Pacemakers, Cardiac Mapping and EEG in the Community Hospital: 
a Concise Review of Background and Basic Technical Considerations

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Introduction

In 1958, cardiac pacing represented a surgical triumph for a catastrophic and uncommon condition (1). Today, pacemaker implantation is no longer rare. Ten thousand pacemakers are implanted monthly and there are over 225,000 pacemakers outstanding with the lithium power source alone (2).

Moreover, application has broadened as the capacity for cardiac rhythm analysis has increased. Long term rhythm monitoring, in the coronary care unit and with the ambulatory Holter monitor, electrophysiological studies and sinus node recovery time (SNRT) (3-7) are commonly employed in patient selection.

Diagnosis has become more specific. Hazardous rhythm or conduction patterns may be an indication for pacing even in the absence of symptoms. Temporary pacemakers are employed to protect the patient during a period of stress and are then removed or replaced with permanent units.

The Heart Is A Pump

The fascination for pacemakers has not subsided. The search for a better power source has dominated the literature of the past decade. Minimization, improved circuitry, non-invasive programming and trans-telephonic pacemaker analysis has produced such a clutter of minutiae, it seems forgotten that the heart is a pump; if pacing does not improve the pumping of the heart, the patient becomes worse and not better. The heart as a pump is the concern of this paper.

Pacemaker Aggravation of Neurological Symptoms

The patient who has a pacemaker implanted to relieve syncope or bradycardia may find himself disabled with dizziness and ataxia that is pacemaker related. Most pacemakers are NOT PHYSIOLOGIC and stimulate the right ventricle (RV). RV pacing results in reduced stroke volume by the loss of the atrial contribution and by mitral and tricuspid insufficiency (8-10). When the cardiac reserve is adequate, RV pacing may be well tolerated, but it can be catastrophic (11) or bizarre (12) but more commonly worsens the neurological status of the patient, especially vertebral basilar symptoms (13). When this occurs, physiologic pacing may resolve the problem. An introduction to basic background information and technical considerations follows.

Conduction System of the Heart

Normally, the sinus node high in the right atrium (RA) (Fig. 1) initiates the impulse which spreads to the atria and the A-V node, down the Bundle of His to the right and left bundle branches which result in synchronized chamber contraction. The atria contract and fill the ventricles; the papillary muscles contract, close and stabilize the A-V valves (mitral and tricuspid) before the ventricles contract.

Physiologic Pacing — Not Popular

Transvenous RV pacing is the most popular because it is the easiest to accomplish, has the lowest morbidity and mortality and employs the most reliable components with the fewest technical problems. But RV pacing results in...
Normally, the stimulating impulse originates in the sinus node of the right atrium, proceeds to the AV node and down the Bundle of His to the right and left bundle branches.

The least improvement of cardiac output and often significantly reduces it (8-10).

Right Ventricular Pacing (RV)

The right ventricle is stimulated and the impulse radiates from that point. If the conduction system is intact, the impulse travels retrograde to the atria causing late contraction. If complete heart block exists, this does not occur. Not only does RV pacing lose the atrial contribution, but the ventricular contraction may occur before the A-V valves are fully closed permitting regurgitation. The net result is a reduction of stroke output (8-10).

Evolving Pacemaker Technology

Demand pacemakers which are inhibited by spontaneous cardiac activity have largely replaced fixed rate pacemakers because of the high mortality associated with competing rhythms. Programmable units which permit variation of rate and other parameters have as their objectives optimal hemodynamic response and minimal battery depletion (14).

Atrial Pacing — Physiologic Pacing

Arterial pacing simulates normal sinus rhythm (Fig. 2,5). If the conduction system is not intact, then the ventricle must also be stimulated. Three basic types of pacemakers are available which attempt to utilize the atrial contribution:

1. ATRIAL — Stimulates only the atrium, usually the right atrium and is followed by a normally conducted ventricular contraction (Fig’s. 2,5). Usually the atrium is sensed (15).
2. ATRIAL SYNCHRONOUS — Senses the atrial contraction and after a time interval always stimulates the ventricle. Useful in the presence of heart block but atrial arrhythmia has necessitated emergency removal.
3. A-V SEQUENTIAL — Senses the ventricle and stimulates the atrium and ventricle in succession. Only the ventricular contraction inactivates the pacemaker (Fig. 2,5). Despite the wide acceptance of the desirability of atrial pacing less than one percent of pacemakers implanted are of the physiologic type (16).

Experience With Atrial and AV Sequential Pacing

The hemodynamic improvement with AV sequential pacing for heart block complicating acute myocardial infarction has been well documented (17), but it is rarely used. The greatest use of atrial and AV sequential pacing has been in cardiac surgery where easy access to the atria simplifies electrode placement and where external programmable pacemakers can accommodate to a large variety of conditions. Here diagnosis and treatment of arrhythmia (18-20) and improved hemodynamic status has been documented (21,22). But even here, the difficulties encountered have been such that only recently has TEMPORARY atrial pacing developed a strong following. The difficulties, common to both temporary and permanent pacing are related to 1. the pacemaker, 2. the electrode and 3. the pacing site.

1. The Pacemaker

Atrial or A-V pacing may be temporary or
Flexibility — A Necessity

External programmable units have been long employed for temporary pacing. Initial permanent atrial and AV pacemakers were not programmable and implantation of these units required the selection of optimal rate and mode PRIOR to surgery and they could not be changed without further surgery (4). Unfortunately, the needs of the patient may change from day to day and from year to year. A programmable pacemaker permits the selection of optimal pacing rate and mode AFTER implantation.

New Pacemaker in Clinical Evaluation

The A-V sequential pacemaker, Medtronic 5992, holds promise. It may function in the standby mode, or it can pace the atrium or the atrium and ventricle in sequence or the right ventricle alone (Fig.5). The interval between the impulse to the atrium and to the ventricle as well as the rate can be varied by an external radiofrequency coupled electromagnetic device AFTER being implanted. This flexibility permits optimal physiologic pacing under a wide variety of conditions.

permanent. Temporary pacing is commonly employed following cardiac surgery (18-22), myocardial infarction (17), in the catheterization laboratory (23) and for the control of tachyarrhythmias (19). The atrial electrogram (AEG) facilitates diagnosis and treatment of arrhythmia (18,19,20). The objectives are to achieve the optimum cardiac output (4,10,17), to stress the heart (23), to suppress tachyarrhythmia (5,18,19) and to determine the sinus node recovery time (6). Permanent pacemakers may be for intermittent use as with rapid atrial stimulation (to 300 bpm) for control of tachyarrhythmia (24) or for constant demand operation to achieve optimal cardiac output (22).

Figure 2. RIGHT ATRIAL AND A-V SEQUENTIAL PACING

Right Atrial Pacing - The atrial pacemaker artifact precedes the P-wave and is followed by a normally conducted QRS complex

A-V Sequential Pacing - The atrial pacemaker artifact precedes the P-wave and the higher voltage ventricular pacemaker artifact triggers the distorted QRS characteristic of RV pacing.
Figure 3. RIGHT VENTRICULAR PACING
The ventricular pacemaker artifact is closely associated with a distorted QRS complex which pervades and distorts the entire EEG.

2. The Atrial Electrode
Transvenous Route
A prime difficulty has been the high degree of skill required to position and maintain electrode position. The J-shaped electrode was developed to hook into the right atrium when passed transvenously; because dislodgment was problem, tines were added (Fig. 4A) and favorable reports have followed (25). Both atrial and ventricular electrodes are required for atrial synchronous and AV sequential pacing. Two veins, then, must be sacrificed, for if one vein is used for two electrodes, dislodgment of the first electrode often results from the manipulation of the second (22).

Surgical Approach
Steel wires have routinely been affixed to the ventricle following open heart surgery for years. Temporary post-operative atrial pacing (18,19,21) employs these same wires and the first attempt at permanent atrial pacing employed electrodes of this type (4).

The Atrial Pinch-On Electrode (Figure 4B), still in clinical evaluation may prove to be a significant development, for prior to it, there has been NO SATISFACTORY PERMANENT ELECTRODE available for surgical placement. This electrode permits the atrium to be paced at any accessible site with precision, security and minimal trauma.

3. The Pacing Site
Pacemaker Function and Pacing Site
Pacemaker sensing is critical for performance reliability and is dependent upon the electrical potential and the area of the electrode in contact with the tissue (14,26,27). Low pacing thresholds permit long battery life by reducing current drain. Pacing thresholds will vary with the surface area of the electrode, duration of the stimulus, wave configuration, type of pacing and the pacing site. Low threshold sites may not have optimal sensing capacity. Endocardial and epicardial sites may be well suited for either pacing or sensing or both, but not necessarily both.
Figure 4. ATRIAL STIMULATING AND MAPPING ELECTRODES

A. Atrial Tined Electrode (Medtronic 6990) The J-shape has been used to enhance transvenous placement by hooking it high in the right atrium. The tines have been added to minimize dislodgement of the electrode and loss of pacing.

B. Atrial Pinch-On Electrode (Medtronic 6995) The pincer jaw is applied surgically to the atrial wall. Two electrodes are required for a bipolar configuration.

C. Atrial Mapping Electrode (Medtronic 6902) This bipolar endocardial pacing electrode also serves as a mapping electrode. When the tip is applied to the right atrium, the potentials recorded and thresholds determined approximate those of the permanent atrial pinch-on electrode.

Furthermore, thresholds tend to rise and sensing potentials may fall after acute implant as the tissue responds to the foreign body. Electrode design and pacemaker circuitry must meet the requirement of chronic thresholds.

Specialized Nature of the Right Atrium

The complex nature of the right atrium must be appreciated. The highly specialized sinus and AV nodes, the thin and highly mobile atrial wall, dysfunction of the sinus node, atrial dysrrhythmia and the disturbed function created by metabolic disturbance, e.g. cardiopulmonary bypass, are very real. Moreover, slight variation in pacing site may alter conduction and refractory times (28).

The Right Atrium — All Parts Are NOT Equal

The intrinsic activity of the sinus node surpasses that of any other part of the heart. The marked variation of electrical potential recorded at elective atrial pacemaker implantation (Fig.6 A,B), correlates well with endocardial electrophysiological studies (5-7). In our limited experience the high right atrium has high electrical potential and high pacing threshold. It would appear the high RA
FIGURE 5. - MODES OF PROGRAMABLE A-V SEQUENTIAL PACEMAKER
(Medtronic 5992)

A. Standby Mode - Spontaneous cardiac activity. Pacemaker inactive.
B. Atrial Pacing - The atrium is pacemaker stimulated. The QRS complex that follows the induced P-wave is normally conducted.
C. A-V Sequential - Both the atrium and the ventricle are stimulated in succession by the pacemaker. Only the ventricular electrode can sense and the ventricular R-wave inhibits the pacemaker.
D. Ventricular Demand - Only the ventricle is stimulated and sensed. If the conduction system is intact, an atrial contraction may occur late in the cardiac cycle.
Figure 6. EEG RECORDING OF THE ELECTROCARDIOGRAM AND THE RIGHT ATRIAL ELECTROGRAM

A. HIGH ATRIAL ELECTROGRAM
Note the high electrical potential of the high atrium. This finding is noted in endocardial recordings of the atrium. The pacing threshold at this site was 4.0 V with the exploring electrode.

B. LOW ATRIAL ELECTROGRAM
The low electrical potential noted correlates with endocardial recordings. The pacing threshold at this site was 0.9 V with the exploring electrode and 0.7 V with the permanent atrial electrode.
might be best for sensing and the low RA with low potential best for pacing (Fig. 6 A,B).

Cardiac Mapping
Cardiac mapping has been a complex research tool requiring sophisticated personnel and equipment which has been applied to the physiological evaluation of arrhythmias (29,30), identification of aberrant conduction pathways (31), and delineating the extent of myocardial infarction (32). More recently, endocardial electrograms (Bundle of His) have aided in identifying the malfunction of the sinus node (Sick Sinus Syndrome) (3-7) and evaluating the endocardial pacing site (26,33). Mapping of the atrium prior to permanent (4) or temporary implantation of electrodes (18,21,22) has not been reported. Rarely has mapping of the ventricle with surgical electrode placement been reported (34), but the sites of highest thresholds were noted to have the highest electrical potential.

Cardiac Mapping With the EEG
Sophisticated cardiac mapping devices are expensive and unnecessary for the pacemaker application. An isolated electrode system and a precisely calibrated writer are adequate. We have utilized a technique employing equipment generally available in the community hospital. The EEG (Grass Model 89) with a biopotential isolator (Fig. 7) is satisfactory but a larger ten channel unit may be preferred. The advantage is that the equipment and trained personnel are already at hand, no additional cash outlay is required and a written record is retained for subsequent analysis. Threshold determinations can be done with the Pacing System Analyser (Medtronic 5300).

Surgical Approach — Preferred
When the optimal site of pacing is localized, it should be possible to fix the pacing electrode to that site. This cannot be done with a transvenous electrode, therefore a surgical approach is preferred.

The Exploring Electrode
There is a direct relationship between the electrode surface area and the electrical potential measured (26,27). Strictly speaking, an exploring surface electrode and a penetrating electrode are not comparable. But, in our hands, the electrical potentials and the pacing thresholds derived from the tip of the bipolar endocardial electrode (Fig. 4C) approximates that of the permanent atrial "pinch on" electrode (Figure 4B, 6A and B) secured in the atrial wall, but more data is required for statistical significance.

Technique — Atrial Mapping
By securing the bipolar electrode to a surgical forceps (Fig. 8A), positioning of the tip against the atrial wall, mapping is facilitated. An alligator clip is applied to the connection for the tip electrode (Fig. 8B) which in turn is connected to the isolated jack box (Fig. 7) of the EEG. Potentials are recorded in the high, middle and low positions on the lateral and medial aspects of the right atrium.

Technique — Threshold Determination
Pacing thresholds are determined by connecting the negative pole of the external pacemaker to the electrode tip, while the positive pole is grounded to the patient. Pacing thresholds are determined in all locations. The lowest threshold area is selected for the pacing site. The permanent electrodes are fixed to the atrium and thresholds again determined. The low voltage atrial pacing spikes can be easily recorded on the highly sensitive EEG. When the study is completed, the electrode can be used for endocardial pacing.

Pacing Thresholds
In a patient having elective atrial pacing, thresholds may vary by a factor of five in a given atrium (Fig. 6 A,B). The site of lowest electrical potential is often the site of lowest threshold. During atrial fibrillation and following cardiopulmonary bypass, the atria may be refractory to stimulation. Excessive motion or scar from previous open heart surgery may jeopardize thresholds but obliteration of the pericardial sac appears to be no detriment.

Room for Improvement
Modification of EEG gain and calibration controls would facilitate ease of operation. Difference in paper speed (ECG 25 mm/sec vs EEG 30 mm/sec) may initially pose a problem...
Figure 7. BIOPOTENTIAL ISOLATOR
When combined with the EEG, cardiac mapping of the right atrium and ventricle becomes feasible in the community hospital without additional financial outlay.
to the cardiologist or cardiovascular surgeon unless he is familiar with this. More important, though reference to direct atrial recordings is rare (18-20, 35), endocardial atrial electrograms are helpful (5-7). Response of the P-wave to direct atrial stimulation is also of interest (19,20). The increased use of atrial pacing should result in a proliferation of the literature in this area.

Technical Aids
A scale which facilitates ECG time measurements at EEG paper speed would be welcome. The determination of heart rate from the R-R interval (Figure 9) is facilitated with a conversion table (Table 1).

Conclusion
The heart is a pump. The objective of cardiac pacing is to improve the cardiac output. The most popular method of cardiac pacing (RV) is not physiologic and results in reduced stroke output when compared to that of normal sinus or atrial paced rhythm. Recognition of pacemaker induced low output states and pacemaker aggravated neurological symptoms has quickened interest in physiologic atrial pacing.

The increased complexity of atrial pacing has been discouraging in the past, but technical advances in electrode and pacemaker design are promising. Selection of the optimal pacing site appears critical and
THE R-R INTERVAL
The time between the R-waves must be expressed in milliseconds in order to calculate heart rate in beats per minute from Table 1. N.B. The paper speed of the EEG (30 mm/sec) differs from that of the ECG (25 mm/sec) and should be taken into consideration.

TABLE 1

HEART RATE and R-R INTERVALS (sec)
The R-R interval in milliseconds is converted directly to heart rate in beats per minute.

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requires the determination of the focal electrical potential and stimulating threshold before electrodes are positioned. With minimal expense, the EEG can be adapted for this type of cardiac mapping in the community hospital.

BIBLIOGRAPHY

1. WEIRICH, W.L., PANETH, M., GOTT, V.L., and LILLEHEI, C.W., Control of Complete Heart Block by the Use of Artificial Pacemaker and Myocardial Electrode, Circulation Res.6:410, 1958.
2. TYERS, G.F., Monitoring Programs for Pacemaker Post-Graduate Course Cardiac Surgery, American College of Surgeons, October 18, 1978, San Francisco.
12. WERRES, R., PARSONNET, V., GILBERT, L., and ZUCKER, I.R., Symptomatic Unilateral Cannon
126


29 DAVIDSON, R.M., WALLACE, A.G., SEALY, W.C., and GORDON, W.S. Electrical Induced Atrial Tachycardia with Block Circulation. 44:1014-1021.1971


