noncompetitive pacemaker with an escape rate below which it paces asynchronously (60-70 beats/min in the adult) and above which stimulus output is suppressed, leaving the patient and electrocardiogram unaffected.47 The refractory times are foreshortened (75-325 msec) to allow early response to ectopic activity. All models have magnetic switches to convert conducted or other spontaneous rhythms to fixed pacing except the discontinued Medtronic 5841. This enables testing for the ability to pace in a patient, normally in the inhibited mode, and counting of the output rate for battery follow-up. The General Electric, Medtronic 5843 and Vitatron have a rate-hysteresis capability. Several are casted in metal as a radiofrequency interference deterrent and/or to exclude moisture.

Ventricular-inhibited pacing is the most popular mode in use. The lack of artifact output during spontaneous rhythm leaves the electrocardiogram clear and also is battery sparing, with significant improvement in longevity.27, 30 The inability to accelerate rate by triggering (except in the General Electric A7072 and discontinued Medtronic 5841) is discounted.

Complications of use include the following:

(1) The major problem of ectopic (non-QRS) suppression of output, induced by a variety of signals:

(A) Self-inhibition, because the short refractory period of several pacemakers allows feedback of undissipated stimulus afterpotential (capacitance) from the electrode tissue interface. If the current is of trigger magnitude, it is not differentiated from a QRS and inhibits output for another cycle. In the Medtronic 5841 and American Optical DB7 or DM7, one recycle always occurs after a paced beat making the paced-to-paced R-R interval longer than the spontaneous-to-paced R-R interval by the length of one refractory period. Occasionally, stimulation is markedly delayed when a short refractory period, a low trigger sensitivity, and a high pacer output or capacitance combine to recycle these pulse generators from one to four times.27, 43

(B) Partial sensing with incomplete inhibition and rate irregularities from a marginal signal or borderline reception of a normal signal in a narrow zone between the refractory and alert period. These low signals, observed primarily in Medtronic 5841 and 5842 and American Optical pacemakers, cause incomplete saturation of the output circuit and partial, rather than complete, recycling.48 They may occur with other equipment.

(C) Recycling by large P or T waves (particularly if superimposed), which may result in a bradycardia from T-wave sensitivity or asystole from repetitive P-wave stimuli.27, 41, 49 These marginal currents also may induce partial recycling.

(D) Inhibition by local nonpropagated ventricular currents (concealed extrasystoles), which trigger the sensor but not a contraction. They are unseen on a peripheral electrocardiogram, appear as transients on an intracardiac electrogram, and may be suppressed by antiarrhythmic medication or overdrive pacing.60

(E) False signals (transient currents) from any type of incomplete wire break, sheath interruption, intermittent short circuit, wetting, loose connection, contact with an adjacent second electrode (active or inactive), or whipping resistance altering or catheter motion which may be the source of erratic sensing. This is often associated with intermittent failure to pace without evidence of battery depletion.51-53

(F) Suppression by alternating currents, or radiofrequency, electromagnetic, and magnetic interference. Weak alternating current leaks from poorly grounded equipment have no direct route to fibrillate the heart. If of magnitude enough to affect the pacemaker, they will be sensed, and the contact is usually severed before serious effect. Radiofrequency and electromagnetic signals are silent. The patient may appreciate palpitations in synchronous pacemakers, but inhibited pacemakers suppress function without warning and may kill a dependent patient. The signal sources that have been described or tested include various types of electric motors (tools, household, garden) automobile ignition systems, arcing television sets, electric on-off switches (all spark-gap sources), electric razors, diathermy, electric cautery, microwave ovens,
power generators, and television, radio, and radar transmissions.\textsuperscript{2, 8, 20, 54–63}

Fortunately, actual accidents are so infrequent that virtually all are reported. Most small motors (tools and appliances) have too low an output to be dangerous unless they are held directly over the pacemaker (unlikely). Larger signals, such as from on-off switches or arcing equipment (i.e., television sets), are short-term or intermittent and, except in automobile ignitions or razors, not likely to inhibit the pacemaker for more than a beat or two. Specificity further reduces incidence, so that only some pacemakers in some patients are affected by some equipment. The greater degree of vulnerability that could be anticipated with radiofrequency receivers (the semiimplants, the General Electric generators with rate controls) has not, apparently, been an issue. In high-frequency interference, inhibition may be by the carrier wave or a low-frequency modulation, which brings the impulse into the physiologic rate range (microwave-oven fans). The most vulnerable environment, particularly for external pulse generators, is the hospital with its diathermy, cautery, cardioversion, and electroshock therapy, monitoring equipment, microwave ovens, electric beds, and electrical life-support equipment.

A positive use of ectopic inhibition is external chest wall stimulation to suppress the output of an implanted pulse generator and display the underlying rhythm. Care must be taken to protect against asystole or escape arrhythmias.\textsuperscript{62, 63}

(2) Low sensor signals or loss of sensor signal with failure of appropriate inhibition that results in fixed rate, sometimes competitive pacing. The sources of initially poor signals include an underlying myocardial scar, inadequate myocardial or endocardial contact (poor position), poor orientation of a bipolar electrode with a less than 2-mv amplitude in the bipolar voltage (the trigger signal) (fig. 1f), and abnormal signals that do not program appropriately. Abnormal signals include the splintered and discoordinate signals of severe myocardial disease with conduction disruption or tall R waves that rise in steps (seen only on an oscilloscope) and are misread by the pacemaker as a series of subthreshold signals.\textsuperscript{64, 65} Late loss of sensor signal occurs with partial wire break, insulation tear with current leak, malposition to a poor signal area (especially in transvenous systems where it includes myocardial perforation with or without phrenic pacing), a fresh coronary with loss of myocardial voltage, and growth of an insulating sheath around the electrode. In some radiofrequency rate-controllable R-wave inhibited pacemakers, a drop in output occurs with an increase in rate (the discontinued Medtronic External 5840 and General Electric implanted demand pulse generators). At threshold to pace this can result in loss of capture. The obsolete Medtronic 5841, however, may be boosted transiently to threshold by overdrive with its external control (5855). This is specific for this instrument with failure to pace from battery depletion.\textsuperscript{64}

(3) Failure to pace. In an R-wave inhibited pulse generator this has special significance, as it is totally unrecognized in the patient in spontaneous rhythm until that rhythm fails and a bradycardia or asystole results. It is monitored by testing with periodic magnetic fixed-rate pacing.

A-V Sequential Pacemaker

A special pacemaker in the R-wave inhibited category is the A-V sequential pacemaker.\textsuperscript{66, 67} It uses two electrodes to pace the atrium and/or ventricle but senses only in the ventricle. In sinus rhythm or conducted beats at a normal rate, all activity is suppressed. Its sensing interval is from the last ventricular voltage to the next P wave. In atrial asystole, loss of signal, or sinus bradycardia, with a normal P-R interval and atrioventricular conduction, it senses the slow rate and paces the atrium. With P-R prolongation over a preset interval or atrioventricular block, it senses a delay in ventricular response and paces the ventricle also, providing atrioventricular sequential stimulation (fig. 1e). Its magnetic mode tests ability to pace (paces both atrium and ventricle at a higher rate with a shorter P-R interval) and provides a “counting” rate for battery evaluation.

The A-V sequential pacemaker is an excellent concept but, in practice, it is a complex pacemaker with an increased potential for malfunction and a relatively high incidence of trouble.\textsuperscript{67} Sensing difficulties, compounded by a short refractory period, result in complicated competition patterns, and self-inhibition (potentially lethal) may occur, particularly in transvenous installations where an atrial stimulus from a malpositioned electrode may fail to pace the atrium and at the same time inhibit the ventricular stimulus. Battery drain is high (dual-output circuits and a complex sensing system), and trouble-free long-term pacing is not yet a satisfactory clinical reality.

Temporary or implanted ventricular pacing systems can and are used to pace the atrium
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particularly in atrial dysfunction or where there is intact conduction, to overdrive the ventricle in a more physiologic, safer approach.68–70 When the atrial electrode is applied by thoracotomy, and if, in triggered systems, a high-sensitivity pacemaker is used, a stable effective system results. In transvenous systems unstable electrode positions for pacing and sensing and low-strength trigger signals are the major complications for asynchronous or triggered systems.71 Atrial "J" shaped and "barbed" electrodes are either difficult to position or not fully immobile. Placement at the mouth of the coronary sinus offers the best solution for stable pacing and for sensing if combined with an appropriately sensitive pacemaker.68–70 Complications of pacing from the atrium include late development of atrioventricular conduction delay,68 electrode displacement with loss of sensing or pacing, and synchronization to a ventricular rather than supraventricular signal.69 When the electrode is deep in the coronary sinus behind the left ventricle, sensing and pacing may be of the left ventricle, and sometimes the diaphragm is paced.

Two new pacemakers, Medtronic 5931 with magnetically adjustable pulse duration and Cordis Omnico with radiofrequency-controlled ranges of rate (60–100 beats/min) and current (3–11 mA), allow flexibility in use and conserve battery drain. Coupled with small electrode tips with low pacing threshold, they will extend battery life. They are too recent to be evaluated for specific complications.

Comments

Complications common to all pacemakers include failure to pace because of pulse generator power loss (rarely a component failure), wire break, or malposition (including myocardial perforation and phrenic pacing).72–74 Battery depletion usually is signaled by a rate drop before loss of pacing accompanied by changes in artifact amplitude (drop), duration, and shape seen oscillographically but not on the ECG.35,75 Wire breaks, usually caused by angulation or sutures, are very rare in the intravascular portion of transvenous electrodes. Perforation occurs only with transvenous electrodes, often is signaled by loss of pacing, occasionally by diaphragmatic pacing, and responds to replacement of the electrode in the ventricle. Tamponade is rare. Pacemaker damage by DC shock (defibrillation or cardioversion), even of protected models, may give rise to temporary erratic performance.76–78 Unprotected external units may fail. It is not always immediately possible to ascertain whether the pulse generator or the patient’s myocardium is responsible for the “malfunction.”

It is of note that with all of these possibilities for complications most patients and their pacemakers coexist in amity and, more important, survive with substantial success and safety.

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