Longevity of programmable energy output pacemakers

Early results and experiences¹

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To solve the problem of pacemaker longevity, current output, and pulse width programmable pacing systems were introduced for clinical use in 1972. Thirty-seven patients with such systems were serially assessed in our pacemaker follow-up clinic for an average of 23 months (range 6 to 36 months). Twenty-five patients received the Cordis Omnicor system (programmable current output), while 12 patients received the Medtronic 5961 system (programmable pulse width). Pacemaker failure caused by battery exhaustion occurred in 5 Omnicor units (average 29.0 months) with an average current output of 4.8 mA in 4. One Medtronic 5961 unit failed after 19 months (0.8 ms pulse width) because of a manufacturing defect in the battery sealing. The 31 remaining programmable pacers remain functional (average 22 months). Special problems encountered included increased early incidence of cardiac perforation attributable to small surface area endocardial electrodes (6 patients); ventricular fibrillation induced by unipolar fixed rate pacing (2 patients) representing the first report of cathode provoked ventricular tachyarrhythmias caused by the R on T phenomenon and pacemaker vulnerability to direct current countershock resulting in fixed rate pacing (1 patient). Despite lack of sufficient prolongation of pacemaker life, unique advantages of the programmable systems constitute ability to alter heart rate to allow evaluation of patients' intrinsic rhythm and QRS complexes, overdrive suppression of ventricular tachyarrhythmias, and determination of chronic threshold and early detection of exit block. This experience to date with the programmable Omnicor system does not appear to provide improved pacemaker lifetime compared with our 22 nonprogrammable Cordis and Medtronic demand pacemakers with an average longevity of 31.5 months. Attention to alternate power sources such as lithium iodide batteries may be a more promising approach to increasing pacemaker life.

It is generally agreed that battery depletion is the primary limiting factor in the service life of permanent pacemakers. Since battery depletion is a function of the amount of energy delivered by the pulse generator, reducing this energy expenditure should allow extension of functional pacemaker life. Standard pacemakers in current use contain four or five mercury-zinc cells each with a capacity of 1000 mA-h and a maximum pacemaker output of 9 to 11 milliamperes. Cardiac thresholds for chronic stimulation in the majority of patients are usually low and average 1.6 milliamperes at a pulse width of

1.0 ms (Furman *et al.*, 1975). Therefore, the constant delivery of 9 to 11 milliamperes of current by permanent pacemakers constitutes considerably more expenditure of energy output than is necessary for chronic stimulation in most patients and thereby results in rapid depletion of pacemaker batteries. The recent advent of programmable pacemakers (Chardack *et al.*, 1971; Morse *et al.*, 1975) allows serial assessment of the patient's chronic stimulating threshold. Thus, pacemaker output can be adjusted to deliver sufficient energy for constant chronic pacing, thereby conserving energy and enhancing functional pacemaker life.

Pacemaker energy output is represented by the product of voltage, current, and pulse duration. Therefore, energy conservation can be affected either by decreasing current output delivered to the

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becomes rectangular. As the output setting is further decreased to 4 mA (low setting) and then to 2.3 mA (test setting), the amplitude declines further. 1 vertical square = 10 millivolts (mV); 1 horizontal square = 0.5 millisecond (ms). The pulse duration is unaffected by change in current output.

heart while keeping pulse width constant (Fig. 1) or by decreasing the duration of current delivery while maintaining current constant (Fig. 2). The former technique has been employed by one pacemaker manufacturer (Cordis Corporation, Miami, Florida) with programmable current output pacemakers identified as the 'Omni' series (Omnicor). The alternative approach is the pulse width controllable pacemakers, which are manufactured by the Medtronic Company (Minneapolis, Minnesota). It is the purpose of this study to evaluate the longevity of these two different externally programmable pacemaker systems relative to the life span of standard demand pacemakers manufactured by the respective companies.

Methods and Materials

A total of 128 patients with permanent pacemakers was evaluated, 56 with programmable demand systems and 72 with standard demand pacemakers. Thirty-two patients received the Omnicor programmable pacemaker and 8 received nonprogrammable Cordis units. Twenty-four patients had the programmable Medtronic 5961 system and 64 the nonprogrammable demand Medtronic units. All 128 patients were serially followed in the pacemaker evaluation clinic for 0.5 to 4.1 years (mean 2.7 years). It is ideal to follow a large group of patients over several years until the majority of pacemakers fail. This allows a definite assessment of longevity

Fig. 2 (A) Representative oscilloscopic recordings illustrating the process of narrowing of pulse width of a programmable Medtronic unit (Model 5961). Starting with the pulse width of 0.8 ms, the external pulse width controller was activated with gradual decrease of pulse width ultimately to 0.22 ms. The simultaneously monitored electrocardiogram with the change in pulse width showed that there was no loss of pacemaker capture. 1 vertical square (div) = 50 mV; 1 horizontal square = 0.1 ms. (B) Representative recordings showing isolated pacemaker artefacts at different pulse width settings. 1 vertical square = 50 mV; 1 horizontal square = 0.2 ms. Note that in both panels A and B, the pulse amplitude remains unaffected by change in pulse width.

for that particular type of pacemaker. However, it is equally important to be aware of the early results and problems related to the use of a newly introduced pacemaker.

In the Omnicor system the unipolar demand pacemaker's rate and output are controlled by an external, battery-powered programmer emitting electromagnetic pulses of 3 ms duration which open and close the magnetic reed switch within the pacemaker. Because programming pulses are recognised and counted by a binary counter in the pacer, invasive penetration of the patient is not required. The pacemaker rate can be adjusted from a low of 60 to a high of 100 pulses per min. Within this range the available rate selections are 60, 65, 70, 80, 90, and 100 pulses/min. There are 4 current output selections in the Omnicor system of 2.3 mA, 4 mA, 6 mA, and 9 mA (Fig 1). The respective dial settings on the programmer for the current output are labelled test (2.3 mA), low (4 mA), medium (6 mA), and high (9 mA). The programmer contains control switches for rate, stimulus current intensity, and the type of pacer being programmed.

In the Medtronic programmable 5961 system, the pacemaker is unipolar, with a titanium housing, and is capable of having the pulse duration (preset to 0.8 ms) changed noninvasively from 0.15 to 1.7 ms (Fig. 2). The potentiometer regulating pulse width is connected by a gear train to a small rotating magnet. This assembly is sealed in a metal cylinder in the centre of the pulse generator. The magnet in the pulse generator is driven by a rotating magnet of a hand-cranked external actuator. Coupling between the two magnets obtains at distances up to 3 in (7.5 cm). It is important to implant the pacemaker with the lettering facing upward, so that rotation of the external programmer results in pulse width changes indicated on the programmer. Pulse width changes are observed on the oscilloscope and it is essential that the electrocardiogram be simultaneously monitored to detect any unanticipated loss of pacing.

All pacemaker patients were systematically assessed in our special pacemaker follow-up clinic. The oscilloscopic analysis of the pacemaker pulse artefact was carried out using a Hewlett-Packard oscilloscope model 1201A. The pacemaker fixed rate was documented by the use of a customised Hewlett-Packard electronic counter, model 5307A, after application of a magnet to the pacemaker generator to induce a fixed rate. The chronic stimulation threshold in each patient was determined 6 to 8 weeks after permanent pacemaker implantation. The current output of the Omnicor pacemakers was programmed at two settings above the output level at which pacing ceased. For

Fig. 3 Representative pacemaker artefacts and corresponding electrocardiogram rhythm strips (lead II) showing the method for determining pacing threshold and thereby selecting chronic pacemaker current output using the Omnicor system. The electrocardiogram rhythm strips are shown on the right and the pacemaker artefact amplitude changes on the left. At the output setting of 9 mA (top row), there was 1:1 capture (A); the stimulus (St) artefact measured 2.8 mV. Decreasing the output to 6 and 4 mA, respectively (recordings B and C), showed decreasing oscilloscopic amplitude; the artefact amplitude decreased to 2 mV and 1.6 mV, respectively, and the electrocardiogram strips continued to show 1:1 capture. However, in the bottom strip D, decreasing pacemaker output to 2.3 mA resulted in loss of capture; pacemaker artefact amplitude declined to 1.4 mV. Note that in the bottom strip normal sensing is documented by the R-triggered pacemaker of all conducted QRS complexes occurring beyond the pacemaker refractory period.

example, the setting was positioned at medium (6 mA) when no pacing resulted at the test setting (2.3 mA) (Fig 3). In the case when pacing was accomplished at test (2.3 mA), the setting was programmed at low (4 mA).

With the Medtronic system, the pulse width setting was programmed to 50 to 100 per cent above threshold width (Fig 4). The final pulse-width setting was determined by the pacemaker dependency of the patient. Thus, in our pacemaker clinic we have devised a system of grading how dependent a patient is on pacemakers by evaluating the intrinsic ventricular rate of the individual by terminating the pacemaker output pulses using chest-wall stimulation (Barold *et al.*, 1970). A patient with an intrinsic heart rate of 60 beats or more per minute is graded 1+; between 50 and 60 2+; 40 and 50 3+; 30 and 40 4+; and less than 30 beats

Fig. 4 Representative pacemaker artefacts and corresponding electrocardiogram rhythm strips (lead II) showing the method for determining pulse width threshold and thereby selecting chronic pacemaker pulse width using the Medtronic system. The top strip shows pacemaker exit block (arrows) indicated by periods of noncapture of the pacemaker spike. The corresponding pulse width was 0.70 ms (top oscilloscopic tracing). Pulse width widening by the external pulse width controller to only 0.75 ms (bottom oscilloscopic tracing) resulted in constant 1:1 capture (bottom electrocardiogram strip). This patient had the highest pacing pulse width threshold of our Medtronic programmable series.

per minute 5+. Patients with maximal dependency (4 and 5+) received at least a 100 per cent increase in pulse-width greater than threshold pulse width. Thereby patients at greatest risk of cardiac standstill received extra safeguard for uninterrupted pacing. Chronic stimulation thresholds were re-evaluated at least once every 6 months with both the Cordis and Medtronic units. When any significant fluctuation occurred from the initial threshold, appropriate current output (Cordis) or pulse-width (Medtronic) changes were made. All pacemakers showing impending battery exhaustion as determined by change in pacemaker fixed rate and/or alterations in the oscilloscopic amplitude or pulse-width (Parsonnet *et al.*, 1970) were replaced and the generator was sent to the manufacturer for analysis. All of our documented pacemaker failures were also proved by the manufacturer's analysis to have battery depletion.

Results

Of the 32 patients with Omnicor pacers, 4 died as a

result of cardiac disease unrelated to pacemaker disorders or to the reason for pacer implantation before pacemaker battery depletion, and 3 who moved from the area were unavailable for follow-up assessment. Table 1 shows the current output and longevity of the demand Omnicor pacemakers in the remaining 25 patients. The current output and duration of pacemaker implant are presented on the horizontal axis. Pacemaker failure occurred in 5 of these patients because of battery exhaustion, with an average pacemaker life of 29.0 months (range 24 to 37 months). The mean current output during the functional life of 4 pacemakers which failed ranged from 4.0 to 5.2 mA (average 4.8 mA). The fifth patient, a 26-year-old woman (P.S.) with congenital heart block received her pacemaker in the first trimester of pregnancy. The current output was programmed to 9.0 and maintained at this setting until the onset of battery exhaustion at 27 months. Though this pacemaker never functioned as a low output unit, the average longevity of the other 4 units was 29.6 months. Therefore, the Omnicor

Table 1 *Omnivor longevity profile*

Case No.	Time in months										4
	0	4	8	12	16	20	24	28	32	36	
1	6	.	.	.	.	4	.	.	.	.	X
2	6	9	.	.	4	.	.	.	.	.	→
3	6	.	.	.	.	.	.	.	.	.	→
4	6	.	.	9	.	.	.	.	.	.	→
5	6	.	.	.	.	4	.	.	.	.	X
6	6	.	.	.	.	.	.	.	.	.	→
7	6	.	.	.	.	.	.	.	.	.	→
8	6	.	4	.	.	.	.	.	.	.	X
9	6	9	.	.	.	.	.	.	.	.	X
10	6	.	.	.	9	.	.	.	.	.	→
11	6	9	.	.	.	.	6	.	.	.	→
12	6	.	.	4	.	.	.	.	.	.	→
13	6	4	.	.	.	.	.	.	.	.	X
14	6	.	.	.	.	.	4	.	.	.	→
15	6	.	.	.	.	.	.	.	.	.	→
16	6	.	.	.	.	.	.	.	.	.	→
17	6	4	.	.	.	9	.	.	.	.	→
18	6	.	.	.	4	.	.	.	.	.	→
19	4	.	.	.	.	.	.	.	.	.	→
20	6	.	.	4	.	.	.	.	.	.	→
21	6	.	.	4	.	.	.	.	.	.	→
22	6	.	.	.	.	.	.	.	.	.	→
23	6	.	.	.	.	.	.	.	.	.	→
24	6	.	.	.	.	.	.	.	.	.	→
25	6	.	.	.	.	.	.	.	.	.	→

Abbreviations: Numerical values of chronic current output (mA) used for pacing are indicated at the time of any change during follow-up.
X=Pacemaker battery failure.

pacemaker longevity did not exceed that with non-programmable pacemakers in general (Furman and Escher, 1975). Furthermore, in 4 of 8 patients with non-programmable Cordis pacers in whom battery failure occurred, the range of longevity was 24 to 32 months (average 27.8 months), essentially the same as patients receiving programmable Cordis pacemakers. The relatively small number of the non-programmable Cordis pacemakers in our series reflects the almost exclusive use of the non-programmable Medtronic pacemakers at our institution before the introduction of programmable units. However, the longevity of the non-programmable Cordis units in our patients is not substantially

different from that reported by others (Furman *et al.*, 1975).

Of the 24 patients receiving programmable Medtronic 5961 demand pacemakers (Table 2), 12 either died from cardiac disease which was not attributable to pacer dysfunction or to heart disease requiring pacemakers before battery exhaustion, or were unavailable for follow-up examination. Pacemaker failure occurred 19 months after implantation in one of the remaining 12 patients; manufacturer analysis revealed an open cap weld on one of the batteries as a cause of pacemaker failure. The other 11 programmable pacemakers are functioning now. Duration of operation has been 35 months in 1

Table 2 Programmable Medtronic 5961 pacemaker longevity profile

Case No.	Time in months										
	0	4	8	12	16	20	24	28	32	36	40
1	0.76	1.53			1.0						→
2	0.8	0.3									→
3	0.72	0.4									→
4	0.8	0.3					0.34				→
5	0.80										→
6	0.76				0.2						→
7	0.8	0.52									→
8	0.9										→
9	0.8					X					
10	0.8										→
11	0.8			0.4							→
12	0.8										→

Abbreviations: Numerical values of chronic pulse width used for pacing are indicated temporally for individual patients at each change during follow-up.

X = Pacemaker battery failure.

Fig. 5 Ventricular flutter-fibrillation resulting from the R on T phenomenon with unipolar pacing in a patient with the Omnitor system who had sick sinus syndrome. In the normal fashion, the external magnet was placed over the normally functioning demand pacemaker for assessment of function. In the top strip of the electrocardiogram (lead II) (A), pacemaker spikes (first and second arrows) fall within the ST segments of the third and fourth QRS complexes. The fifth QRS complex is followed by two pacemaker-induced beats since the stimulus artefacts (third and fourth arrows) now fall beyond the refractory period of the conducted QRS complexes. The fifth pacemaker spike falls within the ST-T segment of a conducted QRS complex which resulted in the precipitation of ventricular-flutter fibrillation. In the second strip of the electrocardiogram (B), a chest thump (arrow) resulted in termination of the ventricular tachyarrhythmia with restoration of normal sinus rhythm (bottom electrogram strip C).

patient, 28 months in 3, and approximately 24 months in another 2 patients (range 6 to 35 months; average 21.5 months). Though the exact longevity of the programmable Medtronic 5961 system is difficult to evaluate from the present information, it does appear that this pacemaker system may possess greater longevity than the programmable Omnicor units. Of 64 non-programmable Medtronic units, 14 failed during follow-up with an average of 32.6 months (range 23 to 48 months).

In a recent review of all documented instances of pacemaker-induced ventricular tachycardia or ventricular fibrillation in humans resulting from pacemaker stimulation during the vulnerable period of the preceding ventricular beat (R on T phenomenon), it was pointed out that all such episodes occurred with bipolar catheters and thereby anodal stimulation (Preston, 1973). However, in the course of this study we observed the first documented case of ventricular flutter fibrillation resulting from unipolar cathodal pacing in a patient with the Omnicor system who had sick sinus syndrome (Fig. 5). In the process of evaluating the patient's pacemaker

function by applying a magnet over the pulse generator to convert from demand to fixed mode of operation, normally functioning pacemaker spikes were revealed. However, within a few seconds pacemaker spikes falling on the ST-T segment initiated a run of ventricular flutter-fibrillation (Fig. 5). Delivery of a timely chest thump resulted in the immediate reversion of the ventricular flutter-fibrillation to normal sinus rhythm.

Both types of programmable units have been claimed to withstand direct current countershock. However, in one instance in our series a patient with sick sinus syndrome with the demand Medtronic 5961 unit was cardioverted intraoperatively with direct current countershock from ventricular tachycardia to normal sinus rhythm. Immediately subsequent to countershock, the pacemaker lost its sensing ability. The patient was monitored for two days in the surgical intensive care unit and no episode of ventricular tachyarrhythmia resulting from fixed rate pacing was encountered. However, while awaiting surgical reimplantation of a new demand unit, the patient after disconnecting his

Fig. 6 Illustration of the loss of pacing with the Omnicor system occurring at the test current setting. Simultaneous electrocardiogram strips A, B, and C show 1:1 capture at the current amplitude settings of 9, 6, and 4 mA settings, respectively. Ventricular asystole occurred because of lack of capture (electrocardiogram strips D and E) at the test setting of 2.3 mA between the arrow on strip D and the arrow on strip E. 1:1 capture immediately returned with the resetting of the current output at 6 mA following the arrow on strip E.

monitoring leads, died suddenly during a short period of ambulation. Since no evidence of cardiovascular or pulmonary pathology was found at necropsy, the possibility of ventricular tachycardia resulting from fixed rate unipolar pacing was suspected. These two patients provide evidence that ventricular fibrillation can be induced by unipolar electrodes and, in addition, the latter patient indicates that demand pacemaker circuitry may be damaged by electroshock.

Because the threshold of cardiac stimulation is a linear function of the size of the cathode in contact with the endocardium (Furman *et al.*, 1975), the small surface area (12 mm²) pacing electrode is commonly used. Introduction of programmable pacemakers was associated with an initial increase in the incidence of perforation of the right ventricle. This untoward complication was largely attributable to lack of familiarity of the physician to small surface area unipolar endocardial electrodes which tend to perforate the ventricular apex more readily as compared with larger bipolar electrodes. Within

the first 5-month period of the present study, 6 patients undergoing programmable pacemaker insertion developed perforation of the right ventricle with the unipolar electrode catheter presenting as either sensing or pacing problems and requiring repositioning of intracardiac electrode. However, with careful intraoperative monitoring of the intracardiac electrogram from the unipolar pacemaker electrode catheter (Vera *et al.*, 1976), the incidence of perforation with implantation of programmable pacemakers has been virtually eliminated.

Caution is emphasised in evaluating pacing thresholds both with the Omnicor and Medtronic systems. Fig. 6 shows loss of pacing at the test current setting associated with ventricular asystole. Likewise, Fig 7 shows loss of capture and ventricular asystole associated with narrowing of the pulse width using the Medtronic programmer.

Since their introduction in November 1972 the Omnicor pacemakers revealed defects resulting in premature battery depletion because of unforeseen manufacturing defects observed in late 1973 and

Fig. 7 Illustration of the problem of loss of pacing and ventricular asystole with the Medtronic system occurring during narrowing of pulse width. The top strip on the electrocardiogram shows 1:1 capture with a pulse width of 0.8 ms (top oscilloscopic tracing). The middle portion of the bottom strip of the electrocardiogram shows ventricular asystole because of lack of pacemaker capture with the narrowed pulse width (bottom oscilloscopic tracing). Capture was immediately regained with widening of the pulse width. The undulations at the beginning and end of the bottom strip of the electrocardiogram indicate artefact induced by rotation of the handcrank programmer.

Fig. 8 Programmable pacemaker overdrive suppression of multiple premature ventricular contractions using the Omnicor system. This patient with trifascicular disease had spontaneous ectopy at the pacemaker rate of 60/min despite oral antiarrhythmic therapy (top strip of electrocardiogram). In the middle strip at the pacemaker rate of 70/min fewer ectopic beats occurred. Complete overdrive suppression was achieved by increasing the pacemaker rate to 80/min (bottom strip of the electrocardiogram).

early 1974. These instances of premature failure occurred in certain substandard lots within 5 to 14 months of implant and resulted from inclusion or intrusion of moisture causing malfunction of the sealed hybrid circuits. This problem has since been corrected. Occasional transient periods of non-sensing were encountered in the early months of Omnicor use. However, pacemaker replacement has not been necessary because of the brief and diminishing frequency of this defect and no patient complications have been encountered.

Discussion

Since 1960 with the onset of the era of permanently implantable cardiac pacemakers, it has been realised that two important prerequisites for an ideal pacemaker are: (1) atrial synchronised ventricular pacing and (2) long lasting power source. The former feature re-establishes atrioventricular conduction in complete heart block. However, because of several problems, especially the unavailability of a stable atrial electrode, routine use of a transvenous atrial synchronous ventricular pacemaker is not yet possible.

Concerning the second principal characteristic, the mercury-zinc cell has been the mainstay power source since the original pacemakers. With improvements in pacemaker technology and engineering, component failure is rarely encountered at the

present time. Therefore, the majority of pacemaker replacements are undertaken because of battery exhaustion. Despite improvements in battery design and the reduction of current leakage, pacemaker life by 1974 averaged only 32 months (Furman *et al.*, 1975). Thus, frequent replacements of the pulse generator continue to be necessary.

The two alternatives available to the pacemaker industry relative to the problem of pacemaker longevity have been the development of new power sources and more efficient use of energy available in the mercury-zinc cell. With the introduction of programmable units in late 1972, it was predicted that battery life would be considerably extended by judicious matching of the pacemaker energy output to patient need. The functional battery life of the Cordis Omnicor pacemaker system was projected to be 2 years, with an output setting of 9 mA, nearly 3 years at an output setting of 6 mA, 3.5 years with 4 mA, and 4.5 years with an output setting of 2.3 mA. From these data the reported expected life of the Omnicor pacers has been estimated to be between 3 and 7 years.

The Medtronic pulse width controllable system (Model 5961) has a projected longevity of nearly 5 years with a pulse width setting of 0.3 ms. The pulse width of the programmable Medtronic pacemakers automatically increases with depletion of the first mercury cell in the five-battery stack compensating for voltage reduction to maintain capture.

There are two independent indicators of battery depletion, pulse width increase and decrease in pacing rate. The current drain at narrower pulse width settings is much less than at wider pulse durations. Decreasing the pulse width of the Medtronic 5961 model from 1.0 ms to 0.3 ms has been shown to reduce the current drain from 19 microamperes per pulse to 10 microamperes, a saving of nearly 50 per cent in energy. Therefore, the reported theoretical life of the same pacemaker has been estimated to be 3.5 years (pulse width 1.0 ms) to nearly 5 years (pulse width 0.3 ms). Postulations of longevity are calculated theoretical battery life and do not take into account pacemaker malfunction caused by random component failure. These projections by the manufacturers were based on knowledge of current drains delineated above using the Medtronic 5816 endocardial lead with an uninhibited pacing rate of 72/min. In arriving at these predicted life spans, only 27 months of actual pacemaker testing had been carried out *in vitro*.

From the above theoretical considerations of anticipated extension of lifetime of pacemakers by programmable units, it is clear that actual evaluation of such systems in patients is of the utmost importance. No published reports before the present study have been available concerning the actual life-span of current programmable pacemakers in clinical trials. The data presented herein of programmable pacemaker longevity in 36 patients who were followed for an average of 23 months indicate that the pacemaker life span postulated by the manufacturers appears to be considerably overestimated. Thus, 6 of the 37 patients experienced pacemaker failure (5 Cordis and 1 Medtronic) because of battery exhaustion at an average of only 27.3 months after implantation. Furthermore, these early results for Omnicor pacemakers were not significantly better than the control longevity of the standard Cordis and Medtronic demand pacemakers which failed an average of 31.5 months after insertion.

Although the added manipulations which attend programmable pacemakers do not appear to increase pacemaker longevity substantially at this time, there are several important reasons for retaining the programmable function (albeit with a longer lived power source). First, the ability to change heart rate is useful in patients in whom optimal cardiac output is achieved at relatively higher heart rates. Secondly, in patients with sinus bradycardia or in second degree atrioventricular

heart block a slower programmed rate allows atrial transport of ventricular filling. Thirdly, the programmable systems with ability to pace at higher rates provide overdrive suppression of ventricular tachyarrhythmias (Fig. 8). Fourthly, serial evaluation of the patient's chronic stimulation threshold provides early diagnosis and appropriate management of the occasional patient with high pacing threshold (exit block). Finally, a very slow pacemaker rate allows evaluation of the patient's intrinsic rhythm QRS complexes and ST-T segments.

From the above observations it appears evident that the available Omnicor system using mercury-zinc batteries probably will not provide the hoped for extension of pacemaker longevity of greater than 5 years. The alternative power source of lithium iodide appears to be a most promising approach to the problem of longer pacemaker life and deserves thorough clinical evaluation which is under way at our institution.

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