Pacemakers during open heart surgery

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Since the initiation of the modern era of cardiac pacing by Bigelow and Callaghan in 1951, and the subsequent development of the implantable pacemaker by Chardack in 1960, great strides have been made in refining pacing technology.

Types of pacemakers

Various types of pacemakers are available and can be generally classified as asynchronous, synchronous, and sequential. The asynchronous type is also called a fixed-rate pacemaker and, as this implies, emits an impulse about 70 times a minute, regardless of the electrical activity of the heart. The synchronous pacemakers are ventricular inhibited, ventricular triggered, and atrial. The ventricular inhibited model is the one most commonly used. This device is suppressed by the occurrence of a QRS complex, and thus in the absence of this complex, will pace the ventricle. The ventricular triggered pacemaker senses the R wave and fires harmlessly into the absolute refractory period. When an R wave is not sensed, the unit is preset to fire automatically. The atrial pacemaker uses a double electrode system, senses the P wave and triggers ventricular contraction after a long refractory period corresponding to a prolonged PR interval, which can be set. The long refractory period

prevents the ventricles from contracting more than 140/min. When no P wave is sensed, the unit converts to an asynchronous type.

Various types of atrioventricular sequential pacemakers are available. However, units that rely on sensing the P wave are rarely used as it is generally accepted that electrical potentials, particularly from abnormal atria, are not reliable to subserve a sensing purpose. The type of atrioventricular sequential pacemaker with which we have had experience uses two sets of wires, one being placed high on the free wall of the right atrium in the area of the sinoatrial node and the other on the outflow tract of the right ventricle. The ventricular wires serve a dual function, i.e., R-wave sensing and ventricular pacing. The pacing unit has two stimulators served by an R-wave sensing device, which has programmable atrial and ventricular escape intervals. In this manner the unit can be used in six ways: (1) atrial or ventricular asynchronous pacing, (2) ventricular demand pacing, (3) asynchronous atrioventricular sequential pacing, (4) demand atrioventricular sequential pacing, (5) paired atrial stimulation, and (6) rapid atrial stimulation.

Pacemakers and open heart surgery

There is no question that the introduction of artificial pacemaking capabilities has reduced morbidity and mortality in patients undergoing open heart surgery. However, the enthusiasm with which pacemakers are used in different centers varies considerably. All centers have had experience in using a ventricular asynchronous or synchronous pacemaker to treat patients who have third degree atrioventricular block or patients with supraventricular bradyarrhythmias who have had open heart surgery. It would appear, however, that the use of atrioventricular sequential pacing is currently in limited use, not because of limitations with the technique or exorbitant cost, but rather because ventricular synchronous pacing will suffice in the majority of cases and is easier to implement than atrioventricular sequential pacing. We believe that there are limitations with the sole use of ventricular synchronous pacing, which, if not appreciated, may increase morbidity in patients who are having open heart surgery and have an indication for a pacemaker. It is generally appreciated that atrial contraction contributes approximately 20% to ventricular filling[1] and that ventricular pacemakers lose the advantage of this atrial kick. What may not be appreciated is that with slow ventricular rhythms there also tends to be overdistention of the atria, which will compensate somewhat for the loss of atrial contraction during ventricular diastole provided the ventricle is compliant and can accommodate a greater than normal volume of blood. When patients have conduction problems after open heart surgery that may require pacemaker treatment, they may also have a decreased ventricular compliance so that their cardiac output, reduced by a decrease in heart rate, may also be severely compromised by a decrease in stroke volume. It is evident then that the diseased noncompliant ventricle relies heavily on atrial contraction for filling during diastole. That this is true has been shown by Sasaki et al[2] who studied 11 patients with a ventricular pacemaker, six of whom were asymptomatic and five New York Heart Association Class II. The six patients who presumably had good ventricular compliance had a constant cardiac index over a heart range of 60 to 90/min, while the others showed a peak effect, i.e., a heart rate below and above which

cardiac index fell dramatically (*Fig. 1*).

Although antegrade atrioventricular conduction may be partially or completely blocked, retrograde ventriculoatrial conduction may occur. Ogawa et al[3] have shown that persistent ventriculoatrial conduction producing atrial contraction during the ejection period appears most unfavorable. They stated that if the timing of atrial contraction and its resultant cannon a wave occur just before opening of the atrioventricular valve, there will be a significant decrease in ventricular end-diastolic volume and a reduction in the magnitude of ventricular contraction. The effect of inappropriately timed atrial contraction as shown by cannon a waves occurring within the ejection period in reducing cardiac output and left ventricular and aortic systolic pressures is shown in *Figure. 2*. It should be obvious that initiation of ventricular pacing to increase cardiac output may have limitations, and that critical evaluation of the effectiveness of this mode of pacing must be made, particularly in patients with limited myocardial reserve.

In view of the importance of the

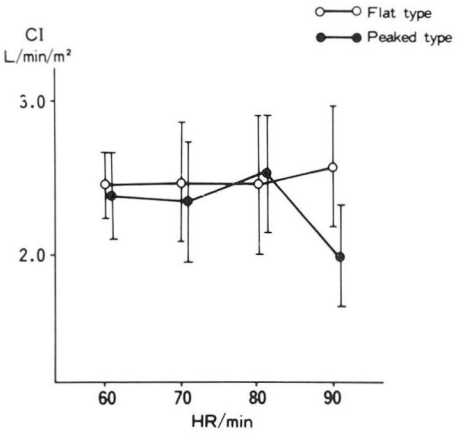

Fig. 1. Resting rate-output curve in ventricular pacing. (Reproduced with permission from Sasaki S. Kishida H, Ohzeki M, et al. Effect of heart rate on cardiac output in patients with rate programmable pacemaker at rest and after exercise. Cardiac Pacing. Proceedings of the VIth World Congress on Cardiac Pacing 1979, 19–26.)

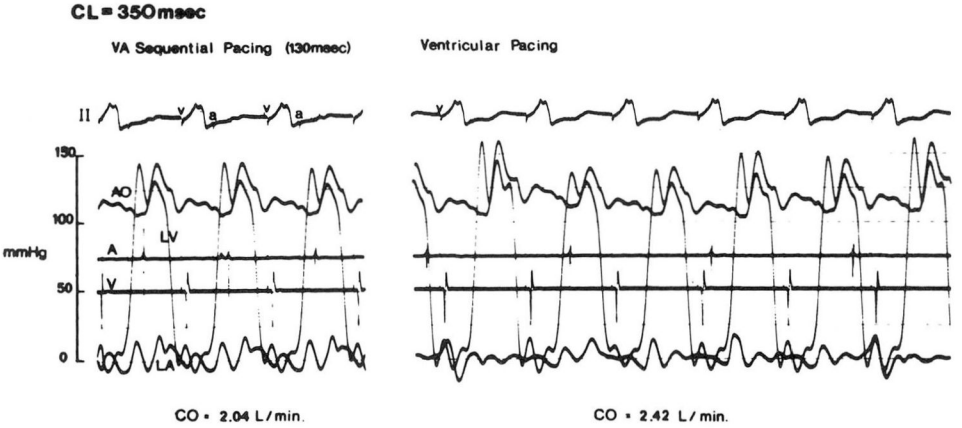

Fig. 2. Comparison of hemodynamic effects of ventricular pacing in the presence and absence of ventriculoatrial conduction. (Left panel) At a cycle length of 350 msec (ventriculoatrial = 130 msec, atrioventricular = 220 msec), left ventricular and aortic systolic pressures were 146 mm Hg and cardiac output, 2.04 L/min. Cannon a waves appear regularly within the ejection period. (Right panel) Random appearance of cannon a waves within the ejection period is associated with a reduction in systolic pressure, but increased pressure is observed during other periods when atrial contraction randomly falls outside the preejection or ejection period (peak systolic pressure = 160 mm Hg) and increased cardiac output = 2.22 L/min. (Reproduced with permission from Dreifus LS. Hemodynamic consequences of atrioventricular and ventriculoatrial pacing. PACE 1978; 1: 8–15.)

properly timed atrial contraction relative to ventricular contraction and its even greater role in hearts with decreased compliance and the adverse effect that ventriculoatrial conduction may have on cardiac output, it is not surprising that hemodynamic data consistently show that atrial and atrioventricular sequential pacing are preferable to ventricular pacing. Litwak et al[4] reported that ventricular pacing produced a 23.7% increase in cardiac index in patients with abnormal atrioventricular conduction but no consistent change in patients with normal atrioventricular conduction. In patients who had mitral valve surgery, Woodson and Starr[5] found a 33% increase in cardiac index with atrial pacing as compared to ventricular pacing at the same rate (>100/min), and a 43% increase over intrinsic values. They did find, however, that patients with coronary artery disease had a lesser degree of improvement. Curtis et al[1] studied patients 24 hours after open heart surgery. Ventricular pacing in patients with normal sinus rhythm reduced cardiac output as much as 42% (average, 14%). Atrial and atrioventricular sequential pacing at the same rate increased cardiac output by averages of 13% and 19%, respectively. In patients with junctional rhythm, increase of the heart rate by ventricular pacing increased the cardiac output, but a further increase of 25% was accomplished by atrioventricular sequential pacing at the same rate. Rost et al[6] reported a 25% increase in cardiac output with the use of atrioventricular sequential pacing as compared to ventricular pacing. Friesen et al[7] compared atrial pacing with ventricular pacing in postoperative cardiac patients and found the former consistently produced better stroke index and cardiac index at the same heart rate. The best indices were found in patients who had nodal rhythm, and the indices did not vary with the size of the left atrium but were better in patients with left ventricular hypertrophy.

The implantation of Teflon-coated steel wires, 0.5 to 1.5 cm apart on the right atrium and the outflow tract of the right ventricle and the utilization of an atrioventricular sequential pacemaker provide great versatility in the treatment of a wide range of electrical and mechanical cardiac abnormalities. The atrial wires can be used to record an atrial electrogram that can be of great value in differentiating arrhythmias that may be difficult to identify by a conventional 12-lead electrocardiogram. Waldo et al[8] studied 70 consecutive patients after open heart surgery in whom bipolar leads were placed on the right atrium and the outflow tract of the right ventricle. An atrial electrogram was used to make a primary diagnosis of an arrhythmia 41 times, and 22 times to confirm an arrhythmia originally suspected from interpretation of a standard or monitor electrocardiogram (*Table 1*). Atrial pacing was used to treat abnormalities of rhythm or conduction or both in 75 instances in 49 of the 70 patients (*Table 2*). In only 13 of the 70 patients the wires were not used for diagnosis or treatment of an arrhythmia. They concluded that routine placement of atrial wire electrodes at the time of operation is indicated regardless of the nature of the open heart procedure or the preoperative rhythm. Mills and Ochsner[9] implanted atrial and ventricular wires in 325 consecutive patients; 16% of the patients had significant rhythm disturbances, which were documented by an atrial electrogram. Rapid atrial fibrillation (25%), atrial flutter (19%), and multiple ventricular premature contractions (15%) were the most

Table 1. Diagnoses obtained by use of atrial wire electrodes in 70 consecutive surgical patients

Rhythm	Diagnosis	
	Primary	Confirmed
Premature atrial beats	2	0
Premature ventricular beats	5	1
Atrial fibrillation	5	6
Atrial flutter	6	1
PAT, atrial tachycardia	3	0
Aberrant AV conduction	1	0
AV junctional rhythm	5	1
Ventricular tachycardia	1	0
AV dissociation	2	2
Normal sinus rhythm	5	8
AV block*	2	0
Other†	4	3
Totals‡	41	22

PAT = paroxysmal atrial tachycardia, AV = atrioventricular,

* Atrial pacing used to assess AV conduction.

† Sinus bradycardia, atrial bigeminy, sinus tachycardia, and atrial standstill.

‡ Thirty-six patients had no indication for recording an atrial electrogram. Thirteen patients had two or more indications for recording an atrial electrogram.

Reproduced with permission from Waldo AL, MacLean WAH, Cooper TB, Kouchoukos NT, Karp RB. Use of temporarily placed epicardial atrial wire electrodes for the diagnosis and treatment of cardiac arrhythmias following open-heart surgery. J Thorac Cardiovasc Surg 1978; 76: 500–5.

common arrhythmias. The great value of the atrial wires was the immediate diagnosis and treatment of supraventricular arrhythmias. The availability of atrial pacing permits the overdrive of ventricular arrhythmias when atrioventricular conduction is normal and the treatment of virtually all supraventricular arrhythmias, with the exception of atrial fibrillation and some cases of atrial flutter by paired atrial or rapid atrial pacing.

Wells et al[10] studied 27 patients in whom atrial flutter developed following open heart surgery. They divided them into two types: type 1 had a rate varying between 240 and 338/min and type 2 varied between 340 and 433/min. Type 1 flutter could always be influenced by rapid atrial pacing. In 14 of 18 patients submitted to rapid atrial pacing, normal sinus rhythm or atrial fibrillation was produced. Four of the 18 converted to type 2 flutter. Rapid atrial pacing to 600/min never influenced the rhythm in patients with type 2 flutter.

Table 2. Reasons for pacing treatment with the use of electrodes in 70 consecutive surgical patients

Rhythm disturbance	Atrial pacing	Ventricular pacing*
Sinus bradycardia (<80 beats/min)	24	1
Premature atrial beats	11	0
Premature ventricular beats	22	2
AV junctional rhythm	3	1
Atrial flutter†	6	0
Paroxysmal atrial tachycardia†	2	0
Atrial tachycardia†	1	0
Ventricular tachycardia	2	2
AV dissociation	2	1
Second degree AV block	2	1
Totals‡	75	8

AV = atrioventricular.

* Demand mode ventricular pacing excluded.

† Rapid atrial pacing to interrupt arrhythmias, or continuous rapid atrial pacing to suppress recurrent arrhythmia.

‡ Twenty-one patients had no indication for cardiac pacing. Eighteen patients had two or more indications for cardiac pacing.

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It should be emphasized that although atrial pacing is of great value in the treatment of supraventricular tachyarrhythmias and bradyarrhythmias and, in the presence of normal atrioventricular conduction, markedly improves hemodynamics, there are circumstances that make it unwise to rely entirely on atrial pacing. Rhythm aberrations after open heart surgery are often complex, changing and certainly of many etiologies. The use of a cardioplegic technique to protect the myocardium during bypass has, in our experience, produced varying arrhythmias, presumably on the basis of electrolyte imbalance within myocardial cells. The inability to predict which arrhythmia may be encountered early in the postoperative period and the fact that an arrhythmia that initially is amenable to atrial pacing may with time, because of failure of atrioventricular node conduction, no longer be appropriate, makes it mandatory to at least implant backup wires on the right ventricle, should this mode of pacing become necessary.

It must also be pointed out that it may not be possible to pace the atrium. Waldo et al[11] have called this state "atrial quiescence," which differentiates it from atrial standstill in that in the latter situation the atria can be paced. Atrial quiescence is presumed to be due to depolarization of cell membrane, and success has been reported in treating this state by infusing small amounts of isoproterenol, which repolarizes cell membranes. We have been impressed that when a cardioplegic technique is used longer than 1 to 1.5 hours it may take some time (20 to 30 minutes) for spontaneous cardiac rhythm to occur. An idioventricular rhythm usually initiates spontaneous cardiac activity. Early in the rewarming period of the heart it may be difficult to pace even the ventricles, let alone the atria, which suggests that the whole heart is undergoing a process of repolarization such as that described by Waldo et al for the atria. It is our clinical impression that the administration of a mixture of noradrenalin, 32 μg/cc, and phentolamine, 20 μg/cc, significantly enhances the response of the ventricle to pacing and to the development of spontaneous activity.

Summary

We believe that sufficient pacing technology now exists that makes it difficult to justify simply attaching a ventricular synchronous pacemaker to the right ventricle to try to increase the heart rate without regard for the etiology or site of the problem and, more importantly, the effect on cardiac output, which, in most cases, is what must be improved. When wires are applied to the high right atrium and the outflow tract of the right ventricle and an atrioventricular sequential pacemaker is available, great versatility in pacing technique is afforded. Atrial control can be secured and atrioventricular synchrony restored in patients having open heart surgery with a great variety of atrial, atrioventricular and ventricular arrhythmias that may be difficult to treat with conventional therapy. Requirements for antiarrhythmic drugs are being reduced and when such drugs are required atrioventricular sequential pacing may permit the use of larger doses than normally tolerated by the heart.

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