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CHAPTER 1

Indications for permanent and temporary cardiac pacing

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Introduction

Defects of cardiac impulse generation and conduction can occur at various levels in the cardiac conduction system. In general, intrinsic disease of the conduction system is often diffuse. For example, normal atrioventricular (AV) conduction cannot necessarily be assumed when a pacemaker is implanted for a disorder seemingly localized to the sinus node. Similarly, normal sinus node function cannot be assumed when a pacemaker is implanted in a patient with AV block. Conduction disorders that lead to important bradycardia or asytole may result from reversible or irreversible causes. Recognition of reversible causes is critical to avoid unnecessary commitment to long-term pacemaker therapy. This chapter reviews the common disorders that warrant cardiac pacing and lists the recommended indications set out by published guidelines.

Anatomy and physiology of the conduction system

For a complete understanding of rhythm generation, intracardiac conduction, and their pathology, a brief review of the anatomy and physiology of the specialized conduction system is warranted.

Sinus node

The sinus node or sinoatrial (SA) node is a crescent shaped sub-epicardial structure located at the junction of the right atrium and superior vena cava along the terminal crest. It measures 10–20 mm (with larger extension in some studies) and has abundant autonomic innervation and blood supply, with the sinus node artery commonly coursing through the body of the node. Endocardially, the crista terminalis overlies the nodal tissue, although the inferior aspect of the node has a more subendocardial course. Histologically, the sinus node is comprised of specialized nodal cells (P cells) packed within a dense matrix of connective tissue. At the periphery, these nodal cells intermingle with transitional cells and the atrial working myocardium, with radiations extending toward the superior vena cava, the crista terminalis, and the intercaval regions.[1,2] The absence of a distinct border and the presence of distal fragmentation explain the lack of a single breakthrough of the sinus node excitatory wavefront. The radiations of the node, although histologically distinct, are not insulated from the atrial myocardium. Hence, a clear anatomical SA junction is absent. The sinus node is protected from the hyperpolarizing effect of the surrounding atria, probably by its unique structure wherein electrical coupling between cells

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and expression of ion channels vary from the center of the node to the periphery. The pacemaker cells at the center of the node are more loosely coupled, while those at the periphery are more tightly coupled with higher density I_f (funny current; a slow sodium current) and I_{Na} currents.[2]

The SA node has the highest rate of spontaneous depolarization (automaticity) in the specialized conduction system and is responsible for the generation of the cardiac impulse under normal circumstances, although normal human pacemaker activity may be widely distributed in the atrium. The unique location of the sinus node astride the large SA nodal artery provides an ideal milieu for continuous monitoring and instantaneous adjustment of heart rate to meet the body's changing metabolic needs. Impulse generation in the sinus node has been extensively studied in mammalian hearts, but remains incompletely understood. Sinus nodal cells have a low resting membrane potential of −50 to −60 mV. Spontaneous diastolic (phase 4) depolarizations are probably triggered by several currents, including I_f. T type calcium current is activated early during the diastolic depolarization, followed by the L type calcium current that triggers a "slow" action potential. Differential sensitivity to adrenergic and vagal inputs exists along the nodal pacemaker cells, such that superior sites tend to dominate during adrenergic drive while the inferior sites predominate during vagal stimulation.[3] Interventions including premature stimulation, autonomic stimulation, and drugs have been shown to induce pacemaker shifts (due to multicentric origins) with variable exit locations.[4]

Atrioventricular node

The compact AV node is a sub-endocardial structure situated within the triangle of Koch and measuring 5–7 mm in length and 2–5 mm in width.[5,6] On the atrial side, the node is an integral part of the atrial musculature, in contrast to the AV bundle which is insulated within the central fibrous body and merges with the His bundle. Based on action potential morphology in rabbit hearts, atrial (A), nodal (N), and His (H) cells have been defined. Intermediate cell types such as AN and NH define areas toward the atrial and His bundle ends of the compact node, respectively. Histologically, the mid nodal part has densely packed cells in a basket-like structure interposed between the His bundle and the loose atrial approaches to the node. The AN cells are comprised primarily of transitional cells. Distinct electrical and morphological specialization is seen only in the progressively distal His fibers. Rightward and leftward posterior extensions of the AV node were described by Inoue and Becker.[7] These extensions have clinical implications for defining re-entrant circuits that act as a substrate of AV nodal re-entrant tachycardia.

The AV node has extensive autonomic innervation and an abundant blood supply from the large AV nodal artery, a branch of the right coronary artery, in 90% of patients, and from the left circumflex artery in 10% (Figure 1.1). AV nodal conduction is mediated via "slow" calcium-mediated action potential and demonstrates decremental conduction due to post repolarization refractoriness as a result of delayed recovery of the slow inward currents. AV nodal tissue closer to the His bundle (NH

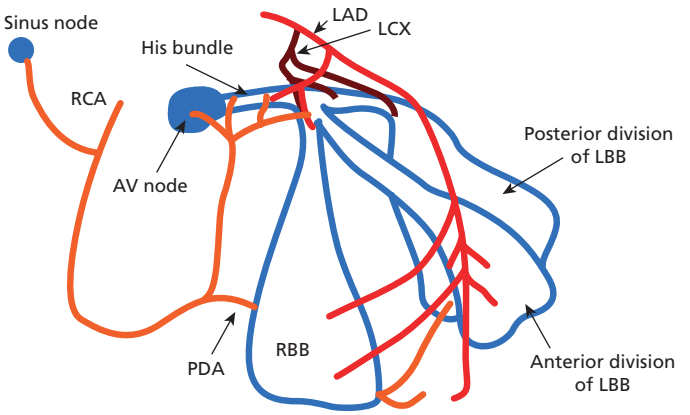

Figure 1.1 Schematic of the conduction system with arterial supply shown. LAD, left anterior descending coronary artery; LBB, left bundle branch; LCX, left circumflex coronary artery; RBB, right bundle branch; RCA, right coronary artery.

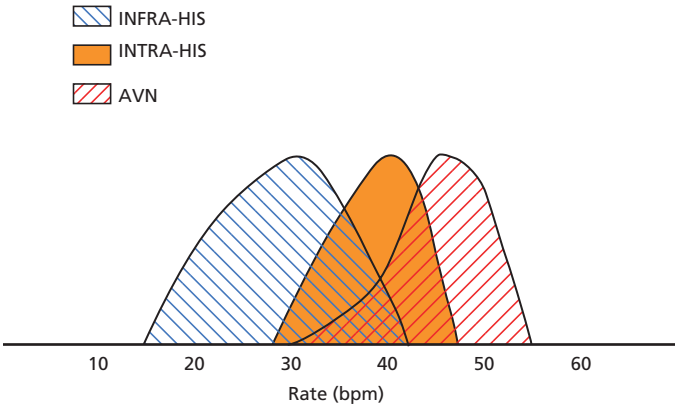

Figure 1.2 Rate of escape rhythm from various areas of the conduction system. AVN, atrioventricular node; Infra-His, below the bundle of His; Intra-His, within the His bundle.

and proximal His bundle area) generates junctional escape rhythms (Figure 1.2). Escape rates are dependent on the site of dominant pacemaker activity. Isoproterenol stimulation, for example, accelerates junctional escape and shifts the dominant activity to the transitional cells in the AN region and posterior extensions of the node.[8–10]

His–Purkinje system

Purkinje fibers emerging from the area of the distal AV node converge gradually to form the His bundle, a narrow tubular structure that runs through the membranous septum to the crest of the muscular septum, where it divides into the bundle branches. The His bundle has relatively sparse autonomic innervation, although its blood supply is quite ample, emanating from both the AV nodal artery and the septal branches of the left anterior descending artery (Figure 1.1). Longitudinal strands of Purkinje fibers, divided into separate parallel compartments by a collagenous skeleton, can be discerned by histological examination of the His bundle. Relatively sparse P cells can also be identified, embedded within the collagen. The rapid conduction of electrical impulses across the His–Purkinje system is responsible for the almost simultaneous activation of the right and left ventricles.

The bundle branch system is a complex network of interlaced Purkinje fibers that varies greatly among individuals. It generally starts as one or more large fiber bands that split and fan out across the ventricles until they finally terminate in a Purkinje network that interfaces with the myocardium (Figure 1.1). In some cases, the bundle branches clearly conform to a tri- or quadrifascicular system. In other cases, however, detailed dissection of the conduction system has failed to delineate separate fascicles. The right bundle is usually a single, discrete structure that extends down the right side of the interventricular septum to the base of the anterior papillary muscle, where it divides into three or more branches. The left bundle more commonly originates as a very broad band of interlaced fibers that spread out over the left ventricle, sometimes in two or three distinct fiber tracts. There is relatively little autonomic innervation of the bundle branch system, but the blood supply is extensive, with most areas receiving branches from both the right and left coronary systems.

Indications for permanent pacemakers

Permanent pacing is considered in a number of clinical situations, some of which are unambiguous whereas others require a higher level of expertise for determination of potential benefit. However, two major factors determine the need for cardiac pacing: (1) symptoms associated with a bradyarrhythmia and (2) the site of conduction abnormality in the conduction system. In addition, the determination will depend on whether the conduction disease is likely to be permanent or reversible, such as due to a drug effect or acute inflammatory or ischemic process. A permanent pacemaker is generally a life-long commitment for a patient; the

need for a generator changes and surgical revisions for malfunction become important considerations in younger patients. Hence, the decision to implant a pacemaker is not to be taken lightly.

A joint committee of the American College of Cardiology (ACC) and the American Heart Association (AHA) was formed in the 1980s to provide uniform criteria for pacemaker implantation. These guidelines were first published in 1984 and most recently revised in 2008 in conjunction with the Heart Rhythm Society (HRS).[11] A task force for cardiac pacing and cardiac resynchronization therapy published similar guidelines in 2007.[12] A recent focused update to the ACC/AHA/HRS guidelines of 2008 was published in 2012.[13] It is recognized that there will be occasional cases that cannot be categorized based on these guidelines. Nevertheless, these guidelines have received wide endorsement and are periodically updated to incorporate important emerging data. A recent publication addressed the important issue of mode selection for cardiac pacing.[14] This subject is discussed in detail in Chapter 3.

All guideline recommendations are subdivided into three classes to reflect the magnitude of treatment effect (Table 1.1). A class I indication pertains to a condition in which the procedure or intervention confers definite benefits. A class III indication is one where the intervention is not helpful and potentially harmful, and hence, not recommended.

Table 1.1 Classes of guideline recommendations

Class I	Conditions for which there is evidence and/or general agreement that a pacemaker implantation is beneficial, useful, and effective
Class II	Conditions for which there is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of pacemaker implantation
Class IIa	Weight of evidence/opinion in favor of efficacy
Class IIb	Usefulness/efficacy less well established by evidence/opinion
Class III	Conditions for which there is evidence and/or general agreement that a pacemaker is not useful/effective and in some cases may be harmful

Additionally, the ACC/AHA Committee ranked evidence supporting its recommendations by the following criteria:

- *Level A:* Data derived from multiple randomized trials involving a large number of patients.
- *Level B:* Data derived from a limited number of trials involving a relatively small number of patients or from well-designed analyses of non-randomized studies or data registries.
- *Level C:* Recommendations derived from the consensus of experts.

Some class I indications will necessarily lack support from level A evidence due to early non-randomized studies documenting clear benefits such that randomized trials become unethical.

Sinus node dysfunction

Disorders of the sinus node can be divided into those primarily due to intrinsic pathology of the node and surrounding atrium, or extrinsic factors such as autonomic stimulation or drug effects. The terms sinus node disease (SND), sick sinus syndrome, and SA disease are often used interchangeably. All these refer to a broad range of abnormalities in the sinus node and atrial impulse formation and propagation (Table 1.2). They include persistent sinus bradycardia and/or chronotropic incompetence without identified cause, intermittent or persistent sinus arrest, and SA exit block. Frequently, atrial arrhythmias and sinus nodal dysfunction co-exist and cause symptomatic sinus pauses at cessation of an atrial arrhythmia (Figure 1.3). The term tachy–brady syndrome is applied because of the frequent need for bradycardia support with pacing to allow antiarrhythmic therapy for the tachycardia.

Pathology intrinsic to the sinus node is quite common, and its incidence increases with advancing age. Several patterns have been identified: A diffuse or localized atriopathy has been suggested. Electrophysiological studies have shown structural remodeling, particularly along the long axis of the crista terminalis, and associated with a more caudal migration of the atrial pacemaker activity.[8] Progressive down-regulation of the I_{CaL} channel and loss of connexin-43 expression are features in the guinea pig model.[15] In humans, such atriopathy is also associated with atrial arrhythmias, particularly

Table 1.2 Manifestations of sinus node dysfunction and their diagnosis

Sinus bradycardia	Sinus rates persistently <60 bpm and associated with symptoms. Prolonged sinus node recovery time (following atrial pacing) is helpful in diagnosing sinus node disease but has low sensitivity
Chronotropic incompetence	Sinus rate does not increase with exertion. Diagnosis made with exercise test or ambulatory ECG monitoring
Sinoatrial (SA) block	Sinus beats are "dropped" in a regular pattern (e.g.2:1 SA block, 3:2 SA Wenckebach, etc.) due to blocking of impulses in the perinodal area between the sinus node and atrial muscle (by disease, medications, etc.). Diagnosis is made by the use of continuous ECG monitoring
Sinoatrial pause	Failure of impulse formation in the sinus node due to pathology, medications, etc. The diagnosis is made electrocardiographically by an absence of sinus P waves that occurs without any discernible pattern
Tachy–brady syndrome	The diagnosis is made electrocardiographically by alternating periods of sinus bradycardia and tachycardia (most commonly atrial fibrillation or flutter). The bradycardia is often manifested by periods of prolonged sinus arrest that often occur at termination of tachycardia

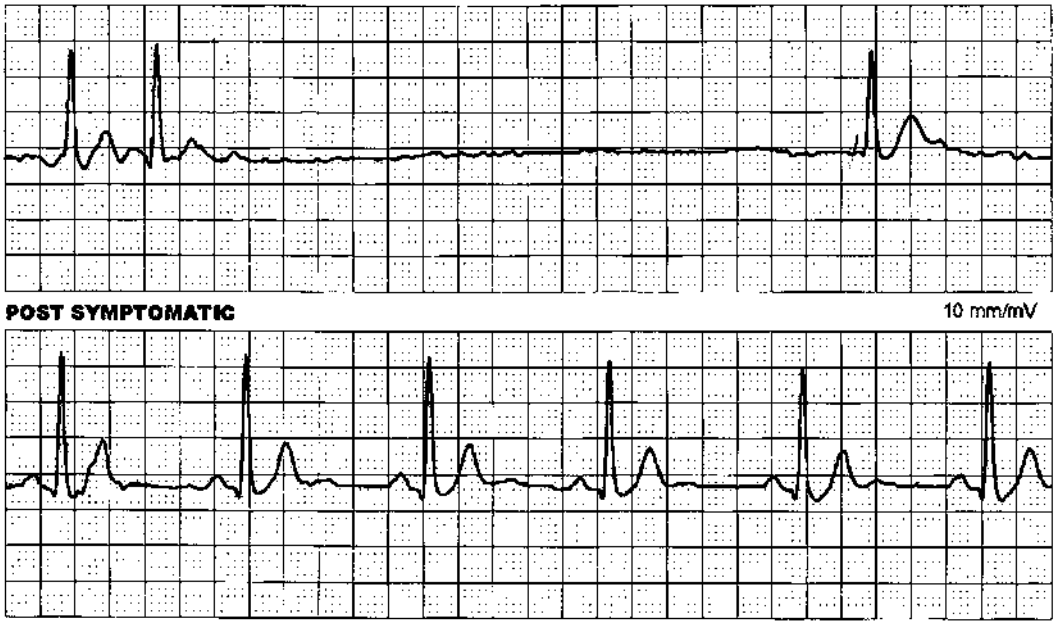

Figure 1.3 Tachy–brady syndrome due to sinus arrest at termination of atrial fibrillation. Patient-triggered event recording during presyncope in a 56-year-old male with paroxysmal atrial fibrillation shows an asystolic pause in excess of 4 s at termination of fibrillation. The sinus offset pause is intercepted by a junctional escape beat before resumption of normal sinus rhythm.

atrial fibrillation that develops in 50% of patients with SND. Atrial arrhythmias further aggravate SND and catheter ablation of fibrillation, and flutter has been shown to reverse some of the adverse electrical remodeling of the sinus node.[16] Atrophic or hypoplastic sinus node has been described in association with congenital anomalies. A familial form of SND is also recognized. Finally, idiopathic SND without any detectable morphological abnormality can occur and may be related to abnormal neural innervation.

In patients with sinus node dysfunction, the correlation of symptoms with bradyarrhythmias is *critically* important. This is because there is a great deal of disagreement about the absolute heart rate or length of pause required before pacing is indicated. If the symptoms of SND are dramatic (e.g. syncope, recurrent dizzy spells, seizures, or severe

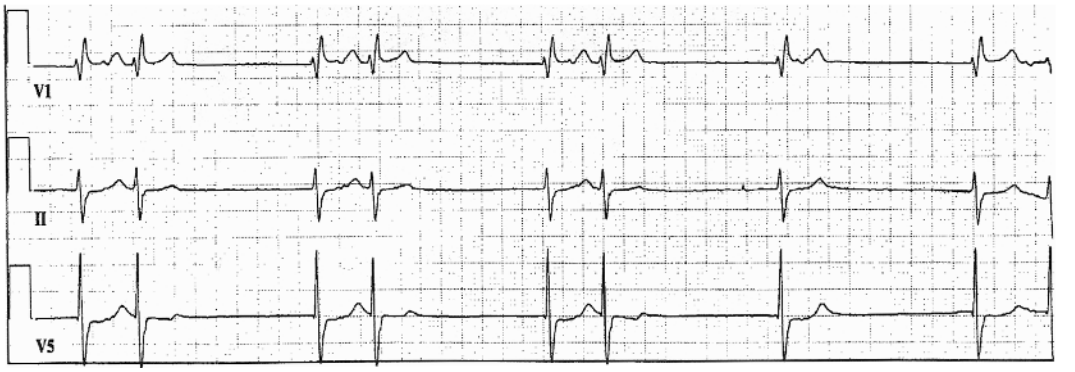

Figure 1.4 A 69-year-old male had been started on atenolol 75 mg/day for treatment of hypertension approximately 2 weeks earlier. He was seen in the emergency room complaining of feeling weak and lightheaded. The ECG shows a slow junctional escape rhythm followed by a sinus beat in a pattern termed "escape–capture bigeminy." Discontinuation of atenolol resulted in return of normal sinus rhythm within 36 h. Patients with sinus node dysfunction may be dependent upon sympathetic stimulation, and β-blockers, even in low doses, may result in profound bradycardia.

heart failure), then the diagnosis may be relatively easy. However, symptoms are often non-specific (e.g. easy fatigability, depression, listlessness, early signs of dementia) and may be easily misinterpreted in the elderly. Electrophysiological studies have a low sensitivity for detection of SND and ambulatory monitoring with symptom correlation has the best diagnostic yield.

Essential drugs used for co-existing conditions can accentuate SND (Figure 1.4). If cessation of a drug is anticipated to cause deterioration of the primary condition, permanent pacing may be needed to allow continuation of medical therapy in some patients. A group of patients has been identified who have a relatively fixed heart rate during exercise; this condition is referred to as chronotropic incompetence and can result in marked exercise intolerance in some patients. Heart rate response to exercise compared with that of an age- and gender-matched population is often necessary for clear diagnosis, although no specific parameter has been established as a diagnostic standard.

Patients with SND may have associated disease in the AV node and His–Purkinje conduction system. However, the rate of lone SND progressing to AV block is low. The mean annual incidence of complete AV block developing in patients implanted with AAI pacemakers for SND is 0.6% (range 0–4.5%) with an overall prevalence of 2.1% (range 0–11.9%).[11] The natural history of untreated SND is highly variable. Syncope resulting from sinus arrest tends to be recurrent and may result in falls and significant orthopedic injuries, especially in the elderly. The incidence of sudden death is low and SND very rarely affects survival regardless of whether or not it is treated with a pacemaker.

Indications for permanent pacing in sinus node dysfunction

Class I indications

1 Sinus node dysfunction with documented symptomatic bradycardia or sinus pauses. (Level of evidence: C)

2 Symptomatic chronotropic incompetence. (Level of evidence: C)

3 Sinus node dysfunction as a result of essential long-term drug therapy of a type and dose for which there are no acceptable alternatives. (Level of evidence: C)

Class IIa indications

1 Sinus bradycardia with a heart rate of less than 40 bpm when a clear symptom correlation has not been established with documented bradycardia. (Level of evidence: C)

2 Syncope of unexplained origin when clinically significant abnormalities of sinus node function are detected or provoked during electrophysiological studies. (Level of evidence: C)

Class IIb indications

1 In minimally symptomatic patients with persistent bradycardia with a heart rate of less than 40 bpm during awake hours. (Level of evidence: C)

Class III (permanent pacing not indicated)

1 Permanent pacing is not indicated in asymptomatic patients with SND. (Level of evidence: C)

2 Sinus node dysfunction in patients with symptoms suggestive of bradycardia that are clearly documented as not associated with a slow heart rate.

3 Sinus node dysfunction with symptomatic bradycardia due to non-essential drug therapy.

Acquired atrioventricular block

In the majority, sclerodegenerative changes account for progressive conduction system disease. However, in a significant proportion, AV block is secondary to other causes that are potentially reversible or associated with progressive heart disease with added risk of ventricular arrhythmias such that an implantable cardioverter–defibrillator (ICD) should be considered as a means of providing pacing therapy. In a recent review of unexplained heart block in patients under 55 years of age, cardiac sarcoidosis or giant cell myocarditis accounted for 25% of cases and these patients had a high incidence of sudden death, ventricular tachycardia, or need for cardiac transplantation.[17] In younger patients presenting with advanced conduction system disease, further evaluation with cardiac magnetic resonance (CMR) imaging or positron emission tomography (PET) is useful for detection of pathology that merits the use of an ICD as opposed to provision of cardiac pacing alone.

Based on electrocardiography (ECG) characteristics, AV block is classified as first, second, and third degree. Anatomically, block can occur at various levels in the AV conduction system; above the His bundle (supra-His), within the His bundle (intra-His), and below the bundle of His (infra-His). First-degree AV block is defined as abnormal prolongation of the PR interval to greater than 200 ms and is commonly due to delay in the AV node irrespective of QRS width. Type I second-degree heart block refers to progressive PR prolongation before a non-conducted beat and a shorter PR interval after the first blocked beat. This is the classical Wenckebach type AV block usually seen in conjunction with narrow QRS complexes, implying a more proximal level of block, usually in the AV node (Figure 1.5). Type II second-degree heart block is characterized by fixed PR intervals before and after blocked beats, and is usually associated with a wider QRS complex, indicating distal levels of block in the conduction system. Type II second-degree AV block is usually below the level

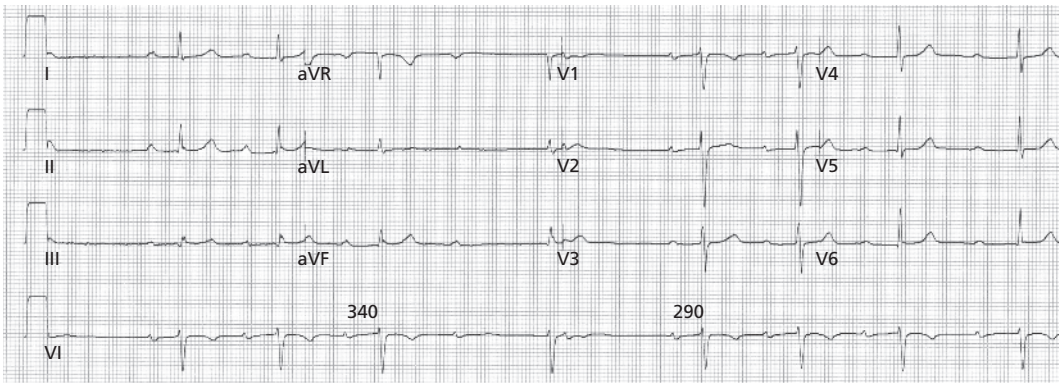

Figure 1.5 Type 1 second-degree atrioventricular (AV) block associated with Lyme disease. This 32-year-old male presented with complaints of palpitation due to heart beat irregularity. He had features of Lyme disease several weeks previously. There is progressive PR prolongation before the fourth P wave fails to conduct. The fourth QRS complex is a junctional escape beat. The sixth P wave that conducts has a shorter PR interval (290 ms) compared to the last conducted beat before block occurred (340 ms).

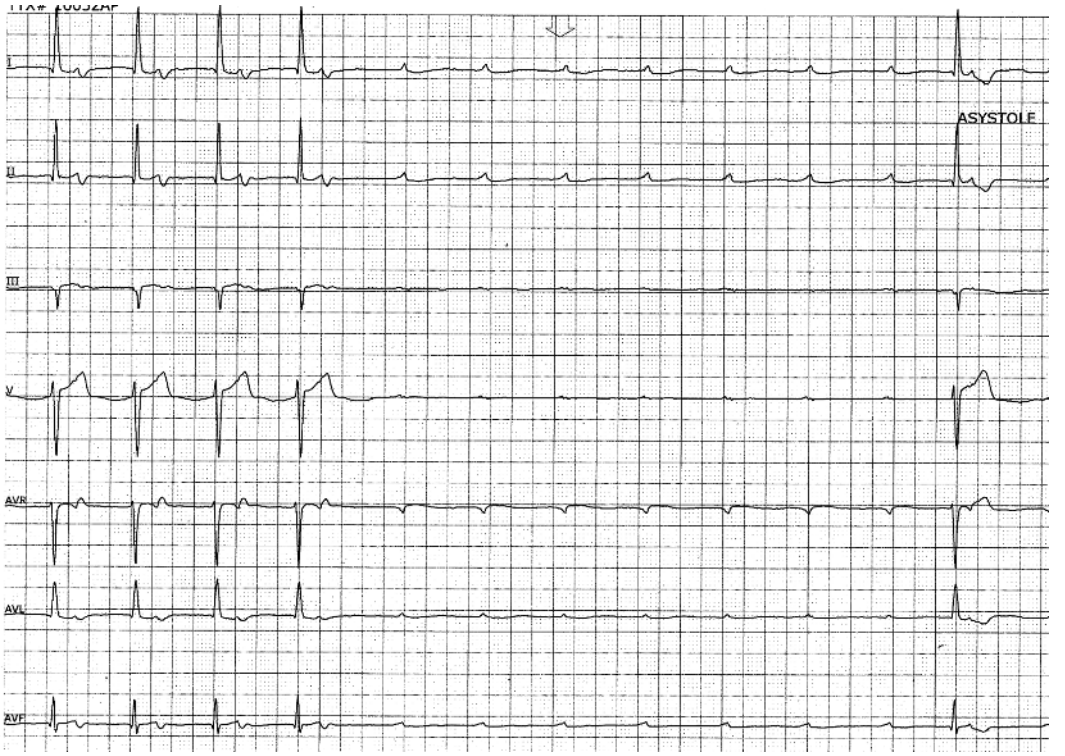

Figure 1.6 High-grade atrioventricular (AV) block. This 60-year-old female with hypertension and coronary artery disease presented with syncope. Baseline ECG showed marked first-degree AV block and voltage changes of left ventricular hypertrophy. Telemetry recorded abrupt interruption of AV conduction with multiple non-conducted P waves with spontaneous recovery. Her β-adrenergic blockers were continued as essential treatment for coronary artery disease and a permanent pacemaker was implanted.

of the AV node (within or below the His bundle); symptoms and progression to complete AV block are common. AV conduction in a 2:1 pattern can be due to proximal or distal block, although the width of the QRS can help differentiate these based on the above principle. Advanced second-degree block or "high-grade" AV block refers to two or more non-conducted sinus P waves, but with resumption of conducted beats suggesting preservation of some AV conduction (Figure 1.6). In the setting of atrial fibrillation or flutter, a prolonged pause (e.g. >5 s) is often due to advanced second-degree AV block. Third-degree AV block is defined as the absence of AV conduction. In the case of atrial fibrillation, complete AV block often manifests as a regularized slow ventricular rate.

The site of AV block will to a great extent determine the adequacy and reliability of the underlying escape rhythm (Figure 1.7 and Figure 1.8). While ECG characteristics are helpful in defining levels of block, they are not always reliable and occasionally, an electrophysiological study is required. Type I second-degree block, for example, can occasionally be infranodal, even with a narrow QRS, and may warrant the consideration of pacing.[18] Certain clinical maneuvers may be helpful in determining the level of block. Increased AV conduction with exercise and atropine generally indicate block at the AV nodal level, while maneuvers that slow the atrial rate, such as carotid massage, improve His–Purkinje conduction by allowing for recovery from refractoriness (Table 1.3).

There is considerable variation in the symptomatic manifestation of AV block, ranging from an asymptomatic status to syncope and sudden death. First-degree AV block and asymptomatic type I second-degree AV block are in general benign and not an indication for cardiac pacing. However,

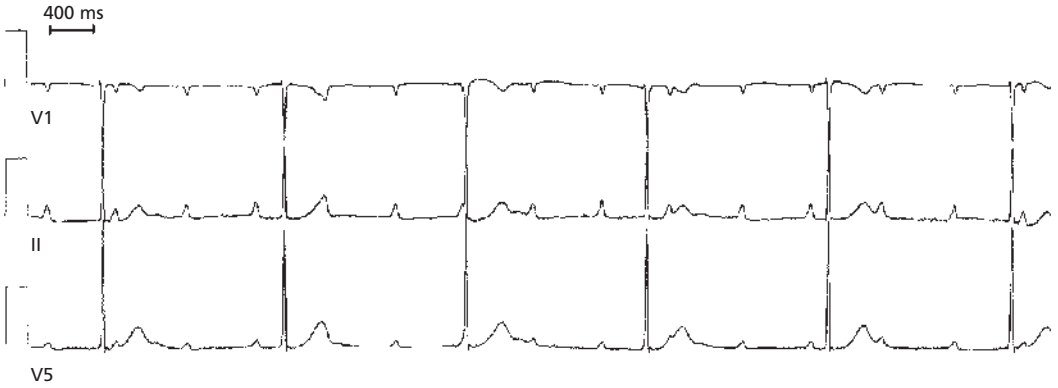

Figure 1.7 Complete heart block with narrow QRS escape rhythm. This 70-year-old male presented with fatigue. Rhythm strips reveal complete AV block and a slow junctional escape rhythm with narrow QRS complexes. A permanent dual chamber pacemaker completely relieved his symptoms.

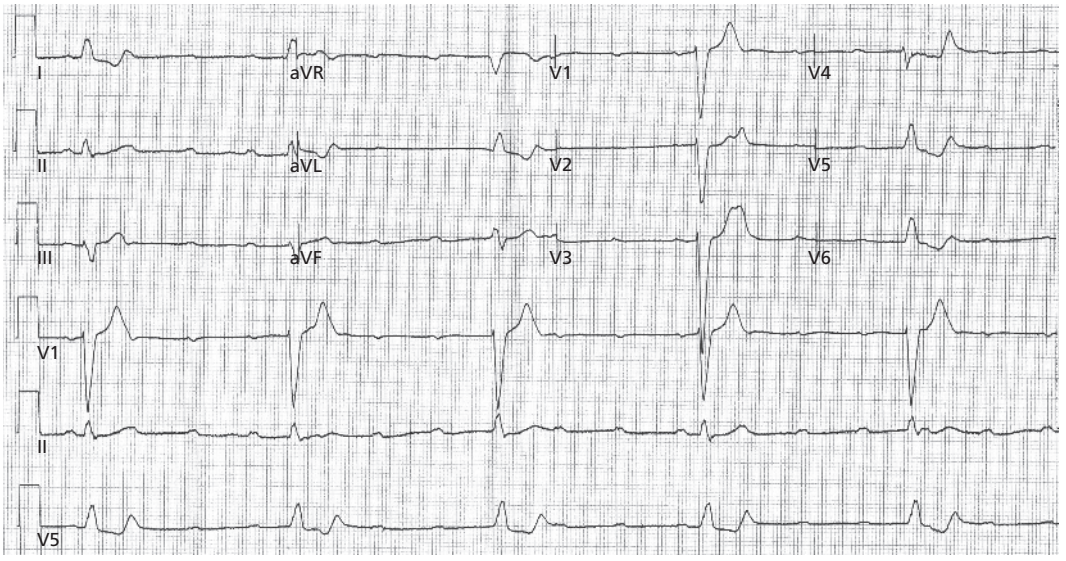

Figure 1.8 Complete AV block with wide QRS escape rhythm. This 77-year-old male presented with syncope without warning and sustained facial injuries. The slow ventricular escape rhythm at 30 bpm likely originates from the right bundle branch. Intermittent asystole due to unstable escape rhythm was the most likely cause of syncope.

Table 1.3 Responses to maneuvers to identify level of block in patients with 2:1 atrioventricular (AV) block

	Block above AV node	*Block below AV node*
Exercise	+	± or −
Atropine	+	± or −
Carotid sinus massage	−	+ or ±
Isoproterenol	+	− or ±

+, improved AV conduction; −, worsened AV conduction.

rarely, first-degree block with marked PR prolongation can potentially cause atrial systole to occur in close proximity to the preceding ventricular systole and give rise to symptoms similar to those of a pacemaker syndrome.[19] Prolongation of the PR interval is particularly important in patients with left ventricular (LV) dysfunction as marked PR prolongation in excess of 250–300 ms can lead to impaired LV filling, increased pulmonary capillary wedge pressure, and decreased cardiac output.[20]

Similar consequences can ensue in patients with type I second-degree AV block even in the absence of bradycardia-related symptoms.

Type II second-degree AV block is important as it has a high rate of progression to third-degree AV block. It usually reflects diffuse conduction system disease and often warrants permanent pacing even in the absence of symptoms. Third-degree AV block with a wide QRS escape rhythm, often present with fatigue, dyspnea, pre-syncope or frank unheralded syncope. Rarely, ventricular fibrillation and torsades de pointes ventricular tachycardia (VT) can result from marked bradycardia and prolonged pauses. Permanent cardiac pacing should be strongly considered even if the escape rate is greater than 40 bpm, because it is not necessarily the escape rate that determines a safe and reliable heart rhythm but the site of origin of the escape rhythm. Infra-His escape rhythms are more likely associated with prolonged asystole, syncope, and death (Figure 1.8).

AV block, usually with 2:1 AV conduction, can be provoked by exercise (Figure 1.9). Patients typically complain of exertional dyspnea and dizziness. The abnormality is often reproducible by exercise testing. Once ischemia is excluded as a cause, permanent pacing is remarkably effective for symptom relief. Without pacing, these patients have a poor prognosis because the site of conduction block is below the AV nodal level.[21]

A distinct form of paroxysmal AV block associated with syncope has been described in patients without structural heart disease or evidence for conduction disturbance on ECG.[22] Patients present with abrupt syncope associated with abrupt onset of high-grade AV block and prolonged asystole, with recovery of normal AV conduction soon afterward. Electrophysiological studies do not indicate the presence of His–Purkinje disease. The majority tends to have an exaggerated response to intravenous adenosine, raising the possibility of a variant of reflex syncope (see "Reflex syncope"). However, the classical sinus slowing prior to onset of AV block that is typical of vagally-mediated AV block, is usually absent in this group of patients.

In general, the presence of symptoms documented to be due to AV block is an indication for permanent pacing regardless of the site of the block (e.g. above the His bundle as well as below the His bundle). However, it is important to recognize potentially reversible causes of AV block despite their presentation with symptoms. Important examples include acute myocarditis (particularly that associated with Lyme carditis), AV block related to drug toxicity, transient vagotonia, and hypoxic events. Many of these conditions tend to resolve with disease-specific treatment and although temporary pacing may be required, permanent pacing is seldom necessary. One exception is drug-related AV block that may not always resolve completely on cessation of the medication and may need permanent pacing (see "Temporary pacing indications"). The indications for permanent pacing of heart block due to acute myocardial infarction (MI), congenital AV block, and increased vagal tone differ and are discussed in "Reflex syncope," "Congenital complete AV block," and

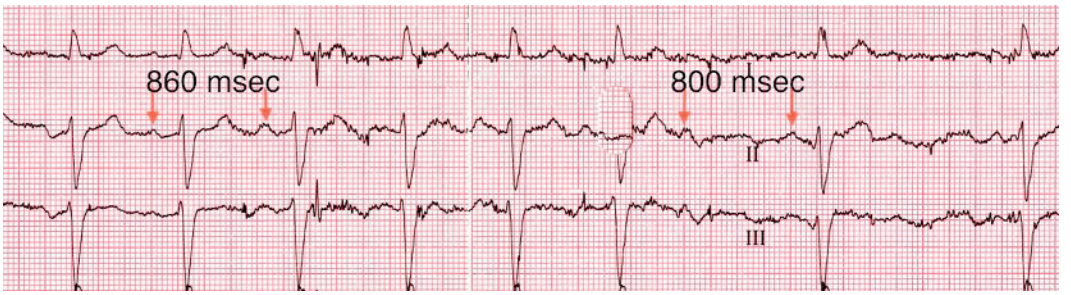

Figure 1.9 Exercise-induced atrioventricular (AV) block. This 68-year-old male presented with exertional dyspnea. His baseline ECG showed sinus rhythm with first-degree AV block and left anterior hemiblock. With gentle leg elevation exercise in the examination room while connected to the ECG, 2:1 AV block developed as the PP intervals shortened from 860 ms to 800 ms. This finding is typical of block below the AV node. Permanent dual chamber cardiac pacing relieved his symptoms.

"Permanent pacing after acute myocardial infarction."

Indications for permanent pacing in acquired AV block

Class I indications

1 Third-degree and advanced second-degree AV block at any anatomical level, associated with any one of the following conditions:

- **a** Bradycardia with symptoms (including heart failure) presumed to be due to AV block. (Level of evidence: C)
- **b** Arrhythmias and other medical conditions requiring drugs that result in symptomatic bradycardia. (Level of evidence: C)
- **c** Documented periods of asystole of 3.0 s or longer, any escape rate of less than 40 bpm or with any escape rhythm below the AV node in awake, symptom-free patients. (Level of evidence: C)
- **d** Atrial fibrillation and bradycardia with one or more pauses of at least 5 s or longer in awake, symptom-free patients. (Level of evidence: C)
- **e** Following catheter ablation of the AV junction. (Level of evidence: C)
- **f** Postoperative AV block that is not expected to resolve after cardiac surgery. (Level of evidence: C)
- **g** Neuromuscular diseases with AV block, such as myotonic muscular dystrophy, Kearns–Sayre syndrome, Erb muscular dystrophy, and peroneal muscular atrophy, with or without symptoms, because there may be unpredictable progression of AV conduction disease. (Level of evidence: B)

2 Second-degree AV block regardless of type or site of block, with associated symptomatic bradycardia. (Level of evidence: B)

3 Third-degree AV block with evidence for cardiomegaly or LV dysfunction. (Level of evidence: B)

Class IIa indications

1 Persistent third-degree AV block with an escape rate of greater than 40 bpm in asymptomatic adult patients without cardiomegaly. (Levels of evidence: C)

2 Asymptomatic type II second-degree AV block at intra-His or infra-His levels found at electrophysiological study. (Level of evidence: B)

3 First- or second-degree AV block with symptoms similar to those of pacemaker syndrome or hemodynamic compromise. (Level of evidence: B)

4 Asymptomatic type II second-degree AV block with narrow QRS. Note that when type II second-degree AV block occurs with wide QRS, including isolated right bundle branch block (RBBB), pacing becomes a class I indication. (Level of evidence: B)

Class IIb indications

1 Neuromuscular diseases such as myotonic muscular dystrophy, Kearns–Sayre syndrome, Erb muscular dystrophy, and peroneal muscular atrophy with any degree of AV block (including first-degree AV block), with or without symptoms, because there may be unpredictable progression of AV conduction disease. (Level of evidence: B)

2 AV block in the setting of drug use and/or toxicity when the block is expected to recur even after the drug is withdrawn. (Level of evidence: B)

Class III (not indicated)

1 Asymptomatic first-degree AV block. (Level of evidence: B)

2 Asymptomatic type I second-degree AV block at the AV nodal level or not known to be intra- or infra-Hisian. (Levels of evidence: C)

3 AV block expected to resolve and/or unlikely to recur (e.g. drug toxicity, Lyme disease, or transient increases in vagal tone or during hypoxia in sleep apnea syndrome in the absence of symptoms). (Level of evidence: B)

Chronic bifascicular block

In bifascicular block, the ECG shows evidence of conduction delay in both bundles such as complete RBBB with anterior or posterior hemiblock or complete left bundle branch block (LBBB) alone. The term alternating bundle branch block (BBB; or bilateral BBB) refers to evidence for impaired conduction in the right bundle and both fascicles of the left bundle on successive ECGs. In strict terms, evidence for disease in all three fascicles should justify the term trifascicular block. However, the term trifascicular block has also been loosely applied to bifascicular block with first-degree AV block where the block may actually be due to either

or a combination of AV nodal and infra-His conduction disease.

The prevalence of BBB increases with age (approximately 1% in middle age and rising to 17% at age 80).[23] LBBB is less common but its presence is associated with a higher incidence of structural heart disease. In bifascicular block, the risk of progression to advanced heart block is related to the presence of symptoms. Syncope is the sole predictor. In the absence of syncope, the annual incidence is 0.6–0.8%, whereas syncopal patients have a 5–11% annual risk of progression to AV block.[24,25] The finding of an His–ventricular (HV) interval of greater than 100 ms or the demonstration of intra- or infra-Hisian block during incremental atrial pacing at a rate of less than 150 bpm is highly predictive for the development of high-grade AV block (Figure 1.10), but their prevalence is low and hence, sensitivity is low.[26,27] Care has to be exercised during atrial pacing so as not to misinterpret physiological AV block that is often seen with long–short intervals. The majority of patients with bifascicular block who undergo electrophysiological studies will have normal or mildly prolonged HV intervals. However, in patients with BBB and normal electrophysiological study, implantable loop monitors have shown that recurrent syncope is often due to a bradyarrhythmia, most commonly sudden onset paroxysmal AV block.[28] Hence, unexplained syncope is a better indicator of the need for pacing than electrophysiological studies.

Because chronic bifascicular block is associated with other forms of heart disease, pacing alone, although successful for symptom relief, has not been shown to improve mortality. In the presence of ventricular dysfunction, ventricular tachycardia is an alternative mechanism for syncope and sudden death. Programmed stimulation of the ventricle may demonstrate inducibility for ventricular arrhythmia, necessitating the consideration of an ICD.

Indications for pacing in chronic bifascicular block

Class I indications

1 Advanced second-degree AV block or intermittent third-degree AV block. (Level of evidence: B)
2 Type II second-degree AV block. (Level of evidence: B)
3 Alternating BBB. (Level of evidence: C)

Class IIa indications

1 Syncope not demonstrated to be due to AV block and when other likely causes have been

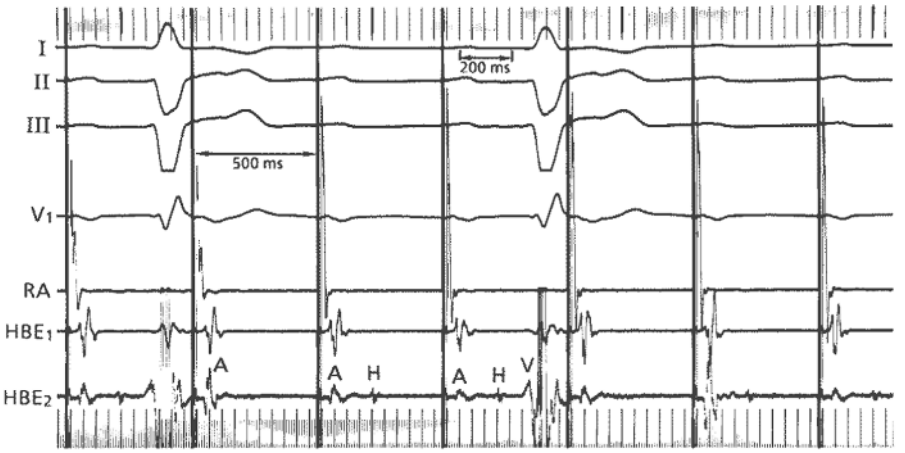

Figure 1.10 Infra-His atrioventricular (AV) block induced with atrial pacing. A 68-year-old male was admitted complaining of recurrent dizziness and syncope. His baseline 12-lead ECG showed a PR interval of 0.20 s and a right bundle block QRS morphology. With decremental atrial pacing, block below the His bundle was demonstrated at 500 ms (120 bpm). These findings are indicative of severe diffuse conduction system disease. A permanent dual chamber pacemaker was implanted, and the patient's symptoms resolved. From top to bottom: I, II, III, and V_1 are standard ECG leads; intracardiac recording from the right atrial appendage (RA) and His bundle (HBE_1 for the proximal His bundle and HBE_2 for the distal His bundle). A, atrial depolarization; H, His bundle depolarization; V, ventricular depolarization.

excluded, specifically ventricular tachycardia. (Level of evidence: B)
2 Incidental finding at electrophysiology study of markedly prolonged HV interval ($\geq$100 ms) in asymptomatic patients. (Level of evidence: B)
3 Incidental finding at electrophysiology study of pacing-induced infra-His block that is not physiological. (Level of evidence: B)

Class IIb indications

1 Neuromuscular diseases such as myotonic muscular dystrophy, Kearns–Sayre syndrome, Erb muscular dystrophy, and peroneal muscular atrophy with any degree of fascicular block with or without symptoms, because there may be unpredictable progression of AV conduction disease. (Level of evidence: C) (*Note that this is a class IIa indication in European guidelines.*)

Class III (not indicated)

1 Fascicular block without AV block or symptoms. (Level of evidence: B)
2 Fascicular block with first-degree AV block without symptoms. (Level of evidence: B)

Reflex syncope

Reflex syncope includes a group of conditions that are neurally mediated and result in a common cardiovascular response of vasodilation and/or bradycardia. Cerebral hypoperfusion results in loss of consciousness. Any one of the two components of the reflex may predominate. The cardioinhibitory response with predominant bradycardia results from increased parasympathetic tone and is characterized by sinus slowing, sinus arrest (Figure 1.11), prolongation of the PR interval, and less commonly, AV block that occurs alone or in combination. The vasodepressor response is secondary to a reduction in sympathetic activity and marked by loss of vascular tone and hypotension. This effect is independent of heart rate changes.

The two most common types of reflex syncope are neurocardiogenic (vasovagal) and carotid sinus syndrome. The other types are generally referred to as situational syncope because they are generally associated with a particular stimulus (Table 1.4). Several forms are recognized based on the triggering mechanism, although the triggers may vary considerably in and between individual patients. The classical vasovagal syncope is most common in young patients and occurs as isolated episodes. Generally, patients experience a distinct prodrome of dizziness, nausea, diaphoresis, and visual changes, followed by loss of consciousness. Recovery is fairly rapid and it is unusual to experience post-ictal states. However, a third of patients (commonly older adults) may have minimal or no prodromal symptoms and syncope can be sudden with bodily injuries. When vasovagal syncopal spells begin at an older age, they may be an expression of a pathological process heralding early autonomic failure.[29]

Table 1.4 Types of neurally-mediated syncope (Source: Adapted from Taskforce 2009.[29] Reproduced with permission of Oxford University Press.)

Vasovagal	Mediated by emotional stress such as fear, pain, sight of blood, instrumentation
	Mediated by orthostatic stress
Carotid sinus syncope	
Situational	Cough, sneeze
	Gastrointestinal stimulation: swallow, defecation, visceral pain
	Micturition syncope
	Post exercise
	Post prandial
Other	Triggered by increased intrathoracic pressure, e.g. laughing, playing brass instruments, weightlifting
Atypical forms	No identified precipitant

Reflex syncope becomes important when frequent syncope alters quality of life, occurs with a very short prodrome exposing patients to risk of trauma, or occurs during high-risk activity such as driving, flying, or heavy machine operation. Non-pharmacological measures such as avoidance measures, physical counter-pressure maneuvers, and tilt training are useful initial interventions for control of vasovagal syncope.[30] Pharmacological interventions predominantly address the vasodepressor component and may occasionally be effective for individual patients, but randomized trials have not proven clear benefit from any particular drug. Observational studies suggest that β-adrenergic blockers may be effective in patients over the age of 40 years by alleviating the

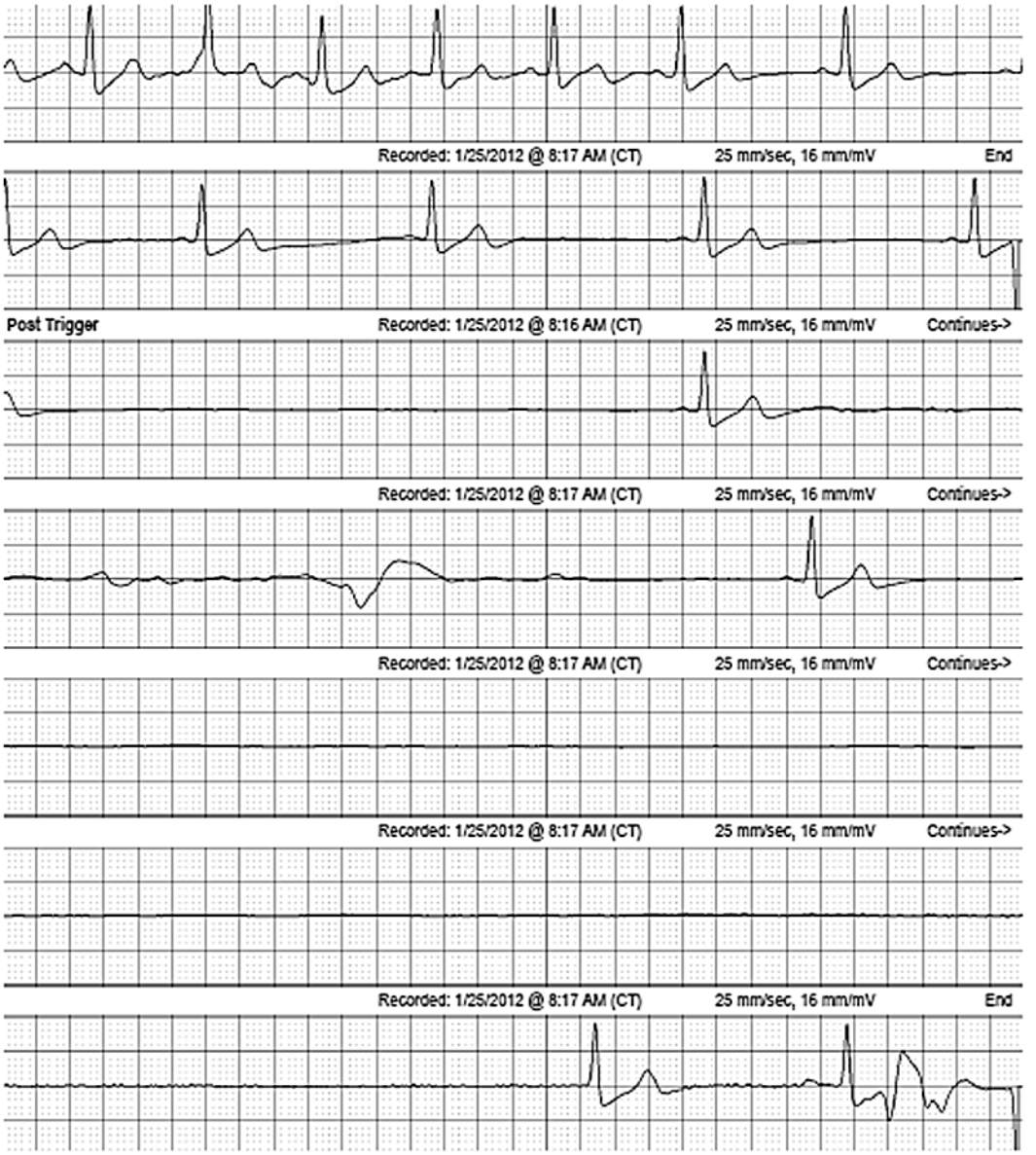

Figure 1.11 Marked cardioinhibitory response to neurally-mediated syncope. This 45-year-old female presented with syncope preceded by nausea while wearing an event monitor. There was gradual sinus slowing with prolonged sinus arrest resulting in syncope. Intense vagal stimulation can suppress junctional escape rhythms.

hyperadrenergic initial response that often precedes vasovagal syncope.[31]

The role of cardiac pacing in vasovagal syncope has been evaluated in multiple clinical trials with varying results. Meta-analysis of these studies suggested a 17% non-significant reduction in syncope in double-blind studies when both the paced and unpaced groups received pacemaker implants (thereby eliminating a placebo effect). More recent trials using implantable loop recorders (ILRs) to document asystole during vasovagal syncope have been more favorable toward permanent cardiac pacing for symptom relief. The ISSUE 3 study randomized patients aged 40 years or older, with three

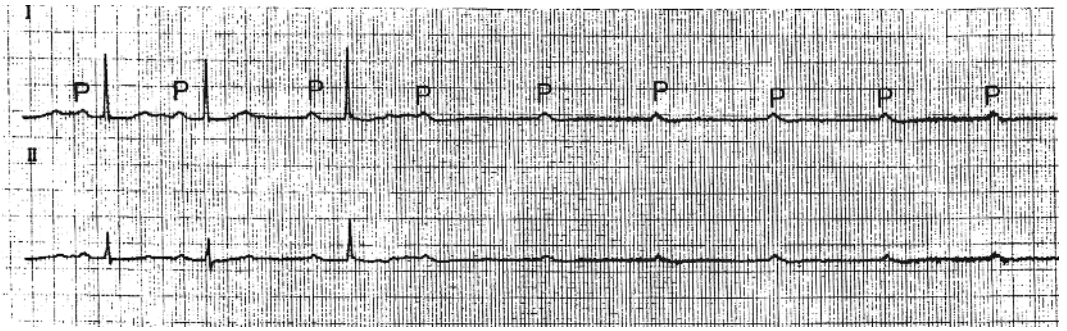

Figure 1.12 Response to gentle carotid massage in carotid hypersensitivity syndrome. A 49-year-old male complained of near-syncope, which typically occurred while shaving or turning his neck. Carotid sinus massage was performed shortly before the second QRS complex. Note that the sinus rate slows prior to the third QRS complex, followed by complete heart block with ventricular asystole.

or more syncope episodes and documentation of syncope with greater than 3-s asystole or 6s asystole without syncope, to pacing-activated or -inactivated modes after implantation. The study showed a significant reduction in recurrent syncope at 2 years from 57% in the pacing inactivated group to 25% in the paced group.[32] However, it should be noted that 511 patients with highly symptomatic vasovagal syncope underwent implantation of an ILR in order to identify 89 (17%) patients with important asystole.

In the presence of predominantly cardioinhibitory responses, cardiac pacing tends to be effective for attenuation of symptoms and is a reasonable consideration in the older patients. Because the cardioinhibitory and vasodepressor components can variably manifest in the same patient during different episodes, patients should be warned of the possibility of recurrence relating to hypotension. In younger patients, however, simple measures should be exhausted before considering commitment to life-long pacemaker therapy. In the ISSUE 3 study, pacemaker implantation was associated with complications in 6%. Longer-term complications of pacemaker generator changes and lead malfunction are more pertinent to younger patients.

One variant of neurally-mediated syncope is the hypersensitive carotid sinus syndrome. A mildly abnormal response to vigorous carotid sinus massage may occur in up to 25% of patients, especially if co-existing vascular disease is present. Some patients with an abnormal response to carotid sinus massage may have no symptoms suggestive of carotid sinus syncope. On the other hand, the typical history of syncope such as blurred vision and lightheadedness or confusion in the standing or sitting position, especially during movement of the head or neck, should suggest the diagnosis. Classical triggers of carotid sinus syncope are head turning, tight neckwear, shaving, and neck hyperextension. Syncopal episodes are generally reproducible in a given patient. Because of the predominantly bradycardic (cardioinhibitory) response to carotid hypersensitivity, permanent pacing has a high success rate for alleviating symptoms (Figure 1.12).

Indications for pacing in neurally-mediated syncope and hypersensitive carotid sinus syndrome

Class I indications

1 Recurrent syncope caused by spontaneous carotid sinus stimulation; carotid sinus pressure induces ventricular asystole of greater than 3-s duration. (Level of evidence: C)

Class IIa indications

1 Recurrent syncope without clear, provocative events and with a hypersensitive cardioinhibitory response of 3 s or longer. (Level of evidence: C)

Class IIb indications

1 Significantly symptomatic and recurrent neurocardiogenic syncope associated with bradycardia documented spontaneously or at the time of tilt table testing. (Level of evidence: B)

The 2007 European guidelines state that recurrent severe vasovagal syncope with prolonged asystole during ECG recording or tilt table testing, after failure of medical therapy, is a class IIa indication in patients aged over 40 years and a class IIb indication in patients under 40 years.

Class III (not indicated)

1 A hyperactive cardioinhibitory response to carotid sinus stimulation in the absence of symptoms or in the presence of vague symptoms.

2 Situational vasovagal syncope in which avoidance behavior is effective and preferred.

The European guidelines recommend avoidance of pacing in patients with vasovagal symptoms in whom significant bradycardia cannot be documented.[12]

Idiopathic orthostatic hypotension

Idiopathic orthostatic hypotension is a related neurocirculatory disorder that may respond to permanent pacing. Small single-center studies have documented a beneficial response to atrial or AV sequential pacing in a small number of patients with idiopathic orthostatic hypotension refractory to salt and steroid therapy.[33,34] A potential mechanism for benefit includes increased cardiac output from pacing at higher rates (the lower rate in these series varied from 80 to 100 bpm), and consequent vasoconstriction. The therapy, while beneficial in some, has significant variability in response from patient to patient. There are currently no class I or class II indications for permanent pacing for idiopathic orthostatic hypotension.

Specific conditions associated with cardiac conduction disease

Chronic neuromuscular disorders

A number of neuromuscular disorders are associated with cardiomyopathy and a high incidence of sudden death. In general, the direct consequence of the neuromuscular defects, such as respiratory failure, limits life span. However, in some of these conditions, cardiac disease may be responsible for greater morbidity and mortality. Most often, bradyarrhythmias in neuromuscular disorders are due to direct involvement of the specialized AV conduction system. The relatively small numbers of patients involved and the absence of randomized, placebo-controlled clinical trials make it difficult to provide definitive guidelines for pacemaker implantation. Since mortality and the incidence of sudden cardiac death are high in this group of disorders, and because conduction system disease tends to be unpredictable, the development of second- or third-degree AV block, even in the absence of symptoms, is considered a class I indication for permanent pacing. In addition, suggestive symptoms such as syncope should be promptly and aggressively investigated. Some authorities recommend yearly ECGs and 24-h ambulatory recordings for patients with one of these disorders to facilitate early recognition of AV block. It should also be realized, however, that life-threatening ventricular arrhythmias are also fairly common in this population, especially when LV function is impaired or complicated by hypertrophic cardiomyopathy (HCM), so use of a permanent pacemaker will not necessarily prevent sudden cardiac death.

The neuromuscular disorders most frequently associated with symptomatic conduction system disease are as follows.

Myotonic muscular dystrophy

The type 1 form (Steinert disease) is the most common adult form of neuromuscular disease and is inherited as an autosomal dominant disorder that usually becomes clinically manifest in the third decade. A third of deaths are sudden and related to heart block or ventricular tachyarrhythmias.[35,36] Permanent pacemakers are warranted for second- or third-degree AV block, even in the absence of symptoms. A recent large nonrandomized study of type 1 myotonic dystrophy patients compared an invasive electrophysiological evaluation when PR interval exceeded 200 ms and/or QRS was prolonged in excess of 100 ms with a non-invasive clinical approach. The invasive group who underwent pacemaker implantation based on the finding of an HV interval greater than 70 ms had a significant reduction in sudden death.[37]

Duchenne muscular dystrophy

This progressive X-linked disease usually becomes clinically apparent in the mid-teens and is fatal by the end of the third decade. The ECG typically

shows prominent R waves in V1 with deep narrow Q waves in the lateral precordial leads. Although cardiac involvement is almost universal, the incidence of arrhythmias is variable, with many patients dying from heart failure. In the absence of definitive data, it seems prudent to recommend permanent pacemaker implantation in patients who develop second-degree or higher degrees of AV block, especially in the setting of a wide QRS complex.

Becker muscular dystrophy

This is an X-linked condition closely related to Duchenne muscular dystrophy. It has similar electrocardiographic abnormalities, but progresses more slowly. The severity of cardiac involvement does not parallel the severity of neuromuscular disease. Although there is less experience with this disorder, the indications for permanent pacing are similar to those for patients with Duchenne muscular dystrophy.

Emery–Dreifuss muscular dystrophy

This is a slowly progressive X-linked muscular dystrophy with a high incidence of conduction system disease and arrhythmias. Sudden cardiac death due to bradyarrhythmias has been well documented, and permanent pacemakers are often necessary.

Limb girdle muscular dystrophy

This is a heterogeneous group of disorders that usually begin with weakness in the upper legs and pelvic musculature. Cardiac involvement is variable, although there is a familial form with a high incidence of conduction system disease. Patients with a family history of heart block or sudden death should be considered for permanent pacing relatively early in the course of their disease.

Kearns–Sayre syndrome

This is a multisystem mitochondrial disorder characterized by progressive external ophthalmoplegia, pigmentary retinal degeneration, and AV block. Involvement of the distal conduction system is the rule and high-degree AV block is common. Although definitive data are lacking, it seems prudent to implant a permanent pacemaker prophylactically when marked first-degree AV block becomes manifest.

Indications for pacing in the chronic neuromuscular disorders

These are included under "Acquired atrioventricular block."

Infiltrative and inflammatory disorders

The infiltrative cardiomyopathies are characterized by deposition of abnormal substances that commonly lead to stiffening of the ventricular myocardium, causing diastolic dysfunction. Many of these diseases increase wall thickness, and may present with small ventricular volume and occasional LV outflow tract (LVOT) obstruction so as to mimic HCM. Some may have minimal structural abnormalities by echocardiography but involve the conduction system early such that initial presentation may be with heart block or ventricular arrhythmias. Infiltrative and inflammatory cardiomyopathies particularly prone to manifest cardiac conduction disease include sarcoidosis, giant cell myocarditis, amyloidosis, Wegener's granulomatosis, metabolic diseases such as hemochromatosis, primary oxaluria, and hematological malignancies and cardiac tumors. Some metabolic diseases such as Fabry disease and the glycogen storage diseases (e.g. Danon disease) demonstrate frequent cardiac involvement. AV block, although rare, is well recognized in these conditions. In South American countries, Chagas disease is a common cause of bradyarrhythmias requiring cardiac pacing.

The prognosis of many of these disorders is usually more closely related to the underlying disease, although the actual cause of death may be cardiac. For example, malignancies involving the heart, especially "solid" tumors, tend to have a uniformly poor prognosis. Nonetheless, infiltrative disorders may directly affect the conduction system and cause life-threatening bradyarrhythmias and tachyarrhythmias. In these situations, permanent pacemakers or defibrillators can be life saving.

Sarcoidosis

This is a relatively common disorder of unknown etiology and is characterized by formation of noncaseating granulomas in various organs, including the myocardium. After an early stage of granulomatous inflammation, sarcoidosis may resolve completely or progress with end organ fibrosis.

Cardiac involvement is common in autopsy studies but infrequently recognized clinically, and is a common cause of death. Approximately 5% of patients will have cardiac-predominant disease without evidence for other organ involvement.[38] Granulomas typically involve the basal septum and posterior wall, resulting in conduction system disease, localized LV aneurysms, and ventricular tachycardia. Definitive diagnosis requires demonstration of cardiac granulomas, but patchy myocardial involvement reduces yield from cardiac biopsy to a low 25–30%. Imaging with fluorodeoxyglucose (^{18}F-FDG) and PET or CMR can identify inflammation and has better diagnostic accuracy compared with older techniques.[39]

Although conduction abnormalities are the most common cardiac presentation, the risk of sudden death from ventricular arrhythmias is high in the presence of significant cardiac involvement. Hence, once a diagnosis of cardiac sarcoidosis is established, it is common to consider an ICD.[11] Treatment with corticosteroids has been shown in retrospective studies to stabilize LV function, but has no significant impact on conduction disease or ventricular arrhythmias.[40]

Amyloidosis

The amyloidoses are a group of multisystem diseases characterized by deposition of the extracellular proteinaceous material, amyloid. These deposits occur as a result of misfolding of a precursor protein.[41] The most common clinical amyloidoses that involve the heart are those due to deposition of light chains (AL amyloid), and a hepatically expressed protein, transthyretin (TTR). A rarer form of wild-type TTR infiltration is seen in men aged older than 70 years and is termed senile amyloidosis. Cardiac involvement is the most common cause of death in amyloidosis and manifests as marked wall thickening due to infiltration in all anatomical distributions, including the atria, ventricles, and perivascular space. Because the infiltration is extracellular, despite the appearance of increased wall thickness on echocardiography, the voltage on surface ECG will be low and is a clue to the diagnosis. Perivascular fibrosis can affect the specialized conduction system, causing SND, intraventricular conduction defects, or AV block. Patients with senile cardiac amyloidosis most commonly progress to heart block. Permanent pacing is helpful in alleviating symptoms, but has not been demonstrated to provide a survival benefit.[42]

Collagen vascular diseases

Several systemic inflammatory diseases can involve the heart and vascular structures, resulting in pericarditis, myocarditis, and vasculitis, including coronary artery disease. Arrhythmias are not common, but fibrosis of the conduction system has been reported to cause AV block, particularly in Wegener granulomatosis, and polymyositis. An acute inflammatory AV block that reverses with treatment has been reported with Wegener granulomatosis. Congenital heart block associated with the transmission of anti-SS A Ro-antibodies from the mother occurs in systemic lupus erythematosis and to a lesser extent in primary Sjögren syndrome (see "Pacing for children and adolescents").[43]

Chagas disease

This chronic inflammatory disease, caused by the protozoa *Trypanosoma cruzi*, is largely restricted to endemic areas in Central and South America. The acute phase of the infection usually goes unrecognized and is rarely life threatening. Approximately 20% of patients will develop chronic Chagas disease several years (10–20 years) after the initial infection. Conduction system disease precedes other manifestations, such as localized cardiac aneurysms, thromboembolism, and a diffuse cardiomyopathy with marked cardiomegaly. Sinus bradycardia, atrial fibrillation, AV block, and ventricular arrhythmias are common. Even the early phases of conduction abnormalities, such as RBBB and fascicular block, are associated with an increased risk of sudden death.[44]

Genetic cardiomyopathies

Familial or genetic cardiomyopathies account for 20–30% of disease originally diagnosed as idiopathic dilated cardiomyopathy. These cardiomyopathies share some management strategies. Once the proband is identified, evaluation of family members can identify clinically silent cardiomyopathy and allow for early interventions. Genetic

testing can be helpful in some diseases, especially if the pathogenic mutation is identified.[45]

Dilated cardiomyopathy

Cardiomyopathies resulting from mutations in the genes coding for the nuclear envelope protein lamina A and C (*LMNA*) and mutations in the *SCN5A* gene are particularly associated with conduction system disease and ventricular arrhythmias.[45] Mutations in *LMNA* associated with cardiomyopathy are highly penetrant, with most carriers demonstrating some evidence of cardiac involvement by 65 years of age. Initial manifestations may be first-degree AV block with gradual progression to compete heart block. Associated atrial arrhythmias are common. Cardiomyopathy usually follows the development of conduction system disease by several years and risk of ventricular arrhythmias is highest when significant systolic dysfunction is present.[40] The diagnostic possibility of an inherited cardiomyopathy has two implications for the relatively young patient presenting with complete heart block: (1) a cardiac evaluation is warranted prior to permanent pacemaker implantation and (2) periodic assessment of LV function is essential after cardiac pacing for early detection of LV dysfunction. Indications for pacing in dilated cardiomyopathy are discussed under "Pacing for systolic heart failure."

Hypertrophic cardiomyopathy

This is a common disease entity caused by autosomal dominant mutations in genes encoding protein components of the sarcomere and its constituent myofilament elements. It is characterized by excessive myocardial hypertrophy without cavity dilatation, but varying degrees of phenotypic expressions exist. The disease may manifest with LVOT obstruction, diastolic dysfunction, mitral regurgitation, myocardial ischemia, arrhythmias including atrial fibrillation, and sudden death. The distinction between the obstructive and non-obstructive varieties is important because management strategies are largely dependent on symptoms of obstruction. LVOT obstruction is well recognized to be dynamic. Although initially attributed to systolic contraction of the hypertrophied basal ventricle encroaching on the outflow tract, recent studies emphasize the importance of drag forces on an abnormally positioned mitral apparatus that push the leaflets into the outflow tract during systole.[46]

In HCM with significant LV outflow obstruction, atrial synchronized RV apical pacing results in decrease in outflow gradient and symptomatic improvement in a subset of patients. The exact mechanism of improvement is unclear, but may be related to paradoxical septal movement during systole, although alternate or additional mechanisms such as ventricular dilatation and chronic remodeling may play a part.

Initial enthusiasm for dual chamber pacing in obstructive HCM was tempered by randomized trials that eliminated a placebo effect. In three randomized cross-over trials of continuous DDD pacing compared with AAI pacing, the overall reduction in outflow tract gradient with DDD pacing was modest (20–40%), with substantial variation among individual patients, and symptomatic improvement was no different from that in AAI paced patients.[46] Acute hemodynamic studies and echocardiographic LV morphology do not predict long-term benefit from dual chamber pacing. One subgroup that appears to derive most benefit is patients over the age of 65 years.[47] When pacing is performed to relieve outflow tract obstruction in HCM, it is important to optimize AV delay to allow ventricular pre-excitation, but not to compromise ventricular filling with too short a delay. In addition, rate adaptive AV delay is necessary to maintain ventricular pre-excitation during exercise. The position of the ventricular lead should be such that it provides distal apical capture.

Permanent pacing is currently not considered an early mode of intervention for symptomatic obstructive HCM. Surgical myomectomy or alcohol septal ablation has been shown to provide more reliable and consistent clinical improvement. Pacing is therefore considered only for patients who are not candidates for these interventions or for those with pre-existing dual chamber pacing devices. Approximately 10–20% of patients will develop persistent complete heart block following alcohol septal ablation and will require permanent cardiac pacing. The risk of ventricular arrhythmias following septal ablation ranges in various reports from 2% to 5% per year. The choice of pacemaker

versus ICD should be based on current guideline recommendations.[46]

Indications for permanent pacing for hypertrophic cardiomyopathy (adapted from guidelines published in 2011[46])

Class I indications

1 Class I indications for sinus node dysfunction or AV block as previously described. (Level of evidence: C)

Class IIa indications

1 In patients with HCM who have had a dual chamber device implanted for non-HCM indications, it is reasonable to consider a trial of dual chamber AV pacing from the RV apex for the relief of symptoms attributable to LVOT obstruction. (Level of evidence: B)

Class IIb indications

1 Permanent pacing may be considered in medically refractory symptomatic patients with obstructive HCM who are suboptimal candidates for septal reduction therapy. (Level of evidence: B)

Class III (not indicated)

1 Permanent pacing implantation for the purpose of reducing gradient should not be performed in patients with HCM who are asymptomatic or whose symptoms are medically controlled. (Level of evidence: C)

2 Permanent pacing implantation should not be performed as a first-line therapy to relieve symptoms in medically refractory symptomatic patients with HCM and LVOT.

Pacing for systolic heart failure

Early studies suggested that dual chamber pacing, especially with a short AV delay, improved hemodynamics by optimizing ventricular filling or reducing diastolic mitral regurgitation. However, randomized studies failed to confirm these beneficial effects. In contrast, there is considerable evidence that the use of biventricular pacing, by providing cardiac resynchronization therapy (CRT), reduces heart failure symptoms and lowers heart failure mortality with or without an ICD.[11] CRT has been well studied in randomized trials involving over 6000 patients and has demonstrated favorable structural remodeling with improved LV function and reduced mitral regurgitation in 70% of patients. Recent trials of less symptomatic patients (NYHA class I and II) show a reduction in composite end points of heart failure hospitalization and death, but mortality reduction is limited to class II patients.[48,49] All but one trial of CRT involved the use of an ICD as opposed to a CRT pacemaker. Consequently, it is common practice to incorporate defibrillator therapy when CRT pacing is indicated. However, CRT pacing alone has a significant impact on improving quality of life and functional status, and is a reasonable choice in older patients when prolongation of life is not the primary consideration. In addition, for patients who demonstrate a cardiomyopathy as a result of dyssynchrony induced by RV pacing, addition of a LV pacing lead to provide biventricular pacing alone may result in adequate reversal of cardiomyopathy and avoid the need for an ICD.

CRT device implantation is more difficult than placement of a non-CRT pacemaker or ICD and complication rates are greater, usually related to the additional manipulations required for the lead and its delivery systems. Lead dislodgement requiring revision is particularly more common.[50] Appropriate patient selection for this therapy is therefore crucial for ensuring benefit. In *post-hoc* subgroup analyses of clinical trials, factors associated with the most benefit from CRT include non-ischemic dilated cardiomyopathy, the presence of LBBB, and QRS duration of 150 ms or longer.[51] The recent 2012 focused update guideline of the ACC/AHA/HRS limits the class I indication for CRT to patients with LBBB and a QRS duration of 150 ms or longer.[13]

The role of biventricular pacing in atrial fibrillation is less well established. As the purpose of pacing is to correct LV dyssynchrony, adequate heart rate control in atrial fibrillation is essential to allow for consistent biventricular pacing. Often, this requires AV nodal ablation.[52]

Indications for pacing in heart failure and impaired LV systolic function

Class I indications

1 Class I indications for sinus node dysfunction or AV block as previously described. (Level of evidence: C)

2 CRT pacing in patients with an LV ejection fraction (LVEF) of 35% or less, sinus rhythm, LBBB, and QRS duration of150 ms or longer, and NYHA class II, III, or ambulatory IV symptoms on guideline directed medical therapy (GDMT). (Level of evidence: A for NYHA III/IV and B for NYHA class II) Most of these patients will qualify for ICD therapy. The choice between a biventricular pacemaker and a biventricular ICD should be made based upon the patient's preference and other clinical factors.

Class IIa indications

1 CRT pacing can be useful in patients with an LVEF of 35% or less, sinus rhythm, LBBB with a QRS duration of 120–149 ms and NYHA class II, III or ambulatory IV symptoms on GDMT. (Level of evidence: B)

2 CRT can be useful in patients with a LVEF of 35% or less, sinus rhythm, non-LBBB pattern with a QRS duration of 150 ms or longer, and NYHA class III or ambulatory IV symptoms on GDMT. (Level of evidence A)

3 CRT can be useful in patients with atrial fibrillation and an LVEF of 35% or less on GDMT if:

a the patient requires ventricular pacing or otherwise meets CRT criteria and

b AV nodal ablation or pharmacological rate control will allow near 100% ventricular pacing with CRT. (Level of evidence: B)

4 CRT can be useful in patients on GDMT who have an LVEF of 35% or less and are undergoing device placement or replacement with anticipated requirement for significant (>40%) ventricular pacing. (Level of evidence: C)

Class IIb indications

1 CRT may be considered for patients who have an LVEF of 35% or less, ischemic etiology for heart failure, sinus rhythm, LBBB with a QRS duration of 150 ms or longer, and NYHA class 1 symptoms on GDMT. (Level of evidence: C)

2 CRT maybe considered for patients who have an LVEF of 35% or less, sinus rhythm, non-LBBB pattern with a QRS duration 120–149 ms, and NYHA class III/ambulatory class IV symptoms on GDMT. (Level of: B)

3 CRT maybe considered for patients who have an LVEF of 35% or less, sinus rhythm, non-LBBB pattern with a QRS duration of 150 ms or longer, and NYHA class II symptoms on GDMT. (Level of evidence: B)

Class III (not indicated)

1 CRT pacing is not recommended for patients with NYHA class I or II symptoms and a non-LBBB pattern with a QRS duration of less than 150 ms. (Level of evidence: B)

2 CRT is not indicated in patients whose functional status and life expectancy are limited predominantly by chronic non-cardiac conditions. (Level of evidence: C)

Pacing to prevent or terminate tachycardias

Pacing techniques may terminate arrhythmias that depend on a re-entrant mechanism. For supraventricular tachycardias (SVTs) and atrial arrhythmias, antiarrhythmic drugs or catheter-based ablation is often effective in preventing recurrence and hence, in contemporary practice, the use of cardiac pacing is limited to patients who have associated bradyarrhythmias. Rarely, a patient who fails on or is unsuitable for drugs or ablation may benefit from antitachycardia pacing if reliable and repetitive termination of the arrhythmia can be demonstrated without pro-arrhythmic effects (Figure 1.13). Such devices for pacing without defibrillation capability are limited to the atrium. Ventricular antitachycardia pacing is currently only available with ICDs.

Ventricular arrhythmias may be pause dependent and pacing prevents prolonged pauses and can prevent the arrhythmia in some patients. Typically, the onset of torsades de pointes VT in patients with a prolonged QT interval is preceded by long RR intervals (Figure 1.14). Pacing combined with β-adrenergic blockers has been shown to reduce the occurrence of sudden cardiac death in patients with the congenital long-QT syndrome.[53] In patients with long-QT syndrome at high risk for sudden death however, such pacing is usually provided via an ICD.

Several modes of permanent pacing therapy have been tested for prevention of atrial fibrillation. However, none of the special pacing techniques, such as dual site atrial pacing, biatrial pacing, alternative sites for atrial pacing in the region of the

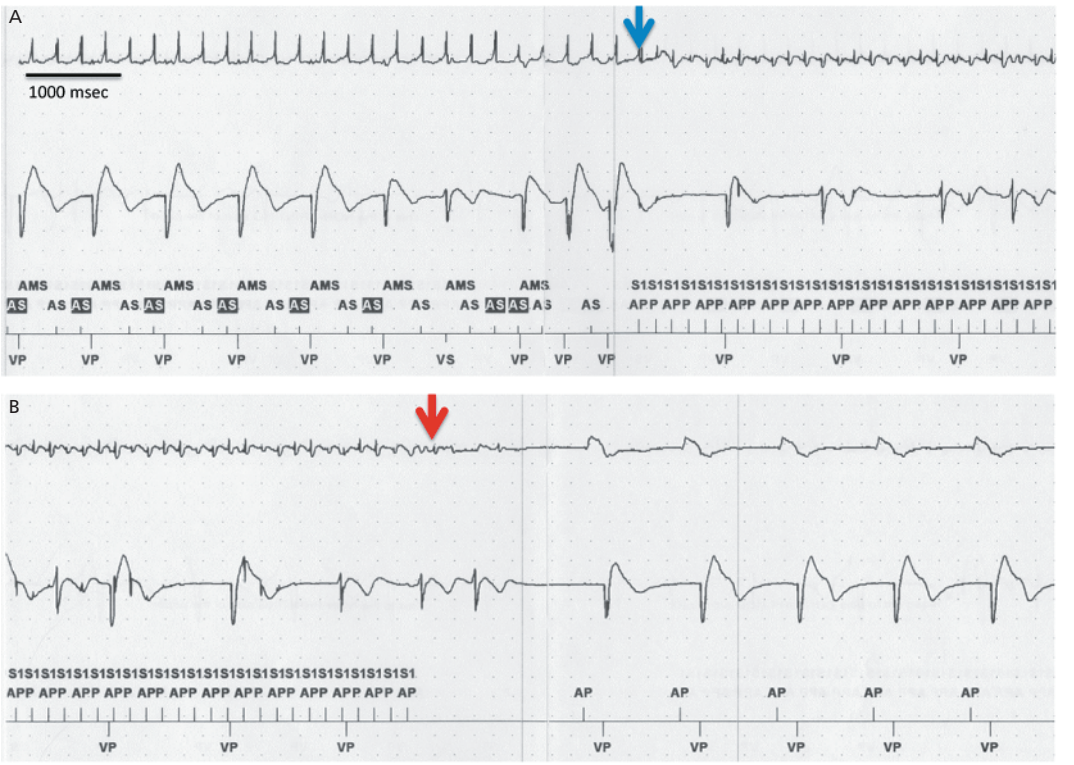

Figure 1.13 Atrial overdrive pacing to terminate atrial tachycardia. This 75-year-old female with pulmonary hypertension and recurrent atrial tachycardia had a dual chamber pacemaker for tachy–brady syndrome. Her atrial arrhythmia was reproducibly terminated with atrial overdrive pacing. (A,B)From top to bottom: atrial bipolar electrograms, ventricular electrograms, and marker channels. At baseline, an atrial tachycardia at a cycle length of 240 ms (250 bpm) was present with ventricular pacing. Rapid atrial overdrive pacing was delivered (blue arrow, A) and resulted in termination of tachycardia (red arrow, B) with resumption of AV synchronized pacing.

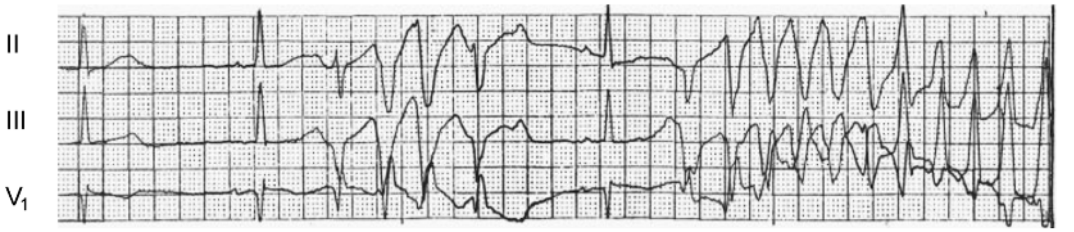

Figure 1.14 Onset of torsades de pointes ventricular tachycardia. This rhythm strip of ECG leads II, III, and V_1 shows paroxysms of polymorphic ventricular tachycardia in an individual with recurrent syncope. There is baseline QT interval prolongation and bradycardia. Note the long–short cycle length sequence that initiates the arrhythmia.

Bachmann bundle or low septum, or atrial overdrive pacing algorithms, has shown significant benefit.[54] In patients with SND, the use of atrial-based pacing is superior to VVI pacing in reducing atrial fibrillation and stroke. Benefit is maximal when ventricular pacing is minimized.

Indications for permanent pacing to prevent or terminate tachycardias

Class I indications

1 Permanent pacing is indicated for sustained pause-dependent VT, with or without QT prolongation. (Level of evidence: C)

Class IIa indications

1 Permanent pacing is reasonable for high-risk patients with congenital long-QT syndrome. (Level of evidence: C) (Note that most of these patients will qualify for an ICD.)

2 Symptomatic recurrent SVT that is reproducibly terminated by pacing in the unlikely event that catheter ablation and/or drugs fail to control the arrhythmia or produce intolerable side effects. (Level of evidence: C)

Class IIb indications

1 Prevention of symptomatic, drug-refractory recurrent atrial fibrillation in patients with co-existing sinus node dysfunction. (Level of evidence: B)

Class III (not indicated or recommended)

1 The presence of accessory pathways with the capacity for rapid anterograde conduction whether or not the pathway(s) participate in the mechanism of the tachycardia.

2 Frequent or complex ventricular ectopic activity without sustained VT in the absence of the long-QT syndrome.

3 Torsades de pointes VT due to reversible causes.

Pacing for children and adolescents (including all patients with congenital heart block)

There are no randomized clinical trials of permanent pacing in pediatric patients and those with congenital heart disease. Hence, the level of evidence for most recommendations is consensus based. The general indications for pacing in children and adolescents are similar to those for adults but with several additional considerations. The diagnosis of important bradycardia in children is age dependent. Whereas a heart rate of 45 bpm would be considered normal for an adult, the same rate would indicate profound bradycardia in a newborn or infant with marked hemodynamic consequences. In addition, the abnormal cardiovascular physiology resulting from palliative surgery for congenital heart diseases can place postsurgical patients at risk for decompensation from bradycardia or loss of AV synchrony that may have been well tolerated by patients with normal physiology. Further, the risk of paradoxical embolism from thrombus on endocardial leads is a consideration in patients with significant intracardiac shunts. Finally, the technical challenges of vascular access and long-term consequences of endovascular leads in children often prompt the consideration of epicardial systems at early ages. While this may be appropriate for children weighing less than 10–15 kg, in larger children, the risk of thoracotomy and the higher rate of epicardial lead failures have to be balanced against vascular occlusions from endovascular lead placement. Long-term RV pacing can lead to ventricular dysfunction and periodic assessment by echocardiography is helpful in the detection of early LV dysfunction, especially in patients with congenital heart disease and genetic cardiomyopathies.

The common indications for pacing in children, adolescents, and patients with congenital heart disease can be broadly divided into: (1) sinus bradycardia, (2) tachy–brady syndrome, and (3) congenital or postsurgical advanced second- or third-degree AV block. SND is rare in pediatric patients but when present, may be associated with mutations in the *SCN5A* gene.[55] Pacing is usually reserved for situations where symptoms such as syncope can be correlated with bradyarrhythmias (<40 bpm or >3-s pause). It should be recognized that apnea, seizures, and neurocardiogenic mechanisms might cause concurrent bradycardia. Correction of the primary abnormality is more effective than long-term pacing for these conditions.

The common form of tachy–brady syndrome seen in children follows surgery for congenital heart disease. Intra-atrial re-entrant tachycardia with loss of sinus node function can manifest as recurrent palpitation, hemodynamic compromise, and prolonged sinus pauses at termination of the atrial tachycardia. Although permanent atrial-based pacing, including antitachycardia pacing to terminate intra-atrial re-entry, is a potential treatment option, catheter-based ablation of these arrhythmias is optimal if it can be achieved successfully.

Congenital complete AV block is a rare anomaly that results from abnormal embryonic development of the AV node and is not associated with structural heart disease in 50% of cases. Patients

can be broadly divided into antibody (maternal anti-SS/Ro and/or anti-SSb/La antibodies) positive and antibody negative groups. When anti-SSA/Ro antibodies are present in the sera of mothers with connective tissue disease, the incidence of congenital heart block in live births has been reported to be 1–2%.[56] The antibodies cross the placenta and damage the conduction system; heart block develops *in utero* and in the early neonatal stage. Less commonly, late postnatal development of heart block has been described. The antibody negative group tends to present at a later stage and heart block is progressive.

Most children with isolated congenital complete AV block have a stable escape rhythm with a narrow complex. The indications for pacing continue to evolve. Pacing is generally indicated in symptomatic children with complete heart block or if the heart rate in the neonate is less than 55 bpm. In the asymptomatic child or adolescent with complete congenital AV block, several criteria, including average heart rate, pauses in intrinsic rate, associated structural heart disease, QT interval, and exercise tolerance, have been suggested as indications for pacing.[57,58]

Congenital heart diseases such as corrected transposition of the great arteries, ostium primum atrial septal defects, and ventricular septal defects may be associated with complete heart block. Patients who develop permanent postsurgical complete AV block have a poor prognosis without cardiac pacing. Hence, advanced AV block that persists for longer than 7–10 days postoperatively is considered a class 1 indication for pacing.

Indications for permanent pacing in children and adolescents

Class I indications

1 Advanced second- or third-degree AV block associated with symptomatic bradycardia, ventricular dysfunction, or low cardiac output. (Level of evidence: C)

2 Sinus node dysfunction with correlation of symptoms during age-inappropriate bradycardia. The definition of bradycardia varies with the patient's age and expected heart rate. (Level of evidence: B)

3 Postoperative advanced second- or third-degree AV block that is not expected to resolve or persists for at least 7 days after cardiac surgery. (Levels of evidence: B)

4 Congenital third-degree AV block with a wide QRS escape rhythm, complex ventricular ectopy, or ventricular dysfunction. (Level of evidence: B)

5 Congenital third-degree AV block in the infant with a ventricular rate of less than 55 bpm or with congenital heart disease and a ventricular rate of less than 70 bpm. (Levels of evidence: C)

Class IIa indications

1 Patients with congenital heart disease and sinus bradycardia for prevention of recurrent episodes of intra-atrial re-entrant tachycardia; SND may be intrinsic or secondary to antiarrhythmic treatment. (Level of evidence: C)

2 Congenital third-degree AV block beyond the first year of life with an average heart rate of less than 50 bpm, abrupt pauses in ventricular rate that are two or three times the basic cycle length, or associated with symptoms due to chronotropic incompetence. (Level of evidence: B)

3 Sinus bradycardia with complex congenital heart disease and a resting heart rate of less than 40 bpm or pauses in ventricular rate of longer than 3 s. (Level of evidence: C)

4 Patients with congenital heart disease and impaired hemodynamics due to sinus bradycardia or loss of AV synchrony. (Level of evidence: C)

5 Unexplained syncope in a patient with prior congenital heart surgery complicated by transient complete heart block with residual fascicular block after a careful evaluation to exclude other causes of syncope. (Level of evidence: B)

Class IIb indications

1 Transient postoperative third-degree AV block that reverts to sinus rhythm with residual bifascicular block. (Level of evidence: C)

2 Congenital third-degree AV block in asymptomatic children or adolescents with an acceptable heart rate, narrow QRS complex, and normal ventricular function. (Level of evidence: B)

3 Asymptomatic sinus bradycardia after biventricular repair of congenital heart disease with resting heart rate of less than 40 bpm or pauses in ventricular rate longer than 3 s. (Level of evidence: C)

Class III (not indicated)

1 Transient postoperative AV block with return of normal AV conduction in the otherwise asymptomatic patient. (Level of evidence: B)

2 Asymptomatic postoperative bifascicular block with or without first-degree AV block in the absence of prior transient complete AV block. (Level of evidence: C)

3 Asymptomatic type I second-degree AV block. (Level of evidence: C)

4 Asymptomatic sinus bradycardia in the adolescent with longest RR interval of less than 3 s and minimum heart rate of greater than 40 bpm. (Level of evidence: C)

Permanent pacing after the acute phase of myocardial infarction

Bradyarrhythmias and conduction defects are relatively common after acute myocardial infarction (MI). They are the result of both autonomic stimulation and ischemia or necrosis of the conduction system. In a large randomized trial of thrombolysis in acute MI, AV block occurred in approximately 7%.[59] The location of the infarction influences the type of conduction defect; AV block associated with inferior wall MI is often at the AV nodal level with narrow QRS escape rhythms, is usually transient, and has a good prognosis. Permanent pacing is rarely required. AV block in association with an anterior MI is most often due to extensive myocardial necrosis that includes the conduction tissue, tends to be infranodal with unstable wide QRS escape, and carries a high mortality, although acute revascularization strategies have improved outcomes in these patients (Figure 1.15 and Figure 1.16). Intraventricular conduction defects (IVCDs) after acute MI occur transiently in up to 18.4% of patients and in a permanent form in 5.3%.[60] The incidence of AV block is higher in post MI patients who develop transient AV block associated with a persisting peri-infarct IVCD other than isolated left anterior fascicular block.

Although temporary pacing is often necessary in the acute phase of infarction, the need for permanent pacing is less common and mostly dictated by the presence of IVCDs and not necessarily by the presence of symptoms. The long-term prognosis for patients who develop AV block and an IVCD is strongly influenced by the extent of myocardial injury and hemodynamic status (Figure 1.15). The need for temporary pacing in the acute stages of infarction is not by itself an indication for permanent pacing. Patients who have an indication for permanent pacing after ST elevation MI and severe LV dysfunction should be evaluated for an ICD indication if recovery of ventricular function is not anticipated.

Indications for permanent pacing following acute myocardial infarction

Class I indications

1 Persistent second-degree AV block in the His–Purkinje system with alternating BBB or third-degree AV block within or below the His–Purkinje system after ST segment elevation MI. (Level of evidence: B)

2 Transient advanced (second- or third-degree) infranodal AV block and associated BBB. If the site of block is uncertain, an electrophysiology study may be necessary. (Level of evidence: B)

3 Persistent and symptomatic second- or third-degree AV block. (Level of evidence: C)

Class IIb indications

1 Persistent second- or third-degree AV block at the AV node level even in the absence of symptoms. (Level of evidence: B)

Class III (not indicated)

1 Transient AV block in the absence of IVCDs. (Level of evidence: B)

2 Transient AV block in the presence of isolated left anterior fascicular block. (Level of evidence: B)

3 New BBB or fascicular block in the absence of AV block. (Level of evidence: B)

4 Persistent first-degree AV block in the presence of BBB or fascicular block. (Level of evidence: B)

Pacing after cardiac surgery and transcatheter aortic valve implantation

Approximately 3–5% of patients will develop persistent bradyarrhythmias after open heart surgery, with a higher incidence following repeat surgery. Sinus node dysfunction may result from right atrial cannulation for cardiopulmonary bypass, but

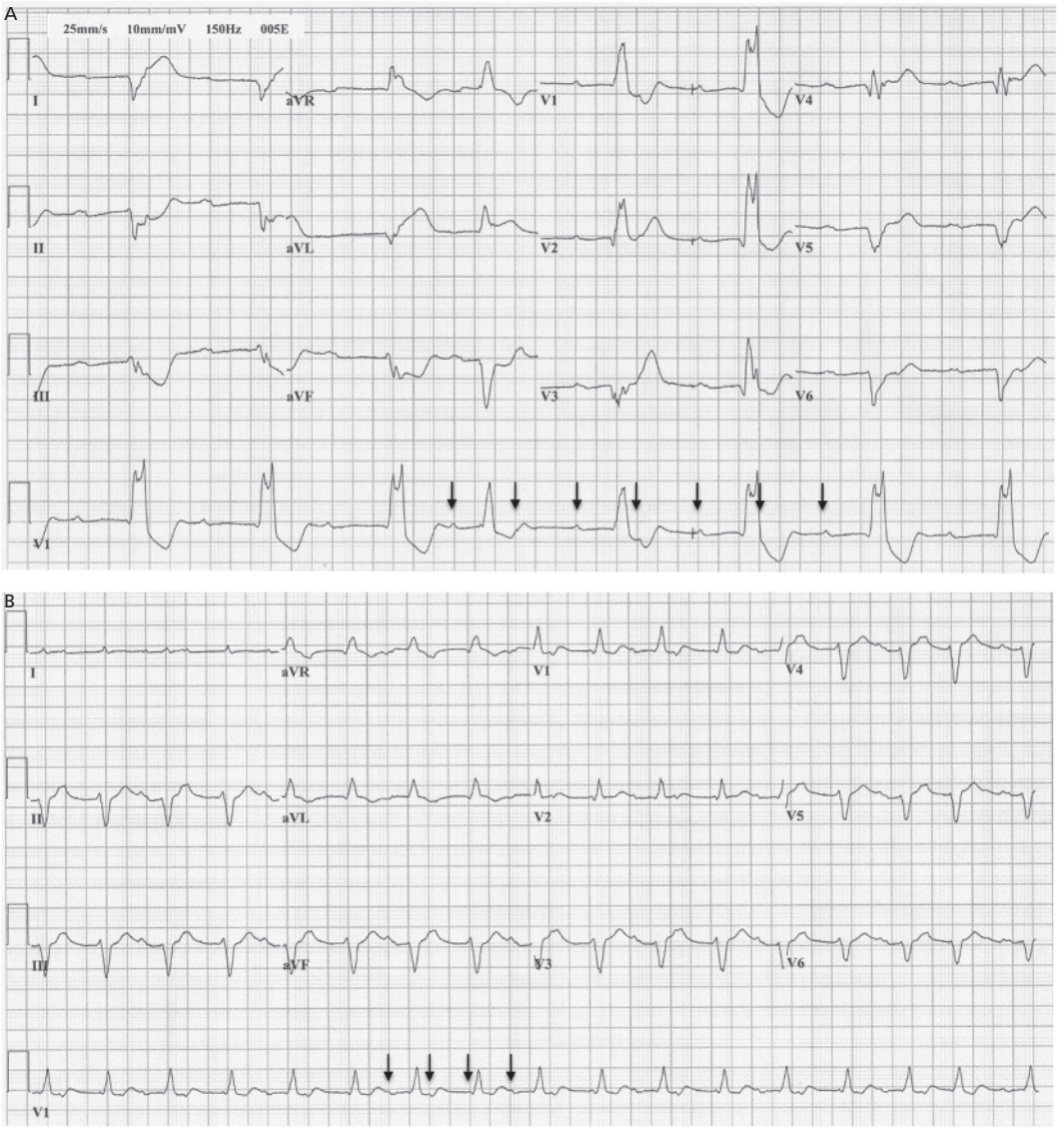

Figure 1.15 Acute anterior myocardial infarction complicated by complete atrioventricular (AV) block. This 82-year-old male presented with acute left main coronary artery occlusion in cardiogenic shock. (A) The initial ECG shows complete AV block with wide complex escape and evidence of ST elevation MI. The fourth and probably also the fifth complexes are conducted beats. P waves are indicated by arrows. He underwent temporary pacing, percutaneous intervention for acute revascularization and hemodynamic support with a percutaneous LV assist device. (B) ECG on the following day shows persistent complete AV block and an accelerated junctional rhythm with RBBB and left anterior hemiblock. Although the conduction abnormalities are indications for pacing, the associated myocardial damage and hemodynamic compromise limit prognosis. This patient succumbed to progressive multiorgan failure.

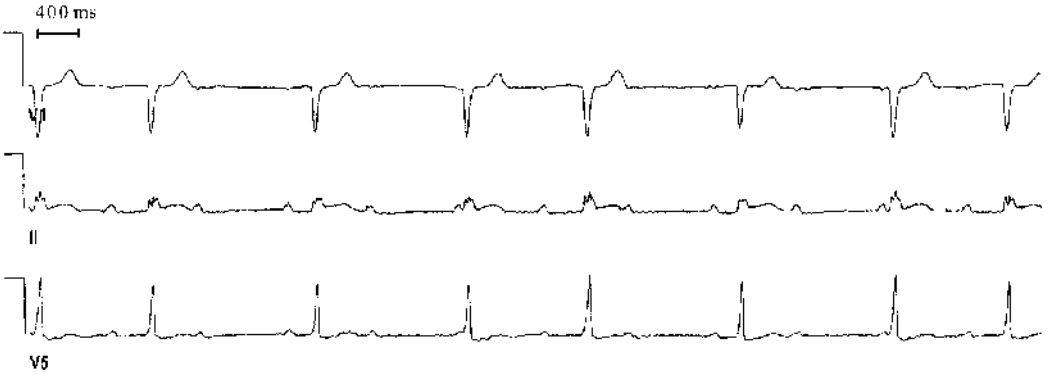

Figure 1.16 AV block associated with acute inferior myocardial infarction. Rhythm strips recorded from a 63-year-old female with an acute inferior wall myocardial infarction showing high-grade AV block with junctional escape beats. The second, fourth, and sixth QRS complexes are conducted with a prolonged PR interval (note shortening of the RR interval with the conducted beats). The presence of junctional escape beats precludes typical Wenckebach conduction. Because the patient was asymptomatic, no therapy was administered. Normal AV conduction resumed the following morning.

mostly resolves within a week. The development of paroxysmal atrial arrhythmia in conjunction with SND can be particularly troublesome to treat without temporary pacing support. However, once sinus node function recovers, antiarrhythmic drugs can often be employed safely for postoperative atrial arrhythmias.

In adults, persistent AV block is most common after valvular surgery, particularly tricuspid valve replacement. Risk is higher with multivalvular surgery.[61] In one large retrospective study, preexisting RBBB was more predictive than LBBB, but preoperative PR prolongation, repeat surgery, and age over 70 years were all predictors for the need for permanent pacing.[61] Because the majority of patients who develop bradyarrhythmias following cardiac surgery recover, it is customary to wait 7–10 days before consideration of permanent pacing. In the absence of the above risk factor and if there is evidence for continued improvement in sinus node function or AV conduction, longer waiting times may be justified. Patients who ultimately undergo permanent cardiac pacing tend to have a good prognosis and only about 40% remain dependent on pacing in the longer term.[62]

Transcatheter aortic valve implantation (TAVI) is rapidly evolving as an effective alternative to valve surgery for non-surgical patients with aortic stenosis. Unlike in the surgical procedure where the valve is excised prior to replacement, the calcified valve remains *in situ* in TAVI. Transcatheter placement of a valve prosthesis and balloon dilatation within this calcified valve produce a mass effect in the region of the membraneous septum and adjoining conduction system. This potential mechanism leads to persistent heart block requiring cardiac pacing in a fifth of patients.[63] New LBBB occurs in 5–6% of patients, but does not necessarily progress to heart block.[64] A third of cases of new AV block may be related to the acute balloon dilatation during the procedure and recover during the first 24 hours. QRS duration of less than 120 ms was predictive of recovery.[65] The risk of persistent AV block appears to be specific to the type of prosthestic valve used (27–33% for the Corevalve and 4–12% for the Edwards Sapiens valve). A valve prosthesis oversized for the native annulus was a risk factor in one series.[63]

Indications for temporary cardiac pacing

Temporary cardiac pacing is utilized for:

1 Treating a reversible condition causing bradycardia for which permanent pacing is unlikely to be necessary.

2 An interim measure while awaiting further assessment and implantation of a permanent system.

3 Prophylaxis against asystole during interventions expected to worsen a pre-existing conduction abnormality.
4 Overdrive pacing to terminate re-entrant supraventricular, atrial, and ventricular arrhythmias.
5 Suppression of bradycardia-dependent tachycardias such as torsades de pointes VT.

Acute myocardial infarction

Acute myocardial ischemia and infarction can precipitate sinus node dysfunction, AV block and IVCDs (see "Permanent pacing after the acute phase of myocardial infarction"). In the era of primary coronary interventions or thrombolysis, the need for temporary pacing is rare, although the incidence of IVCDs has not altered significantly compared with the prethrombolytic area. Abnormalities of sinus and AV nodal tissues are more common with inferior–posterior infarction because their blood supply is derived from the right coronary artery or left circumflex coronary artery and these are commonly involved in an inferior MI. Another potential reason is chemically-mediated activation of receptors on the posterior left ventricular wall; these receptors stimulate vagal afferent fibers, resulting in marked vagotonia and bradyarrhythmias.

Sinus bradycardia is the most common arrhythmia in inferior MI, occurring in 40% of patients in the initial 2 h. Half of these resolve by the end of the first day. Sinus node dysfunction occurring later in the course of acute MI might be secondary to atrial or sinus node ischemia. Treatment of sinus bradycardia is not usually necessary, unless symptoms such as worsening myocardial ischemia, heart failure or hypotension are documented. If bradycardia is prolonged and severe, or is not responsive to atropine, temporary cardiac pacing is indicated. A special circumstance to bear in mind involves sinus arrest with junctional rhythms that can occur in the context of a large right ventricular (RV) infarction. Here, maintenance of AV synchrony with AV sequential or atrial pacing is often necessary for maintenance of hemodynamic stability.

AV block can be progressive in the early phases of an acute inferior MI. A third of patients with first- or second-degree AV block can progress to complete AV block. However, block is located at the AV nodal level above the His bundle in 90% of patients with a stable junctional escape rhythm that responds to intravenous atropine. Hence, even complete AV block may not require temporary pacing if the patient is hemodynamically stable. Pacing is instituted only in the event of persisting heart block associated with hemodynamic compromise. Recovery is expected in 5–7 days. On the rare occasions that heart block persists, concomitant involvement of the left coronary system is likely with poor collateralization of the infarct region.

In contrast to inferior wall infarction, high-grade AV block complicating an anterior wall infarction is usually located within the His–Purkinje system. The transition from the first non-conducted P wave to high-grade AV block is often abrupt, and the resulting escape rhythm is typically slow and unreliable. Conducted beats usually have a wide QRS complex. In general, an interruption of the blood supply to the anterior wall and the interventricular septum severe enough to cause AV block usually causes severe LV dysfunction and results in high mortality. Emergency temporary pacing and prophylactic pacing are indicated, although survival may not be significantly improved because of the associated extensive myocardial damage.

New BBB is three times more likely during anterior infarction than during inferior infarction, because the left anterior descending coronary artery provides the major blood supply to the His bundle and the bundle branches (Figure 1.1). As with anterior MI and complete heart block, new BBB reflects extensive myocardial damage and is associated with a four-fold increase in risk of progression to high-grade AV block (an increase from 4% to 18%). Both in-hospital and out-of-hospital mortality are higher for patients presenting with BBB during acute infarction. Development of RBBB tends to carry a worse prognosis than LBBB. The effect of thrombolytic and early interventional therapies on the subsequent development of high-grade AV block in patients presenting with acute infarction and IVCD has been poorly studied.

Indications for temporary transvenous pacing in acute myocardial infarction[66]

Class I indications
1 Asystole.
2 Symptomatic bradycardia (includes sinus bradycardia with hypotension and type I

second-degree AV block with hypotension not responsive to atropine).
3 Bilateral BBB [alternating BBB or RBBB with alternating left anterior fascicular block (LAFB)/left posterior fascicular block (LPFB)] (any age).
4 New or indeterminate age bifascicular block (RBBB with LAFB or LPFB, or LBBB) with first-degree AV block.
5 Mobitz type II second-degree AV block.

Class IIa indications
1 RBBB and LAFB or LPFB (new or indeterminate).
2 RBBB with first-degree AV block.
3 LBBB, new or indeterminate.
4 Incessant VT, for atrial or ventricular overdrive pacing.
5 Recurrent sinus pauses (>3 s) not responsive to atropine.

Class IIb indications
1 Bifascicular block of indeterminate age.
2 New or age-indeterminate isolated RBBB.

Class III (not indicated)
1 First-degree heart block.
2 Type I second-degree AV block with normal hemodynamics.
3 Accelerated idioventricular rhythm.
4 BBB or fascicular block known to exist before acute MI.

Temporary pacing for procedural interventions
Cardiac catheterization
During catheterization of the right side of the heart, manipulation of the catheter may induce a transient RBBB in up to 10% of patients. This block generally lasts for seconds or minutes, but can occasionally last for hours or days. Trauma induced by RV endomyocardial biopsy also may result in temporary, or rarely long-lasting, RBBB. This is a problem only in patients with pre-existing LBBB, in whom complete heart block may result. A temporary transvenous pacing wire is therefore recommended in patients who are undergoing right heart catheterization or biopsy in the presence of previously known LBBB. Catheterization of the left side of the heart in patients with known pre-existing RBBB only rarely gives rise to complete heart block because of the short length and more diffuse nature of the left bundle branch. Significant bradycardia and asystole can occur during injection of the right coronary artery. This complication is extremely rare, and the placement of a temporary pacing catheter does not alter the morbidity or mortality of catheterization. The bradycardia usually resolves after several seconds. The same comments apply in general to placement of a temporary pacing wire during angioplasty.

Temporary pacing prior to non-cardiac surgery
Both surgeons and anesthesiologists frequently ask about the need for a preoperative temporary pacing catheter in patients with bifascicular block. Several studies have suggested a low incidence of intraoperative and perioperative complete heart block. Hence, there is minimal benefit from preoperative prophylactic pacemaker insertion. Even in patients with first-degree AV block and bifascicular block, there is a very low incidence of perioperative high-grade heart block.

However, in patients who have bifascicular block and also type II second-degree AV block or a history of unexplained syncope or presyncope, the risk of development of high-grade AV block is higher, and temporary pacing is warranted. The appearance of new bifascicular block in the immediate postoperative period should also lead to consideration of temporary pacing and raise suspicion of an intraoperative MI. The general availability of transcutaneous pacing may make it an acceptable alternative to temporary transvenous pacing in lower risk individuals, although low patient tolerance is often a limitation.

Temporary pacing following cardiac surgery
This is usually achieved via epicardial wires placed at the time of surgery. Occasionally, epicardial wires may not have been placed or the existing epicardial wires fail to capture. In such situations, transvenous pacing is often implemented while awaiting recovery of sinus node function or AV conduction, or until a decision regarding permanent pacing is made (see earlier).

Drug-induced bradycardia
A number of medications may produce transient bradycardia that may require temporary pacing until the effect of the drug dissipates. These drugs

may cause sinus node dysfunction and/or AV block; if drugs are used in combination, their effects may become more potent and exacerbate mild or latent conduction system disease. If long-term therapy with these agents is necessary for an underlying disorder and a substitute cannot be found, permanent pacing may be required (Figure 1.6). Drug-induced AV block might not always resolve after discontinuation of the potentially offending drug. In one series, approximately half of patients who developed heart block in the context of therapy with an AV nodal blocking agent required permanent pacing for persistent or recurrent AV block.[67] Cessation of digoxin therapy has the best chance of recovery of AV nodal conduction, but β-adrenergic blocker therapy often unmasks underlying conduction disease.[68]

Other indications for temporary pacing

Temporary pacing is indicated in patients with new AV or BBB in the setting of *acute bacterial endocarditis*. The development of a new conduction system abnormality generally suggests that there is a perivalvular (ring) abscess that has extended to involve the conduction system near the AV node and/or the His bundle. The endocarditis generally involves the non-coronary cusp of the aortic valve. In one study, high-grade or complete heart block developed in 15% of patients with aortic valve endocarditis.[69] Patients who develop a new AV block or BBB, especially in the setting of aortic valve endocarditis, should be considered for temporary pacing while cardiac evaluation is in progress.

Treatment of *tumors* of the head and/or neck or around the carotid sinus may in some circumstances give rise to high-grade AV block. Temporary pacing may be required during surgical treatment, radiation therapy, or chemotherapy. If the tumor responds poorly, permanent pacing may be necessary in some cases. The long-term risk for recurrent heart block due to tumor recurrence is unknown.

Lyme disease, a tick-borne spirochete infection, causes a systemic infection with arthritis, skin lesions, myalgias, meningoencephalitis, and cardiac involvement in 5–10% of patients. Lyme disease is epidemic in the summer months in the northeastern USA. Carditis typically occurs relatively late in the course of the illness, usually 4–8 weeks after the onset of symptoms. AV block is the most common manifestation of carditis and tends to be transient. Block is most common at the level of the AV node, and fluctuation between first-degree and higher degrees of AV block is frequent. Temporary cardiac pacing may be required, but the conduction disturbances usually resolve spontaneously, especially with antibiotic treatment, so permanent cardiac pacing is rarely necessary. Similar conduction disturbances can occasionally be seen in patients with viral myocarditis, as well as with other tick-borne infections.

Rarely, temporary pacing may be required during periods of *acidosis and hyperkalemia* until the metabolic derangements are corrected. The bradycardia that is associated with *hypothyroidism* rarely warrants pacing unless concomitant QT prolongation leads to torsades de pointes VT (see next section).

Temporary pacing for tachycardias

Temporary cardiac pacing has been used for the termination and/or prevention of a variety of arrhythmias. Type I atrial flutter can be successfully pace terminated, especially after cardiac surgery. Due to the development of radiofrequency catheter ablation techniques, there is currently less interest in pace termination of atrial flutter outside of the postoperative situation. Similarly, the most common varieties of paroxysmal SVT are usually pace terminable, but tend to be equally amenable to radiofrequency ablation. Recurrent torsades de pointes VT can sometimes be suppressed with pacing, especially if there is underlying bradycardia. Pacing to increase the heart rate will shorten the QT interval. Intravenous magnesium, correction of other metabolic derangement, and cessation of any offending drugs should be performed in conjunction with pacing.

Summary

In patients with symptomatic and potentially life-threatening bradyarrhythmias, cardiac pacing is a cost-effective intervention to relieve symptoms and prevent death. However, the possible complications and the potentially complex longer-term management of permanent pacemaker systems require

that careful consideration be given to the indications before implantation.

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