Electrophysiology, Pacing, and Arrhythmia

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Contemporary Issues in Rate-Adaptive Pacing

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Summary: This review addresses a number of questions pertaining to contemporary rate-adaptive pacemakers that include the role of dual sensor systems, sensor blending and cross-checking, automaticity, nonrate-related sensor functions, prevention of arrhythmias, and several other areas of clinical importance.

Key words: pacemakers, rate-adaptive pacing, arrhythmia, sensors

Introduction

The development of rate-adaptive (RA) pacing almost 15 years ago revolutionized cardiac pacing.¹ Many of the important and clinically relevant advances of this technology are not always appreciated because progress occurs so rapidly. This brief review focuses on the contemporary issues in RA pacing by addressing a number of clinically important questions.

Should All Patients Routinely Receive Rate-Adaptive Pacemakers?

It makes a great deal of sense for all patients to receive RA pacemakers routinely. Only economic considerations limit the universal use of RA devices. It is impossible to predict which patients will eventually develop significant atrial chronotropic

incompetence either spontaneously or related to drug therapy. The RA function of a DDD or VVI pacemaker should be simply one of the many programmable parameters, rather than imparting the designation "R," which gives such devices unwarranted elevation in the widely used pacemaker code.²

What Are the Limitations of Single Sensor Pacemaker Systems?

Activity and minute ventilation single sensor-driven pacemakers are the most popular of these systems, and they have performed remarkably well despite their limitations.³

Activity-Driven Rate-Adaptive Pacemakers

Activity-driven rate-adaptive pacemakers are nonphysiologic and nonspecific because they do not respond to an increased metabolic demand unrelated to exercise. Indeed, a response to emotional stimuli may not be clinically important and may actually be a disadvantage in some patients.

An activity system exhibits a fast response to brief periods of exercise, an important characteristic in older patients who do not perform much physical exercise and do so primarily in short bursts such as walking or climbing stairs. The rapid response contrasts sharply with other sensor-driven systems that exhibit a delayed response at the start of exercise and reach a maximum rate after the end of exercise, making them less desirable, especially for the elderly. The plateau response of activity RA pacemakers after the initial increase in rate represents a disadvantage, as does the lack of feedback at the end of exercise. Furthermore, an activity RA pulse generator does not respond to isometric exercise or postural changes and the pacing rate does not correlate well with the level of exertion or the amount of work.² The limitations and idiosyncrasies of piezoelectric-driven RA systems should not detract substantially from their impressive clinical performance. Activity RA pacemakers are still the largest selling pacemakers in the world because they are simple and work well in practice, in contrast to the theoretical advantages of a host of more sophisticated and specific sensors. Some of the limitations of vibration-driven,

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can-bonded systems have been partially eliminated by accelerometer-based devices. These devices contain a piezoelectric crystal integrated into the circuit (rather than on the can). Accelerometer-driven devices respond to motion rather than vibration and provide higher discrimination to various work loads, better correspondence with normal sinus rhythm, and less susceptibility to environmental noise than vibration-controlled pacemakers.⁴⁻⁶

Minute Ventilation Pacemakers

Minute ventilation pacemakers are highly physiologic and therefore highly specific. This system works well, but occasionally the reaction to the onset of exercise may be delayed, and the rate may be too fast after the end of exercise. Early response to exercise has been improved with the new generation of devices.⁷ The system requires a bipolar lead and cannot be used with a unipolar or epicardial system. Swinging of the arm on the side of the pulse generator and rotating shoulder movements cause displacement of the pacemaker in its pocket, as well as a rate increase secondary to artifactual changes in transthoracic impedance. Hyperventilation, Cheyne Stokes respiration, coughing, and tachypnea from a chest infection or congestive heart failure can increase the pacing rate. The device probably is contraindicated in patients with chronic obstructive pulmonary disease.

Dual Sensor Systems: A Technologic Achievement Looking for an Indication?

No single sensor equipped with a well-designed algorithm can reproduce the rate response of the normal sinus node. In this context, Lau and Camm indicated recently that

sensors for the purpose of rate modulation may be combined to improve the speed of rate response at the onset of exercise, proportionality of heart rate to work load, differential sensitivity to physiologic changes induced by exercise, and nonexercise stresses, and rejection of unwanted environmental artifacts. These combinations aim to create a sensor system that best simulates the sinus node response in normal individuals.⁸

Dual sensor devices were developed on this premise to minimize or eliminate the shortcomings of single sensor systems by providing a rate profile closer to normal sinus node function. Popular combinations of sensors include a basic activity sensor for a rapid response to light exercise of short duration. Another sensor, such as minute ventilation or QT, is added to provide a somewhat delayed proportional and stable physiologic response to exercise and recovery. These combinations of sensors are easy to use because they work with conventional leads.⁹⁻²⁰ "Sensor blending" refers to the relative contribution of each sensor to rate control. Sensor integration was originally programmable, but it is automatic in contemporary devices, thereby obviating complex and time-consuming programming of RA function.

What Is the Clinical Benefit of Dual Sensor Systems?

Most patients with single sensor systems do not perceive various degrees of underprogramming as long as there is some rate response on exercise. It is therefore questionable whether patients will feel better in terms of exercise performance with a dual sensor device than with a single-sensor system (e.g., activity) with a well-designed algorithm.^{20, 21} The real value of dual sensor pacing will be difficult to establish,²² but is important because such devices tend to be more costly and may deplete battery capacity faster. In terms of quality-of-life and the incidence of long-term complications, atrioventricular (AV) synchrony at rest is more beneficial than a physiologic rate response on exercise by a dual sensor VVIR device with a design that reproduces precisely the normal function of the sinus node.^{23, 24}

Is Automaticity Important?

There is still no universally accepted method for programming RA devices despite the spectacular improvement in pacemaker technology over the last decade.⁴ It seems, however, that the recent development of sensor autocalibration in single- and dual-sensor systems may resolve this issue by virtually eliminating the need for manual programming of sensor function. Now a pacemaker automatically learns the "slope" for rate response during the daily activities of the patient and then programs its rate response automatically. It is difficult to assume, at this juncture, that present sensor autocalibration systems are perfect, and that after implantation and initial programming one can forget their RA parameters. Consequently, manual sensor programming in the classic sense should also be available to provide flexibility in manipulating sensor interactions and to permit turning off one sensor or the other.^{1, 2} The rate response provided by recorded autoslope data should be compared with the identical slope manually programmed to verify sensor algorithm efficacy.²⁵ The automatic RA function should be evaluated in patients without atrial chronotropic incompetence to compare sensor rate with normal or near normal sinus node function.²⁵ Ultimately, the most valuable contribution of dual sensor technology to RA pacing may not be its original purpose of improved exercise response or tolerance, but the development of concomitant automatic sensor calibration to facilitate the use of these complex systems.²²

Correction of False Positive Responses: Sensor Cross-Checking

Sensor cross-checking is designed to avoid inappropriately high pacing rates if there is disagreement between the two sensors, in other words, it improves specificity. Sensor cross-checking prevents the inappropriately high pacing rate caused by hyperventilation in a system utilizing activity and minute ventilation sensors. False positive responses of an activity sensor (traveling in a car on a bumpy road, tapping on the pacemaker, etc.) can also be avoided when the input to a QT or minute ventilation sensor indicates that there is no need to in-

crease the pacing rate.⁹ This protection against unphysiologic pacing rates may ultimately prove to be the greatest benefit of dual sensor systems.

Is Sensor-Controlled Physiologic Reduction of Pacing Rate at Rest Beneficial?

Sensor-controlled reduction in the pacing rate during sleep (without clock settings) is technically feasible, especially with dual sensor systems.²⁶ This concept is the opposite of rate increase on exercise. Its impact on battery longevity probably will be marginal in contrast to its potential disadvantage of precipitating bradycardia-dependent supraventricular or ventricular tachyarrhythmias in susceptible patients. In the case of the VDDR (VDD/VVIR) mode, automatic reduction of the lower rate during sleep in patients with AV block can prevent a nocturnal pacemaker syndrome. Similarly, a VVIR device with sensor-controlled slowing of the pacing rate would be useful in the prevention of a nocturnal pacemaker syndrome in a patient with a VVI pacemaker implanted for occasional sinus pauses if sinus slowing induces sustained ventricular pacing only during sleep.²⁷

Is Sensor Input Important in the Diagnosis of Supraventricular Tachycardia by DDDR Devices with Automatic Mode Switching Algorithms?

At rest during supraventricular tachycardia (SVT), the atrial channel of a DDDR pacemaker senses a rapid rate while the input to the nonatrial sensor indicates physical inactivity and therefore no need to increase the pacing rate. The pacemaker can use this information to make the diagnosis of SVT and activate automatic mode switching to a nontracking mode (to control the paced ventricular rate). Although theoretically appealing, this approach has not yet been used commonly because of the complexity of design and programmability according to the circumstances associated with SVT in the individual patient.²⁸ For SVT detection, it seems simpler at present for DDDR devices to rely only on the pattern of sensed atrial signals without sensor input.

Should the Pacing Mode Always Be Rate-Adaptive during Automatic Mode Switching?

Pacing mode should not always be rate-adaptive during automatic mode switching, because flexibility may be clinically important.

Is the DDIR Mode Superior to the VVIR Mode during Automatic Mode Switching?

During automatic mode switching, the DDI and DDIR mode do not provide hemodynamic benefit from AV syn-

chrony. Indeed, with continual atrial sensing of rapid SVT, the DDI mode functions effectively in the VVI mode, and the DDIR mode functions exactly like the VVIR mode. The claim that the DDI(R) mode maintains AV synchrony during automatic mode switching makes no sense.

Is Atrial Rate-Adaptive Pacing Useful in the Prevention of Atrial Arrhythmias?

There exist at present only preliminary and conflicting data, so that these important questions cannot be answered at this time.^{29,30}

What is the Role of Rate-Adaptive Pacing in Ventricular Tachycardia?

The induction of sustained or unsustained ventricular tachycardia by an increase in the ventricular pacing rate is a rare complication of RA pacing.³¹ On the other hand, DDD and DDDR pacemakers have actually been used to prevent ventricular tachycardia (possibly working best with a relatively short AV interval) with the DDDR mode probably more useful than the DDD mode for exercise-induced ventricular tachycardia,³ but this experience should be considered to be preliminary.

Is Rate-Adaptive Pacing Contraindicated in Patients with Coronary Artery Disease?

Rate-adaptive pacing is not contraindicated in patients with coronary artery disease, provided the upper rate is not excessively high. During fixed-frequency unphysiologic VVI pacing on exercise, compensatory factors such as enhanced wall tension (due to greater end-diastolic volume) and contractility (increased sympathetic activity) increase the cardiac output and stroke volume, but at the expense of additional energy, and therefore cause an increase in MVO₂ and development of angina. Furthermore, VVI pacing increases left ventricular end-diastolic pressure, which in turn reduces myocardial coronary flow. In patients with RA devices (e.g., VVIR), the higher MVO₂ related to rate increase on exercise is counterbalanced by the increased MVO₂ during fixed-frequency VVI pacing.³ With careful programming of the upper rate and evaluation of cardiac ischemia, most patients with coronary artery disease can be managed safely with RA pacemakers that provide improved exercise tolerance compared with fixed-rate VVI pacing.

What Are Some of the Nonrate-Related Functions of Implanted Sensors?

Most sensor-based algorithms can adjust nonRA parameters, such as shortening of the AV interval and the postven-

tricular atrial refractory period, in association with faster sensor-indicated rates.¹ The QT sensor provides a simple way to confirm ventricular capture by determining the presence of a QT interval. Alternatively, impedance technology (similar to that of minute ventilation systems) using standard leads can also document capture by recording the impedance signal related to its hemodynamic effect.^{32,33} The sensors will also be used to determine posture or hypotension, important considerations when relatively fast pacing delivered earlier in a particular situation would enhance the benefit of an implanted device.^{34,35} Finally, pressure and O₂ saturation sensors will provide an implanted hemodynamic laboratory for the more precise management of patients with serious cardiac or pulmonary conditions.

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