Recent advances in surgery

Conducted by JAMES D. HARDY, M.D.

Electronic pacemakers of the heart, gastrointestinal tract, phrenic nerve, bladder, and carotid sinus: Current status

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Recent advances in electronics for telecommunication and their introduction into medicine have provided the opportunity for medical investigators, physiologists, and engineers to develop safe, efficient electronic control systems for certain bodily functions. Advances in miniaturization of electronic circuitry have enabled these systems to incorporate portable instrumentation. One such system, the most commonly applied clinically, is the cardiac pacemaker. Referred to by most investigators by that name, it gave rise to the concept of "electronic pacing" which for the sake of simplicity, will be referred to in this paper as "pacing," or "pacemaking."

THE HEART

It is now generally agreed that the indications for pacing the heart are A-V dissociation complicated by Stokes-Adams attacks (due to cardiac arrest, ventricular fibrillation, or tachycardia) or heart failure, or A-V dissociation resulting from intracardiac operative repair though not at the time complicated by Stokes-Adams syndrome or heart failure.

Supported by United States Public Health Service Grant HE-06451, The Victoria Foundation, and a gift from Charles W. Ohse.

Received for publication Jan. 3, 1966.

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Reports describe the use of cardiac pacemakers for other conditions: cardiac arrest,[9] acetylcholine-induced arrest during coronary angiography,[11] glossopharyngeal neuralgia,[63] digitalis toxicity,[70] diabetic coma with arrest,[21] ventricular arrhythmia,[99] and ipecac intoxication.[75] It is also used for therapeutic testing.[49]

Congestive heart failure with tachycardia may be treated with the recently introduced method of paired or coupled stimulus pacing.[20]

Types of cardiac pacemakers.

I. Indirect, external pacemakers, temporary: Electrodes not making direct contact with the heart. Clinical application of these was initiated in 1952.[112] The electrodes terminate in paddles which are placed on the patient's chest. The advantage of this indirect type is its ability to control the heart rate immediately. However, the stimulus can cause painful contractions of the pectoral muscles and, if its use is prolonged, localized burns. Both line- and battery-powered models are available commercially.

II. Direct wire pacemakers: Electrodes extending from the power source to the heart.

A. TRANSCUTANEOUS-MYOCARDIAL (TRANSTHORACIC).

1. For temporary use.
2. For prolonged use.

Experiments with transcutaneous stimulation led to implantation of electrodes in

Vol. 60, No. 2, pp. 480-494

patients with surgically induced heart block to control the heart rate postoperatively.[109]

Pacemakers using the direct wire method are either line- or battery-powered. Electrodes may be implanted in the myocardium under direct vision, or "blindly" through a needle inserted through the skin into the pericardial sac or heart.[97] The latter is a simple technique for directly stimulating the heart, but the possibility of injuring a coronary vessel and the relative instability of fixation of the wires has discouraged use of this method except in an emergency; furthermore, the possibility of an infection extending from the skin along the wire tract to the myocardium has discouraged use of all transcutaneous electrodes in long-term situations.

B. INTRAVENOUS-ENDOCARDIAL.

1. For temporary use (transcutaneous).[89]
2. Permanent.
   a. Transcutaneous.[44]
   b. Implantable.[30]

Since 1958[43] intravenous endocardial stimulation has been used both as a temporary and as a "permanent" method. Its principal advantage is relative simplicity of application, which is particularly important in the poor-risk patient. Its disadvantages are those of the transcutaneous method mentioned just above.

Both line- and battery-powered models using this method are available commercially.

Modification of the unit permitting synchronization to the P or R waves of the electrocardiogram, as well as "coupled stimulus" pacing, has recently been reported.[49]

C. TOTALLY IMPLANTABLE, MYOCARDIAC OR EPICARDIAC (PERMANENT).

1. Asynchronous, fixed[32, 39, 96, 114] and variable.[29, 30, 58]
2. Synchronous.[82]

Battery-powered transistorized pacemakers for implantation within the body were introduced in 1958 to 1962, and various forms of these, manufactured in the United States, England, France, and Sweden, are the pacemakers now in general use. They have been designed to operate with disposable or rechargeable batteries, are of varying sizes, the smallest about the size of a paper matchbook,[78] and may be synchronized to the P wave or the R wave.[69]

One advantage of a totally implanted pacemaker is that the patient tends not to be aware of it. However, in the fixed type of direct wire asynchronous pacemaker it is impossible to control the rate and output, and in the variable type controls are not always instantly accessible. Synchronous pacemakers, which are used principally in younger, active patients, introduce many more electronic components, thus possibly increasing the chances of failure. Also, the hazard of fainting is present when the ventricular rate is reduced by half by the automatic cut-off in response to a fast atrial beat.[27]

Further, in all these models, expected battery life is limited to three years, in some models to less than two[49] and the rechargeable batteries which have been tried have not had much success.[16]

III. Remote-control pacemakers, permanent: Electrodes making direct contact with the heart but not with the power source.

A. RADIOFREQUENCY INDUCTION.

1. Wire electrodes.[111]
2. Nonwire electrodes.[5, 35, 94]

B. MAGNETIC INDUCTION COUPLING.[1, 2, 83]

Clinical application of the first permanently implantable pacemaker, in the current sense of the term, was reported in 1959.[47] With this type, impulses are transmitted by radiofrequency from a transmitter located outside the body to a receiver embedded in the subcutaneous tissue and thence by electrode wires to the myocardium. Another type of remote control system utilizes magnetic induction.[1, 2] In recent procedures, electrode wires have been passed into the endocardium from a peripheral vein[42, 46] or have been replaced by solid peg electrodes attached to a radiofrequency receiver sewed to the epicardium.[5, 35, 94]

The accessibility of the external parts, as mentioned above, makes it possible to set the stimulus to just above the stimulation threshold to prevent fibrillation; to increase

its strength in cases of poor contact between electrodes and myocardium due to fibrosis or, in some cases, broken wires (observation of a rising threshold is useful in forewarning of component failure); to accelerate the cardiac rate, and thus cardiac output, during stress, or, when there are irritable ventricular foci or tachycardia, to bring the ventricle under control of the pacemaker; to permit the patient to change his own battery; and to inspect and replace parts and substitute improved units.

The principal disadvantage of the remote-control pacemaker is the care that is necessary to preserve a close coupling of the antenna and receiver.

Table I lists the features of the several types of pacemakers.

Treatment of heart block.

Drugs. Before the advent of electric pacemakers, complete A-V dissociation was treated with several drugs that accelerated the heart rate and improved rhythmicity. These drugs were epinephrine, ephedrine, isoproterenol, atropine, steroids, chlorothiazide, molar lactate, and others.[8] At the present time drugs are used by some surgeons for emergency treatment of heart block during operative placement of a permanent pacemaker.[49] Chlorothiazide has been particularly effective in intermittent heart block.[105]

Pacemakers. For emergency or short-term pacing the totally external (indirect) pacemaker is efficient. But, because its use causes uncomfortable contractions of the pectoral muscles, direct pacing is preferable, with either transcutaneous insertion of a myocardial uni- or bipolar wire electrode, or transvenous insertion of a uni- or bipolar[15] endocardiac electrode, via an external jugular vein, an antecubital vein, or a femoral vein in cases where a totally implantable or intravenous unit is to be applied later for long-term control; the transvenous insertion is probably less dangerous than the transcutaneous, but usually requires fluoroscopic guidance.[53]

Most patients who require pacing do so on a permanent basis (months or years). Exceptions are the patients with an A-V dissociation induced by surgery or by myocardial infarction; in these two groups a spontaneous, permanent reversion to normal sinus rhythm is common.[111] In the former, the direct wires are left in place for four to six weeks on the chance of resolution and disappearance of the block.[72] If the block persists, a permanent pacemaker is implanted. The remote controlled unit is preferable here because of the relative smallness of its implanted component (receiver) and, more important, accessibility of its external components which in case of a delayed return to a normal rhythm can easily be disconnected to interrupt pacing. It is quite common in complete heart block to see a return to a second or first degree block or a normal sinus rhythm intermittently, but, except in the two types noted above, it is uncommon for this rhythm to persist. It is probably not safe, therefore, to discontinue pacing until a normal sinus rhythm has been observed for at least two months.

THE ELECTRODE PROBLEM. Breakage of the electrodes and electrode wires is a problem

Table I. *Characteristics of cardiac pacemakers*

1. Energy source	Disposable batteries	Rechargeable batteries	Line-powered	Biological
2. Programming	Asynchronous	R—demand or coupled	Paired	P—synchronous
3. Regulation	Rate variable	Output variable	Rate and output fixed	Rate and output variable
4. Location	External	Internal	Mixed	Variable
5. Impulse energy transmission	Direct, with wire	Direct, without wire electrodes	Remote controlled, with wire electrodes	Remote controlled, without wire electrodes
6. Cardiac contact	Myocardiac	Epicardiac	Endocardiac	Mixed

common to all pacemakers and is a frequent cause of pacemaker failure. No unbreakable electrode wire has yet been developed for a bipolar system of stimulation. The kind of metal, the electrode design and configuration, the type of insulation, the type of wave form and the technique for placing them in the body are important factors determining the ability of the electrodes to resist breakage.

1. The several kinds of metals or alloys in current use for myocardiac or epicardiac electrodes are stainless steel, either plain or plated with one or more noble metals,[58, 66] or platinum-iridium,[25] or Elgiloy.[48] (A palladium alloy, Paliney-7, is presently under investigation in our laboratory.) Of all the electrodes, only those of Elgiloy in the unipolar (cathode) configuration have not shown breakage in patients.[48]

2. The electrode wires may be multifilament braided or single or multifilament coiled. Both may terminate in the heart or the anode may terminate as a steel plate or a coil of platinum-iridium wire some distance from the heart. Several types of helical coils are made with a core of supporting material.

3. The insulating materials have been epoxy, Silastic, polyethylene, and Teflon. Leakage of body fluids into or through these materials has resulted in a localized electrolytic process causing breakage at the point of stress[108] or dissolution of the junction between the electrode wire and the electrode plate.[46] Ceramic in a bond with the electrode, also now being tested in our laboratory, appears to allow the least penetration by surrounding fluids.

4. At least four "different" types of wave form are being used:

The pure "monophasic-DC" type pulse, in experiments.

The "monophasic-RF" type pulse, allowing polarization between pulses which increased the threshold to stimulation; the shorter the pulse interval the greater the threshold. The peak voltage reached is higher than that of the DC pulse, which results in increased electrolysis of a non-noble anode and increased chlorine and oxygen gas formation.

The biphasic DC pulse[29] allowing a minimum of polarization and a prolonged electrode life. Recent studies in our laboratory show that anode and cathode electrode life in a monophasic system is as long as cathode life in a biphasic system.[107]

An "equivalent" biphasic DC pulse, in the magnetic non-radiofrequency induction coil method.[1] Its advantages are similar to those of the more commonly used biphasic pulse.

5. Transthoracic epicardiac or myocardiac electrodes are handled gently, with little instrumentation, and positioned without acute bends or fixed points and in such a way as to form one or more strain-relieving loops. The braided electrode may be inserted into the heart swaged on a needle, which is afterward withdrawn. The coiled wire electrode may be formed into a right angle at its point of insertion in the myocardium or laid in a short tunnel of myocardium with the aid of an infant tracheostomy tube.[48] Suturing the electrodes, if bipolar, approximately 1 inch apart and at least 1 inch distant from the phrenic nerve, prevents late-developing short circuits and stimulation of the phrenic nerve.[100]

THRESHOLD PROBLEMS. Bipolar stimulation requires less energy than unipolar[95] and endocardiac less than myocardiac or epicardiac.[51] The reason for the initial rise in threshold with the latter two types, though not clear, is probably due to edema or hemorrhage at the site of electrode implantation.[3] In some cases, after an initial rise, the threshold returns to a low level where it remains even after prolonged stimulation. Not all threshold rises are due to "tissue reaction" or to dislodgment, however, but electrode or electronic component failure may indeed be manifested by such a rise.

In some of the "fixed" output implantable models, to insure continuation of stimulation the current is set to exceed the threshold by as much as five times.[113] Yet such a fixed high setting may not only be unnecessary, it may increase the chance of pacemaker-induced fibrillation in cases of "competi-

tion."[68] Units with accessible adjustable current output controls are for this reason preferable.

RATE PROBLEM. Currently, units with a fixed rate, an adjustable rate and P as well as R wave synchronous pacing are available. Opinions concerning the setting of the rate differ. A rate of 60 to 90 is adequate for most patients during normal activity, but may be inadequate during induction of anesthesia, fever, extrasystole, ventricular tachycardia, or competition from a returning sinus rhythm.[71] In these patients an increase from a slow idioventricular rate to a physiologic rate of 60 to 75 increased the cardiac output. Yet reports on the changes in cardiac output occurring with a still further increase of the rate are conflicting.[57, 67] This disagreement, however, probably reflects the variation in the ventricular response because of disease or other factors, or in the relation of the atrial contractions to the pacemade ventricular beats, which influences the output determinations in a negative or positive direction, depending on the relative number of synchronous atrioventricular contractions during the sampling period.[10]

In pacemade patients with impairment of ventricular function, cardiac output continues to increase as the pacemaker rate increases in these patients, up to a point, usually somewhat higher than 100 per minute. In these patients, an increase to an above average rate is beneficial during exercise or stress.[71] In resting patients with complete A-V dissociation but no impairment of ventricular function, the increase in cardiac output at rates above 75 per minute is slight. These latter patients show an increase in output in response to stress or exercise at a fixed rate, due to changes in myocardiac contractility, ventricular filling, and peripheral reflexes.[57]

P wave synchronous pacing causes an increase in cardiac output in response to exercise because, at these higher rates with smaller diastolic intervals and stroke volumes, optimum end-filling of the ventricle is still achieved by the appropriate contraction of the atria.[101]

The opinion of some is that a fixed, slow rate (around 60) is the ideal because it provides sufficient pacing while sparing the heart from an increase of stress such as would obtain at a higher rate.[26] Others feel that synchronization to the P wave, by restoring atrioventricular harmony, produces the ideal and "natural" sequence.[82] Finally, there are those who support asynchronous pacing at a fixed rate provided there is access to rate controls for the reasons explained above.[48, 58]

FAILURE OF PACEMAKING. Failure of pacemaking, if it does not result in death, can usually be detected by the patient himself. An irregular pulse may simply represent competition from intermittently conducted sinus pacemaker impulses. Competition between the patient's own pacemaker and an electrical pacemaker may not give rise to any complication, but the theoretical danger exists, however, that the electrical impulse will fall in the vulnerable phase of the cardiac cycle and may, under conditions of increased irritability, precipitate ventricular fibrillation.[110, 111]

A common cause of failure of the totally implantable units is battery exhaustion. In at least one model this is indicated by a very fast pulse—"runaway pacemaker." It is a serious complication which, since it may lead to ventricular fibrillation, must be treated as an emergency by immediate severance of the electrode wires.[4] One of the totally implantable pacemakers (General Electric) has been designed with a self-regulatory mechanism that on acceleration of the rate of stimulus causes a drop in intensity, and ultimately, with rates around 140, depending on the threshold to stimulation, produces only an intermittent or no further myocardiac response.[49]

The return to an idioventricular rate suggests the loss of electrical contact between electrodes and heart[39] or mechanical failure of the component parts of the pacemaker. It may be difficult to diagnose precisely the cause of failure. Electrocardiograms, x-rays, specialized probes,[56] and a variety of charts[58, 85, 98] have been devised to help pinpoint the fault. Unless both wires of the

bipolar pacemaker have lost contact with the ventricle or are broken inside the chest, a correction can be effected relatively simply under local anesthesia, either by grounding the one broken or loose electrode subcutaneously or, if it is the pulse generator or battery that is at fault, by substituting a new part. Failure of the electronic components, except from normal wear, has been uncommon but a realistic evaluation of the reliability of these components will require a longer period of observation.

Pacemaking may fail in that, under certain circumstances, it may not maintain an adequate cardiac output for an increased metabolic demand. Units equipped with controls to vary the rate according to the need will not fail from underperformance as fixed-rate units may.

COMPLICATIONS. The mortality and morbidity from thoracotomy for electrode implantation has been gratifyingly low (5.7 percent operative mortality in the questionnaire review mentioned below) despite the advanced age of most of the patients requiring it. Complications are those common to thoracotomy and pericardiotomy[88] and those related specifically to implanting the pacemaker, such as (1) ventricular fibrillation,[68] (2) myocardial infarction,[77] (3) pacemaker infection and erosion through the skin,[49] and (4) diaphragmatic contraction.[100]

Death may occur suddenly in pacemade patients with no explanatory pathological findings.[16] It may be due to fibrillation induced by the pacemaker, though probably not if the pacemaker is correctly set just above the stimulation threshold.[110] Cases have been recorded of ventricular arrhythmias caused by stimulation delivered from a single pacemaker or from two pacemakers functioning simultaneously.[54]

The ventricle in failure or during digitalis toxicity, hyperkalemia, hypoxemia and acidosis,[110] or during anesthesia induction may fibrillate if an appropriate electrical stimulus falls during the vulnerable period. All pacemakers attached to the myocardium by wires should be battery powered. If any equipment is line powered, it must be well grounded so that no direct low-resistance pathway can carry continuous current to the heart via the electrodes.[79] High frequency diathermy or electrocautery should not be used,[48] because the pacemaker's electronic circuitry is not isolated from external interference by intense electromagnetic or electrostatic fields[24]; patients wearing units should be cautioned against coming into close contact with such fields.

PROGNOSIS. Electronic pacemakers have been useful in producing an optimum heart rate and have dramatically improved the outlook of patients with Stokes-Adams-Morgagni attacks. In an attempt to determine the prognosis of pacemade patients with complete heart block, we have reviewed, through personal communications,* 1,512 cases of pacemaker implantation.

The accumulated evidence shows that in patients with complete A-V dissociation prolongation of a useful life is achieved by the use of cardiac pacemakers.

Patients treated thus far have had symptoms for 12.4 months (on the average) preoperatively. More than 60 percent are alive at least 24 months after the initial pacemaker operation (Table II).

Forty-three percent of the patients had more than one additional operation for readjustment or replacement of a part of the pacemaker. One patient in our own series on continuous pacing has survived her original placement operation more than four and one half years without an additional operation.[46] Another patient had an intravenous pacemaker installed in 1959, but she has required

*For the data used in this survery we are gratelul to: Drs. J. L. Ankeney, T. D. Bartley, C. S. Beck, J. W. Bell, R. Berg, Jr., W. G. Bigelow, W. E. Bloomer, L. H. Bosher, H. H. Bradshaw, I. Brown, J. Bruneau, W. F. Bugden, L. Cammilli, W. M. Chardack, D. A. Cooley, F. X. Costeas, C. Crafoord, R. A. Deterling, Jr., J. Fourny, S. Furman, H. L. Gadboys, E. D. Gagnon, P. H. Gerst, L. Groves, G. R. Holswade, D. Honoré, P. M. Ikins, L. Johansson, F. R. Johnston, J. R. Jude, A. Kantrowitz, K. E. Karlson, R. W. Kendall, J. H. Kennedy, H. Lagergren, C. R. Lam, G. H. Lawrence, W. Lee, D. S. Leighninger, A. Levy, R. S. Litwak, A. Logan, J. Mackenzie, G. J. Magovern, J. D. Morris, D. A. Nathan, V. Parsonnet, R. Schramel, A. Stranahan, R. E. Taber, A. S. Trimble, J. D. Wade, R. N. Westcott, R. E. Whalen, and R. H. Wylie.

Table II. *Current status, 407 patients**

	Years of survival				
	0-1	*1-2*	*2-3*	*3-4*	*4-5*
Total No. patients	177	134	45	32	19
No. patients living	155	116	30	20	9
Percent of survival	87.5	86.5	66.6	62.5	46.3

*Data available on 407 of the 1,512 patients in the questionnaire series (patients surviving out of total undergoing operation per year).

later procedures.[42] So, too, did 8 out of 16 patients of one series who survived their initial operation more than four years.[28]

These additional operations are a matter of course with systems employing totally implantable units. Batteries frequently become exhausted in about two years, in some instances sooner than one year, and, in any case, require prophylactic replacement at intervals specified by the manufacturer. The biggest problem is still loss of pacing caused by interruption in the wire-heart communication, usually from breakage of the wires or from dislodgment of the wires from the myocardium.

Operations both under local anesthesia and involving a thoracotomy were done (Table III).

Wire breakage was an almost inevitable cause of failure with chronic pacemaking in this review. Table IV shows the incidence of wire breakage and dislocation reported to us.

RECENT DEVELOPMENTS. Paired or coupled-stimulus pacemaking was recently introduced as a means of slowing the heart rate as well as increasing contractility of the myocardium.[29] If a second, appropriately delayed stimulus is delivered to the ventricle following each "excitatory" stimulus,[20, 55, 62, 74] the functional refractory period is prolonged, even doubled, and the effective mechanical contractions and pulsations are reduced considerably. Coupled stimulus pacemaking has been suggested as a way to increase cardiac output in postoperative arrhythmia and in congestive heart failure.[20]

Work on improving and lengthening the life of batteries, making them rechargeable[17] or utilizing radioisotopes,[78] and on simplifying the remote control apparatus is in progress.[35]

Table III. *Operations on 1,512 patients*

Original	*Subsequent*	
1,512	652 (43%)	
275*	37 (13%)* Repeated thoracotomies	112 (40%)* Repeated under local

*Data concerning the type of subsequent operation (repeated thoracotomy vs. local) are available on 275 out of the 1,512 patients, 53% of whom had repeat operations.

Self-energizing pacemakers utilizing biological energy sources,[40, 64, 115] as well as entirely implantable mechanical hearts controlled electrically by direct current or radio-frequency are also being investigated.

Cardiac pacemakers for use in patients are now manufactured in many countries of the world. As a conservative estimate, more than 15,000 units have been employed thus far for long-term control.

GASTROINTESTINAL TRACT—ELECTROPERISTALSIS

Studies on the response of the upper small intestine to electrical stimulation promoted, in 1959, the use of electric current for treatment of paralytic ileus.[61] Subsequent methods for stimulating the adynamic gastrointestinal tract attempted to apply stimuli strong enough for good contractility to an organ which, though "paralytic," still maintained good reflex irritability.[13, 14]

Methods. Intermittent application of electrical stimuli of about 5 v. or 10 ma. was found to initiate peristaltic waves[13, 37, 61] (Table V). Peristaltic waves could be initiated by bipolar stimulation of the proximal jejunum with stainless steel electrodes, affixed during operation, or transluminal unipolar stimulation with one electrode in the antrum or in the first or second part of the duodenum or in the rectum with a plate

Table IV. *Wire breakages and dislocations*

	Pairs or patients	Breakages	Dislocations
Steel spikes (Hunter-Roth)	16	11	
Steel ribbon–platinum plates (Elema-Schonander)	20	0	5
Steel ribbon–platinum plates (Elema-Schonander, modified by Sessions, used with RF monophasic stimulation)	6	5*	
Multifilament steel–platinum wire (Electrodyne-Zoll)	111	39	
Coiled steel wire, platinum tipped (Lagergren-Johansson intravenous catheter)	104†	0	
Platinum-iridium (Medtronics-Chardack)	647	60	3
Bipolar Elgiloy (Glenn)	5	3*	
Unipolar Elgiloy (Glenn)	9†	0	
Platinum-iridium (Cordis-Nathan)	56	16	5
Stainless steel (General Electric-Kantrowitz)	92	43	5
Total	1,066‡	177‡	18‡

*Anodes only.

†Cathodes only.

‡Data on type of electrodes are available on 1,066 of the 1,512 patients.

Table V. *Parameters of electroperistalsis*

Authors	Single pulse duration	Pulse frequency	Pulse "train" duration	Pulse "train" repetition	Pulse intensity	Electrodes
DeVilliers and associates[36]	5 - 7 msec.	40 - 70 c.p.s.	6 - 8 sec.	Every 3 - 4 min. for 3 - 5 times/hr.	4 - 6 v.	Bipolar
Bilgutay and associates[13]		50 c.p.s.	5 - 10 sec.	11/min.	7 - 10 ma.	Unipolar
Katona and associates[61]	Continuous	50 - 80 c.p.m.	Continuous	0	30 v.	1 in stomach, 1 in rectum

electrode on the abdomen. Unipolar stimulation was imperceptible to the patients.[37]

"Pacemade" patients recovering from an abdominal operation passed flatus earlier than patients with similar operations without electrical stimulation of the bowel.[13]

In a double blind study involving 24 patients, the efficiency of electroperistalsis was evaluated.[84] Ten of the 24 patients seemed to benefit; the study, however, is incomplete. One report[87] is guarded regarding the value of the method.

It is too early in the management of cases of adynamic ileus to judge the efficacy of electrical pacing for the gut; the evidence of benefit has not been adequately substantiated to recommend it now for general use.

THE PHRENIC NERVE AND DIAPHRAGM—ELECTROPHRENIC RESPIRATION (EPR)

In a series of experiments, Sarnoff[90-93] demonstrated that normal ventilation and, indeed, hyperventilation could be produced by applying an undulating current to one phrenic nerve. When the voltage was increased, the spread of current included more fibers of the phrenic nerve, which induced forceful contractions of the diaphragm, resulting in a depth of respiration proportional to the voltage used. The animals' own respirations usually are suppressed during EPR.[36, 48, 106] The mechanism of suppression of spontaneous respiration has been studied in our laboratory.[106]

Most animals respond to 1 v. or less at 0.3 msec. pulse duration, although in some animals an increase in the threshold to stimulation is encountered soon after stimulation is begun, related perhaps to the amount of operative dissection or to the partial exclusion of the vascular supply to the nerve.[36, 48]

To stimulate normal diaphragmatic respiratory movements, the wave-form envelope generated in the externally located RF transmitter may be varied in contour, amplitude, or frequency by modulation of the carrier wave. The internally placed receiver unit delivers monophasic or biphasic impulses to the phrenic nerve by electrodes applied directly to the nerve or indirectly through the cavae or pulmonary artery.[34, 106]

Clinical application of EPR was first carried out by Sarnoff[92] many years ago. Recently, with the development of new techniques, interest in this method of assisting respiration has been revived[48] and can be expected to be extended to include patients with bulbar poliomyelitis and other central nervous system lesions involving the respiratory center, narcotic poisoning, and chronic emphysema and to assist respirations in the postoperative period.

In summary, electrophrenic respiration, whether with direct wires, external appliances, or radiofrequency induction, has been shown to control ventilation effectively. The RF technique would appear to have an advantage over other techniques but its clinical application to postoperative hypoventilation, bulbar poliomyelitis, central hypoventilation, or chronic emphysema awaits the corroboration of our preliminary experimental results.[106]

Electrical stimulation of the phrenic nerve in a pedicle supplying a diaphragmatic graft to the heart or around the aorta has successfully produced an elevation in blood pressure when synchronized with ventricular systole.[59, 80]

URINARY BLADDER—ELECTROMICTURITION

Management of neurogenic bladder is ordinarily complicated by intercurrent urinary tract infection. Antibiotics suppress but do not eliminate such infection and prevention at the outset is important. Electrical control of the bladder instead of the use of infection-promoting indwelling catheters should thus greatly aid the management of various types of neurogenic bladder, particularly in cases of long-term care.

Electrical stimulation of the bladder and the bladder nerves was reported as long ago as 1900.[102] In recent years, interest in the technique has been revived. Various forms of it have been used successfully to produce micturition: stimulation of the external anal sphincter,[103] of the bladder wall using direct wires or magnetic induction,[18] and of the pelvic nerves bilaterally.[51] Radiofrequency induction has recently been adapted to stimulation of the sacral nerves, the vesical nerves where they enter the bladder wall, and the bladder muscle directly.[19, 52, 60]

Experimental use. The radiofrequency technique adapted to electromicturition was investigated in our laboratory in acute and chronic studies with paraplegic dogs. Four treated with this technique have lived more than a year without requiring catheterization.

Dogs with upper motor neuron lesions showed an inability to void due to a spasticity of the external sphincter caused by a spread of the electrical current. A pudendal neurectomy successfully relieved this.[52]

Parameters of stimulation are shown in Table VI. The least voltage caused the bladder to empty when the two electrodes were placed on the "neural triggers,"[51, 52] that is, gross nerve trunks of the detrusor motor nerves underneath the serosal covering or the vesical nerves directly, or the anterior roots of the second or fourth pair of sacral nerves.

Studies on bladder stimulation in animals with lower motor neuron lesions have not been completed.

Clinical use. Direct-wire stimulation of the bladder detrusor has been attempted in normal and paraplegic patients.[18, 22] Increases in intravesical pressure were seen but the procedure was reported to be uncomfortable, and short-circuiting by pelvic fluid greatly altered the square wave form of the stimulus. More recently, induction coils were implanted subcutaneously with electrodes leading to the bladder; one patient so treated voided whenever his bladder accumulated 300 to 500 c.c. of urine; another voided well, leaving minimal residual, until a break in the leads occurred. In other patients direct transcutaneous leads were used, the number of electrodes required to produce adequate voiding being proportional to the degenerative changes in the bladder.[18]

It has been confirmed in patients that "neural trigger" stimulation requires less voltage for contraction of the bladder. One investigator emptied the bladders of five patients successfully by this means.[51]

There are several problems remaining regarding the clinical application of electromicturition.

Selection of candidates. On the basis of the results of radiofrequency electromicturition with disk or tape detrusor muscle electrodes in 22 patients, a detailed preoperative evaluation program has been suggested.[103] Bladder function was tested by administering Urecholine and by stimulating the bladder wall directly and the sacral nerves through the sacral foramen. Intravesical pressure changes, sphincter resistance, and total emptying capacity of the bladder were determined using cinefluoroscopy and cystometry.

Immediately after the onset of neurogenic bladder, the collagen content, as determined by biopsy, increases to more than the normal 15 percent and eventually to as much as 44 percent of the total bladder mass, though there is no decrease in the muscle mass.[103] It is the opinion of some investigators that patients who have bladders with a high collagen content are not good candidates for electromicturition.

The optimum time of implantation of the electrodes. This has not been determined,[103] but since catheterization, the only other means of emptying a bladder in the acute

Table VI. *Parameters of electromicturition*

Authors	*Intensity*	*Frequency*	*Duration*	*Site*	*Wave form*	*Electrode*
Burghele, Ichim, and Demetresco[22]	4 - 8 ma.	15 - 30 c.p.s.	7 msec.	Bilateral pelvic nerves		
Katona, Benyo, and Lang[61]	0.2 - 30 v.	70 - 100 c.p.m.		Intravesical		Catheter
Bradley, Wittmers, and Chou[19]	5 - 15 v.		1 - 5 msec.	Detrusor muscle	Biphasic	Disk or tape, multiple
DeVilliers, Nose, Meier, and Kantrowitz[36]	2.5 - 10 v.	20 c.p.s.	4 msec.	Detrusor muscle	Biphasic	Stainless steel
Habib[51]	1 - 2 v.	20 c.p.s.	15 msec.	"Neural triggers"		Platinum plates
Hageman, Flanigan, Harvard, and Glenn[52]	1 - 12 v.	5 - 20 c.p.s.	1 - 3 msec.	Vesical nerves, detrusor muscle, sacral nerves	Monophasic RF	Cuff or disk
Boyce, Lathem, and Hunt[18]	10 - 40 v.			Detrusor muscle		Multiple pairs

stage following the onset of neurogenic bladder, is undesirable for several reasons, electromicturition should probably be initiated soon after bladder paralysis is established.

Some human or canine bladders subjected to prolonged catheter drainage have failed to empty completely when electrically stimulated. This reaction may be related to an intrinsic response of the detrusor muscle fibers after a prolonged period of shortening.[45]

Pain. This has usually not been a problem if damage to the spinal cord is complete at the cervical or thoracic level or a complete cauda equina lesion is combined with sympathectomy.[33]

Pudendal neurectomy in relation to sexual function. When relieving sphincter obstruction by pudendal neurectomy appears necessary for achieving electromicturition, the possibility of sexual impotence must, of course, be discussed with the patient. It is hoped that use of sacral nerve roots or vesical nerves instead of the detrusor directly will cause less of a spread of current, therefore less sphincter obstruction, and pudendal neurectomy will be unnecessary.

In summary, the ideal conditions for electrical stimulation of the paralyzed bladder have not been determined. Successful control of the bladder by electrical stimulation in man has been uncommon. Further research in this field is badly needed. The radiofrequency technique would appear to be ideal for the procedure.

CAROTID SINUS NERVE AND BARORECEPTOR STIMULATION

The baroreceptors located at the origin of the internal carotid arteries (carotid sinus) and in the aortic arch or in the major branches rising from it, will respond to direct electrical stimulation of the carotid sinus nerve or baroreceptor area (carotid body). Griffith and Schwartz[50] have emphasized the specific vasomotor center effect of "baropacing" in contrast to the diffuse effect, for example, of sympathectomy. Continuous, intermittent, and R-synchronous stimulation with varying trains of impulses lowers the blood pressure in experimentally induced and in clinical hypertension.[12, 38, 50]

Carotid sinus nerve pacemakers have been applied to a few patients with hypertension.[76] A reduction in systolic and diastolic blood pressure in five patients for at least six months is encouraging.[49] From the evidence presently available there is no certainty that the technique will be a practicable or efficient method of reducing systemic hypertension.

STIMULATION OF OTHER TISSUES

Electrical stimulation of the brain to produce electronarcosis or electroanesthesia, of the peripheral nerves including the sympathetic and parasympathetic,[41, 72, 86] of muscle directly as well as of the uterus to control bleeding, and of the extremities to control motor function have all been investigated. Stimulation of the anal sphincter in an attempt to control incontinence has also been reported.[23]

GENERAL SUMMARY

Electronic pacing has been demonstrated to be the treatment of choice for complete heart block. The advantages and disadvantages of the several electrical cardiac pacemakers are presented. The present state of development and use of electrical stimulation for the gastrointestinal tract, diaphragm (electrophrenic respiration), bladder (electromicturition), carotid sinus nerve, baroreceptors, and other tissues is reviewed briefly.

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