Chapter 23
Cardiac Pacemakers

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Currently, three approaches to permanent cardiac pacing are in common use. Single-chamber pacemaker is a device wherein one pacing lead is implanted in either the right atrium or right ventricle. Dual-chamber pacemaker has two pacing leads, one in the right ventricle and one in the right atrium, this is the most commonly used type of pacemaker. Biventricular pacemaker or cardiac resynchronization therapy (CRT) is a device wherein in addition to single- or dual-chamber right heart pacing leads, a third lead is advanced to the coronary sinus for left ventricular epicardial pacing.

Indications

The decision to implant a permanent pacemaker is based on the association of symptoms with a bradyarrhythmia, the location of the conduction abnormality, and the absence of a reversible cause.

A careful history taking and documentation of cardiac rhythm, with either an electrocardiogram or ambulatory monitoring, should be done. Symptoms include dizziness, lightheadedness, syncope, fatigue, and poor exercise tolerance. The direct correlation between symptoms and bradyarrhythmia will increase the likelihood that the pacemaker therapy would result in clinical improvement.

The most common indications for permanent pacemaker implantation are sinus node dysfunction (SND) and high-grade or symptomatic atrioventricular (AV) block. SND refers to abnormalities in sinus node and atrial impulse formation and propagation. It is primarily a disease of the elderly and is thought to be due to senescence of the sinus node and atrial muscle. SND encompasses a wide array of

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R.C. Hendel, C. Kimmelstiel (eds.), *Cardiology Procedures*,
DOI 10.1007/978-1-4471-7290-1_23

abnormalities which include: persistent sinus bradycardia and chronotropic incompetence without identifiable causes, paroxysmal or persistent sinus arrest with replacement by subsidiary escape rhythms in the atrium, AV junction, or ventricular myocardium, and "tachy-brady syndrome". There is no evidence that cardiac pacing prolongs survival in patients with sinus node dysfunction.

Type II second-degree AV block is characterized by fixed PR intervals before and after blocked beats and is usually associated with a wide QRS complex. It is usually infranodal (either intra- or infra-His), especially when the QRS is wide, and typically indicates diffuse conduction system disease. Thus, this type of block constitutes an indication for pacing even in the absence of symptoms. Symptoms are frequent, prognosis is compromised, and progression to third-degree AV block is common and sudden. Third-degree AV block (complete heart block) is defined as absence of AV conduction.

Bifascicular block refers to ECG evidence of impaired conduction below the AV node in the right and left bundles. Please refer to Tables 23.1, 23.2, and 23.3 for a full listing of all the indications for pacemaker pacing in SND, AV block, and chronic bifascicular block.

Pacemaker may also be indicated in neurocardiogenic syncope in which there is a severe or persistent component of bradycardia and more conservative therapeutic attempts have failed. There are other special circumstances which require permanent cardiac pacing: after the acute phase of myocardial infarction, after cardiac transplantation, in sleep apnea syndrome, infiltrative disorders, and neuromuscular disorders [1].

Contraindications

Once it has been established that the bradycardia or a conduction disorder warrants permanent pacing, there are a few contraindications for the actual permanent pacemaker insertion. These include local infection at implantation site and/or active systemic infection with bacteremia.

In general, pacemakers are not indicated for asymptomatic patients. Symptoms due to sinus node dysfunction have to occur during the documented episodes of bra-

Table 23.1 Indications for permanent pacing in sinus node dysfunction [1, 2]

Indication	Strength of indication
Sinus node dysfunction with documented symptomatic bradycardia, including frequent sinus pauses that produce symptoms	Class I
Symptomatic chronotropic incompetence	Class I
Symptomatic sinus bradycardia that results from required drug therapy for medical conditions	Class I
Sinus node dysfunction with heart rate less than 40 bpm when a clear association between significant symptoms consistent with bradycardia and the actual presence of bradycardia has not been documented	Class IIa
Syncope of unexplained origin when clinically significant abnormalities of sinus node function are discovered or proved in electrophysiological studies	Class IIa
Minimally symptomatic patients with chronic heart rate less than 40 bpm while awake.	Class IIb

Table 23.2 Indications for permanent pacing in acquired atrioventricular block in adults [1]

Indication	Strength of indication
3rd degree and advanced 2nd degree AV block at any anatomic level associated with bradycardia with symptoms (including heart failure) or ventricular arrhythmia presumed to be due to AV block	Class I
3rd degree and advanced 2nd degree AV block at any anatomic level associated with arrhythmias and other medical conditions that require drug therapy that results in symptomatic bradycardia	Class I
3rd degree and advanced 2nd degree AV block at any anatomic level in awake, symptom-free patients in sinus rhythm, with documented periods of asystole greater than or equal to 3.0 s, or any escape rate <40 bpm, or with an escape rhythm that is below AV node	Class I
3rd degree and advanced 2nd degree AV block at any anatomic level in awake, symptom-free patients with atrial fibrillation and bradycardia with one or more pauses of at least 5 s or longer	Class I
3rd degree and advanced 2nd degree AV block at any anatomic level associated with postoperative AV block that is not expected to resolve after cardiac surgery	Class I
3rd degree and advanced 2nd degree AV block at any anatomic level after catheter ablation of the AV junction	Class I
3rd degree and advanced 2nd degree AV block at any anatomic level associated with neuromuscular diseases with AV block	Class I
2nd degree AV block with associated symptomatic bradycardia regardless of type or site of block	Class I
Asymptomatic persistent 3rd degree AV block at any anatomic site with average awake ventricular rates of 40 bpm or faster if cardiomegaly or LV dysfunction is present or if site of block is below the AV node	Class I
2nd or 3rd degree AV block during exercise in the absence of myocardial ischemia	Class I
Persistent 3rd degree AV block with an escape rate greater than 40 bpm in asymptomatic adult patients without cardiomegaly	Class IIa
Asymptomatic 2nd degree AV block at intra- or infra- His levels found at electrophysiological study	Class IIa
1st or 2nd degree AV block with symptoms similar to those of pacemaker syndrome or hemodynamic compromise	Class IIa
Asymptomatic type II 2nd degree AV block with a narrow QRS	Class IIa
Neuromuscular diseases with any degree of AV block (including 1st degree AV block), with or without symptoms	Class IIb
AV block in the setting of drug use and/or drug toxicity when the block is expected to recur even after the drug is withdrawn	Class IIb

dycardia. It is of utmost importance to assess for the etiology of the bradycardia: bradyarrhythmia due to a non-essential drug therapy would require drug therapy cessation, and if due to reversible cause (e.g., Lyme disease, increased vagal tone, hypoxia in sleep apnea syndrome in absence of symptoms), would require treatment of underlying cause. Finally, an appropriate diagnosis of the type or level of block is mandatory. Asymptomatic 1st degree, type I 2nd degree AV block at the supra-His (AV node) level, and fascicular block without AV block, do not need a pacemaker.

Table 23.3 Indications for permanent pacing in chronic bifascicular block [1]

Indication	Strength of indication
Advanced 2nd degree AV block or intermittent 3rd degree AV block	Class I
Type II second-degree AV block	Class I
Alternating bundle-branch block	Class I
Syncope not demonstrated to be due to AV block when other likely causes have been excluded, specifically ventricular tachycardia	Class IIa
Incidental finding at electrophysiological study of a markedly prolonged HV interval >100 ms in asymptomatic patients	Class IIa
Incidental finding at electrophysiological study of pacing-induced infra-His block that is not physiological.	Class IIa
Neuromuscular diseases with bifascicular block or any fascicular block, with or without symptoms	Class IIb

Equipment

The basic equipment required for a permanent pacemaker insertion includes: fluoroscope, topical anesthesia (1–2% lidocaine or bupivacaine), instrument tray, pacing system analyzer, introducer kit, suture material, electric cautery, external pacemaker, antimicrobial flush and saline for pocket irrigation. A single-plane fluoroscopy using anteroposterior, 30° right anterior oblique, and 45° left anterior oblique views is used. A pacemaker system consists of two major components: a pulse generator and one or more electrodes. The pulse generator (Fig. 23.1) is the "battery" component of the pacemaker and it provides the electrical impulse for the myocardial stimulation. The electrodes, also known as "leads" (Fig. 23.2a), deliver the electrical impulse from the generator to the myocardium. Currently, the most common cardiac pacing system utilizes transvenous electrodes (leads). However, there are certain clinical situations wherein transvenous leads are not possible (i.e., infection, venous thrombosis/stenosis). In these situations, the epicardial or leadless pacing systems may be considered. A full discussion of these types of pacing system is beyond the scope of this chapter.

Technique

The implantation usually involves a combination of local anesthesia and conscious sedation. The pacing generator is typically placed subcutaneously, superficial to the pectoralis, however, under certain conditions, it may also be placed subpectoral/infra-mammary, or intra-abdominal (i.e., surgically via thoracotomy).

Antibiotic prophylaxis, either with cefazolin or vancomycin, is a standard for device implantation. A central vein: subclavian, internal jugular, or axillary vein, is

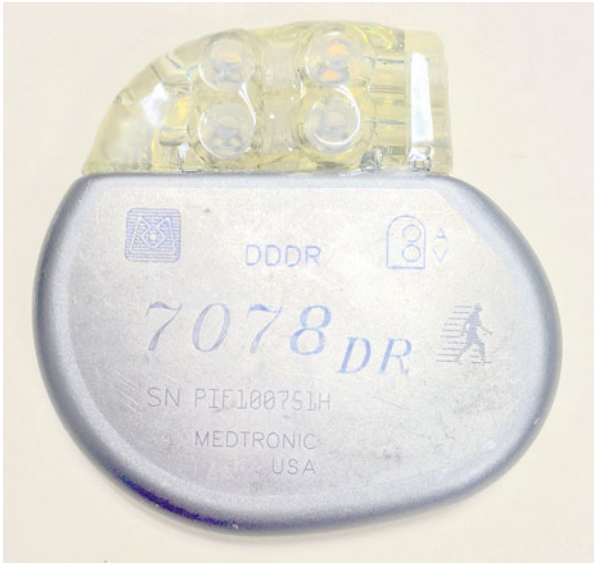

Fig 23.1 Example of a pacemaker generator

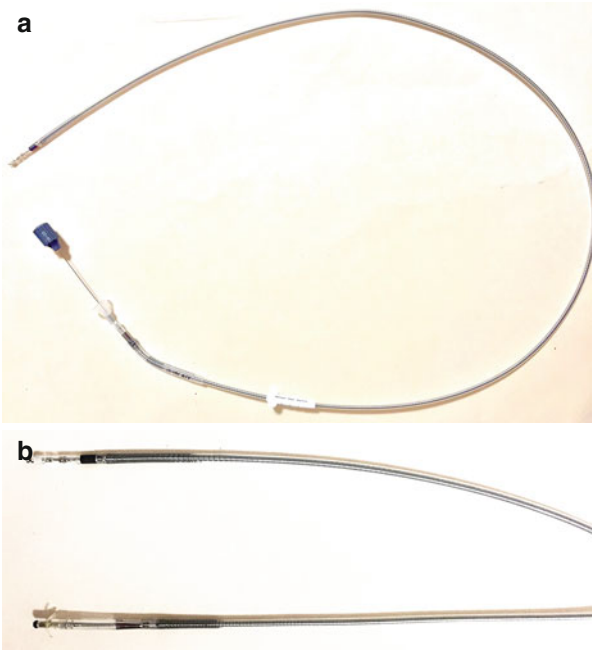

Fig. 23.2 (**a**) Example of an intravenous lead. (**b**) Two types of lead tips: helical screw (*above*) and grappling hook (*below*)

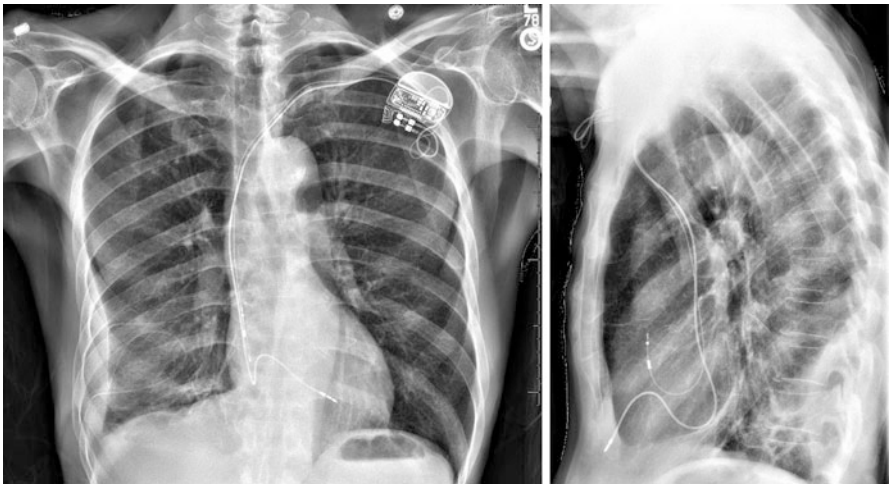

Fig. 23.3 Chest radiograph PA and lateral of a patient with dual chamber pacemaker

access via percutaneous approach. A venous cut down of the cephalic vein may also be done. After venous access is obtained, a guidewire is advanced and subsequently, a sheath and dilator are advanced. The pacemaker lead is then advanced to the chamber of interest (i.e., right atrium, right ventricle). Usually, the ventricular lead is positioned before the atrial lead to prevent its dislodgment.

Once the correct lead positioning is confirmed, lead is affixed to the endocardium either passively with tines (grappling hook) or actively via a helical screw located at the tip (Fig. 23.2b). Pacing and sensing thresholds and lead impedances are measured with the pacing system analyzer. Pacing is also performed at 10 V to assess for diaphragmatic stimulation. After confirmation of lead position and threshold, the proximal end of the lead (s) is then secured to the underlying tissue and connected securely to the pulse generator. The pacemaker pocket is usually irrigated with antimicrobial solution. The incision is closed in layers with absorbable sutures and skin with either adhesive strips or skin glue. An arm sling is applied to the unilateral arm for 12–24 h to limit movement. A post-procedure chest radiograph is usually done for lead position confirmation and to rule out pneumothorax (Fig. 23.3). On the following day, postero-anterior (PA) and lateral chest radiographs will again be done to confirm lead positions and exclude any delayed pneumothorax.

Data Interpretation

A universal pacing code system, also known as NBG pacemaker code, is used to facilitate the understanding of pacemakers. It describes the five-letter code for operation of implantable pacemakers and defibrillators.

Position I reflects the chamber (s) paced. "**A**" indicates the atrium, "**V**" indicates the ventricle, and "**D**" means dual chamber (i.e., both atrium and ventricle).

Position II refers to the chamber (s) sensed. The letters are the same as those for the first position: "**A**", "**V**",or "**D**". An addition option "**O**" indicates an absence of sensing. If a device is programmed in this mode, it will pace automatically at a specific rate, ignoring any intrinsic rhythm.

Position III refers to how the pacemaker responds to a sensed event. "**I**" indicates that a sensed event inhibits the output pulse and causes the pacemaker to recycle for one or more timing cycles. "**T**" indicates that the output pulse is triggered in response to a sensed event. "**D**" indicates dual modes of response and is restricted to dual chamber systems.

Position IV reflects rate modulation, also known as rate adaptive or rate responsive pacing. "**R**" indicates that the pacemaker has rate modulation and incorporates a sensor to adjust its programmed paced heart rate in response to patient's activity. "**O**" indicates that rate modulation is either unavailable or disable.

Position V is rarely used and specifies only the location of multisite pacing or absence thereof. Multisite pacing is defined as stimulation sites in both atria, both ventricles, more than one stimulation site in any single chamber, or a combination of these. "**O**" indicates no multisite pacing. "**A**" means multisite pacing in the atria. "**V**" means multisite pacing in the ventricles, and "**D**" for both atrium and ventricle. The most common application of multisite pacing is biventricular pacing.

Complications

Although considered a minimally invasive procedure, the incidence of complications in modern pacing therapy is still substantial. Permanent pacemaker placement poses various risks ranging from minor to serious life-threatening complications. These complications may be classified according to severity (minor or major), component of pacing system involved (lead, generator/pocket, patient), or to timing of occurrence: in-hospital or acute, sub-acute, or late.

Acute complications occur peri-procedural or in-hospital. Pneumothorax may occur in 1–3 % in patients undergoing pacemaker implantation. Due to this known complication, chest radiographs are performed immediately after, and often, the day after the procedure. Vascular access complications may also occur. Direct subclavian vein punctures are associated with a higher incidence of pneumothorax and lead damage from subclavian crush syndrome. The axillary venous puncture approach and cephalic venous cut down, on the other hand, are associated with lower incidence of pneumothorax and lead damage. Myocardial perforation has been reported to occur in 1 % of patients, with the asymptomatic subclinical perforation occurring to as much as 15 %. Device pocket hematoma is also a common complication. It has an incidence of approximately 5 %, with a higher incidence in patients on anticoagulation or antithrombotic medications. Finally, in-hospital death generally occurs in less than 1 % of pacemaker implantations [3].

Subacute post-implantation complications occur after hospital discharge and less than 30 days after placement. During this period, several types of pacemaker and lead function/failures have been reported: failure to capture, failure to output, undersensing, and inappropriate pacemaker rate [3].

Late complications occur more than 30 days after placement. The most common complications include infection, device/lead advisories, lead function problems/failures, venous thrombosis or stenosis. Localized infection involving the device pocket may occur up to 60 % of the patients, with the rest presenting as endovascular infection. Device malfunction leading to device explantation occurs in <1 % of patients. A rise in capture threshold may occur beyond 6 weeks of implantation. As this threshold rises, it may exceed the maximum output of pulse generator. This phenomenon is called "exit block". Venous stenosis, less commonly thrombosis, has also been reported after implantation of pacing leads [3].

Clinical Vignettes

Case 1

A 76 year old man with hypertension and dyslipidemia comes in for an annual check-up. He is feeling well, active, and runs yearly in a marathon. His medications include lisinopril and atorvastatin. His resting heart rate was found to be 43 beats/min with blood pressure of 120/75. An ECG was done which shows sinus bradycardia 44 beats per minute, with normal PR and QRS intervals.

The most important feature in this patient's history is the absence of any symptom. It is a Class III recommendation to implant a permanent pacemaker for SND in asymptomatic patients. ECG monitoring may be done should any symptom arise and if there is a need to correlate it with bradyarrhythmia. Given the lack of symptoms and patient's high level of activity, pacemaker is not indicated.

Case 2

A 68 year old woman with hypertension and coronary artery disease, presented to the hospital for two episodes of syncope. She has been having palpitations and several pre-syncopal episodes for 3 months. Upon arrival, patient is awake and alert. A rhythm strip was obtained which showed atrial fibrillation with a ventricular rate of 185 bpm. Her BP was 115/70. Metoprolol 2.5 mg IV was given and patient became pre-syncopal. She then had a heart rate of 30 bpm and a BP of 90/60. An hour later, she was again in atrial fibrillation with a ventricular rate of 170 bpm.

This association of paroxysmal atrial fibrillation and sinus bradycardia, accompanied by symptom, is worrisome for a "tachy-brady syndrome", a type of sinus

node dysfunction. Individuals with tachy-brady syndrome have diseased SA nodes and often display exaggerated overdrive suppression. Given the patient's symptoms and sinus node dysfunction, a pacemaker is recommended.

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