Regular Review

Permanent pacing

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Disease of the sinus node and conducting tissue of the heart commonly develops without other heart disease. It may present as bradycardia, causing symptoms of fatigue, breathlessness, lightheadedness, confusion, or heart failure; or intermittent episodes of profound bradycardia or asystole may cause Stokes-Adams attacks.¹ Permanent implantable pacemakers have been used to treat such patients for a quarter of a century, but current pacemakers are a far cry from their predecessors. They are more sophisticated, versatile, and long lived and are also more compact, the smallest being little bigger than a 50p coin. For years it was always the ventricle that was paced, but now the atrium or both chambers can also be readily paced.

Indications for pacing

The indications for pacing are summarised in table I.

SINUS NODE DYSFUNCTION

The sick sinus syndrome, which manifests itself as the tachycardia-bradycardia syndrome, sinus arrest, sinoatrial block, or abnormal sinus bradycardia, is now the commonest indication for the permanent implantation of a pacemaker.²⁻⁵ Patients with the tachycardia-bradycardia syndrome have periods of atrial tachyarrhythmia followed by periods of bradycardia or sinus arrest. They may have palpitations with the tachycardia and syncope or dizziness with either the

tachycardia or the bradycardia. Drugs to control tachycardia may exacerbate episodes of bradycardia. The diagnosis is made almost invariably by 24 hour ambulatory electrocardiographic monitoring, and ideally the doctor should show a correlation between symptoms and bradycardia before implanting a pacemaker. Symptoms, however, may be uncommon, and a patient with a history of Stokes-Adams attacks and with clear evidence of sinus node dysfunction should be given a pacemaker.

Persistent sinus bradycardia of less than 40-50 beats a minute in waking hours may occasionally cause symptoms that can be relieved by implanting a pacemaker.⁵ During sleep, however, bradycardia and even periods of sinus arrest may occur in normal individuals.

Patients with sinus node dysfunction and no symptoms have a good prognosis and do not need a pacemaker.^{3,5,6}

ATRIOVENTRICULAR BLOCK

First degree block—First degree atrioventricular block is prolongation of the PR interval beyond 0.2 s, and the patient does not need a pacemaker.^{5,7}

Second degree block—Second degree atrioventricular block occurs when a single atrial impulse that should be conducted to the ventricles is not conducted. Type 1 second degree atrioventricular block (Wenckebach) is characterised by progressive lengthening of the PR interval culminating in a P wave that is not conducted. The QRS complex is usually narrow, and the block is usually at the atrioventricular node.

TABLE I—Indications for implanting a permanent pacemaker (for more comprehensive guidelines see reference 3)

	Indicated	Probably indicated	Not indicated
Sinus node dysfunction	Sick sinus syndrome with symptomatic bradycardia occurring spontaneously or with drug treatment necessary to suppress symptomatic tachycardia		Asymptomatic sinus node dysfunction
Atrioventricular block: Second degree	Symptomatic type I. Symptomatic or asymptomatic type II	Asymptomatic type I. 2:1 atrioventricular block	
Complete heart block	Acquired complete heart block of any aetiology. Symptomatic congenital complete heart block	Asymptomatic congenital complete heart block with slow ventricular rate or broad QRS complex, or both	Asymptomatic congenital complete heart block with rate >50 beats/min
After infarction: Inferior Anterior	Complete heart block persisting for over two weeks Persistent type II second degree or complete heart block Newly acquired bundle branch or bifascicular block with transient type II second degree or complete heart block		Bundle branch or bifascicular block without progression to type II second degree or complete heart block
Carotid sinus hypersensitivity	Recurrent syncope despite measures to avoid inadvertent carotid sinus stimulation in patients with asystole of >3 s with carotid sinus massage	Recurrent syncope not clearly related to carotid stimulation but asystole of >3 s with carotid sinus massage, and no other identifiable cause of syncope	Asymptomatic with a positive response to carotid sinus massage

Type II second degree atrioventricular block is usually associated with bundle branch block, and the PR interval of conducted beats is constant. The block is usually at or distal to the bundle of His. If atrioventricular conduction is in a ratio of 2:1 then type I and type II second degree atrioventricular block cannot be distinguished. Type II second degree atrioventricular block is likely to progress to complete heart block, and patients should be given a pacemaker regardless of whether they have symptoms.^{2,3,5} Recent evidence suggests that all patients with 2:1 atrioventricular block should receive a pacemaker.⁸ Type I second degree atrioventricular block has traditionally been thought benign, but recent evidence suggests that this is not so.⁸ The patient's prognosis may be improved with a pacemaker even in the absence of symptoms.⁸ Asymptomatic patients with type I second degree or 2:1 atrioventricular block who do not receive a pacemaker should be followed up for the development of symptoms.⁹

Complete heart block—Patients with intermittent or persistent complete heart block causing symptoms need a permanent pacemaker. Implantation of a permanent pacemaker also improves the prognosis of patients with acquired complete heart block and therefore is advisable even in asymptomatic patients.¹⁰⁻¹⁴ Patients with asymptomatic congenital complete heart block who reach adult life usually have a good prognosis and do not need a pacemaker, but they do need lifelong follow up. Symptoms are more likely to develop in patients with a heart rate of less than 50 beats a minute or a broadened QRS complex.^{15,16} Recent evidence suggests that patients with a resting heart rate of less than 50 beats a minute and instability of the escape rhythm on ambulatory monitoring are likely to become symptomatic, and so they should probably have a pacemaker implanted prophylactically.¹⁷ After they are given a pacemaker some patients may become aware of previously unnoticed limitations.

CHRONIC BIFASCICULAR BLOCK

The atrioventricular conduction system below the atrioventricular node has three fascicles—the right bundle branch and the anterior and posterior divisions of the left bundle branch.¹⁸ Bifascicular block indicates disease of two of these fascicles and is represented in a surface electrocardiogram as complete left bundle branch block, right bundle branch block with appreciable left or right axis deviation, or, less commonly, alternating left and right bundle branch block.^{19,20}

A few patients with bifascicular block will progress to complete heart block, but these patients cannot be readily identified even by invasive electrophysiological studies.¹⁹⁻²⁴ Complete heart block may be intermittent, and implantation of a permanent pacemaker should be considered in patients with bifascicular block and recurrent syncope for which another cause cannot be found.^{3,23,24} Asymptomatic patients do not need a pacemaker.^{3,5,21,22}

PERMANENT PACING AFTER MYOCARDIAL INFARCTION

Temporary pacing for complete heart block after inferior myocardial infarction does not normally need to be followed by permanent pacing as the atrioventricular block almost invariably resolves within two weeks.

Patients with anterior myocardial infarction who develop either right or left bundle branch or bifascicular block have a poor prognosis that is primarily related to the extent of the

infarction, but the prognosis is worse if type II second degree or complete heart block occurs.²⁵⁻²⁷ Those with right bundle branch block and appreciable left or right axis deviation or alternating left and right bundle branch block are at particular risk of a progressive conduction abnormality, and they should be given a temporary pacemaker.²⁶ The temporary pacemaker can be removed before discharge from those patients in whom progression does not occur as there is no clear evidence that this group benefits from permanent pacemakers, although late mortality is high.²⁶ For patients who do progress (usually temporarily) to type II second degree or complete heart block a permanent pacemaker should be implanted before discharge as their prognosis will then be improved.²⁵⁻²⁷

CAROTID SINUS HYPERSENSITIVITY

Stimulation of the carotid sinus baroreceptors by pressure over the carotid artery causes a vagally mediated slowing of the heart rate and a slowing of atrioventricular conduction. Some patients have an exaggerated response, and syncope can occur. The reflex in some patients has a vasodepressor as well as cardioinhibitory effect.^{29,30} Patients are advised to avoid tight clothing around the neck but may need a pacemaker if they remain symptomatic. The pacemaker may not, however, eliminate symptoms in patients whose hypersensitivity has a strong vasodepressor component.

Pacemaker implantation

Pacemakers are usually implanted under local anaesthetic. The lead can be introduced through a cannula after puncturing the subclavian vein. The pacemaker unit is inserted into a pocket in the subcutaneous tissues lying over the pectoral muscles. Fluoroscopy is needed to obtain a satisfactory lead position, and implantation is usually done in the cardiac catheterisation laboratory. As with any surgical procedure that necessitates implanting foreign material strict aseptic technique is essential.³¹ Important complications are unusual, and patients can be discharged 24 hours after the procedure.

Types of pacemaker

Programmable pacemakers can have their function modified by telemetry, and in some telemetry can register stored information such as the degree of battery depletion and previously programmed functions. Pacemakers may sense a depolarisation and then respond by being inhibited or by triggering a paced response. There is a five letter code that describes pacemaker function, but a commonly used one has just three letters: the first designates the chamber paced, the second the chamber sensed, and the third the mode of response (table II).³²

TABLE II—Three letter code of pacing modes and functions

1st: Chamber paced	2nd: Chamber sensed	3rd: Mode of response
V = Ventricle A = Atrium D = Double	V = Ventricle A = Atrium D = Double O = None	T = Triggered I = Inhibited D = Double O = None

SINGLE CHAMBER DEMAND PACEMAKERS (AAI, VVI)

Ventricular demand pacemakers (VVI) both pace and sense in the ventricle and are inhibited by intrinsic depolarisation. They are the simplest, least costly, and in Britain by far the most widely used systems. Atrial demand pacemakers (AAI) require more sophisticated programmability than VVI units and have not been as widely used partly because atrial leads have until recently been less reliable than ventricular leads. AAI pacemakers are useful in patients with the sick sinus syndrome with intact atrioventricular conduction and have the advantage of maintaining atrioventricular synchrony. They may also reduce the incidence of atrial fibrillation in patients with the sick sinus syndrome.³³ Some patients with the sick sinus syndrome may develop atrioventricular block, which has discouraged the routine use of AAI pacemakers, but this problem may have been overestimated.^{33 34}

VVI pacemakers are indicated in all patients with established atrial flutter or fibrillation with intermittent or established complete heart block. They may also be used in patients with the sick sinus syndrome and impaired atrioventricular conduction; if symptoms are mainly related to tachycardia they may provide a safety net for the intermittent bradycardia that may occur with drug treatment. They may also be used in patients with sinus rhythm and complete heart block, but their drawback in these patients is that their rate does not increase with increased activity, which means that the ability to exercise is impaired in some patients. Recently single chamber pacemakers (AAI and VVI) have been developed that can increase their rate with exercise by responding to changes in respiratory rate, generalised muscle activity, or catecholamine induced shortening of the QT interval.^{32 35}

A further drawback with VVI pacemakers is that they may cause the pacemaker syndrome.³⁶ Ventricular pacemakers may cause a dramatic fall in blood pressure and cardiac output, especially if the patient has retrograde ventriculoatrial conduction. Patients may be aware of dizziness, precordial distress, or jugular pulsations. Symptoms are probably caused by both loss of atrioventricular synchrony and activation of atrial stretch receptors causing further reflex changes. Patients may be helped by reducing the pacemaker rate so that sinus rhythm predominates, but the pacemaker may have to be replaced by one that allows preservation of synchronous atrioventricular contraction.

DUAL CHAMBER PACEMAKERS

Pacemakers that stimulate both the atrium and the ventricle retain the physiological sequence of atrioventricular contraction and the benefit of atrial contraction, which may contribute importantly to cardiac output. They avoid the potentially deleterious effects of ventriculoatrial conduction, and they may cure the pacemaker syndrome. Furthermore, because they sense atrial activity the sinus rate can be followed and the paced rate can increase in parallel with activity.

DDD pacing—DDD pacemakers have superseded other types of dual chamber pacemakers. They provide atrial pacing during atrial bradycardia and ventricular pacing after a spontaneous or paced atrial beat if there is no spontaneous ventricular beat. The paced rhythm therefore closely mimics sinus rhythm, but an important limitation is that if sinus

node function is abnormal the paced rate does not increase with activity. Attempts are being made to develop a DDD pacemaker that can increase the paced rate with activity.

Another problem with DDD pacemakers is that if they sense a retrogradely conducted P wave after ventricular depolarisation they trigger another ventricular beat, which may in turn cause another retrogradely conducted P wave. This may lead to "pacemaker mediated tachycardia," which can be overcome by increasing the refractory period of the atrial channel so that the retrogradely conducted P wave is not sensed, or by shortening the atrioventricular delay so that retrograde conduction does not occur.

DDD pacemakers can be programmed to simpler modes—for example, AAI or VVI—if necessary.

DVI pacemakers—DVI pacemakers are now rarely used. They pace both the atrium and the ventricle if depolarisation is not sensed via the ventricular lead. They maintain atrioventricular sequential contraction during atrial bradycardia, but as the atrium is not sensed the paced rate does not follow the sinus rate; thus asynchronous atrial pacing may lead to atrial fibrillation. Because the atrium is not sensed there is no danger of pacemaker mediated tachycardia.

ANTITACHYCARDIA PACEMAKERS

All of the pacemakers we have mentioned so far are designed to treat bradycardias, but pacing the atrium or ventricle may terminate a tachycardia—and pacemakers designed to do this have been developed.

Choosing the pacemaker

Permanent pacemakers are expensive even though they are often much cheaper in Britain than in other western European countries or the United States.³⁷ The simplest VVI pacemaker and lead costs about £500, and the more sophisticated dual chamber systems can cost three or four times as much. The doctor should choose the simplest and most economic pacemaker that will treat the patient's symptoms. Elderly patients with complete heart block may often be adequately managed with a non-programmable VVI pacemaker, whereas a young active patient may need a dual chamber or rate responsive system as effort tolerance may be much improved.³⁸ Temporary use of ventricular or dual chambered pacemakers with exercise testing may identify both those patients who do not tolerate ventricular pacing and those who may need a dual chambered pacemaker. This information may be useful in deciding which permanent pacemaker to implant.

Programmable functions

Several functions of a pacemaker can be programmed.

PACING RATE

Traditionally pacemakers have been produced to maintain a heart rate of 70 beats/minute, but in some circumstances a faster or slower rate may be advantageous. In patients with

intermittent symptoms caused by the sick sinus syndrome or atrioventricular block a VVI pacemaker that responds only when the heart rate drops below 50 beats/minute may allow sinus rhythm to be maintained for most of the day. Patients with angina may benefit from a slower paced rate, as may patients with the pacemaker syndrome. An increase in the paced rate may benefit patients with heart failure or those who have had an operation.

PACING OUTPUT

The minimum stimulus required to activate the myocardium at the tip of the pacing electrode, the pacing threshold, normally rises and then falls after implantation. By three months the threshold is usually stable; the output may then be reduced to conserve battery life.

SENSITIVITY

Malfunction occurs if the pacemaker fails to detect appropriate signals. Extrasystoles may be "undersensed," and the pacemaker may deliver an impulse, inappropriately causing an arrhythmia. Conversely, the pacemaker may "oversense" electrical signals like those from skeletal muscle; such "myoinhibition" may transiently inhibit a pacemaker and lead to syncope. Diathermy used during an operation may also be sensed, causing pacemaker inhibition. These sensing problems may be rectified by programming the pacemaker to detect signals of greater or lesser magnitude or by altering the mode of pacing—for example, to VVT or VOO.

REFRACTORY PERIOD

During the refractory period no sensing occurs. This function is particularly important in atrial and dual chambered pacemakers as the atrial lead would otherwise detect the larger ventricular depolarisation. This period may need to be prolonged to avoid inappropriate sensing of the T wave or a retrogradely conducted P wave, which may cause a pacemaker mediated tachycardia.

Following up patients with pacemakers

Permanent pacemakers have a finite life determined by their current drain, the frequency of pacing, and the capacity of the battery. Battery depletion is usually shown by a small fall in pacing rate, although in more sophisticated units the state of the battery can be directly determined by telemetry. Patients with programmable pacemakers should be followed up at a specialist centre with programming facilities. Patients with non-programmable pacemakers can be monitored by rate alone. Most patients have few problems and can be followed up at yearly intervals, though more frequent visits are necessary as the pacemaker approaches the end of its anticipated life.

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