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2018 ACC/AHA/HRS Guideline on the Evaluation and Management of Patients With Bradycardia and Cardiac Conduction Delay

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2018 ACC/AHA/HRS Guideline on the Evaluation and Management of Patients With Bradycardia and Cardiac Conduction Delay

A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society

Developed in Collaboration With the American Association for Thoracic Surgery, the Pediatric & Congenital Electrophysiology Society, and the Society of Thoracic Surgeons

Endorsed by the American Association for Thoracic Surgery, the Pediatric & Congenital Electrophysiology Society, and the Society of Thoracic Surgeons

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Top 10 Take-Home Messages For the Management of Bradycardia and Cardiac Conduction Delay

1. Sinus node dysfunction is most often related to age-dependent progressive fibrosis of the sinus nodal tissue and surrounding atrial myocardium leading to abnormalities of sinus node and atrial impulse formation and propagation and will therefore result in various bradycardic or pause-related syndromes.
2. Both sleep disorders of breathing and nocturnal bradycardias are relatively common, and treatment of sleep apnea not only reduces the frequency of these arrhythmias but also may offer cardiovascular benefits. The presence of nocturnal bradycardias should prompt consideration for screening for sleep apnea, beginning with solicitation of suspicious symptoms. However, nocturnal bradycardia is not in itself an indication for permanent pacing.
3. The presence of left bundle branch block on electrocardiogram markedly increases the likelihood of underlying structural heart disease and of diagnosing left ventricular systolic dysfunction. Echocardiography is usually the most appropriate initial screening test for structural heart disease, including left ventricular systolic dysfunction.
4. In sinus node dysfunction, there is no established minimum heart rate or pause duration where permanent pacing is recommended. Establishing temporal correlation between symptoms and bradycardia is important when determining whether permanent pacing is needed.
5. In patients with acquired second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or third-degree atrioventricular block not caused by reversible or physiologic causes, permanent pacing is recommended regardless of symptoms. For all other types of atrioventricular block, in the absence of conditions associated with progressive atrioventricular conduction abnormalities, permanent pacing should generally be considered only in the presence of symptoms that correlate with atrioventricular block.
6. In patients with a left ventricular ejection fraction between 36% to 50% and atrioventricular block, who have an indication for permanent pacing and are expected to require ventricular pacing >40% of the time, techniques that provide more physiologic ventricular activation (e.g., cardiac resynchronization therapy, His bundle pacing) are preferred to right ventricular pacing to prevent heart failure.
7. Because conduction system abnormalities are common after transcatheter aortic valve replacement, recommendations on postprocedure surveillance and pacemaker implantation are made in this guideline.
8. In patients with bradycardia who have indications for pacemaker implantation, shared decision-making and patient-centered care are endorsed and emphasized in this guideline. Treatment decisions are based on the best available evidence and on the patient's goals of care and preferences.
9. Using the principles of shared decision-making and informed consent/refusal, patients with decision-making capacity or his/her legally defined surrogate has the right to refuse or request withdrawal of pacemaker therapy, even if the patient is pacemaker dependent, which should be considered palliative, end-of-life care, and not physician-assisted suicide. However, any decision is complex, should involve all stakeholders, and will always be patient specific.
10. Identifying patient populations that will benefit the most from emerging pacing technologies (e.g., His bundle pacing, transcatheter leadless pacing systems) will require further investigation as these modalities are incorporated into clinical practice.

Preamble

Since 1980, the American College of Cardiology (ACC) and American Heart Association (AHA) have translated scientific evidence into clinical practice guidelines with recommendations to improve cardiovascular health. These guidelines, which are based on systematic methods to evaluate and classify evidence, provide a foundation for the delivery of quality cardiovascular care. The ACC and AHA sponsor the development and publication of clinical practice guidelines without commercial support, and members volunteer their time to the writing and review efforts.

Clinical practice guidelines provide recommendations applicable to patients with or at risk of developing cardiovascular disease. The focus is on medical practice in the United States, but these guidelines are relevant to patients throughout the world. Although guidelines may be used to inform regulatory or payer decisions, the intent is to improve quality of care and align with patients' interests. Guidelines are intended to define practices meeting the needs of patients in most, but not all, circumstances, and should not replace clinical judgment.

Recommendations for guideline-directed management and therapy, which encompasses clinical evaluation, diagnostic testing, and both pharmacological and procedural treatments, are effective only when followed by both practitioners and patients. Adherence to recommendations can be enhanced by shared decision-making between clinicians and patients, with patient engagement in selecting interventions on the basis of individual values, preferences, and associated conditions and comorbidities.

The ACC/AHA Task Force on Clinical Practice Guidelines strives to ensure that the guideline writing committee both contains requisite expertise and is representative of the broader medical community by selecting experts from a broad array of backgrounds representing different geographic regions, sexes, races, ethnicities, intellectual perspectives/biases, and scopes of clinical practice, and by inviting organizations and professional societies with related interests and expertise to participate as partners or collaborators. The ACC and AHA have rigorous policies and methods to ensure that documents are developed without bias or improper influence. The complete policy on relationships with industry and other entities (RWI) can be found at http://www.acc.org/guidelines/about-guidelines-and-clinical-documents/relationships-with-industry-policy.

Beginning in 2017, numerous modifications to the guidelines have been and continue to be implemented to make guidelines shorter and enhance "user friendliness." Guidelines are written and presented in a modular knowledge chunk format, in which each chunk includes a table of recommendations, a brief synopsis, recommendation-specific supportive text and, when appropriate, flow diagrams or additional tables. Hyperlinked references are provided for each modular knowledge chunk to facilitate quick access and review. More structured guidelines—including word limits ("targets") and a web guideline supplement for useful but noncritical tables and figures—are 2 such changes. This Preamble is an abbreviated version, with the detailed version available at: http://jaccjacc.acc.org/Clinical_Document/Bradycardia_GL_Web_Supplement.pdf.

Glenn N. Levine, MD, FACC, FAHA
Chair, ACC/AHA Task Force on Clinical Practice Guidelines

1. Introduction

1.1. Methodology and Evidence Review

The recommendations listed in this guideline are, whenever possible, evidence based. An initial extensive evidence review, which included literature derived from research involving human subjects, published in English, and indexed in MEDLINE (through PubMed), EMBASE, the Cochrane Library, the Agency for Healthcare Research and Quality, and other selected databases relevant to this guideline, was conducted from January 2017 to September 2017. Key search words included but were not limited to the following: *AV block, bradycardia, bundle branch block, conduction disturbance, left bundle branch block, loop recorder, pauses, permanent pacemaker, sick sinus syndrome, sinus node dysfunction,* and *temporary pacemaker.* Additional relevant studies, published through January 2018 during the guideline writing process, were also considered by the writing committee and added to the evidence tables when appropriate. The final evidence tables are included in the Online Data Supplement (http://jaccjacc.acc.org/Clinical_Document/Bradycardia_GL_Online_Data_Supplement.pdf) and summarize the evidence used by the writing committee to formulate recommendations. References selected and published in the present document are representative and not all-inclusive.

As noted in the detailed version of the Preamble, an independent evidence review committee was commissioned to perform a formal systematic review of 1 critical clinical question related to bradycardia, the results of which were considered by the writing committee for incorporation into this guideline. Concurrent with this process, writing committee members evaluated study data relevant to the rest of the guideline. The findings of the evidence review committee and the writing committee members were formally presented and discussed, and then recommendations were developed. The systematic review, titled "Impact of Physiologic Versus Right Ventricular Pacing Among Patients With Left Ventricular Ejection Fraction Greater Than 35%: A Systematic Review for the 2018 ACC/AHA/HRS Guideline on the Evaluation and Management of Patients With Bradycardia and Cardiac Conduction Delay," is published in conjunction with this guideline (S1.1-1) and its respective data supplements are available online (http://jaccjacc.acc.org/Clinical_Document/Bradycardia_Systematic_Review_Online_Data_Supplement.pdf). The evidence review committee report informed recommendations in Section 6.4.4.1.

1.2. Organization of the Writing Committee

The writing committee consisted of cardiac electrophysiologists, clinicians, cardiologists, surgeons, an anesthesiologist, and a lay/patient representative. The writing committee included representatives from the ACC, AHA, Heart Rhythm Society (HRS), American Association for Thoracic Surgery (AATS), Pediatric & Congenital Electrophysiology Society (PACES), and the Society of Thoracic Surgeons (STS). Appendix 1 of the present document lists writing committee members' relevant RWI. For the purposes of full transparency, the writing committee members' comprehensive disclosure information is available online (http://jaccjacc.acc.org/Clinical_Document/Bradycardia_GL_Comprehensive_Author_RWI.pdf).

1.3. Document Review and Approval

This document was reviewed by 2 official reviewers each nominated by the ACC, AHA, and HRS; 1 official lay reviewer nominated by the AHA; 1 organizational reviewer each from the AATS, PACES, and STS; and 31 individual content reviewers. Reviewers' RWI information was distributed to the writing committee and is published as an abbreviated table in this document (Appendix 2). The reviewers' detailed RWI information is available online

(http://jaccjacc.acc.org/Clinical_Document/Bradycardia_GL_Comprehensive_Reviewer_RWI.pdf).

This document was approved for publication by the governing bodies of the ACC, the AHA, and the HRS; and was endorsed by the American Association for Thoracic Surgery, the Pediatric & Congenital Electrophysiology Society, and the Society of Thoracic Surgeons.

1.4. Scope of the Guideline

The purpose of this ACC/AHA/HRS guideline is to provide guidance to clinicians for the management of patients with bradycardia, or symptoms thought to be associated with bradycardia or cardiac conduction system disorders. This guideline supersedes the pacemaker recommendations made in the "ACC/AHA/HRS 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities" (S1.4-1, S1.4-2) and "2012 ACCF/AHA/HRS Focused Update Incorporated Into the ACCF/AHA/HRS 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities" (S1.4-2). The guideline will be useful to general internists, family physicians, emergency physicians, anesthesiologists, surgeons, cardiologists, and arrhythmia specialists. This document is aimed at the adult population (>18 years of age) and offers no specific recommendations in pediatric patients, although some of the evidence review included pediatric patients. Although background on the pathophysiology and epidemiology of bradycardia and cardiac conduction disorders is summarized, this guideline is not intended to be an exhaustive review. Rather, it focuses on practical clinical evaluation and management. Specific objectives and goals include:

- Describe the clinical significance of bradycardia with respect to mortality, symptoms (e.g., syncope, impaired functional capacity), and exacerbations of associated disorders (e.g., ischemia, heart failure, provoked tachyarrhythmias).
- Address inherited and acquired disorders of the sinus node, atrioventricular node, His-Purkinje fibers, and intramyocardial conducting tissue, including the effects of medications, aging, metabolic derangements, trauma, radiation, infiltrative, ischemic, and inflammatory disorders, infectious and toxic agents, and iatrogenic factors.
- Delineate the clinical presentation and general approach to clinical evaluation of patients with overt or suspected bradycardias or conduction diseases.
- Comprehensively evaluate the evidence supporting recommendations for the selection and timing of available diagnostic testing modalities, including monitoring devices and electrophysiologic testing.
- Define the evidence base supporting recommendations for the use of available treatment modalities, including lifestyle interventions, pharmacotherapy, and external and implanted device-based therapies, with particular attention to indications for temporary and permanent pacing.
- Address special considerations that may be applicable to distinct populations based on age (>18 years of age), comorbidities or other relevant factors.
- Identify knowledge gaps, pertinent trials in progress and directions for future research.

Table 1 lists other guidelines and pertinent documents that the writing committee considered for this guideline. The listed documents contain relevant information for the management of patients with bradycardia or cardiac conduction system disorder.

Table 1. Associated Guidelines and Related References

Title	Organization	Publication Year (Reference)
Guidelines		
Ventricular arrhythmias and sudden cardiac death	ACC/AHA/HRS	2017 (S1.4-3)
Syncope	ACC/AHA/HRS	2017 (S1.4-4)
Stable ischemic heart disease	ACC/AHA/AATS/PCNA/SCAI/STS	2014* (S1.4-5) 2012 (S1.4-6)
Atrial fibrillation	AHA/ACC/HRS	2014 (S1.4-7)
Perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery	ACC/AHA	2014 (S1.4-8)
Non–ST-elevation acute coronary syndromes	AHA/ACC	2014 (S1.4-9)
Heart failure	ACC/AHA	2013 (S1.4-10)
ST-elevation myocardial infarction	ACC/AHA	2013 (S1.4-11)
Device-based therapy for cardiac rhythm abnormalities	ACC/AHA/HRS	2013 (S1.4-2)
Coronary artery bypass graft surgery	ACC/AHA	2011 (S1.4-12)
Hypertrophic cardiomyopathy	ACC/AHA	2011 (S1.4-13)
Percutaneous coronary intervention	ACC/AHA/SCAI	2011 (S1.4-14)
Guidelines for CPR and emergency cardiovascular care—part 9: post-cardiac arrest care	AHA	2010 (S1.4-15)
Other related references		
Expert consensus statement on cardiovascular implantable electronic device lead management and extraction	HRS	2017 (S1.4-16)
Management of cardiac involvement associated with neuromuscular diseases	AHA	2017 (S1.4-17)
Expert consensus statement on magnetic resonance imaging	HRS	2017 (S1.4-18)
Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: Task Force 9: arrhythmias and conduction defects	ACC/AHA	2015 (S1.4-19)
Expert consensus statement on the diagnosis and treatment of postural tachycardia syndrome, inappropriate sinus tachycardia, and vasovagal syncope	HRS	2015 (S1.4-20)
Expert consensus statement on the recognition and management of arrhythmias in adult congenital heart disease	PACES/HRS	2014 (S1.4-21)
Expert consensus statement on the use of implantable cardioverter-defibrillator therapy in patients who are not included or not well represented in clinical trials	HRS/ACC/AHA	2014 (S1.4-22)
Expert consensus statement on the diagnosis and management of arrhythmias associated with cardiac sarcoidosis	HRS	2014 (S1.4-23)
Cardiac pacing and cardiac resynchronization therapy	ESC	2013 (S1.4-24)
Expert consensus statement on pacemaker device and mode selection	HRS/ACCF	2012 (S1.4-25)
Expert consensus statement on the state of genetic testing for the channelopathies and cardiomyopathies	HRS/EHRA	2011 (S1.4-26)
Expert consensus statement on the management of cardiovascular implantable electronic devices (CIEDs) in patients nearing end of life or requesting withdrawal of therapy	HRS	2010 (S1.4-27)

Recommendations for the standardization and interpretation of the electrocardiogram: part III: intraventricular conduction disturbances: a scientific statement	AHA/ACCF/HRS	2009 (S1.4-28)
Recommendations for the standardization and interpretation of the electrocardiogram: part V: electrocardiogram changes associated with cardiac chamber hypertrophy: a scientific statement	AHA/ACCF/HRS	2009 (S1.4-29)

*Focused Update.

AATS indicates American Association for Thoracic Surgery; ACC, American College of Cardiology; ACCF, American College of Cardiology Foundation; AHA, American Heart Association; CPR, cardiopulmonary resuscitation; EHRA, European Heart Rhythm Association; ESC, European Society of Cardiology; HRS, Heart Rhythm Society; PACES, Pediatric & Congenital Electrophysiology Society; PCNA, Preventive Cardiovascular Nurses Association; SCAI, Society for Cardiovascular Angiography and Interventions; and STS, Society of Thoracic Surgeons.

1.5. Class of Recommendation and Level of Evidence

Recommendations are designated with both a class of recommendation (COR) and a level of evidence (LOE). The class of recommendation indicates the strength of recommendation, encompassing the estimated magnitude and certainty of benefit in proportion to risk. The level of evidence rates the quality of scientific evidence supporting the intervention on the basis of the type, quantity, and consistency of data from clinical trials and other sources (Table 2) (S1.5-1).

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Table 2. Applying Class of Recommendation and Level of Evidence to Clinical Strategies, Interventions, Treatments, or Diagnostic Testing in Patient Care* (Updated August 2015)

CLASS (STRENGTH) OF RECOMMENDATION	
CLASS I (STRONG)	**Benefit >>> Risk**

Suggested phrases for writing recommendations:
▪ Is recommended
▪ Is indicated/useful/effective/beneficial
▪ Should be performed/administered/other
▪ Comparative-Effectiveness Phrases†:
  ○ Treatment/strategy A is recommended/indicated in preference to treatment B
  ○ Treatment A should be chosen over treatment B	

CLASS IIa (MODERATE)	**Benefit >> Risk**

Suggested phrases for writing recommendations:
▪ Is reasonable
▪ Can be useful/effective/beneficial
▪ Comparative-Effectiveness Phrases†:
  ○ Treatment/strategy A is probably recommended/indicated in preference to treatment B
  ○ It is reasonable to choose treatment A over treatment B	

CLASS IIb (WEAK)	**Benefit ≥ Risk**
Suggested phrases for writing recommendations: ▪ May/might be reasonable ▪ May/might be considered ▪ Usefulness/effectiveness is unknown/unclear/uncertain or not well established	
CLASS III: No Benefit (MODERATE) *(Generally, LOE A or B use only)*	**Benefit = Risk**
Suggested phrases for writing recommendations: ▪ Is not recommended ▪ Is not indicated/useful/effective/beneficial ▪ Should not be performed/administered/other	
CLASS III: Harm (STRONG)	**Risk > Benefit**
Suggested phrases for writing recommendations: ▪ Potentially harmful ▪ Causes harm ▪ Associated with excess morbidity/mortality ▪ Should not be performed/administered/other	

LEVEL (QUALITY) OF EVIDENCE‡	
LEVEL A	
▪ High-quality evidence‡ from more than 1 RCT ▪ Meta-analyses of high-quality RCTs ▪ One or more RCTs corroborated by high-quality registry studies	
LEVEL B-R	**(Randomized)**
▪ Moderate-quality evidence‡ from 1 or more RCTs ▪ Meta-analyses of moderate-quality RCTs	
LEVEL B-NR	**(Nonrandomized)**
▪ Moderate-quality evidence‡ from 1 or more well-designed, well-executed nonrandomized studies, observational studies, or registry studies ▪ Meta-analyses of such studies	
LEVEL C-LD	**(Limited Data)**
▪ Randomized or nonrandomized observational or registry studies with limitations of design or execution ▪ Meta-analyses of such studies ▪ Physiological or mechanistic studies in human subjects	
LEVEL C-EO	**(Expert Opinion)**
Consensus of expert opinion based on clinical experience	

COR and LOE are determined independently (any COR may be paired with any LOE).

A recommendation with LOE C does not imply that the recommendation is weak. Many important clinical questions addressed in guidelines do not lend themselves to clinical trials. Although RCTs are unavailable, there may be a very clear clinical consensus that a particular test or therapy is useful or effective.

* The outcome or result of the intervention should be specified (an improved clinical outcome or increased diagnostic accuracy or incremental prognostic information).

† For comparative-effectiveness recommendations (COR I and IIa; LOE A and B only), studies that support the use of comparator verbs should involve direct comparisons of the treatments or strategies being evaluated.

‡ The method of assessing quality is evolving, including the application of standardized, widely used, and preferably validated evidence grading tools; and for systematic reviews, the incorporation of an Evidence Review Committee.

COR indicates Class of Recommendation; EO, expert opinion; LD, limited data; LOE, Level of Evidence; NR, nonrandomized; R, randomized; and RCT, randomized controlled trial.

1.6. Abbreviations

Abbreviation	Meaning/Phrase
ACHD	adult congenital heart disease
AF	atrial fibrillation
CIED	cardiovascular implantable electronic devices
CRT	cardiac resynchronization therapy
HV	His-ventricular
ICD	implantable cardioverter defibrillator
ICM	implantable cardiac monitor
ECG	electrocardiogram
EPS	electrophysiology study
LBBB	left bundle branch block
LVEF	left ventricular ejection fraction
MI	myocardial infarction
MRI	magnetic resonance imaging
PPM	permanent pacemaker
QOL	quality of life
RBBB	right bundle branch block
RCT	randomized controlled trial
RV	right ventricle
SACT	sinoatrial conduction time
SND	sinus node dysfunction
SNRT	sinus node recovery time
TAVR	transcatheter aortic valve replacement

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2. Epidemiology and Definitions

2.1. Bradycardia and Conduction Disorders

Because slower heart rates and changes in intercellular conduction can be observed as both part of normal aging and disease progression, bradycardia and conduction abnormalities are more commonly identified in the elderly. Abnormalities of the sinus node, atrial tissue, atrioventricular nodal tissue, and the specialized conduction system can all contribute to bradycardia, discordant timing of atrial and ventricular depolarization, and abnormal ventricular depolarization.

Sinus node dysfunction (SND), historically referred to as sick sinus syndrome, is most often related to age-dependent, progressive, degenerative fibrosis of the sinus nodal tissue and surrounding atrial myocardium (S2.1-1–S2.1-3). This can result in abnormalities of sinus node and atrial impulse formation and propagation and can be associated with various bradycardia or pause-related syndromes. In addition, the same milieu of degenerative fibrosis is also responsible for the development of atrial arrhythmias, which can coexist with sinus node disease and the combination often called “tachy-brady syndrome.” There is evidence that heart block occurs in a portion of patients who have required permanent atrial pacing for SND, suggesting that, in some patients, a similar fibrotic process likely involves the specialized atrioventricular conduction system (S2.1-3, S2.1-4). Data gathered from permanent pacemaker (PPM) studies and the large cohort studies of ARIC (Atherosclerosis Risk In Communities) and CHS (Cardiovascular Health Study) suggest that SND is most common in individuals who are in their 70s or 80s (S2.1-5–S2.1-7). SND appears to mirror the incidence of pacemaker implantation for atrioventricular nodal disease because both are age related (S2.1-7). In these analyses, ischemic heart disease, heart failure, valvular heart disease, cerebrovascular disease, and atrial fibrillation (AF) were found to be common concurrent issues in this subgroup of patients who require treatment for their atrioventricular nodal disease (S2.1-5–S2.1-7). The intrinsic sinus and atrioventricular nodal diseases present in a similar clinical manner to extrinsic/secondary processes that can injure the sinus node, atrioventricular node or conduction system tissues. Multiple pathophysiologic processes (e.g., myocardial ischemia or infarction, infiltrative diseases, collagen vascular disease, surgical trauma, endocrine abnormalities, autonomic effects, neuromuscular disorders (S2.1-2, S2.1-8–S2.1-10), individually or in combination, can compromise impulse initiation and propagation. Whether intrinsic or extrinsic, the clinical manifestations of these pathologies can be identical.

2.2. Definitions

The National Institutes of Health defines bradycardia as a heart rate <60 bpm in adults other than well trained athletes (S2.2-1). However, population studies frequently use a lower cutoff of 50 bpm (S2.2-2, S2.2-3). In an analysis of 4 population studies from The Netherlands, in adults from 20 to 90 years of age, the lowest second percentile for heart rate ranged from 40 to 55 bpm depending on sex and age (S2.2-3). Sinus pauses of 2 seconds and 3 seconds have been described during 24-hour ambulatory electrocardiographic monitoring in healthy elderly patients and long-distance runners, respectively (S2.2-4, S2.2-5). On the basis of the available evidence, for the purposes of this document, we have chosen a sinus rate <50 bpm and/or a sinus pause >3 seconds as potential components of the definitions of SND. However, the presence of sinus bradycardia or a pause >3 seconds alone should not be used for the diagnosis of SND; multiple factors should be recognized and be taken into consideration for the individual patient (Table 3). With rare exceptions, the sole reason for considering any treatment for SND is the presence of symptoms.

Chronotropic incompetence represents failure to reach a target heart rate with exertion relative to expected for age that is inadequate to meet metabolic demand. Because the incremental heart rate achieved with exercise will be dependent on resting heart rate, the most commonly used definition in

the literature has been failure to reach 80% of the expected heart rate reserve. Expected heart rate reserve is defined as the difference between the age-predicted maximal heart rate (220 – age) and the resting heart rate. Percentage of expected heart rate reserve is the ratio of demonstrated and predicted heart rate reserve. Although this definition has been used in literature, in practice, specifically defining chronotropic incompetence is difficult (S2.2-8–S2.2-11). Other investigators suggest that another age-related equation (220 – 0.7 x age) is a better predictor for heart rate, while others stress the importance of sex and the presence of comorbidities (S2.2-8–S2.2-10). Collectively, the data suggest that the diagnosis of chronotropic incompetence in a patient requires careful individualized clinical assessment and probably cannot be determined by age alone. The definitions for atrioventricular block and conduction tissue disorders have been adopted from the 2009 AHA/ACCF/HRS recommendations for the standardization of electrocardiographic measurements (both intraventricular conduction disorders and chamber hypertrophy) (S2.2-7, S2.2-12), although some have argued that stricter criteria are required for left bundle branch block (LBBB) (S2.2-13).

Table 3. Table of Definitions

Term	Definition or Description
Sinus node dysfunction (with accompanying symptoms)	• Sinus bradycardia: Sinus rate <50 bpm • Ectopic atrial bradycardia: Atrial depolarization attributable to an atrial pacemaker other than the sinus node with a rate <50 bpm • Sinoatrial exit block: Evidence that blocked conduction between the sinus node and adjacent atrial tissue is present. Multiple electrocardiographic manifestations including “group beating” of atrial depolarization and sinus pauses. • Sinus pause: Sinus node depolarizes >3 s after the last atrial depolarization • Sinus node arrest: No evidence of sinus node depolarization • Tachycardia-bradycardia (“tachy-brady”) syndrome: Sinus bradycardia, ectopic atrial bradycardia, or sinus pause alternating with periods of abnormal atrial tachycardia, atrial flutter, or AF (S2.2-6). The tachycardia may be associated with suppression of sinus node automaticity and a sinus pause of variable duration when the tachycardia terminates. • Chronotropic Incompetence: Broadly **defined** as the inability of the heart to increase its rate commensurate with increased activity or demand, in many studies translates to failure to attain 80% of expected heart rate reserve during exercise. • Isorhythmic dissociation: Atrial depolarization (from either the sinus node or ectopic atrial site) is slower than ventricular depolarization (from an atrioventricular nodal, His bundle, or ventricular site).
Atrioventricular block (S2.2-7)	• *First-degree atrioventricular block:* P waves associated with 1:1 atrioventricular conduction and a PR interval >200 ms (this is more accurately defined as atrioventricular delay because no P waves are blocked) • *Second-degree atrioventricular block:* P waves with a constant rate (<100 bpm) where atrioventricular conduction is present but not 1:1 o Mobitz type I: P waves with a constant rate (<100 bpm) with a periodic single nonconducted P wave associated with P waves before and after the nonconducted P wave with inconstant PR intervals o Mobitz type II: P waves with a constant rate (< 100 bpm) with a periodic single nonconducted P wave associated with other P waves before and after the nonconducted P wave with constant PR intervals (excluding 2:1 atrioventricular block) o 2:1 atrioventricular block: P waves with a constant rate (or near constant rate because of ventriculophasic sinus arrhythmia) rate (<100 bpm) where every

	other P wave conducts to the ventricles o Advanced, high-grade or high-degree atrioventricular block: ≥2 consecutive P waves at a constant physiologic rate that do not conduct to the ventricles with evidence for some atrioventricular conduction • *Third-degree atrioventricular block (complete heart block):* No evidence of atrioventricular conduction • *Vagally mediated atrioventricular block:* Any type of atrioventricular block mediated by heightened parasympathetic tone • *Infranodal block:* Atrioventricular conduction block where clinical evidence or electrophysiologic evidence suggests that the conduction block occurs distal to the atrioventricular node
Conduction tissue disease (S2.2-7)	• RBBB (as defined in adults): o Complete RBBB: 1. QRS duration ≥120 ms 2. rsr′, rsR′, rSR′, or rarely a qR in leads V_1 or V_2. The R′ or r′ deflection is usually wider than the initial R wave. In a minority of patients, a wide and often notched R wave pattern may be seen in lead V_1 and/or V_2. 3. S wave of greater duration than R wave or >40 ms in leads I and V_6 in adults 4. Normal R peak time in leads V_5 and V_6 but >50 ms in lead V_1 o Incomplete RBBB: Same QRS morphology criteria as complete RBBB but with a QRS duration between 110 and 119 ms • LBBB (as defined in adults): o Complete LBBB: 1. QRS duration ≥120 ms in adults 2. Broad notched or slurred R wave in leads I, aVL, V_5, and V_6 and an occasional RS pattern in V_5 and V_6 attributed to displaced transition of QRS complex 3. Absent Q waves in leads I, V_5, and V_6, but in the lead aVL, a narrow Q wave may be present in the absence of myocardial pathology 4. R peak time >60 ms in leads V_5 and V_6 but normal in leads V_1, V_2, and V_3, when small initial R waves can be discerned in the precordial leads 5. ST and T waves usually opposite in direction to QRS o Incomplete LBBB: 1. QRS duration between 110 and 119 ms in adults 2. Presence of left ventricular hypertrophy pattern 3. R peak time >60 ms in leads V_4, V_5, and V_6 4. Absence of Q wave in leads I, V_5, and V_6 • Nonspecific intraventricular conduction delay (as defined in adults): QRS duration >110 ms where morphology criteria for RBBB or LBBB are not present • Left anterior fascicular block: o QRS duration <120 ms o Frontal plane axis between −45° and −90° o qR (small r, tall R) pattern in lead aVL o R-peak time in lead aVL of ≥45 ms o rS pattern (small r, deep S) in leads II, III, and aVF • Left posterior fascicular block: o QRS duration <120 ms o Frontal plane axis between 90° and 180° in adults. Because of the more rightward axis in children up to 16 years of age, this criterion should only be applied to them when a distinct rightward change in axis is documented.

	o rS (small r, deep S) pattern in leads I and aVL o qR (small q, tall R) pattern in leads III and aVF

Maximum predicted heart rate for age calculated as 220 – age (y).
AF indicates atrial fibrillation; bpm, beats per minute; LBBB, left bundle branch block; and RBBB, right bundle branch block.

3. Clinical Manifestation of Bradycardia and Conduction Disorders

3.1. Clinical Manifestations of Bradycardia

The clinical manifestations of bradycardia can vary widely from insidious symptoms to episodes of frank syncope. Bradycardia can be broadly classified into 2 general categories: SND and atrioventricular block. The associated wide range of clinical presentations can be explained by the disparate electrophysiologic manifestations, ventricular rates, transience of these abnormalities, overall medical conditions, and medications.

The electrocardiographic findings in patients with SND are varied and the diagnosis may be considered in patients with sinus bradycardia or atrial depolarization from a subsidiary pacemaker other than the sinus node (i.e., ectopic atrial rhythm, junctional rhythm, or ventricular escape), intermittent sinus pauses, or a blunted heart rate response with exercise (chronotropic incompetence) (S3.1-1). The clinical manifestations of atrioventricular block will also depend on whether the atrioventricular block is fixed or intermittent and the ventricular rate or duration of ventricular asystole associated with atrioventricular block. In addition, symptoms will vary depending on underlying cause and timing. For example, patients with vagally mediated atrioventricular block can be asymptomatic if the periods of atrioventricular block occur at night while sleeping when parasympathetic tone is increased. Vagally mediated atrioventricular block during sleep can be recognized by the presence of concomitant sinus node slowing (P-P prolongation). Conversely the sudden increase in parasympathetic tone with vasovagal syncope can cause bradycardia (usually sinus node slowing or sinus arrest, but sometimes with atrioventricular block) (S3.1-2).

Regardless of whether the bradycardia is caused by SND or atrioventricular block, the term “symptomatic bradycardia” is used throughout this document and has been defined as a “documented bradyarrhythmia that is directly responsible for development of the clinical manifestations of syncope or presyncope, transient dizziness or lightheadedness, heart failure symptoms, or confusional states resulting from cerebral hypoperfusion attributable to slow heart rate” (S3.1-3). Direct attribution of bradycardia as the sole source of symptoms is challenging. For example, in patients with vasovagal syncope, bradycardia is often accompanied by a significant vasodepressor effect. In addition, nonspecific symptoms such as fatigue can be multifactorial and therefore difficult to correlate with bradycardia particularly in the setting of modest resting sinus bradycardia or with exercise (S3.1-4).

3.2. Clinical Manifestations of Conduction Disorders

The clinical manifestations of conduction tissue disease primarily will depend on the underlying cause of the conduction tissue disorder. Patients may often be asymptomatic, particularly in the setting of isolated right bundle branch block (RBBB) or fascicular block. However, patients with LBBB may present with heart failure that may be attributable to cardiac dyssynchrony or because of an underlying cardiomyopathy. The definitions outlined in the “AHA/ACCF/HRS Recommendations for the Standardization and Interpretation of the Electrocardiogram: Part III: Intraventricular Conduction

Disturbances" (S3.2-1) are used for this document, although it is acknowledged that these recommendations are not without controversy (S3.2-1).

4. General Evaluation of Patients With Documented or Suspected Bradycardia or Conduction Disorders

4.1. History and Physical Examination of Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendation for History and Physical Examination in Patients With Documented or Suspected Bradycardia or Conduction Disorders		
COR	**LOE**	**Recommendation**
I	**C-EO**	**1. In patients with suspected bradycardia or conduction disorders a comprehensive history and physical examination should be performed.**

Synopsis

The history and physical examination remains the foundation for the medical evaluation of any patient and is particularly helpful for the patient with possible arrhythmias (Figures 1, 2, and 3). The 2017 ACC/AHA/HRS guideline for the evaluation of syncope and the 2017 AHA/ACC/HRS guideline for management of patients with ventricular arrhythmias and the prevention of sudden cardiac death emphasize the importance of the history and physical examination in the initial evaluation particularly for identifying those patients with structural heart disease (S4.1-1, S4.1-2).

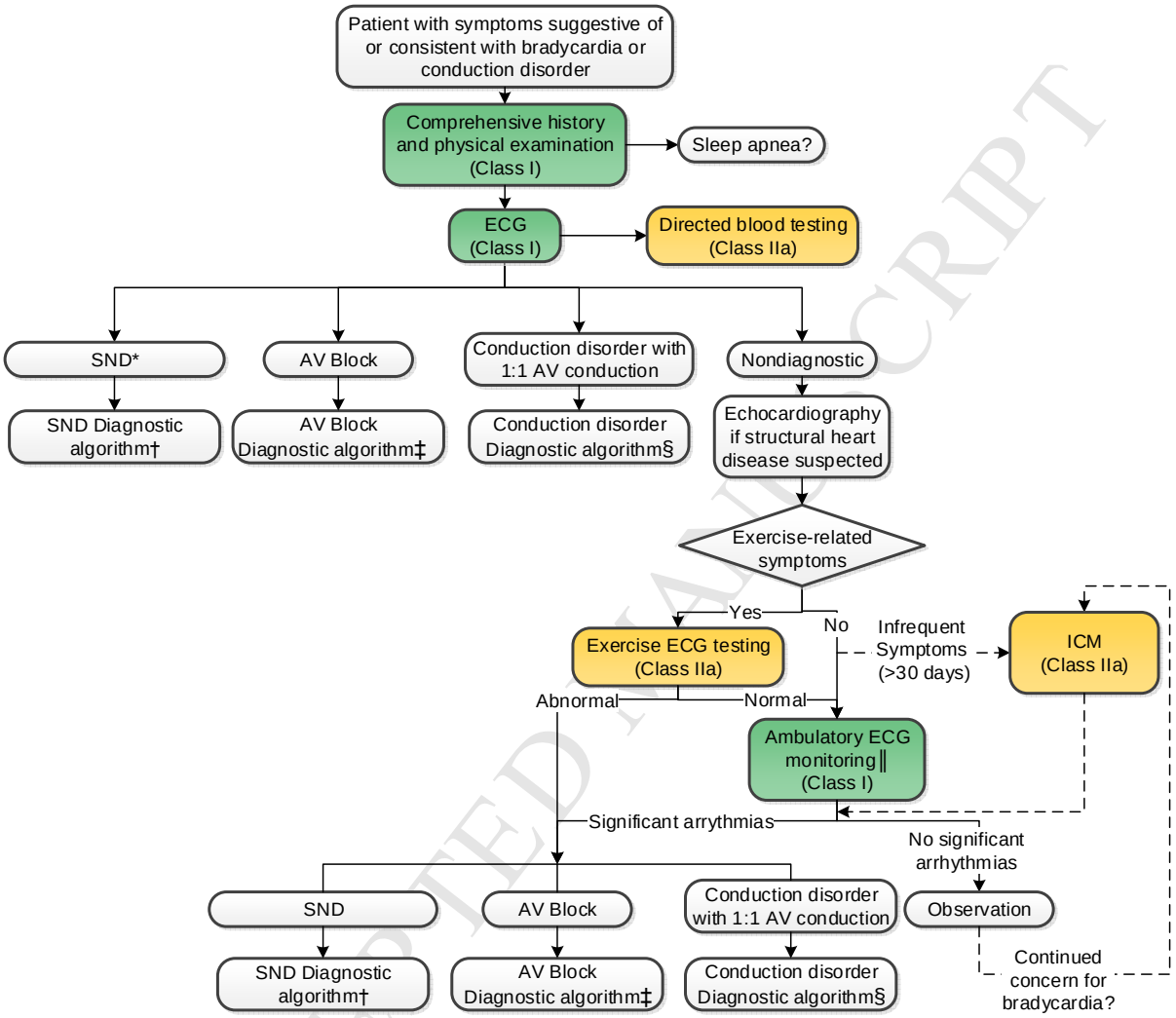
Recommendation-Specific Supportive Text

1. The history should outline the frequency, timing, duration, severity, longevity, circumstances, triggers and alleviating factors of symptoms suspicious for bradycardia or conduction disorders. The relationship of the symptoms to medications, meals, medical interventions, emotional distress, physical exertion, positional changes, and triggers (e.g., urination, defecation, cough, prolonged standing, shaving, tight collars, and head turning) can help narrow the broad differential diagnosis. Because of the propensity of some commonly prescribed medications (and nutraceuticals) to elicit or exacerbate bradyarrhythmias, a thorough review of both prescription and over-the-counter medications is essential (Table 4 and Table S1 in the Web Supplement). Bradycardia and conduction tissue disorders can be the first manifestation of a systemic illness or heart disease (Table 5). A complete history should include comprehensive cardiovascular risk assessment, family history, travel history, and review of systems. Like the medical history, the physical examination should not only focus on manifestations of bradycardia but also signs of underlying structural heart disease and systemic disorders. Care should be taken to correlate slow radial pulses with precordial auscultation or carotid pulse assessment as some rhythms (e.g., ventricular or conducted atrial bigeminy) can be misinterpreted as bradycardia if premature beats generate inadequate stroke volume to be palpable peripherally. As disorders of autonomic regulation figure prominently in the differential diagnosis of syncope and near syncope, orthostatic changes in heart rate and blood pressure can be helpful. Carotid sinus massage can be helpful in patients with symptoms suggestive of carotid sinus

hypersensitivity syndrome (syncope or near syncope elicited by tight collars, shaving, or turning the head). Carotid sinus massage should be performed in both the supine and upright position in a safe environment with careful blood pressure and electrocardiographic monitoring. Careful carotid auscultation (and/or carotid ultrasound) to exclude an ipsilateral carotid bruit (or significant abnormalities) is mandatory before performing this maneuver as strokes precipitated by carotid sinus massage have been reported (S4.1-5).

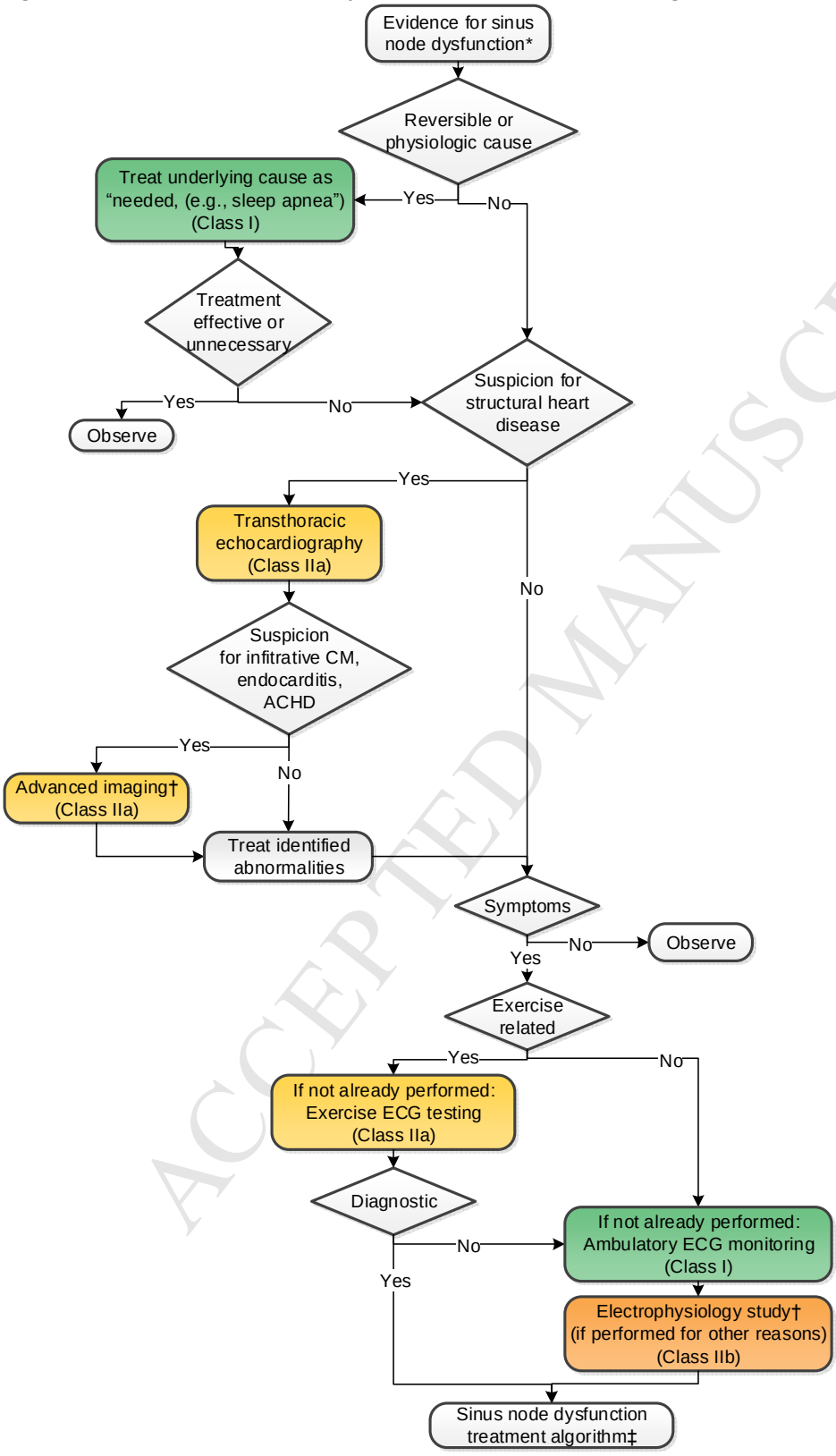
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Figure 1. Evaluation of Bradycardia and Conduction Disease Algorithm



Colors correspond to Class of Recommendation in Table 2.
See Section 4 for discussion.
Dashed lines indicate possible optional strategies based on the specific clinical situation.
*Sinus bradycardia, ectopic atrial rhythm, junctional rhythm, sinus pause.
†Refer to Section 4.3.2., Figure 2.
‡Refer to Section 4.3.2., Figure 3.
§ Refer to Section 7.4., Figure 8.
‖ Monitor choice based on the frequency of symptoms.
AV indicates atrioventricular; and ECG, electrocardiogram/electrocardiographic.

Figure 2. Initial Evaluation of Suspected or Documented SND Algorithm



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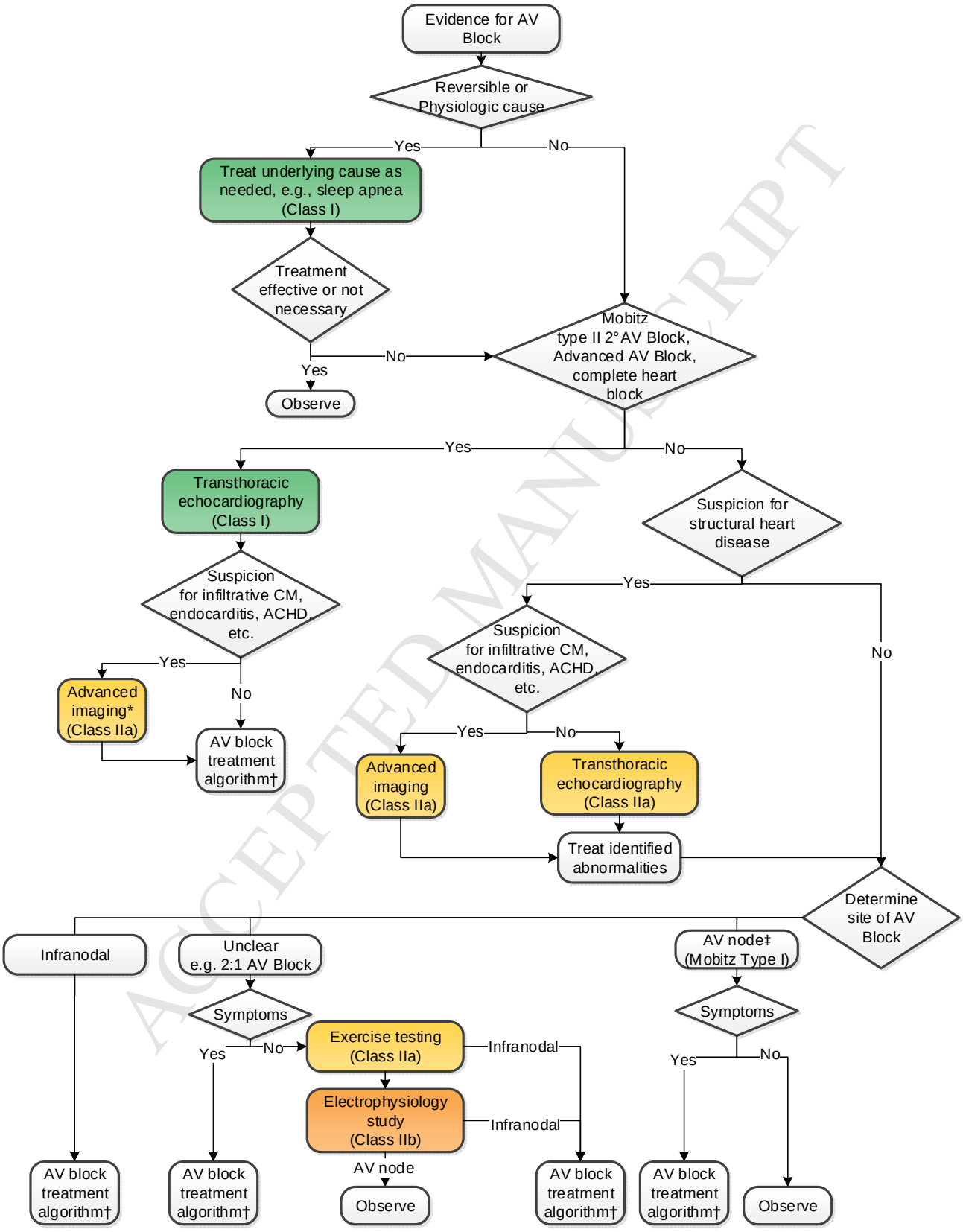
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Colors correspond to Class of Recommendation in Table 2.
See Section 4 for discussion.
*Sinus pauses, sinus bradycardia, junctional rhythm, ectopic atrial rhythm (all with heart rates <50 bpm) while awake.
†The electrophysiology test should not be done primarily for sinus node dysfunction. If electrophysiology testing is being performed for another reason (e.g., risk stratification for sudden cardiac death), evaluation of sinus node function may be useful to help inform whether an atrial lead for atrial pacing would have potential benefits.
‡Refer to Section 5.5.4.1., Figure 6.
ACHD indicates adult congenital heart disease; CM, cardiomyopathy; and ECG, electrocardiogram/electrocardiographic.

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Figure 3. Initial Evaluation of Suspected Atrioventricular Block Algorithm

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Evidence for AV Block
Reversible or Physiologic cause
Yes
No
Treat underlying cause as needed, e.g., sleep apnea (Class I)
Treatment effective or not necessary
No
Yes
Observe
Mobitz type II 2° AV Block, Advanced AV Block, complete heart block
Yes
No
Transthoracic echocardiography (Class I)
Suspicion for infiltrative CM, endocarditis, ACHD, etc.
Yes
No
Advanced imaging* (Class IIa)
AV block treatment algorithm†
Suspicion for structural heart disease
Yes
No
Suspicion for infiltrative CM, endocarditis, ACHD, etc.
Yes
No
Advanced imaging (Class IIa)
Transthoracic echocardiography (Class IIa)
Treat identified abnormalities
Determine site of AV Block
Infranodal
Unclear e.g. 2:1 AV Block
AV node‡ (Mobitz Type I)
Symptoms
Yes
No
Exercise testing (Class IIa)
Infranodal
Electrophysiology study (Class IIb)
Infranodal
AV node
AV block treatment algorithm†
AV block treatment algorithm†
Observe
AV block treatment algorithm†
Symptoms
Yes
No
AV block treatment algorithm†
Observe

Colors correspond to Class of Recommendation in Table 2.
*Targeted Advanced Imaging—Magnetic Resonance Imaging (MRI): Amyloidosis, myocarditis, hemochromatosis, sarcoidosis, CHD, sinus of Valsalva aneurysm, aortic dissection, arrhythmogenic right ventricular cardiomyopathy; fluoro-deoxy-glucose (fludeoxyglucose)-positron emission tomography (FDG PET): sarcoidosis; 99m technetium pyrophosphate (Tc PYP) or 99m technetium 3,3-diphosphono-1,2-propanodicarboxylic acid (TC-DPD): Transthyretin (TTR) amyloidosis; cardiac computed tomography (CT): CHD, sinus of Valsalva aneurysm, aortic dissection, arrhythmogenic right ventricular cardiomyopathy; echo longitudinal strain: Amyloidosis; transesophageal echocardiogram (TEE): Endocarditis, sinus of Valsalva aneurysm, aortic dissection, CHD.
†Refer to Section 6.4., Figure 7.
‡The atrioventricular node is more likely the site of block with second-degree Mobitz type I atrioventricular block and a narrow QRS complex or severe first-degree atrioventricular block (>0.30 s) with a narrow QRS complex.
AV indicates atrioventricular; ACHD, adult congenital heart disease; CHD, congenital heart disease; and CM, cardiomyopathy.

Table 4. Medications That Can Induce/Exacerbate Bradycardia or Conduction Disorders

Antihypertensive	Antiarrhythmic	Psychoactive	Other
• Beta-adrenergic receptor blockers (including beta-adrenergic blocking eye drops used for glaucoma) • Clonidine • Methyldopa • Non-dihydropyridine calcium channel blockers • Reserpine	• Adenosine • Amiodarone • Dronedarone • Flecainide • Procainamide • Propafenone • Quinidine • Sotalol	• Donepezil • Lithium • Opioid analgesics • Phenothiazine antiemetics and antipsychotics • Phenytoin • Selective serotonin reuptake inhibitors • Tricyclic antidepressants	• Anesthetic drugs (propofol) • Cannabis • Digoxin • Ivabradine • Muscle relaxants (e.g., succinylcholine)

Table 5. Conditions Associated With Bradycardia and Conduction Disorders

Intrinsic
Cardiomyopathy (ischemic or nonischemic)
Congenital heart disease
Degenerative fibrosis
Infection/inflammation • Chagas disease • Diphtheria • Infectious endocarditis • Lyme disease • Myocarditis • Sarcoidosis • Toxoplasmosis
Infiltrative disorders • Amyloidosis • Hemochromatosis • Lymphoma
Ischemia/infarction

Rheumatological conditions • Rheumatoid arthritis • Scleroderma • Systemic lupus erythematosus
Surgical or procedural trauma • Cardiac procedures such as ablation or cardiac catheterization • Congenital heart disease surgery • Septal myomectomy for hypertrophic obstructive cardiomyopathy • Valve surgery (including percutaneous valve replacement)
Extrinsic

Autonomic perturbation
• Carotid sinus hypersensitivity
• Neurally-mediated syncope/presyncope
• Physical conditioning
• Situational syncope
  o Cough
  o Defecation
  o Glottic stimulation
  o Medical procedures
  o Micturition
  o Vomiting
• Sleep (with or without sleep apnea)

Metabolic • Acidosis • Hyperkalemia • Hypokalemia • Hypothermia • Hypothyroidism • Hypoxia

Adapted with permission from Mangrum and DiMarco (S4.1-3) and Vogler et al. (S4.1-4).

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4.2. Noninvasive Evaluation

4.2.1. Resting ECG in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendation for Electrocardiogram (ECG) in Patients With Documented or Suspected Bradycardia or Conduction Disorders Referenced studies that the support recommendation are summarized in Online Data Supplement 1.		
COR	**LOE**	**Recommendation**
I	**B-NR**	**1. In patients with suspected bradycardia or conduction disorder, a 12-lead ECG is recommended to document rhythm, rate, and conduction, and to screen for structural heart disease or systemic illness (S4.2.1-1–S4.2.1-4).**

Synopsis

The resting ECG is an essential component of the initial evaluation of those with known or suspected bradycardia or conduction disorder. An appropriately timed ECG during a symptomatic episode may provide a definitive diagnosis. For those in whom physical examination or telemetry monitoring suggest bradycardia or conduction disturbance, a 12-lead ECG is useful to confirm the rhythm and rate, the nature and extent of conduction disturbance, and to document other abnormalities suggestive of structural heart or systemic disease (e.g., left ventricular hypertrophy, diagnostic Q waves, prolonged corrected QT interval, findings suggestive of hyperkalemia).

Recommendation-Specific Supportive Text

1. Unless a patient with suspected bradycardia or conduction disorder is symptomatic or bradycardic at the time of the recording, the 12-lead ECG will not provide a rhythm correlation with symptoms. In patients presenting with syncope, the initial ECG provides a diagnosis in only approximately 5% (S4.2.1-2, S4.2.1-4) and in those with less well-defined clinical presentations and nonspecific symptoms, the diagnostic yield is probably lower. However, an abnormal initial ECG is predictive of adverse outcomes in patients presenting with syncope and near syncope, in large part as an indicator of underlying structural heart disease or the presence of systemic disease. A multicenter, prospective observational study of syncope evaluated in the emergency department concluded that a broad range of electrocardiographic abnormalities was associated with increased all-cause mortality at 1 year (S4.2.1-1). The prognostic value of an abnormal initial ECG in those with syncope and near syncope is reflected in its inclusion in most published multivariate risk scores used to predict adverse outcomes in this population (S4.2.1-5). This risk does not necessarily correlate with pathological bradycardia as the mechanism of syncope, as only approximately 10% of syncope can be attributed to bradycardia or a conduction disorder at the time of initial presentation. An additional 18% can be attributed to neurally mediated syncope which frequently is manifest by both bradycardia and hypotension (S4.2.1-2).

4.2.2. Exercise Electrocardiographic Testing in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendations for Exercise Electrocardiographic Testing in Patients With Documented or Suspected Bradycardia or Conduction Disorders Referenced studies that support recommendations are summarized in Online Data Supplement 2.		
COR	**LOE**	**Recommendations**
IIa	**B-NR**	**1. In patients with suspected chronotropic incompetence, exercise electrocardiographic testing is reasonable to ascertain the diagnosis and provide information on prognosis (S4.2.2-1, S4.2.2-2).**
IIa	**C-LD**	**2. In patients with exercise-related symptoms suspicious for bradycardia or conduction disorders, or in patients with 2:1 atrioventricular block of unknown level, exercise electrocardiographic testing is reasonable (S4.2.2-3, S4.2.2-4).**

Synopsis

Although there is no routine role for exercise electrocardiographic testing in the evaluation of patients with suspected or documented bradycardia/conduction disorder, it may be useful in selected patients. Limited observational data suggest that it can be useful in evaluating those whose symptoms occur during or immediately after exercise, including those suspected of chronotropic incompetence and exercise-induced, neurally mediated syncope. Occasionally, patients manifest conduction disorders precipitated by myocardial ischemia during exercise electrocardiographic testing. Exercise testing can be helpful in evaluating the impact of parasympathetic withdrawal and sympathetic activation on cardiac conduction (e.g., distinguishing atrioventricular nodal versus conduction disturbances in the His Purkinje system below the atrioventricular node [infranodal] in the setting of 2:1 atrioventricular nodal block) (S4.2.2-5).

Recommendation-Specific Supportive Text

1. Exercise electrocardiographic testing is integral to the diagnosis of chronotropic incompetence, a condition broadly defined as an inability to increase heart rate commensurate with the increased metabolic demands of physical activity (S4.2.2-6). Chronotropic incompetence, often considered as failure to achieve 80% of age-predicted maximal heart rate but in practice much more difficult to define particularly in the presence of comorbidities can contribute to exercise intolerance and connotes an adverse prognosis (S4.2.2-1, S4.2.2-2, S4.2.2-7). Although estimates of prevalence range broadly from 9% to 89% it appears to be common in individuals with cardiovascular disease, including one-third of those with congestive heart failure (S4.2.2-6).
2. In patients with exercise-related symptoms, the development or progression of atrioventricular block may occasionally be the underlying cause. Because worsening atrioventricular block with exercise is usually attributable to infranodal disease, exercise electrocardiographic testing may also be helpful for defining the site of atrioventricular block when unclear by ambulatory electrocardiographic monitoring (S4.2.2-4, S4.2.2-5, S4.2.2-8). Only rarely does exercise testing uncover otherwise occult and clinically significant conduction disorders. Although typically associated with signs and symptoms of ischemia during the test, exercise-induced conduction disorders have been reported without evidence of ischemia (S4.2.2-4).

   Conduction disorders elicited by exercise electrocardiographic testing in rare cases may be precipitated by myocardial ischemia or coronary vasospasm (S4.2.2-9–S4.2.2-13). In a review of 2,200 consecutive exercise tests to assess the significance of transient intraventricular conduction

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abnormalities associated with myocardial ischemia, only 10 (0.45%) patients manifested both ischemia and intraventricular conduction abnormalities. Subsequent coronary angiography revealed significant stenosis of the left anterior descending coronary artery at or before the first septal branch in all 10 (S4.2.2-11). In patients presenting with syncope without exercise related symptoms, the yield of exercise electrocardiographic testing even with additional imaging modalities is low (S4.2.2-14).

4.2.3. Ambulatory Electrocardiography in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendation for Ambulatory Electrocardiography in Patients With Documented or Suspected Bradycardia or Conduction Disorders Referenced studies that support the recommendation are summarized in Online Data Supplement 3.		
COR	**LOE**	**Recommendation**
I	**B-NR**	**1. In the evaluation of patients with documented or suspected bradycardia or conduction disorders, cardiac rhythm monitoring is useful to establish correlation between heart rate or conduction abnormalities with symptoms, with the specific type of cardiac monitor chosen based on the frequency and nature of symptoms, as well as patient preferences (S4.2.3-1–S4.2.3-12).**

Synopsis

The intermittent nature of most symptomatic bradycardia and conduction disorders often necessitates a more prolonged form of electrocardiographic monitoring to correlate rhythm disturbances with symptoms. For those with daily symptoms, a 24- or 48-hour continuous ambulatory ECG (Holter monitor) is appropriate and, in active individuals, may help identify the presence or absence of chronotropic incompetence (S4.2.3-13). Less frequent symptoms are best evaluated with more prolonged ambulatory electrocardiographic monitoring that can be accomplished with a broad array of modalities. Contemporary options have been recently reviewed in a comprehensive expert consensus statement (S4.2.3-14).

The yield of ambulatory monitoring for significant bradyarrhythmias varies according to the population studied but is typically <15% (S4.2.3-13, S4.2.3-15, S4.2.3-16). However, in populations with nonspecific symptoms felt to be potentially arrhythmic, one-third of the population will manifest their presenting symptoms during continuous ambulatory monitoring without associated arrhythmia, a useful observation that often excludes arrhythmia or conduction disorder as the source (S4.2.3-13).

Recommendation-Specific Supportive Text

1. In a prospective study of 95 individuals with syncope of uncertain origin after history, physical examination and ECG, up to 72 hours of continuous ambulatory monitoring uncovered significant bradyarrhythmia in 11% (S4.2.3-15). In patients with less specific symptoms, the diagnostic yield of continuous ambulatory electrocardiographic monitoring for bradyarrhythmias is even lower. A study of 518 consecutive 24-hour Holter monitors performed for a broad range of cardiac symptoms revealed significant bradyarrhythmia in only 4%, and none manifested advanced atrioventricular block (S4.2.3-16). External loop recorders, transtelephonic event recorders, adhesive patch recorders, and mobile continuous outpatient telemetry monitoring provide a higher diagnostic yield than 24- or 48-hour Holter monitoring because of the longer period of monitoring. These prolonged

monitoring strategies can be useful in the evaluation of suspected bradycardia or conduction disorders (S4.2.3-1–S4.2.3-3, S4.2.3-5, S4.2.3-7–S4.2.3-12, S4.2.3-17). The characteristics of available ambulatory monitoring systems and their proper selection were recently reviewed (S4.2.3-14, S4.2.3-18) and have been tabulated in the 2017 ACC/AHA/HRS Guideline for the Evaluation and Management of Patients with Syncope (Table 6) (S4.2.3-19). Choice of device is predicated on frequency of symptoms and the degree to which symptoms incapacitate the patient (S4.2.3-13, S4.2.3-14, S4.2.3-18–S4.2.3-20). Whatever monitoring system is chosen, it is important for the appropriate infrastructure to be present to facilitate timely notification of the patient and healthcare provider when a potentially dangerous abnormality is identified.

Table 6. Cardiac Rhythm Monitors

Types of Monitor	Device Description	Patient Selection
Nonphysician prescribed smartphone-based systems	• Commercially available smartphone–based systems • Can record a rhythm strip when the patient has symptoms or continuously depending on the technology	Patient access to the technology
Holter monitor	• Continuous recording for 24–72 h; up to 2 wk with newer models • Symptom rhythm correlation can be achieved through a patient event diary and patient-activated annotations	Symptoms frequent enough to be detected within a short period (24–72 h) of monitoring
Patient-activated, transtelephonic monitor (event monitor)	A recording device that transmits patient-activated data (live or stored) via an analog telephone line to a central remote monitoring station (e.g., physician office)	• Frequent, spontaneous symptoms likely to recur within 2–6 wk • Limited use in patients with incapacitating symptoms
External loop recorder (patient or auto triggered)*	• A device that continuously records and stores rhythm data over weeks to months • Patient activated, or auto triggered (e.g., to record asymptomatic arrhythmias) to provide a recording of events antecedent to (3–14 min), during, and after (1–4 min) the triggered event • Newer models are equipped with a cellular telephone, which transmits triggered data automatically over a wireless network to a remote monitoring system	Frequent, spontaneous symptoms potentially related to bradycardia or conduction disorder, likely to recur within 2–6 wk
External patch recorders	• Patch device that continuously records and stores rhythm data, with patient-trigger capability to allow for symptom-rhythm correlation • No leads or wires, and adhesive to chest wall/sternum • Various models record from 2–14 d • Offers accurate means of assessing burden of AF • Patient activated, or auto triggered (e.g., to record asymptomatic arrhythmias) to provide a recording of events antecedent to, during, and after the triggered event	• Can be considered as an alternative to external loop recorder • Given that it is leadless, can be accurately self-applied, and is largely water resistant, it may be more comfortable and less cumbersome than an external loop recorder, potentially improving compliance • Unlike Holter monitors and other external

		monitors, it offers only 1-lead recording
Mobile cardiac outpatient telemetry	• Device that records and transmits data (up to 30 d) from preprogrammed arrhythmias or patient activation to a communication hub at the patient's home • Significant arrhythmias are detected; the monitor automatically transmits the patient's electrocardiographic data through a wireless network to the central monitoring station, which is attended by trained technicians 24 h/d	• Spontaneous symptoms, potentially related to bradycardia or conduction disorder, that are too brief, too subtle, or too infrequent to be readily documented with patient activated monitors • In high-risk patients whose rhythm requires real-time monitoring
Implantable cardiac monitor	• Subcutaneously implanted device, with a battery life of 2–3 y • Triggered by the patient (or often family member witness) to store the event. • Models allow for transtelephonic transmission, as well as automatic detection of significant arrhythmias with remote monitoring	Recurrent, infrequent, unexplained symptoms, potentially related to bradycardia or conduction disorder after a nondiagnostic initial workup, with or without structural heart disease

*Higher yield in patients who are able to record a diary to correlate with possible arrhythmia.
Adapted with permission from Shen et al. (S4.2.3-19).
AF indicates atrial fibrillation.

4.2.4. Imaging in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendations for Cardiac Imaging in Bradycardia or Conduction Disorders Referenced studies that support recommendations are summarized in Online Data Supplements 3 and 4.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients with newly identified LBBB, second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or third-degree atrioventricular block with or without apparent structural heart disease or coronary artery disease, transthoracic echocardiography is recommended (S4.2.4-1–S4.2.4-10).**
IIa	**B-NR**	**2. In selected patients presenting with bradycardia or conduction disorders other than LBBB, second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or third-degree atrioventricular block, transthoracic echocardiography is reasonable if structural heart disease is suspected (S4.2.4-3, S4.2.4-11–S4.2.4-13).**
IIa	**C-LD**	**3. In selected patients with bradycardia or bundle branch block, disease-specific advanced imaging (e.g., transesophageal echocardiography, computed tomography, cardiac magnetic resonance imaging [MRI], or nuclear imaging) is**

		reasonable if structural heart disease is suspected yet not confirmed by other diagnostic modalities (S4.2.4-14–S4.2.4-22).
III: No Benefit	**B-NR**	**4. In the evaluation of patients with asymptomatic sinus bradycardia or first-degree atrioventricular block and no clinical evidence of structural heart disease, routine cardiac imaging is not indicated (S4.2.4-22–S4.2.4-24).**

Synopsis

Because bradycardia or conduction disorders can be present in a wide variety of cardiovascular and systemic diseases and, because the prognosis of documented bradyarrhythmias is heavily influenced by the presence of underlying structural heart disease, assessment of cardiac structure and function is often clinically indicated. In an international survey of 43 medical centers belonging to the European Heart Rhythm Association's electrophysiology research network, 66% reported that they "always or almost always" perform an echocardiogram in patients presenting with syncope. An additional 27% reported that they pursue such testing in "most cases" (S4.2.4-25). The ACCF/ASE/AHA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 appropriate use criteria for echocardiography endorses the propriety of echocardiography in patients with symptoms suspected to be cardiac in origin, including symptoms potentially caused by bradycardia or conduction disorders such as syncope, or lightheadedness /presyncope with signs or symptoms of cardiovascular disease known to cause such symptoms (e.g., aortic stenosis, hypertrophic cardiomyopathy or heart failure) (S4.2.4-12). Advanced imaging, both cardiac and noncardiac, can be helpful in carefully selected patients suspected to have structural cardiac disease known to be associated with bradycardia or conduction disturbances that is not apparent on echocardiogram and those patients in whom heterotaxy syndromes such as polysplenia is suspected.

Recommendation-Specific Supportive Text

1. In unselected populations, those with LBBB have a higher prevalence of both cardiovascular and noncardiovascular comorbidities (S4.2.4-6) and an increased likelihood of underlying structural heart disease (S4.2.4-4, S4.2.4-8, S4.2.4-10). Longitudinal, community-based and cohort studies suggest an associated increased risk of cardiovascular death, sudden death, and death from congestive heart failure, without an increase in all-cause mortality (S4.2.4-1, S4.2.4-2, S4.2.4-5, S4.2.4-9, S4.2.4-10, S4.2.4-26, S4.2.4-27). Some also suggest increased incident coronary artery disease and congestive heart failure during follow-up (S4.2.4-1, S4.2.4-2, S4.2.4-8, S4.2.4-9). The clinical implications of asymptomatic LBBB in young, apparently healthy individuals may differ from those in an older or sicker population (S4.2.4-28, S4.2.4-29). Nonetheless, excluding associated structural heart disease in all patients with LBBB is prudent as the conduction disorder may not only be a harbinger of occult structural or ischemic heart disease but also connotes an elevated risk should they be present (S4.2.4-1, S4.2.4-7, S4.2.4-30–S4.2.4-36) and may influence management in some forms of structural heart disease. Most notably, LBBB helps identify candidates for re-synchronization therapy in those with heart failure with reduced ejection fraction (S4.2.4-37, S4.2.4-38). Although no prospective studies have defined the outcome of echocardiography-guided management in asymptomatic LBBB, the presence of LBBB in patients referred for echocardiography in evaluation of suspected congestive heart failure confers nearly a 4-fold increased likelihood of left ventricular systolic dysfunction (S4.2.4-3).
2. Transthoracic echocardiography can identify various structural cardiac abnormalities underlying bradycardia or conduction disturbance, including cardiomyopathy, valvular heart disease, congenital anomalies, tumors, infections, infiltrative processes, immunologically mediated conditions, and

diseases of the great vessels and pericardium (S4.2.4-12). However, the yield is higher when there are clinical indications of structural disease, including in patients with syncope who manifest signs or symptoms of cardiac disease (e.g., bradycardia or conduction disorders) (S4.2.4-11, S4.2.4-22, S4.2.4-24). Transthoracic echocardiography can be prognostic, as well, both in those presenting with syncope (S4.2.4-39) and in those who are less profoundly symptomatic. A prospective study of 35 untreated patients age >45 years with symptomatic SND suggested that echocardiographic parameters like left ventricular end-diastolic diameter and ejection fraction predict adverse cardiac events such as syncope, heart failure, and atrial tachyarrhythmias, when followed for up to 4 years (S4.2.4-13).

3. Cardiac MRI and computed tomography can be helpful in carefully selected patients to identify conditions known to contribute to conduction disturbance or SND. Specifically, MRI can be helpful in diagnosing infiltrative processes, including sarcoidosis, hemochromatosis, and amyloidosis (S4.2.4-16–S4.2.4-19, S4.2.4-40–S4.2.4-56). Cardiac computed tomography can be similarly helpful, particularly when MRI is contraindicated or unavailable. It offers superior information regarding calcification of cardiac structures and has some advantages in evaluating coronary artery anatomy when epicardial coronary atherosclerotic disease is suspected (S4.2.4-14, S4.2.4-57). Both computed tomography and MRI offer high-quality information regarding cardiovascular structure in the setting of congenital heart disease (S4.2.4-21, S4.2.4-57). Cardiac nuclear imaging techniques can be useful to detect and/or discriminate amongst infiltrative cardiomyopathies, most notably in distinguishing between wild-type transthyretin and light chain cardiac amyloidosis and diagnosing cardiac sarcoidosis using fluorodeoxyglucose positron emission tomographic imaging (S4.2.4-15, S4.2.4-20). Transesophageal echocardiography can be a useful adjunct for endocarditis with or without perivalvular complications, aortic dissection, or unruptured sinus of Valsalva aneurysm which have all been occasionally associated with bradycardia or conduction block (S4.2.4-58–S4.2.4-64). When bradycardia or conduction disorders are accompanied by clinical suspicion of structural heart disease undiagnosed by echocardiography, ≥1 of these advanced imaging tests is usually helpful.
4. The diagnostic yield of transthoracic echocardiography in patients without clinical evidence (e.g., history, physical examination, ECG) of heart disease is low and echocardiography is not recommended in such patients (S4.2.4-12). In some clinical circumstances, patients may manifest symptoms that might indicate cardiac disease, including symptoms potentially related to bradycardia or conduction disorders, such as syncope and presyncope. Individuals presenting with such symptoms but without other clinical evidence of structural heart disease are unlikely to benefit from routine imaging, as recently reviewed in the 2017 ACC/AHA/HRS guideline for the evaluation and management of patients with syncope (S4.2.4-65).

4.2.5. Laboratory Testing in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendation for Laboratory Testing in Patients With Documented or Suspected Bradycardia or Conduction Disorders		
COR	**LOE**	**Recommendation**
IIa	**C-LD**	**1. In patients with bradycardia, laboratory tests (e.g., thyroid function tests, Lyme titer, potassium, pH) based on clinical suspicion for a potential underlying cause are reasonable (S4.2.5-1–S4.2.5-4).**

Synopsis

Bradycardia attributable to SND or atrioventricular block may be secondary conditions such as hypothyroidism, rheumatologic disorders, and infectious disorders. Although there are many case reports of specific diseases associated with bradycardia where the diagnosis was aided by laboratory testing, there has been no study evaluating the diagnostic yield and benefits of routine comprehensive laboratory testing in patients presenting with bradycardia or conduction tissue abnormalities. Potential causes for bradycardia and conduction abnormalities are provided in Tables 3 and 4.

Recommendation-Specific Supportive Text

1. Isolated case reports have identified medical conditions that can be associated with bradycardia in which laboratory testing directed toward a specific diagnosis can be useful (S4.2.5-1–S4.2.5-5). For example, thyroid function tests in the patient with bradycardia attributable to suspected hypothyroidism or Lyme titer to identify acute Lyme carditis in a young person who develops atrioventricular block in an endemic area (S4.2.5-3, S4.2.5-5). However, there have been no studies that have systematically evaluated the additional value of laboratory testing in patients who present primarily with bradycardia.

4.2.6. Genetic Testing in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendations for Genetic Testing in Documented or Suspected Bradycardia or Conduction Disorders		
COR	**LOE**	**Recommendations**
I	**C-EO**	**1. In patients in whom a conduction disorder-causative mutation has been identified, genetic counseling and mutation-specific genetic testing of first-degree relatives is recommended to identify similarly affected individuals.**
IIb	**C-EO**	**2. In patients with inherited conduction disease, genetic counseling and targeted testing may be considered to facilitate cascade screening of relatives as part of the diagnostic evaluation.**

Synopsis

Although most sinus node disorders and conduction disturbances in adults are attributable to increased vagal tone or acquired disease, genetic mutations may also contribute (S4.2.6-1–S4.2.6-4). Although familial disorders of conduction abnormalities and sinus node function are rare, a growing number of genetic mutations have been linked to a range of abnormalities that may present as isolated SND or conduction disease, or in association with cardiomyopathy, congenital cardiac anomalies, noncardiac developmental disorders, skeletal muscular disorders, or tachyarrhythmias (S4.2.6-5). The implicated genes code for ion channels and their regulatory factors, nuclear envelope proteins, membrane adaptor protein, transcription factors, calcium handling proteins of the sarcoplasmic reticulum, gap junctions, cardiac hormones, and sarcomeric proteins (S4.2.6-1).

Recommendation-Specific Supportive Text

1. An international consensus panel has endorsed mutation-specific genetic testing for “family members and appropriate relatives” after the identification of a progressive cardiac conduction disease -causative mutation in an index case. Although the consensus document does not explicitly define “family members and appropriate relatives,” one can infer this to mean first-degree relatives

(with or without evidence of conduction disease) and more remote relatives with suspicious clinical characteristics for conduction disease. Such testing can be deferred in asymptomatic children because of the age-dependent nature of progressive conduction disease and incomplete penetrance (S4.2.6-5). Asymptomatic family members who carry the conduction disease-associated mutation and those first-degree relatives of an affected proband who have not undergone mutation-specific genetic testing should be followed regularly for signs of evolving conduction disease, cardiomyopathy or tachyarrhythmia. Before mutation-specific testing, genetic counseling is essential to determine whether to proceed in an individual case.

2. The most common identifiable gene responsible for inherited conduction disease (the SCN5A gene encoding the cardiac sodium channel alpha subunit) accounts for only 5% of progressive conduction disease cases (S4.2.6-5). All other identified genes, in aggregate, account for a substantially smaller proportion. Mutations in the cardiac pacemaker channel gene HCN4 have been implicated in idiopathic SND (S4.2.6-6, S4.2.6-7). Nonetheless, most SND is physiologic or acquired, and genetic testing is not routinely indicated (S4.2.6-5).
3. Citing undefined diagnostic yield and “signal-to-noise” ratio for genetic testing in progressive cardiac conduction disease, as well as uncertain rates of rare variants of uncertain significance in control subjects, an international consensus document suggests that the diagnostic, prognostic and therapeutic value of genetic testing is limited in evaluating an index case (S4.2.6-5). The writing committee did not endorse routine genetic testing in patients with SND or conduction disease. Based primarily on expert opinion, the writing committee suggested that genetic testing may still be considered as part of the diagnostic evaluation for select patients with either isolated conduction disease or conduction disease with concomitant congenital heart disease, especially when there is a positive family history of conduction disease.

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4.2.7. Sleep Apnea Evaluation and Treatment in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendations for Sleep Apnea Evaluation and Treatment in Patients With Documented or Suspected Bradycardia or Conduction Disorders Referenced studies that support recommendations are summarized in Online Data Supplement 5.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients with documented or suspected bradycardia or conduction disorder during sleep, screening for symptoms of sleep apnea syndrome is recommended with subsequent confirmatory testing directed by clinical suspicion (S4.2.7-1–S4.2.7-11).**
I	**B-NR**	**2. In patients with sleep-related bradycardia or conduction disorder and documented obstructive sleep apnea, treatment directed specifically at the sleep apnea (e.g., continuous positive airway pressure and weight loss) is recommended (S4.2.7-12–S4.2.7-16).**
IIa	**B-NR**	**3. In patients who have previously received or are being considered for a PPM for bradycardia or conduction disorder, screening for sleep apnea syndrome is reasonable (S4.2.7-10, S4.2.7-11).**

Synopsis

Nocturnal bradyarrhythmias are common in both health and disease. Sinus bradycardia is the most common bradyarrhythmia encountered during sleep. However, sinus arrest, sinus exit block, all degrees of atrioventricular block, junctional rhythm, and periods of asystole also occur on occasion (S4.2.7-17–S4.2.7-19). These are particularly common in the young and in the conditioned athlete and can be profound (S4.2.7-20–S4.2.7-23). In most circumstances these are physiological, vagally mediated, asymptomatic events which require no intervention. The frequency of nocturnal bradyarrhythmias appears to decline in middle-aged and older healthy individuals (S4.2.7-17–S4.2.7-19). Those who manifest sleep apnea syndrome, however, demonstrate a higher prevalence of sleep-related bradycardia and conduction disorders, primarily during apneic episodes (S4.2.7-1–S4.2.7-11). In such individuals, wakeful bradyarrhythmias are uncommon and these nocturnal arrhythmias are usually asymptomatic. In patients with sleep apnea and sleep-related bradyarrhythmias, frequency of episodes is decreased with continuous positive airway pressure and patients are unlikely to develop symptomatic bradycardia in long-term follow-up (S4.2.7-12–S4.2.7-15). Treating the underlying sleep apnea not only alleviates apnea-related symptoms and improves cardiovascular outcome, it also eliminates the need for pacemaker implantation in most patients.

Recommendation-Specific Supportive Text

1. Sleep disordered breathing is common with an estimated prevalence in the United States of 24% in men and 9% in women, much of which is either asymptomatic or unrecognized (S4.2.7-24). The prevalence is higher in populations with cardiovascular diseases, ranging as high as 47% to 83%, depending on the specific disorder (S4.2.7-25). Estimated rates of profound nocturnal sinus bradycardia range from 7.2% to 40%. Rates of second- or third-degree atrioventricular block range from 1.3% to 13.3%, and rates of sinus pauses range from 3.3% to 33% (S4.2.7-1–S4.2.7-3, S4.2.7-5–S4.2.7-9). The prevalence of these arrhythmias appears to increase with the severity of sleep apnea (S4.2.7-1, S4.2.7-2, S4.2.7-5). A stereotypical pattern of progressive bradycardia during apnea/hypopnea (often profound) followed by tachycardia and hypertension during partial arousal

(presumably precipitated by hypoxia) has been frequently described and cited by some as an electrocardiographic means of indirectly diagnosing the condition (S4.2.7-1, S4.2.7-26).

2. Because both sleep disordered breathing and nocturnal bradyarrhythmias are relatively common, and treatment of sleep apnea not only dramatically reduces the frequency of these arrhythmias but also may offer cardiovascular benefits (S4.2.7-25), the presence of nocturnal bradyarrhythmias should prompt screening for sleep apnea, starting with solicitation of suspicious symptoms and pursuing additional testing if appropriate.
3. Nocturnal arrhythmias associated with obstructive sleep apnea are effectively suppressed with treatment of the underlying sleep apnea. Small studies assessing the frequency and distribution of arrhythmias during polysomnography before and after initiating continuous positive airway pressure (and/or bilevel positive airway pressure) consistently demonstrate dramatic improvements in both metrics of sleep disordered breathing and sleep-related bradyarrhythmias with continuous positive airway pressure (S4.2.7-12–S4.2.7-15). Episodes of profound sinus bradycardia, prolonged sinus pauses, and atrioventricular conduction block are reduced by 72% to 89% in these studies. One of these studies followed their patients for 54±10 months on continuous positive airway pressure therapy (with 58% complete compliance rate). None of the 17 participants without pacemakers experienced symptomatic bradycardia during this time (S4.2.7-14).
4. The prevalence of undiagnosed sleep apnea may be high in patients referred for pacemaker implantation for asymptomatic bradycardia and in unselected recipients of cardiovascular implantable electronic devices (CIED) (S4.2.7-10, S4.2.7-11). In a small, but illustrative, study, 7 patients with asymptomatic nocturnal bradyarrhythmias referred for pacemaker were queried for symptoms of sleep apnea. Suspicious symptoms prompted polysomnography that confirmed previously unsuspected obstructive sleep apnea in all. Over 22 months of follow-up, 86% remained free of bradyarrhythmia symptoms on treatment for sleep apnea but without a pacemaker (S4.2.7-10). A second illustrative study involved 98 consecutive patients with PPMs, implanted for a variety of indications, who were systematically screened with the Epworth Sleepiness Scale and polysomnography. Although only 25% of the group had Epworth Sleepiness Scale score >11 (normal, 0-10), 59% were diagnosed with sleep apnea by polysomnography. The sleep apnea was severe in 27% of the 69 subjects receiving a pacemaker for indications other than cardiac resynchronization (S4.2.7-11). Thus, conditions prompting consideration for CIED likely define a population at higher risk of sleep disordered breathing. This likely relates only partially to apnea-induced bradyarrhythmia. The complex interaction between sleep disordered breathing and a broad array of cardiovascular diseases likely contributes, as well (S4.2.7-25).

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4.3. Invasive Testing

4.3.1. Implantable Cardiac Monitor in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendation for Implantable Cardiac Monitor in Patients With Documented or Suspected Bradycardia or Conduction Disorders Referenced studies that support the recommendation are summarized in Online Data Supplement 6.		
COR	**LOE**	**Recommendation**
IIa	**C-LD**	**1. In patients with infrequent symptoms (>30 days between symptoms) suspected to be caused by bradycardia, long-term ambulatory monitoring with an implantable cardiac monitor (ICM) is reasonable if initial noninvasive evaluation is nondiagnostic (S4.3.1-1–S4.3.1-3).**

Synopsis

One of the most debilitating symptoms of bradycardia is syncope resulting in trauma. The suddenness and unpredictability of such events make the ICM an ideal diagnostic tool given its capacity for prolonged monitoring (up to 3 years) and its freedom of reliance on active patient participation. Early work (S4.3.1-4) as well as subsequent randomized and nonrandomized studies evaluating the diagnostic efficacy of ICM were almost exclusively performed in patients presenting with unexplained syncope and/or presyncope and not specifically for identification of bradycardia (S4.3.1-5). In patients with ongoing or frequent symptoms of bradycardia, the 12-lead ECG or external ambulatory electrocardiographic monitoring can usually document SND or atrioventricular conduction disease. However, when patients present with infrequent paroxysmal or infrequent symptoms, culprit bradycardias can evade the detection by standard external monitoring modalities. Longer duration of ambulatory monitoring with ICM may then be necessary to obtain correlation between bradycardia and symptoms.

Recommendation-Specific Supportive Text

1. Several randomized controlled trials (RCTs) have demonstrated the diagnostic value of ICM in patients presenting with unexplained syncope or presyncope (S4.3.1-1–S4.3.1-3). Compared with investigation by conventional testing modalities such as 24-hour ambulatory electrocardiographic monitoring, 12-lead ECG, and treadmill stress test, the strategy of long-term rhythm monitoring with ICM was more effective in obtaining a clinical diagnosis. Many of the conditions diagnosed by ICM were found to be bradycardia-mediated (i.e., high-grade atrioventricular block, SND, neurocardiogenic syncope with predominant cardio-inhibitory component) and were successfully treated with permanent cardiac pacing. Most patients with clinically significant bradycardia presenting with symptoms other than syncope (e.g., fatigue, dyspnea on exertion) do not typically need prolonged ambulatory monitoring for diagnosis. Nevertheless, in some patients, the diagnosis may remain inconclusive or uncertain after initial noninvasive evaluation. External monitors will generally be the first-line choice of diagnostic tools in an effort to obtain potential correlation between bradycardia and symptoms but, for patients with very infrequent symptoms, initial ICM implantation may be the best and most cost-effective initial strategy (S4.3.1-2).

4.3.2. Electrophysiology Study in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Recommendation for Electrophysiology Testing in Patients With Documented or Suspected Bradycardia or Conduction Disorders Referenced studies that support the recommendation are summarized in Online Data Supplement 7.		
COR	**LOE**	**Recommendation**
IIb	**C-LD**	**1. In patients with symptoms suspected to be attributable to bradycardia, an electrophysiology study (EPS) may be considered in selected patients for diagnosis of, and elucidation of bradycardia mechanism, if initial noninvasive evaluation is nondiagnostic (S4.3.2-1–S4.3.2-5).**

Synopsis

An EPS is an invasive, catheter-based procedure that can be used to test the integrity of cardiac conduction system and to assess potential inducibility of various cardiac tachyarrhythmias. EPS are well tolerated and the risk of serious procedural complications such as cardiac tamponade and life-threatening ventricular arrhythmia is minimal (S4.3.2-2, S4.3.2-5). The goal of an EPS in the context of bradycardia evaluation is to identify the presence of abnormal sinus node function or atrioventricular conduction, and the anatomic location of any conduction disorder. Pharmacologic drugs are sometimes administered during an EPS as a part of study protocol to modulate the autonomic tone or to "stress" the sinus node, atrioventricular conduction, and intraventricular conduction. An EPS in a patient thought to have bradycardia may uncover possible tachycardia mechanisms for symptoms. An EPS is generally not performed as the first-line diagnostic assessment in patients with suspected bradycardia. Most patients who undergo an EPS have already undergone a series of noninvasive cardiac evaluations, such as ECG, tilt table testing, echocardiogram, and/or ambulatory electrocardiographic monitoring, which may have been inconclusive. EPS have been performed almost exclusively in patients with unexplained syncope or presyncope, and some of these cases were found to be bradycardia mediated (S4.3.2-1–S4.3.2-4).

Recommendation-Specific Supportive Text

1. The diagnostic yield of EPS in symptomatic patients with suspected bradycardia has been shown to vary widely (range, 12%–80%), depending on the patient population studied (S4.3.2-1, S4.3.2-3). In 1 study of patients presenting with unexplained syncope, those who had history of heart disease (e.g., coronary artery disease, hypertension, mitral valve prolapse) had a higher incidence of an abnormal EPS compared with patients who had a structurally normal heart (S4.3.2-5). In addition, the likelihood of an abnormal EPS was greater in patients who had an abnormal ECG at baseline (e.g., bundle branch block or prior myocardial infarction [MI]) (S4.3.2-4). In most cases, the cause of symptomatic bradycardia can be established without invasive evaluation. The use of an EPS has almost exclusively been examined in patients with syncope or presyncope, and is generally an adjunctive tool in the evaluation of patients in whom bradycardia is suspected but has not been documented after noninvasive evaluation (S4.3.2-6). Although correlation between symptoms and rhythm remain the cornerstone for management of patients with syncope, EPS may be a reasonable approach in a patient with syncope associated with trauma who also has a high pretest probability for significant conduction disease (e.g., LBBB) (S4.3.2-6–S4.3.2-8). EPS may also be performed when the patient is undergoing an invasive procedure such as an endomyocardial biopsy.

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5. Bradycardia Attributable to SND

5.1. Pathology/Pathophysiology/Etiology of SND

The pathophysiology of SND is varied and usually involves complex electrophysiologic and structural remodeling. The sinoatrial node is comprised of a complex matrix of pacemaker cells, transitional cells, endothelial cells, fibroblasts, and extracellular scaffolding, and is characterized by a unique ion channel and connexin expression profile that results in chronotropic automaticity (S5.1-1). Genome-wide association analyses have identified multiple loci in ion channel and channel interacting proteins related to normal and abnormal resting heart rates, providing insight into mechanisms controlling heart rate that may someday translate to new therapeutic targets (S5.1-2–S5.1-7). The specialized cardiomyocytes of the sinus node are surrounded by strands of connective tissue that electrically insulate the pacemaker cells from atrial myocardial tissue; this structural support appears to be essential for normal functioning as it protects pacemaker cells from the suppressive effects of hyperpolarization from adjacent myocytes (S5.1-8). Collagen content of the heart increases with age, however, and this increased fibrosis is correlated with slower heart rate and slower sinoatrial conduction times (SACT) (S5.1-8). A histopathologic study of 111 patients with both normal rhythm, SND and atrial arrhythmias demonstrated an association between more extensive fibrosis and subjects with SND or tachy-brady syndrome (S5.1-9). Notably, fibrosis of the sinus node was also associated with fibrosis in the atrioventricular node (S5.1-1, S5.1-8–S5.1-10).

Asymptomatic sinus bradycardia has not been associated with adverse outcomes (S5.1-11, S5.1-12). However, patients with symptoms attributable to SND have a high risk of cardiovascular events including syncope, AF, and heart failure (S5.1-13). Moreover, the development of chronotropic incompetence with age is associated with increased risk of cardiovascular death and overall mortality (S5.1-14, S5.1-15). Although the underlying causes are not well understood, heart rate variability also decreases with age (S5.1-16).

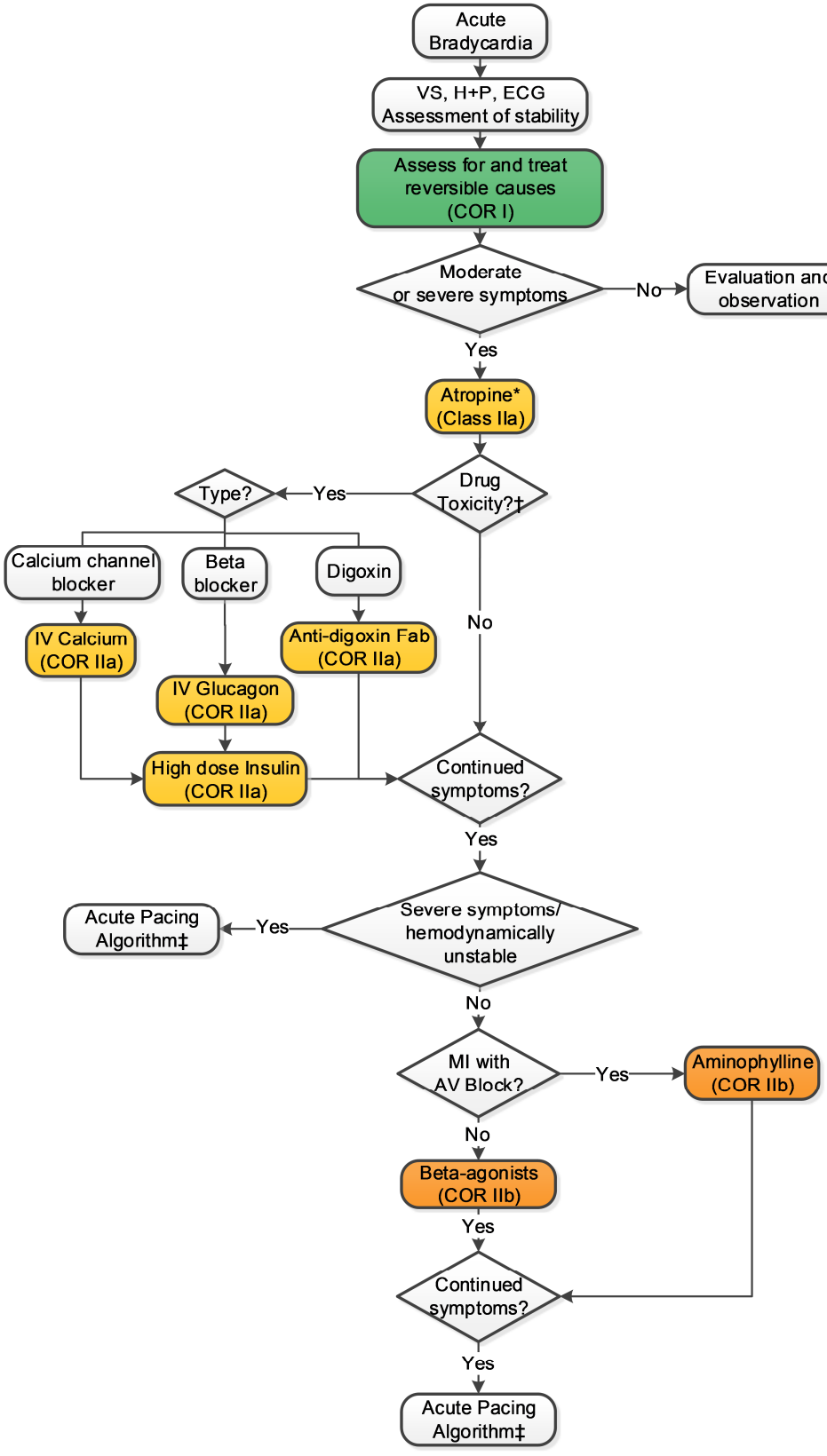
5.2. Clinical Presentation of SND

Symptoms attributable to SND can range from mild fatigue to frank syncope. The severity of clinical manifestations generally correlates with the heart rate or the pause duration. Syncope is a common manifestation and, in 1 trial (S5.2-1), was present in 50% of patients who received pacemakers for SND. Other clinical symptoms include dyspnea on exertion caused by chronotropic incompetence, lightheadedness, and chronic fatigue. Patients with SND may manifest symptoms attributable to sinus bradycardia, sinus arrest or sinoatrial exit block. Correlation between symptoms and bradycardia is considered to be the “gold standard” of diagnosis. However, it may be difficult to establish this correlation in some cases because of the presence of competing etiologies of symptoms as well as limitations in monitoring (e.g., comorbid conditions that prohibit long-term monitoring because of fear of injuries).

5.3. Acute Management of SND

A master algorithm for the acute management of bradycardia is given in Figure 4. Specific subsections address acute management of drug toxicity for bradycardia attributable to SND or atrioventricular block, and reversible causes, acute medical therapies, and temporary pacing specifically in the setting of SND.

Figure 4. Acute Bradycardia Algorithm



Colors correspond to Class of Recommendation in Table 2.
See Sections 5.3. and 6.3. for discussion.
*Atropine should not be given in patients after heart transplant.
†In patients with drug toxicity and severe symptoms, preparation for pacing should proceed simultaneously with pharmacologic treatment of drug toxicity.
‡Refer to Section 5.3.3., Figure 5.
AADs indicates antiarrhythmic drugs; AV, atrioventricular; BB, beta blocker; CCB, calcium channel blocker; COR, Class of Recommendation; ECG, electrocardiographic; H+P, history and physical examination; IMI, inferior myocardial infarction; IV, intravenous; PM, pacemaker; S/P, status post; and VS, vital signs.

5.3.1. Acute Management of Reversible Causes of SND

Recommendation for Acute Management of Reversible Causes for Bradycardia Attributable to SND		
COR	**LOE**	**Recommendation**
I	**C-EO**	**1. In symptomatic patients presenting with SND, evaluation and treatment of reversible causes is recommended.**

Synopsis

Most patients with SND present with chronic complaints that does not require acute treatment. In addition, most causes of SND are chronic and irreversible. In some cases, sinus bradyarrhythmias are attributable to potentially reversible causes such as acute MI, atrial tachyarrhythmias, electrolyte abnormalities, hypothyroidism, medications, infections, and metabolic abnormalities (Table 7).

Recommendation-Specific Supportive Text

1. Because patients are typically stable and minimally symptomatic on presentation with SND, no acute therapy is usually required, and evaluation of SND and assessment for potentially reversible causes can be performed in an outpatient setting (S5.3.1-6, S5.3.1-33–S5.3.1-53). In some cases, although evaluation of reversible causes for SND should be undertaken, treatment may not be necessary (e.g., stopping a beta blocker in an asymptomatic patient with sinus bradycardia after ST-elevation MI) (S5.3.1-54). Notably, some patients with tachy-brady syndrome may have improvement of sinoatrial node function after treatment aimed at maintaining sinus rhythm (S5.3.1-6).

Table 7. Common Potentially Reversible or Treatable Causes of SND (S5.3.1-1).

Acute myocardial ischemia or infarction (S5.3.1-2–S5.3.1-4)
Athletic training (S5.3.1-5)
Atrial fibrillation (S5.3.1-6)
Cardiac surgery • Valve replacement (S5.3.1-7, S5.3.1-8), maze procedure (S5.3.1-7), coronary artery bypass graft (S5.3.1-9, S5.3.1-10)
Drugs or toxins* • Toluene, organophosphates, tetrodotoxin, cocaine (S5.3.1-11)
Electrolyte abnormality • Hyperkalemia (S5.3.1-12), hypokalemia (S5.3.1-13), hypoglycemia (S5.3.1-14)
Heart transplant (S5.3.1-15): Acute rejection, chronic rejection, remodeling (S5.3.1-16, S5.3.1-17)
Hypervagotonia (S5.3.1-18, S5.3.1-19)
Hypothermia • Therapeutic (post-cardiac arrest cooling (S5.3.1-20)) or environmental exposure (S5.3.1-21)
Hypothyroidism (S5.3.1-22)
Hypovolemic shock (S5.3.1-23)
Hypoxemia, hypercarbia, acidosis (S5.3.1-24) • Sleep apnea, respiratory insufficiency (suffocation, drowning (S5.3.1-25), stroke (S5.3.1-26), drug overdose)
Infection (S5.3.1-27) • Lyme disease (S5.3.1-28), legionella, psittacosis, typhoid fever, typhus, listeria (S5.3.1-29), malaria, leptospirosis, Dengue fever, viral hemorrhagic fevers, Guillain-Barre (S5.3.1-30)
Medications* • Beta blockers, non-dihydropyridine calcium channel blockers, digoxin (S5.3.1-31), antiarrhythmic drugs, lithium (S5.3.1-32), methyldopa, risperidone, cisplatin, interferon

*Partial list.

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5.3.2. Acute Medical Therapy for Bradycardia

5.3.2.1. Atropine and Beta Agonists for Bradycardia Attributable to SND

Recommendations for Atropine and Beta Agonists for Bradycardia Attributable to SND Referenced studies that support recommendations are summarized in Online Data Supplements 8, 9, 10, and 11.		
COR	**LOE**	**Recommendations**
IIa	**C-LD**	**1. In patients with SND associated with symptoms or hemodynamic compromise, atropine is reasonable to increase sinus rate (S5.3.2.1-1–S5.3.2.1-4).**
IIb	**C-LD**	**2. In patients with SND associated with symptoms or hemodynamic compromise who are at low likelihood of coronary ischemia, isoproterenol, dopamine, dobutamine, or epinephrine may be considered to increase heart rate and improve symptoms (S5.3.2.1-5–S5.3.2.1-11).**
III: Harm	**C-LD**	**3. In patients who have undergone heart transplant without evidence for autonomic reinnervation, atropine should not be used to treat sinus bradycardia (S5.3.2.1-12, S5.3.2.1-13).**

Synopsis

Several drugs can be used for the acute treatment of bradycardia (Table 8). Atropine is a parasympatholytic drug that blocks the muscarinic acetylcholine receptor. In the sinus node, it facilitates sinoatrial conduction and increases sinus node automaticity at doses of approximately 0.5 to 2 mg with a half-life of approximately 2 hours (S5.3.2.1-14, S5.3.2.1-15).

Isoproterenol is a nonselective beta agonist with both chronotropic and inotropic effects on cardiac myocytes, enhancing sinus and atrioventricular nodal function without exerting a vasopressor effect (S5.3.2.1-16, S5.3.2.1-17). In patients with SND undergoing isoproterenol infusion in the electrophysiology laboratory setting, heart rate increases similar to normal controls are described, although some patients do not demonstrate a robust heart rate response, may require higher dosages, or may have a vasodilatory effect (S5.3.2.1-7, S5.3.2.1-8, S5.3.2.1-10).

Dopamine is a catecholamine with mixed alpha-adrenergic, beta-adrenergic, and dopaminergic effects that depend on dosage, distribution, and metabolism (S5.3.2.1-18). At lower doses of 1 to 2 mcg/kg/min, the effect is predominantly vasodilatory, while at doses of 5 to 20 mcg/kg/min, enhanced chronotropy and inotropy predominate. Higher doses may be required for a chronotropic response but must be used judiciously because of the association with profound vasoconstriction and proarrhythmias (S5.3.2.1-19). Epinephrine is a catecholamine with strong alpha-adrenergic and beta-adrenergic stimulatory effects, including increasing chronotropy, inotropy, blood pressure, and myocardial oxygen consumption (S5.3.2.1-20). The standard dosage for advanced cardiac life support is 2 to 10 mcg/min with titration to hemodynamic response (S5.3.2.1-13).

Recommendation-Specific Supportive Text

1. In patients with sinus bradycardia, atropine at dosages of 0.5 to 2 mg usually enhances automaticity, but in rare cases can be associated with intra-atrial reentry and or sinus pauses (S5.3.2.1-21). The sinoatrial node response to atropine is bimodal, lower doses (usually <0.5 mg) are associated with slower rates and acceleration with higher doses (S5.3.2.1-15, S5.3.2.1-22, S5.3.2.1-23). One clinical trial (S5.3.2.1-1), a post hoc analysis of MI patients (S5.3.2.1-3), and 2 observational studies (S5.3.2.1-2, S5.3.2.1-4) have reported efficacy of atropine in the treatment of bradycardia. In patients with hemodynamically unstable sinus bradycardia and atrioventricular block, atropine has demonstrated some benefit and minimal risk of worsening bradycardia, ischemia or potentiating

ventricular fibrillation (S5.3.2.1-1–S5.3.2.1-4). In an RCT of men undergoing elective laparoscopic prostate surgery, atropine effectively treated anesthetic induced sinus bradycardia (S5.3.2.1-24).

2. There are numerous case reports and series describing the salutary use of isoproterenol in patients presenting with sinus bradycardia (S5.3.2.1-5, S5.3.2.1-6, S5.3.2.1-9); however, there are no clinical trials or observational series data to support or discourage its use in this setting. Because isoproterenol increases myocardial oxygen demand through beta-1 effects while decreasing coronary perfusion attributable to beta-2 effects, it is best avoided in settings where there is concern for coronary ischemia (S5.3.2.1-25, S5.3.2.1-26). From a clinical standpoint, it is predominantly used in the electrophysiology laboratory (1-20 mcg/min intravenously) and has only a second-line role in treatment of bradycardia in the setting of resuscitation (S5.3.2.1-27). Two RCTs of isoproterenol as adjunctive therapy in the setting of cardiac arrest did not show improved return of spontaneous circulation or survival to hospital discharge (S5.3.2.1-28, S5.3.2.1-29). A trial of 82 patients presenting with unstable bradycardia refractory to intravenous fluid bolus and atropine randomized to transcutaneous pacing or dopamine at doses of 5 mcg/kg/min, titrated every 2 minutes by 5 mcg/kg/min to a maximum of 20 mcg/kg/min, showed no difference in survival to hospital discharge or serious adverse events (S5.3.2.1-11).
3. In a study of 25 patients who had undergone heart transplant, atropine at standard clinical doses resulted in paradoxical heart block or less commonly sinus arrest in 20% (S5.3.2.1-12). Although sympathetic reinnervation can be observed after long-term follow-up after orthotopic heart transplant, evidence for parasympathetic reinnervation is far less common: 34% versus 11% in 1 series that used heart rate variability response to neck suction to test autonomic responses (S5.3.2.1-30).

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Table 8. Acute Medical Management of Bradycardia Attributable to SND or Atrioventricular Block

Medication	Dosage	Comments
Symptomatic sinus bradycardia or atrioventricular block		
Atropine	0.5-1 mg IV (may be repeated every 3-5 min to a maximum dose of 3 mg) (S5.3.2.4-20–S5.3.2.4-24)	
Dopamine	5 to 20 mcg/kg/min IV, starting at 5 mcg/kg/min and increasing by 5 mcg/kg/min every 2 min (S5.3.2.4-25)	Dosages of >20 mcg/kg/min may result in vasoconstriction or arrhythmias
Isoproterenol	20-60 mcg IV bolus followed doses of 10-20 mcg, or infusion of 1-20 mcg/min based on heart rate response (S5.3.2.4-26–S5.3.2.4-32)	Monitor for potential development of ischemic chest pain
Epinephrine	2-10 mcg/min IV or 0.1-0.5 mcg/kg/min IV titrated to desired effect (S5.3.2.4-17, S5.3.2.4-31, S5.3.2.4-33)	
Second- or third-degree atrioventricular block associated with acute inferior MI		
Aminophylline	250-mg IV bolus	
Calcium channel blocker overdose		
10% calcium chloride	1-2 g IV every 10-20 min or an infusion of 0.2-0.4 mL/kg/h (S5.3.2.4-34–S5.3.2.4-36)	
10% calcium gluconate	3-6 g IV every 10-20 min or an infusion at 0.6-1.2 mL/kg/h (S5.3.2.4-34–S5.3.2.4-36)	
Beta-blocker or calcium channel blocker overdose		
Glucagon	3-10 mg IV with infusion of 3-5 mg/h (S5.3.2.4-37, S5.3.2.4-38)	
High dose insulin therapy	IV bolus of 1 unit/kg followed by an infusion of 0.5 units/kg/h (S5.3.2.4-36, S5.3.2.4-39, S5.3.2.4-40).	Follow glucose and potassium levels
Digoxin overdose		
Digoxin antibody fragment	Dosage is dependent on amount ingested or known digoxin concentration (S5.3.2.4-41–S5.3.2.4-48)	• One vial binds approximately 0.5 mg of digoxin • Administer over at least 30 min • May be repeated
Post-heart transplant		
Aminophylline	6 mg/kg in 100-200 mL of IV fluid over 20-30 min	
Theophylline	300 mg IV, followed by oral dose of 5-10 mg/kg/d titrated to effect	• Therapeutic serum levels range from 10-20 mcg/mL • Usual posttransplant dosages average 450 mg±100 mg/d
Spinal cord injury		
Aminophylline	6 mg/kg in 100-200 mL of IV fluid over 20-30 min (S5.3.2.4-7)	
Theophylline	Oral dose of 5-10 mg/kg/d titrated to effect (S5.3.2.4-6)	Effective dosages often result in serum levels below the usual effective range of 10-20 mcg/mL

IV indicates intravenous; and MI, myocardial infarction.

5.3.2.2. Therapy of Beta Blocker and Calcium Channel Blocker Mediated Bradycardia Attributable to SND or Atrioventricular Block

Recommendations for Therapy of Beta Blocker and Calcium Channel Blocker Mediated Bradycardia Referenced studies that support recommendations are summarized in Online Data Supplement 12.		
COR	**LOE**	**Recommendations**
IIa	**C-LD**	**1. In patients with bradycardia associated with symptoms or hemodynamic compromise because of calcium channel blocker overdose, intravenous calcium is reasonable to increase heart rate and improve symptoms (S5.3.2.2-1–S5.3.2.2-3).**
IIa	**C-LD**	**2. In patients with bradycardia associated with symptoms or hemodynamic compromise because of beta-blocker or calcium channel blocker overdose, glucagon is reasonable to increase heart rate and improve symptoms (S5.3.2.2-4, S5.3.2.2-5).**
IIa	**C-LD**	**3. In patients with bradycardia associated with symptoms or hemodynamic compromise because of beta-blocker or calcium channel blocker overdose, high-dose insulin therapy is reasonable to increase heart rate and improve symptoms (S5.3.2.2-6, S5.3.2.2-7).**

Synopsis

Cardiovascular effects of beta-blocker and calcium channel blocker toxicity are systemic and can be fatal because of profound negative chronotropic and inotropic effects, as well as vasodilation (S5.3.2.2-8). Pharmacotherapy is supportive and directed toward improving hemodynamic stability (S5.3.2.2-8). Shock often requires adrenergic pressor support (S5.3.2.2-3, S5.3.2.2-6–S5.3.2.2-9). The evidence base and specific treatment considerations for beta-blocker and calcium channel blocker mediated bradycardia are the same for SND and atrioventricular block (Table 8).

Recommendation-Specific Supportive Text

1. Case reports and small series show variable results in response to calcium infusion in the treatment of calcium channel blocker overdose, and no randomized trial data are available to support its use (S5.3.2.2-1, S5.3.2.2-10–S5.3.2.2-12). Because of improvements in heart rate and blood pressure, coupled with low risk of adverse effects, intravenous calcium is often recommended as a first-line therapy if central or reliable peripheral venous access is present (S5.3.2.2-2, S5.3.2.2-13). A systematic review of treatment for calcium channel blocker poisoning not specific to SND found 7 animal studies demonstrating reduced mortality and hemodynamic improvement with intravenous calcium (S5.3.2.2-3). Hemodynamic benefits in humans were less consistent in 11 case series and 21 case reports, but adverse effects, primarily hypercalcemia, were rare (S5.3.2.2-3). Both calcium chloride and calcium gluconate (to minimize peripheral vein irritation) are commonly used (S5.3.2.2-3, S5.3.2.2-13).
2. Glucagon is a vasoactive polypeptide, which counteracts the effects of beta blockers by activation of hepatic adenyl cyclase that promotes glycogenesis (S5.3.2.2-14). Although scores of case reports and case series (the largest comprised of 9 patients (S5.3.2.2-5)) have been published showing increased heart rate in settings of beta-blocker and calcium channel blocker overdose, no clinical trials have been performed (S5.3.2.2-4). The standard therapy in cardiac arrest is a bolus of 3 to 10 mg given over 3 to 5 minutes. Because effects are transient, an infusion of 3 to 5 mg/h is also initiated (S5.3.2.2-9). Side effects of glucagon therapy include nausea and vomiting, which is of particular concern when ability to protect the airway is compromised.

3. High-dose insulin therapy, using a bolus of 1 unit/kg followed by an infusion of 0.5 units/kg/h, has been studied in patients with severe beta-blocker or calcium channel blocker toxicity (S5.3.2.2-3, S5.3.2.2-6, S5.3.2.2-15). High-dose insulin therapy is associated with improved heart rate, hemodynamic parameters, and mortality in beta-blocker and calcium channel blocker overdose (S5.3.2.2-3, S5.3.2.2-6, S5.3.2.2-15). The evidence base is of lower quality, consisting largely of animal studies and case reports and case series (S5.3.2.2-3). Side effects include hypoglycemia and hypokalemia, which are usually mild (S5.3.2.2-6, S5.3.2.2-15).

5.3.2.3. Therapy of Digoxin Mediated Bradycardia Attributable to either SND or Atrioventricular Block

Recommendations for Therapy of Digoxin Mediated Bradycardia Attributable to SND or Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplements 13, 14, and 15.		
COR	**LOE**	**Recommendations**
IIa	**C-LD**	**1. In patients with bradycardia associated with symptoms or hemodynamic compromise in the setting of digoxin toxicity, digoxin Fab antibody fragment is reasonable to increase heart rate and improve symptoms (S5.3.2.3-1–S5.3.2.3-8).**
III: No Benefit	**C-LD**	**2. In patients with bradycardia associated with symptoms or hemodynamic compromise attributable to digoxin toxicity, dialysis is not recommended for removal of digoxin (S5.3.2.3-9).**

Synopsis

Digoxin-specific antibody (Fab) is a monovalent immunoglobulin that rapidly binds to intravascular digoxin (S5.3.2.3-2). Each vial of 40 mg of digoxin Fab binds approximately 0.5 mg of digoxin, and dosage is usually dependent on the estimated amount of the digitalis preparation ingested. Repeat dosing may be necessary, particularly in the setting of chronic use attributable to the large volume of distribution. Clinical response rates to digoxin Fab are as high as 80% to 90%, particularly in the acute setting (S5.3.2.3-2). Patients with hyperkalemia or life-threatening in the setting of digoxin serum levels of >2 mcg/L are at increased risk of death (S5.3.2.3-10). Signs and symptoms of toxicity can manifest at lower serum levels. Adverse events attributable to digoxin Fab therapy are rare and usually clinically insignificant; potassium levels should be monitored. Use of any treatment directed specifically to digoxin toxicity will depend primarily on the presence or likelihood of developing significant toxicity (Table 8). The evidence base and specific treatment considerations for digoxin mediated bradycardia are the same for SND and atrioventricular block.

Recommendation-Specific Supportive Text

1. There are no RCTs of anti-digoxin Fab for treatment of digitalis overdose, but an RCT in patients with poisoning attributable to yellow oleander, a cardiac glycoside with similar clinical toxicity, showed rapid reversal of bradycardia (S5.3.2.3-11). A systematic review of the use of anti-digoxin Fab in digitalis toxicity found 10 observational series including a total 2,080 patients (S5.3.2.3-2). Studies reported a clinical response of improvement to reversal of symptoms in 50% to 90% of patients within 30 to 45 minutes (S5.3.2.3-2). Adverse effects of therapy, including heart failure, tachycardia, hypokalemia, and allergic reactions occurred in <10% of patients (S5.3.2.3-2). Clinical benefit is

therefore clear in patients with life-threatening symptoms, but benefit is less certain in cases of mild toxicity.

2. A systematic review of 77 in vitro, animal, and human case reports and series comprising 84 patients found that digoxin is only slightly dialyzable (S5.3.2.3-9, S5.3.2.3-12), and dialysis is unlikely to improve the outcome of patients with digoxin toxicity (S5.3.2.3-9). Hemodialysis may be considered for treatment of associated life-threatening hyperkalemia (S5.3.2.3-13).

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5.3.2.4. Aminophylline or Theophylline for Bradycardia Attributable to SND

Recommendations for Theophylline/Aminophylline for Bradycardia Attributable to SND Referenced studies that support recommendations are summarized in Online Data Supplements 16 and 17.		
COR	**LOE**	**Recommendations**
IIa	**C-LD**	**1. In post-heart transplant patients, aminophylline or theophylline is reasonable to increase heart rate if clinically indicated (S5.3.2.4-1–S5.3.2.4-4).**
IIa	**C-LD**	**2. In patients with SND associated with symptoms or hemodynamic compromise in the setting of acute spinal cord injury, aminophylline or theophylline is reasonable to increase heart rate and improve symptoms (S5.3.2.4-5–S5.3.2.4-7).**

Synopsis

The methylxanthines theophylline and aminophylline (a theophylline derivative) exert positive chronotropic effects on the heart, likely mediated by inhibition of the suppressive effects of adenosine on the sinoatrial node (S5.3.2.4-8, S5.3.2.4-9). There is no direct evidence supporting the gross effects of aminophylline or theophylline in the setting of acute SND, in the absence of spinal cord injury or post-heart transplantation. However, a Cochrane systematic review of 5 randomized trials evaluating the use of aminophylline in the setting of out of hospital asystolic or bradycardic arrest did not show improved survival or return of spontaneous circulation (S5.3.2.4-10). Refer to Table 8.

Sinus bradycardia attributable to autonomic denervation, surgical trauma, ischemia, rejection, and prior amiodarone use is common after heart transplant (S5.3.2.4-11–S5.3.2.4-13). In contrast to normal heart rate values, bradycardia in heart transplant recipients are sometimes defined as a heart rate persistently <70 or 80 bpm (S5.3.2.4-13). Because of an acute reduction in sympathetic tone, severe sinus bradycardia is common in the acute recovery phase after spinal cord injury; both incidence and severity of bradyarrhythmias are related to the level and severity of spinal cord injury (S5.3.2.4-14). Cardiac arrest, most often attributable to sinus arrest and asystole, during the first 2 to 4 weeks after injury was observed in 16% of patients with severe cervical spinal injury (S5.3.2.4-15).

Recommendation-Specific Supportive Text

1. Sinus bradycardia is common after heart transplant, and sinus rates of <70 to 80 bpm may be inadequate for postoperative demand. Chronotropic incompetence usually improves in the early postoperative period but can be clinically significant and require therapy in a few patients. Atropine is ineffective for treatment of post-heart transplant SND because of denervation (S5.3.2.4-16–S5.3.2.4-18). The use of terbutaline to treat sinus bradycardia after heart transplant has also been described, but data are more limited. Four small observational studies have shown improved heart rate and sinus node function after transplant using the methylxanthines aminophylline or theophylline. In 2 studies of 15 and 29 patients, oral theophylline was associated with restoration of a sinus rate of 90 bpm, and 1 study showed a reduction in PPM implantation compared with historical controls (S5.3.2.4-2, S5.3.2.4-4). The evidence for aminophylline is more limited; in invasive EPS, aminophylline infusion had variable effects on sinus node function and heart rate in heart transplant recipients (S5.3.2.4-1, S5.3.2.4-3).
2. Sinus bradycardia requiring medical therapy is a common complication of spinal cord injury and can be persistent and refractory to atropine and other adrenergic drugs. Although an inciting cause is not always noted, common triggers for bradycardia epi

Typically, temporary transvenous pacing is performed via a pacing wire placed in the RV from a central venous site veins. Reported adverse event rates associated with temporary transvenous pacing range from 14% to 40% (S5.3.3-10, S5.3.3-25). Complications include venous thrombosis (18%–85% in the femoral setting when the femoral vein is used as the access), pulmonary emboli (50%–60% with femoral approach), life-threatening arrhythmias (usually related to instability or position in the RV), loss of capture (10%–37%), perforation, and death, but these associations may be confounded by use of temporary transvenous pacing in critically ill patients (S5.3.3-5, S5.3.3-15, S5.3.3-25–S5.3.3-27). Reported complications may be lower using balloon flotation electrode catheters (S5.3.3-5) or fluoroscopy. The risk of infectious complications in PPM placement is increased in patients who have a temporary pacing wire before permanent implant (S5.3.3-28, S5.3.3-29). Figure 5 provides an algorithm for choosing specific pacing strategy once temporary pacing is thought to be clinically necessary.

Recommendation-Specific Supportive Text

1. There are no RCTs or observational studies specific to the use of temporary transvenous pacing to treat SND, but several case series (S5.3.3-4, S5.3.3-6, S5.3.3-7, S5.3.3-10, S5.3.3-12, S5.3.3-14, S5.3.3-15, S5.3.3-17, S5.3.3-23) and 2 RCTs (S5.3.3-3, S5.3.3-5, S5.3.3-27) include patients with SND. Overall, temporary transvenous pacing was effective, yet associated with complication rates that range from 14% to 40% (S5.3.3-10, S5.3.3-25).
2. Although transcutaneous pacing has not shown a benefit in patients with cardiac arrest caused by asystole (S5.3.3-30), studies that included patients with SND without cardiac arrest have shown effective pacing with increases in heart rate and blood pressure, and tolerable patient tolerance (S5.3.3-1, S5.3.3-18–S5.3.3-20, S5.3.3-22). A systematic review of 3 unblinded RCTs, 3 case series, and 1 subgroup analysis showed a borderline improvement in survival to discharge in nonasystolic patients with symptomatic bradycardia (S5.3.3-21). Analgesic and/or anxiolytic agents should be considered in conscious patients, and effective capture

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5.4. Chronic Therapy/Management of Bradycardia Attributable to SND

5.4.1. General Principles of Chronic Therapy/Management of Bradycardia Attributable to SND

Recommendations for General Principles of Chronic Therapy/Management of Bradycardia Attributable to SND Referenced studies that support recommendations are summarized in Online Data Supplements 22 and 23.		
COR	**LOE**	**Recommendations**
III: Harm	**C-LD**	**1. In asymptomatic individuals with sinus bradycardia or sinus pauses that are secondary to physiologically elevated parasympathetic tone, permanent pacing should not be performed (S5.4.1-1–S5.4.1-7).**
III: Harm	**C-LD**	**2. In patients with sleep-related sinus bradycardia or transient sinus pauses occurring during sleep, permanent pacing should not be performed unless other indications for pacing are present (S5.4.1-1–S5.4.1-7).**
III: Harm	**C-LD**	**3. In patients with asymptomatic SND, or in those in whom the symptoms have been documented to occur in the absence of bradycardia or chronotropic incompetence, permanent pacing should not be performed (S5.4.1-5–S5.4.1-7).**

Synopsis

The goal of anti-bradycardia therapy in SND is to increase the heart rate so that cardiac output is normalized, and the perfusion of brain and other end organs is maintained to meet physiologic demand. Because there is no established minimum heart rate below which treatment is indicated, identifying temporal correlation between symptoms and bradycardia is important when deciding on the necessity of therapy. Healthy young individuals, particularly athletes, have sinus bradycardia that is not associated with symptoms (S5.4.1-8). In some patients presenting with symptomatic bradycardia, a reversible extrinsic cause may be identifiable such as metabolic abnormality, endocrine dysfunction, infection, or overmedication (discussed in Section 5.5.2.). For other patients with symptomatic sinus bradycardia attributable to an intrinsic pathology of sinus node, permanent pacing may be necessary. Complications associated with PPM implantation range from 3% to 7% and there are significant long-term implications for pacing systems that use transvenous leads (S5.4.1-5–S5.4.1-7).

Recommendation-Specific Supportive Text

1. Young individuals, especially well-conditioned athletes, have dominant parasympathetic tone at rest associated with resting sinus rates that can be well below 40 bpm (S5.4.1-1–S5.4.1-4). Sinus bradycardia is also seen in other states of heightened vagal tone such as during sleep or deep rest. In almost all cases, patients are completely asymptomatic and anti-bradycardia therapy is not indicated and the patient should be reassured. Although PPM implantation is a relatively low risk cardiac procedure, procedural complications and death directly related to implant can occur, and implanted leads have long-term management implications (S5.4.1-5–S5.4.1-7, S5.4.1-9).
2. Parasympathetic tone has is more dominant sympathetic tone during rest and sleep. Significant sinus bradycardia (rates <40 bpm) or pauses (>5 seconds) are common during such periods and have been observed across a wide age range (S5.4.1-1–S5.4.1-4). High vagal tone can also affect the atrioventricular node and cause transient and varying degrees of conduction abnormality that is

asymptomatic in nearly all cases. Clinically relevant scenarios are often encountered in hospital settings where patients are monitored continuously on telemetry or at home with the rise of wearable home monitoring systems. Nocturnal sinus bradycardia or pause is a relatively common phenomenon in such settings. With the understanding of the physiologic (not pathologic) basis of bradycardia in such circumstances, anti-bradycardia therapy can be avoided. Although PPM implantation is a relatively low risk cardiac procedure, procedural complications and death directly related to implant can occur, and implanted leads have long-term management implications (S5.4.1-5–S5.4.1-7, S5.4.1-9).

3. SND commonly manifests as sinus bradycardia or recurrent sinus pauses. Because SND is not a life-threatening condition, the benefit of permanent cardiac pacing is essentially symptom relief and quality of life (QOL) improvement. For this reason, asymptomatic or minimally symptomatic patients have no indication for permanent pacing even if they were to have electrophysiologic evidence of SND (e.g., detected on ambulatory electrocardiographic monitoring or at EPS) because permanent pacing is associated with surgical risk and long-term consequences (S5.4.1-7). In some patients, symptoms suggestive of bradycardia are documented to occur in the absence of bradycardia. In these patients, permanent pacing has no clinical benefit and should not be performed. Although PPM implantation is a relatively low risk cardiac procedure, procedural complications and death directly related to implant can occur, and implanted leads have long-term management implications (S5.4.1-5–S5.4.1-7, S5.4.1-9).

5.4.2. Transient/Reversible Causes (Including Medications) of Bradycardia Attributable to SND

Recommendation for Transient/Reversible Causes of Sinus Bradycardia		
COR	**LOE**	**Recommendation**
I	**C-EO**	**1. Patients presenting with symptomatic SND secondary to a reversible cause should first be managed by directing the therapy at eliminating or mitigating the offending condition.**

Synopsis

Patients may present with symptomatic sinus bradycardia attributable to reversible causes (Table 7) (S5.4.2-1). Medications are frequent culprits. Negative chronotropic drugs such as beta blockers, calcium channel blockers, and digoxin are frequently prescribed drugs that can decrease the sinus rate. Sodium-channel and potassium-channel blocking antiarrhythmic drugs can also exacerbate bradycardia in patients with preexisting SND. Hypothyroidism can cause clinically significant bradycardia (S5.4.2-2–S5.4.2-5). Such cardiovascular abnormalities respond well to replacement therapy with thyroxine (T4) (S5.4.2-6). Metabolic abnormalities such as severe systemic acidosis or hypokalemia can uncommonly cause sinus bradycardia in acute settings. Reversible physiological disturbances should be considered and treated first.

Recommendation-Specific Supportive Text

1. When sinus bradycardia is the consequence of nonessential medications, permanent cardiac pacing should not be considered a first-line treatment. In such cases, withdrawal of offending drug or dosage reduction can improve the heart rate and symptoms. For example, a beta-blocking drug that is used solely to control hypertension but is causing significant bradycardia could be switched to a diuretic, angiotensin converting enzyme inhibitor, or an angiotensin receptor blocking drug that are

devoid of negative chronotropic effect. If the offending drug cannot be discontinued completely, a simple dosage reduction may increase the heart rate and therefore improve symptoms. Other treatable conditions predisposing to sinus bradycardia include elevated intracranial pressure, acute MI, severe hypothermia, and obstructive sleep apnea.

5.4.3. Additional Testing of Bradycardia Attributable to SND

Recommendations for Additional Testing of Bradycardia Attributable to SND		
COR	**LOE**	**Recommendations**
IIb	**C-EO**	**1. In patients with symptoms suggestive of bradycardia (e.g., syncope, lightheadedness) who are also undergoing an EPS for another indication, evaluation of sinus node function as part of the EPS may be considered.**
IIb	**C-EO**	**2. In symptomatic patients with suspected SND, EPS for the assessment of sinus node function may be considered when the diagnosis remains uncertain after initial noninvasive evaluations (S5.4.3-1–S5.4.3-5).**
III: No Benefit	**C-LD**	**3. In patients with asymptomatic sinus bradycardia, an EPS should not be performed unless other indications for electrophysiological testing exist (S5.4.3-6, S5.4.3-7).**

Synopsis

SND is a clinical diagnosis based on the combination of history and rhythm documentation. However, in very rare circumstances, when the diagnosis remains elusive, the clinician may elect to perform an invasive EPS to ascertain the diagnosis. Broadly speaking, there are 2 established electrophysiology measures of sinus node function: 1) sinus node recovery time (SNRT) (S5.4.3-4) and 2) SACT (S5.4.3-3, S5.4.3-5). These values can contribute to the assessment of sinus node function. Pharmacologic blockade of the autonomic nervous system using intravenous propranolol (0.1 mg/kg) and atropine (0.02 mg/kg) can be performed before assessment of sinus node function. The measured intrinsic heart rate can then be compared with the calculated intrinsic heart rate (intrinsic heart rate: 118.1 – (0.57 x age)) for assessment of SND (S5.4.3-1, S5.4.3-2). Both SNRT and SACT are limited by variable and modest specificity and sensitivity. EPS for the assessment of sinus node function is currently not widely used in clinical practice and its precise role in the overall diagnostic strategy of SND is not well defined, and there are no data to suggest that an abnormal SNRT or SACT in isolation should be used to justify PPM implantation.

Recommendation-Specific Supportive Text

1. It would be rare that EPS would be performed for the sole purpose of evaluating sinus node function. Most patients undergo diagnostic EPS for a different indication or reason such as evaluation of inducibility of ventricular arrhythmia or presence of His-Purkinje conduction abnormality often in the setting of syncope or nonsustained ventricular tachycardia with reduced left ventricular function (S5.4.3-8, S5.4.3-9). In such cases, sinus node function could be evaluated at little to no added risk to the patient and can provide adjunctive information in patients with symptoms suggestive of bradycardia.
2. Patients with suspected SND sometimes do not have a definitive diagnosis even after undergoing a battery of initial noninvasive tests. EPS can be considered in such cases to help support or refute the diagnosis of SND, and the findings can be used to guide the therapy, provided that the data are used in conjunction with other clinical findings. The most well-known method to assess sinus node

function is the measurement of SNRT. In brief, the atrium is paced using a properly positioned catheter at a predetermined rate for a given duration (30-60 s) of time. The interval to the first spontaneous atrial depolarization from the last paced beat is measured after the pacing is stopped. Corrected SNRT is an indexed value obtained by subtracting the baseline R-R interval from the longest obtained SNRT. An abnormal corrected SNRT is considered to be any value >500 to 550 ms (S5.4.3-4). The SACT is less commonly used but can be calculated by either continuous pacing at different intervals, with premature atrial stimuli, or direct recording of sinus node electrograms (S5.4.3-10).

3. Asymptomatic patients with sinus bradycardia should not undergo EPS because the risk of invasive testing outweighs the potential for clinical benefit. Although risk of EPS is likely low in the modern era, an older study reported a complication rate of 8%, mainly hematoma and induction of AF (S5.4.3-6). In an asymptomatic patient, an incidental finding of abnormal SNRT or SACT has no clinical importance (S5.4.3-7).

5.4.4. Permanent Pacing for Chronic Therapy/Management of Bradycardia Attributable to SND

Recommendations for Permanent Pacing for Chronic Therapy/Management of Bradycardia Attributable to SND Referenced studies that support recommendations are summarized in Online Data Supplements 24 and 25.		
COR	**LOE**	**Recommendations**
I	**C-LD**	**1. In patients with symptoms that are directly attributable to SND, permanent pacing is indicated to increase heart rate and improve symptoms (S5.4.4-1, S5.4.4-2).**
I	**C-EO**	**2. In patients who develop symptomatic sinus bradycardia as a consequence of guideline-directed management and therapy for which there is no alternative treatment and continued treatment is clinically necessary, permanent pacing is recommended to increase heart rate and improve symptoms.**
IIa	**C-EO**	**3. For patients with tachy-brady syndrome and symptoms attributable to bradycardia, permanent pacing is reasonable to increase heart rate and reduce symptoms attributable to hypoperfusion.**
IIa	**C-EO**	**4. In patients with symptomatic chronotropic incompetence, permanent pacing with rate-responsive programming is reasonable to increase exertional heart rates and improve symptoms.**
IIb	**C-LD**	**5. In patients with symptoms that are likely attributable to SND, a trial of oral theophylline may be considered to increase heart rate, improve symptoms, and help determine the potential effects of permanent pacing (S5.4.4-3, S5.4.4-4).**

Synopsis

Permanent cardiac pacing is indicated to alleviate the symptoms of cerebral hypoperfusion attributable to bradycardia when other potential treatable or reversible etiologies have been excluded. Symptomatic SND is the most common indication for permanent pacing, followed closely by atrioventricular block.

Often the best response to pacing therapy is demonstrated when an unequivocal correlation has been established between symptoms and bradycardia. The benefit of pacing in SND is mainly QOL improvement. A strategy for managing a patient with SND is provided in Figure 6.

Recommendation-Specific Supportive Text

1. When there is direct evidence of symptom correlating with sinus bradycardia or pauses, permanent cardiac pacing will lead to clinical improvement. Such a temporal symptom-bradycardia correlation is regarded as the gold standard of diagnosis and confers the highest likelihood of response to therapy. Prolonged sinus pauses can also be debilitating and are associated with significant morbidity because of recurrent presyncope or syncope of sudden and unpredictable onset. Permanent cardiac pacing will also treat such symptomatic pauses (S5.4.4-1, S5.4.4-2).
2. Beta-blocking and calcium channel–blocking drugs are commonly used in patients with cardiovascular disorders. Negative chronotropic drugs exacerbate SND symptoms by diminishing the slope of phase 4 diastolic depolarization, resulting in a decrease in the rate of sinus node discharge. Beta blockers have a wide range of guideline-directed indications for patients after MI and for patients with chronic systolic heart failure (S5.4.4-5–S5.4.4-7). For patients who also have symptomatic sinus bradycardia some should be managed with permanent cardiac pacing so that essential pharmacologic therapy can be continued while, in others, stopping or decreasing the dose of the offending drug may be appropriate. In all cases, the relative benefits and risks of all therapies must be considered collectively for each individual patient (S5.4.4-5–S5.4.4-7).
3. Tachy-brady syndrome describes a subset of symptomatic SND who have periods of fast heart rates (usually AF) and slow sinus rates or pauses. One of the most disabling symptoms of tachy-brady syndrome is recurrent syncope or presyncope secondary to transient asystolic pause that follows termination of paroxysmal episodes of atrial tachyarrhythmia (typically AF) (S5.4.4-8). The severity of symptoms is often related to the length of pause. The pathophysiologic link between SND and AF, however, remains incompletely understood, and is an active area of investigation (S5.4.4-8). No randomized trial has specifically examined the use of permanent cardiac pacing in patients with tachy-brady syndrome. Permanent pacing can alleviate the symptoms attributable to bradycardia or allow use of medications directed toward treatment of atrial tachyarrhythmias that might exacerbate bradycardia such as beta blockers (S5.4.4-9, S5.4.4-10). In those patients where bradycardia is associated with the atrial arrhythmia (AF with slow ventricular rates or post conversion pauses), treatment of atrial tachyarrhythmias with ablation may obviate the requirement for permanent pacing (S5.4.4-11, S5.4.4-12).
4. Chronotropic incompetence describes an inappropriately blunted heart rate response to physiologic need associated with physical activity but is difficult to define by simple age dependent formulas. The diagnosis is typically suggested by ambulatory heart rate monitoring (provided that symptom diaries are accurately kept), or exercise electrocardiographic testing. Cardiac pacing with sensor-based rate-responsive feature has been used to increase the heart rate in times of sensed physical activity. There are different types of sensors that can track various physiologic parameters such as body motion and minute ventilation. One RCT, however, did not demonstrate any benefit in patients with SND (S5.4.4-13). At 6 months follow-up, there was no difference in total exercise time between the dual-chamber paced group and the dual-chamber paced group with additional rate adaption algorithms programmed “on.” group. At one-year follow-up, there were no significant differences between 2 groups with respect to Specific Activity Scale or the secondary QOL endpoints. However, given that the overall right ventricular pacing percentage was >90% in this trial, any potential symptomatic benefit of rate-responsive feature could have been offset by the deleterious effect of high-percentage RV pacing with consequent dyssynchrony. Other nonrandomized studies have also

shown variable clinical benefits from sensor-based rate responsive features (S5.4.4-14, S5.4.4-15). When used, careful programming of rate-responsive features is necessary.

5. Direct attribution of symptoms to SND should always be sought but can be difficult in some situations. A trial of oral theophylline may be considered to help correlate symptoms with bradycardia. In a randomized study of patients with symptomatic SND randomized to no treatment, oral theophylline, or permanent pacing, theophylline was associated with increased resting heart rate compared with control, although permanent pacing was superior for symptom control (S5.4.4-3). Similarly, in a nonrandomized case series of patients with SND, theophylline (200-400 mg daily) decreased the frequency of sinus pauses and improved subjective symptoms in 16 of 17 patients (S5.4.4-4). In patients who are unwilling to undergo PPM implantation or who are not candidates for permanent pacing, oral theophylline could be considered for treatment of symptomatic SND.

5.4.4.1. Permanent Pacing Techniques and Methods for Chronic Therapy/Management of Bradycardia Attributable to SND

Recommendations for Permanent Pacing Techniques and Methods for Chronic Therapy/Management of Bradycardia Attributable to SND Referenced studies that support recommendations are summarized in Online Data Supplement 25.		
COR	**LOE**	**Recommendations**
I	**B-R**	**1. In symptomatic patients with SND, atrial-based pacing is recommended over single chamber ventricular pacing (S5.4.4.1-1–S5.4.4.1-4).**
I	**B-R**	**2. In symptomatic patients with SND and intact atrioventricular conduction without evidence of conduction abnormalities, dual chamber or single chamber atrial pacing is recommended (S5.4.4.1-5).**
IIa	**B-R**	**3. In symptomatic patients with SND who have dual chamber pacemakers and intact atrioventricular conduction, it is reasonable to program the dual chamber pacemaker to minimize ventricular pacing (S5.4.4.1-6).**
IIa	**C-EO**	**4. In symptomatic patients with SND in which frequent ventricular pacing is not expected or the patient has significant comorbidities that are otherwise likely to determine the survival and clinical outcomes, single chamber ventricular pacing is reasonable.**

Synopsis

One area of particular interest in the past has been the investigation of optimal pacing mode in SND. Atrial-based pacing modes (AAI and DDD) have been compared with ventricular-based pacing mode (VVI) in 4 major RCTs and reviewed in a recent expert consensus document (S5.4.4.1-1–S5.4.4.1-4, S5.4.4.1-7). Results were inconsistent across the studies and the reconciliation of findings can be challenging. However, atrial-based pacing modes appeared to confer advantage over ventricular-based pacing mode with respect to a lower incidence of AF. The impact of atrial-based pacing modes on the prevention of heart failure or stroke, and improvement in QOL is less clear (S5.4.4.1-8).

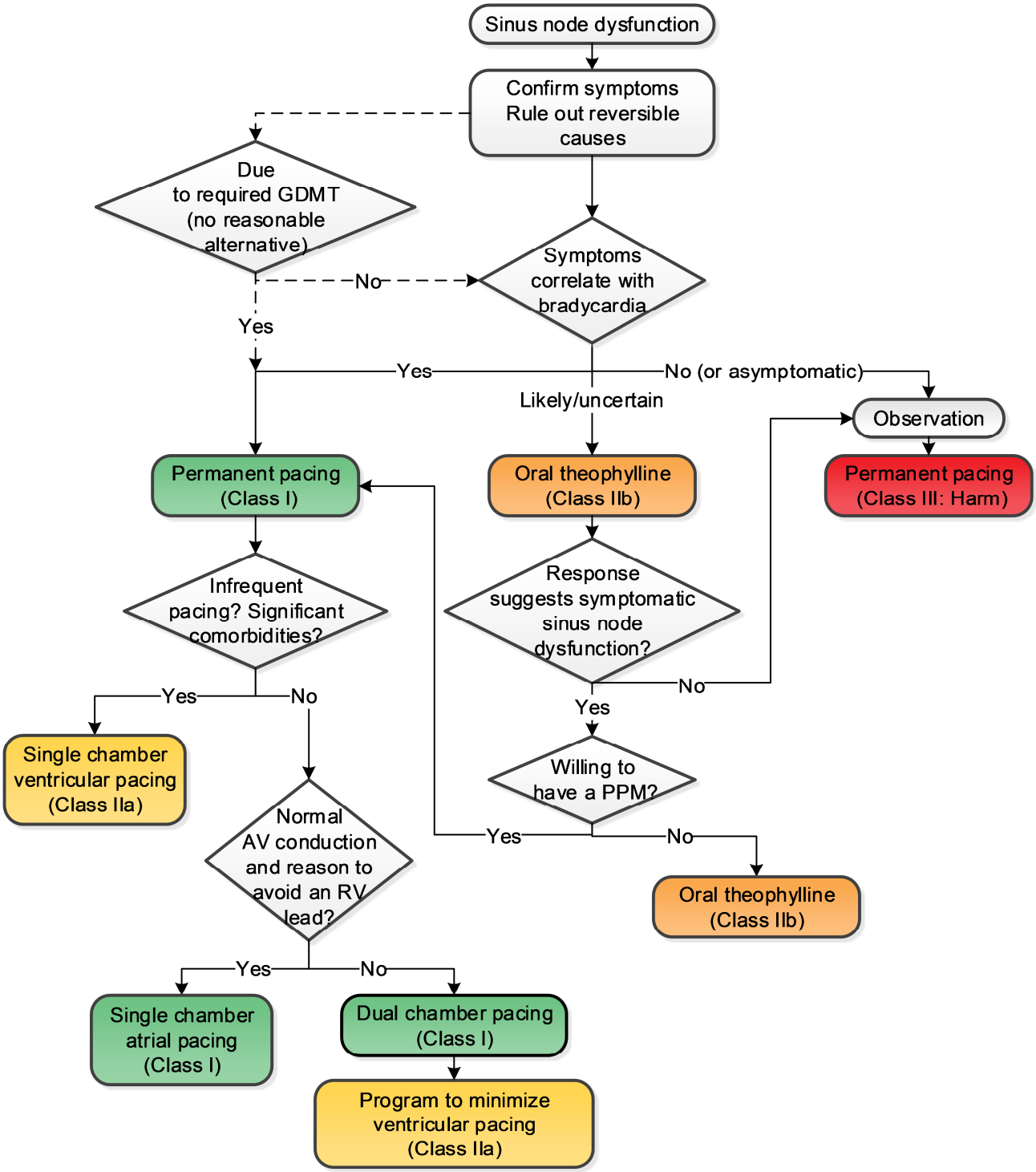
Recommendation-Specific Supportive Text

1. Four trials compared the efficacy of AAI or DDD (collectively known as atrial based) versus VVI (single chamber ventricular) pacing with respect to clinical outcome such as new-onset AF, heart failure hospitalization, stroke incidence, QOL and mortality (S5.4.4.1-1–S5.4.4.1-5). Although the

trials were very different with respect to study design, outcome definition, and duration of follow-up, as well as having significant inter-group crossover rates, the most consistent clinical benefit of dual chamber pacing over single chamber ventricular pacing was reduction in incidence of AF. In addition, single chamber ventricular pacing cannot provide atrioventricular synchrony. This can lead to pacemaker syndrome, which is characterized by uncoordinated depolarizations and contractions between atria and ventricles leading to valvular regurgitation and heart failure–type symptoms such as chronic fatigue, dyspnea on exertion, and symptomatic hypotension. Therefore, atrial based pacing is the preferred mode in symptomatic patients with SND.

2. Superiority of atrial-based pacing (dual chamber or AAI) over single chamber ventricular pacing was demonstrated by 4 RCTs. (S5.4.4.1-1–S5.4.4.1-4). Another RCT (S5.4.4.1-5) subsequently compared the efficacy of dual chamber versus single chamber atrial pacing in symptomatic patients with SND. After a mean follow-up of 8.9 years, no difference in mortality or in any nonfatal clinical outcome (AF hospitalization, stroke, heart failure) was observed between the 2 groups. Dual chamber pacing requires implantation of an additional lead. Additional procedural risk must be carefully weighed against the likelihood of future development of atrioventricular block, which would mandate the placement of ventricular lead. The risk of developing atrioventricular block after pacemaker implantation within 5 years of follow-up has been demonstrated to be between 3% and 35% (S5.4.4.1-9–S5.4.4.1-12). However, patients who have intact atrioventricular nodal conduction without any evidence of bundle branch conduction abnormality at baseline should be among the groups with lowest risk (S5.4.4.1-5). In these patients, it is recommended that either a dual chamber or single chamber atrial PPM be implanted.
3. In multiple studies, right ventricular pacing has been associated with negative physiologic consequences as a result of ventricular dyssynchrony: left ventricular chamber enlargement, worsening functional mitral regurgitation, reduced left ventricular ejection fraction (LVEF), and increased inter- and intraventricular dyssynchrony (S5.4.4.1-13). In 1 study, a programming algorithm designed to minimize ventricular pacing resulted in a 40% risk reduction of persistent AF (S5.4.4.1-6). In addition, among patients with SND and normal QRS duration, an increasing percentage of ventricular pacing was associated with a higher rate of systolic heart failure hospitalization and new onset of AF (S5.4.4.1-14). For these reasons as well as other studies demonstrating similar and consistent findings, it is almost always appropriate to program the pacemaker to minimize unnecessary chronic right ventricular pacing whenever possible other than when accompanying severe first-degree atrioventricular block is associated with inappropriate timing of atrial and ventricular contraction (S5.4.4.1-7).
4. For patients with symptomatic SND that is short-lived or infrequent, single chamber ventricular pacing techniques (e.g., current leadless pacing technology) may be adequate for rate support and obviate the requirement for a second pacing lead. Patients with SND who are frail, bedridden, and/or those with limited functional capacity or unfavorable short-term prognosis for survival (<1 year) may not necessarily have a better clinical outcome from strict maintenance of atrioventricular synchrony. Therefore, the benefit afforded by dual chamber pacing may not outweigh the incremental increase in risk. In such patients, a single chamber ventricular pacemaker could provide a more favorable risk-to-benefit profile compared with a dual chamber pacemaker that carries an incremental risk associated with the addition of a second pacing lead.

Figure 6. Chronic SND Management Algorithm



Colors correspond to Class of Recommendation in Table 2.
See Sections 4.3. and 5.5. for discussion.
Dashed lines indicate possible optional strategies based on the specific clinical situation.
*Symptomatic patients with very infrequent need for pacing for rate support or patients with significant comorbidities.

AV indicates atrioventricular; GDMT, guideline-directed management and therapy; PPM, permanent pacemaker; and RV, right ventricular.

6. Bradycardia Attributable to Atrioventricular Block

6.1. Pathophysiology, Etiology, and Classification of Bradycardia Attributable to Atrioventricular Block

There are numerous disease states that may affect the atrioventricular conduction system resulting in atrioventricular block (Table 9). These include both congenital and acquired forms. The latter are much more common and include infectious, inflammatory, degenerative, ischemic, and iatrogenic causes. Degenerative causes are the most commonly seen in clinical practice and are associated with increased age, chronic hypertension, and diabetes mellitus. Infectious causes, particularly Lyme carditis, are important to consider in the appropriate patient, as atrioventricular block may be reversible with appropriate medical treatment. Ischemic etiologies should also be considered, because atrioventricular block attributable to inferior wall ischemia or MI may be reversible. atrioventricular block caused by vagotonic influences is usually transient and generally does not require cardiac pacing. Iatrogenic causes are usually clear from the clinical circumstances.

Table 9. Etiology of Atrioventricular Block

Congenital/genetic
• Congenital AV block (associated with maternal systemic lupus erythematosus) • Congenital heart defects (e.g., L-TGA) • Genetic (e.g., SCN5A mutations)
Infectious
• Lyme carditis • Bacterial endocarditis with perivalvar abscess • Acute rheumatic fever • Chagas disease • Toxoplasmosis
Inflammatory/infiltrative
• Myocarditis • Amyloidosis • Cardiac sarcoidosis • Rheumatologic disease: Systemic sclerosis, SLE, RA, reactive arthritis (Reiter's syndrome) • Other cardiomyopathy-idiopathic, valvular
Ischemic
• Acute MI • Coronary ischemia without infarction—unstable angina, variant angina • Chronic ischemic cardiomyopathy
Degenerative
• Lev's and Lenegre's diseases
Vagotonic-associated with increased vagal tone
• Sleep, obstructive sleep apnea • High-level athletic conditioning • Neurocardiogenic

Metabolic/endocrine
• Acid-base disorders • Poisoning/overdose (e.g., mercury, cyanide, carbon monoxide, mad honey) • Thyroid disease (both hypothyroidism and hyperthyroidism) • Adrenal disease (e.g., pheochromocytoma, hypoaldosteronism)
Other diseases
• Neuromuscular diseases (e.g., myotonic dystrophy, Kearns-Sayre syndrome, Erb's dystrophy) • Lymphoma
Iatrogenic

• Medication related
  o Beta blockers, verapamil, diltiazem, digoxin
  o Antiarrhythmic drugs
  o Neutraceuticals
• Catheter ablation
• Cardiac surgery, especially valve surgery
• TAVR, alcohol septal ablation

RA indicates rheumatoid arthritis; MI, myocardial infarction; SLE, systemic lupus erythematosus; and TAVR, transcatheter aortic valve replacement.

Atrioventricular block may be classified anatomically by the site of block, usually divided into atrioventricular nodal, intra-Hisian (within the His bundle itself), and infra-Hisian (below the His bundle). The site of block may be clinically important and can be determined by invasive EPS when not apparent from the ECG and clinical circumstances. In general, atrioventricular block at the atrioventricular nodal level is associated with slower progression, a faster and more reliable atrioventricular junctional escape mechanism, and greater responsiveness to autonomic manipulation such as atropine, isoproterenol, and epinephrine administration. In contrast, atrioventricular block within or below the His bundle may progress rapidly and unexpectedly, is associated with a slower and more unpredictable ventricular escape mechanism, will not respond to atropine but will sometimes improve with catecholamines.

First-degree atrioventricular block is a misnomer; true block is not present, as each P wave is conducted, but with a prolonged PR interval >200 ms. Although for historical reasons, management of first-degree atrioventricular block is considered in the discussion of atrioventricular block, it is more accurately referred to as first-degree atrioventricular delay. Second-degree atrioventricular block is sub-classified into Mobitz I (Wenckebach conduction) and Mobitz II. Mobitz I block occurs after gradual PR prolongation and Mobitz II does not. The ECG will show group beating as a result of "dropped" QRS complexes. Atrioventricular block where only 2:1 block is present cannot be classified as Mobitz I or II, so it is important to elucidate the level of block. High-grade, high-degree, or advanced atrioventricular block refers to situations where ≥2 consecutive P waves at a normal rate are not conducted without complete loss of atrioventricular conduction. High-degree atrioventricular block is generally considered to be intra- or infra-Hisian and treated with pacing. In unusual circumstances (at night, with accompanying sinus slowing) a vagal etiology may be considered especially when the QRS in narrow. Third-degree or complete atrioventricular block implies no conduction at all from atria to ventricles and may be paroxysmal or persistent and is usually associated with either a junctional or ventricular escape mechanism. Complete atrioventricular block may be imputed in the setting of AF when the ventricular response is slow (<50 bpm) and regular, although junctional rhythm in the setting of atrioventricular conduction abnormalities may be associated with this electrocardiographic finding.

Careful evaluation of the ECG is required for the diagnosis of atrioventricular block. A 1:1 relationship between P waves and QRS complexes may not be present if the atrial rate and ventricular rates are similar (isorhythmic dissociation) or if the atrial rate is slower than the ventricular rate (sinus bradycardia coupled with an accelerated junctional rhythm without consistent retrograde

ventriculoatrial conduction). In atrial bigeminy, a repetitive premature atrial contraction could be associated with normal conduction, atrioventricular delay, or blocked conduction; any of these scenarios could lead to an erroneous diagnosis of atrioventricular block.

6.2. Clinical Presentation

Symptoms related to atrioventricular block vary and depend largely on the degree of atrioventricular block, the ventricular rate, and the frequency of its occurrence (S6.2-1). Profound first-degree atrioventricular block can lead to symptoms of fatigue or exertional intolerance if the PR interval is long enough to allow for loss of atrioventricular synchrony that results in a decrease in cardiac output and an increase pulmonary capillary wedge pressure (often called “pseudo pacemaker syndrome” and may occur with PR interval >300 ms) (S6.2-2–S6.2-4). Second-degree atrioventricular block type I (Wenckebach) is often asymptomatic and seen in active, healthy patients with no history of heart disease. However, if occurring frequently or during exercise, it can cause symptoms of exertional intolerance or dizziness. Patients who present with complaints of syncope and have a negative initial workup such as a negative physical examination, ECG, and echocardiogram are sometimes found to have intermittent episodes of atrioventricular block with long-term monitoring (S6.2-5–S6.2-7). Intermittent complete atrioventricular block causing syncope or presyncope is more typically seen in patients with underlying heart disease or an underlying bundle branch block at baseline but can also be seen in patients with no baseline heart disease or evident conduction abnormalities. One study found that 8% of syncope patients with a normal ECG and echocardiogram had paroxysmal idiopathic atrioventricular block with no identifiable underlying cause (S6.2-5). Other studies evaluating patients with syncope and underlying bundle branch block or bifascicular block found that 61% had significant, clinically relevant His Purkinje conduction abnormalities identified at EPS (S6.2-8, S6.2-9). Patients with atrioventricular block that conducts in a 2:1 pattern can also have symptoms of fatigue and dizziness particularly if it persists during exertion.

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6.3. Acute Management

6.3.1. Acute Management of Reversible Causes of Bradycardia Attributable to Atrioventricular Block

Recommendations for Acute Management of Reversible Causes of Bradycardia Attributable to Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplement 26.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. Patients with transient or reversible causes of atrioventricular block, such as Lyme carditis or drug toxicity, should have medical therapy and supportive care, including temporary transvenous pacing if necessary, before determination of need for permanent pacing (S6.3.1-1–S6.3.1-5).**
IIa	**B-NR**	**2. In selected patients with symptomatic second-degree or third-degree atrioventricular block who are on chronic stable doses of medically necessary antiarrhythmic or beta-blocker therapy, it is reasonable to proceed to permanent pacing without further observation for drug washout or reversibility (S6.3.1-6–S6.3.1-9).**
IIa	**B-NR**	**3. In patients with second-degree or third-degree atrioventricular block associated with cardiac sarcoidosis, permanent pacing, with additional defibrillator capability if needed and meaningful survival of greater than 1 year is expected, without further observation for reversibility is reasonable (S6.3.1-10, S6.3.1-11).**
IIb	**C-LD**	**4. In patients with symptomatic second-degree or third-degree atrioventricular block associated with thyroid function abnormalities but without clinical myxedema, permanent pacing without further observation for reversibility may be considered (S6.3.1-12).**

Synopsis

In patients presenting with new atrioventricular block, medical evaluation may disclose transient or reversible causes, the treatment or resolution of which may make permanent pacing unnecessary. Lyme carditis is one of the more common reversible causes of atrioventricular block in endemic areas and should be sought in appropriate patients, as atrioventricular block in such cases is almost always reversible (S6.3.1-13, S6.3.1-14). Digoxin toxicity, although increasingly uncommon, is another cause of atrioventricular block that may be reversed with drug washout or neutralizing antibody fragment therapy (S6.3.1-1, S6.3.1-3). Although overdoses of other antiarrhythmic drugs, beta blockers, and calcium channel blockers may cause reversible atrioventricular block, several studies have shown that therapeutic doses of these drugs are not commonly responsible for presentation with new atrioventricular block, and most patients in this scenario ultimately require permanent pacing (S6.3.1-6–S6.3.1-9). Similarly, treatment of hypothyroidism suggested by laboratory testing and cardiac sarcoidosis associated with new atrioventricular block usually does not make permanent pacing unnecessary when otherwise indicated (S6.3.1-10–S6.3.1-12).

Recommendation-Specific Supportive Text

1. Lyme disease is caused by the spirochete *Borrelia burgdorferi* and is transmitted by the Ixodes deer tick (S6.3.1-13). The most common manifestation of Lyme carditis is atrioventricular block, usually at the atrioventricular nodal level (S6.3.1-14). Approximately 40% of patients who are identified clinically require temporary pacing, but permanent atrioventricular block after antibiotic therapy is rare. In 1 review of published cases, median time to resolution of atrioventricular block was 6 days, with a range out to 42 days (S6.3.1-2, S6.3.1-4, S6.3.1-5). Despite the use of lower chronic doses and widespread availability of testing for serum levels, digoxin toxicity as a cause of reversible atrioventricular block still occurs (reference). Most cases of atrioventricular block attributable to digoxin toxicity will respond to observation and supportive care; severe cases may respond to anti-digoxin Fab antibody therapy (S6.3.1-1, S6.3.1-3).
2. Medications that slow or block atrioventricular conduction are commonly used in the treatment of hypertension, arrhythmias, heart failure, and other cardiac disease. Common examples are beta blockers, nondihydropyridine calcium channel blockers, and class I and III antiarrhythmic medications. Therefore, patients may commonly present with atrioventricular block while taking ≥1 of these medications. Moreover, these medications are sometimes part of an essential pharmacologic regimen that should not be interrupted. Although these scenarios may occasionally represent a reversible cause of atrioventricular block, several case series suggest that it is unusual for atrioventricular block to reverse with cessation of medications when used at therapeutic doses and even when reversal of atrioventricular block is observed acutely, later implant of a PPM is often necessary (S6.3.1-6–S6.3.1-9). The decision for whether to proceed with permanent pacing must account for the potentially deleterious effect of high amounts of right ventricular pacing and whether alternate medications without atrioventricular slowing could be used.
3. Cardiac sarcoidosis is an infiltrative/inflammatory cardiomyopathy that is often associated with atrioventricular block and ventricular arrhythmias (S6.3.1-15). Limited, small, nonrandomized studies of patients with cardiac sarcoidosis and atrioventricular block treated with corticosteroids found that only a few patients (13%–47%) had any reversibility of atrioventricular block (S6.3.1-10, S6.3.1-11). Moreover, cardiac sarcoidosis may have a waxing and waning or progressive course and initial improvement in atrioventricular conduction may later reverse. Given the known risks of delay in implantation of PPMs in patients with atrioventricular block, it is often reasonable to proceed to implantation without further delay in this clinical scenario (S6.3.1-16). Because of the risk of ventricular arrhythmias in patients with cardiac sarcoidosis, a CIED with defibrillator capability is often considered in patients who require permanent pacing (S6.3.1-17).
4. Severe thyroid disease, such as myxedema, rarely may be associated with reversible atrioventricular block (S6.3.1-18). However, there is little evidence to suggest reversibility of atrioventricular block presenting in the context of less severe thyroid function abnormalities commonly seen in clinical practice. One series of 50 patients with atrioventricular block presenting in the context of hyperthyroidism or hypothyroidism found that only about 20% of patients had resolution of atrioventricular block with restoration of euthyroid state (S6.3.1-12).

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6.3.2. Acute Medical Therapy for Bradycardia Attributable to Atrioventricular Block

Recommendations for Acute Medical Therapy for Bradycardia Attributable to Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplements 27 and 28.		
COR	**LOE**	**Recommendations**
IIa	**C-LD**	**1. For patients with second-degree or third-degree atrioventricular block believed to be at the atrioventricular nodal level associated with symptoms or hemodynamic compromise, atropine is reasonable to improve atrioventricular conduction, increase ventricular rate, and improve symptoms (S6.3.2-1–S6.3.2-3).**
IIb	**B-NR**	**2. For patients with second-degree or third-degree atrioventricular block associated with symptoms or hemodynamic compromise and who have low likelihood for coronary ischemia, beta-adrenergic agonists, such as isoproterenol, dopamine, dobutamine, or epinephrine, may be considered to improve atrioventricular conduction, increase ventricular rate, and improve symptoms (S6.3.2-3–S6.3.2-7).**
IIb	**C-LD**	**3. For patients with second-degree or third-degree atrioventricular block associated with symptoms or hemodynamic compromise in the setting of acute inferior MI, intravenous aminophylline may be considered to improve atrioventricular conduction, increase ventricular rate, and improve symptoms (S6.3.2-8–S6.3.2-11).**

Synopsis

The acute treatment of bradycardia attributable to atrioventricular block will often begin with timely identification and removal of potential causative factors as well as medical therapy. Atropine has a long track record of use for this indication because of ease of administration and relatively low risk of adverse reactions. It is more likely to be useful for atrioventricular block at the atrioventricular nodal level and for bradycardia attributable to excess vagal tone. Because of its short duration of action, it is generally used as a bridge to longer-lasting therapy, such as infusion of a beta-adrenergic drug or temporary pacing. Aminophylline and glucagon have a possible role in treatment of atrioventricular block in the setting of acute MI and beta-blocker toxicity, respectively, but data are sparse.

Recommendation-Specific Supportive Text

1. Atropine is a parasympatholytic drug that enhances atrioventricular nodal conduction and automaticity, generally given in 0.5- to 1.0-mg IV increments. Current advanced cardiac life support recommendations advise early use of atropine for medical treatment of hemodynamically significant bradycardia, including atrioventricular block. Uncontrolled cohort studies suggest efficacy and clinical benefit, particularly in the setting of acute inferior MI (S6.3.2-1–S6.3.2-3). Atropine is unlikely to improve atrioventricular block at the His bundle or His-Purkinje level and isolated reports have suggested occasional worsened atrioventricular conduction and/or hemodynamic compromise in such patients. For this reason, atropine should be used judiciously in patients with atrioventricular block and wide QRS complexes that suggest the presence of significant His Purkinje disease. Adverse effects of atropine include dry mouth, blurred vision, anhidrosis, urinary retention, and delirium. Excessive increase in heart rate may be problematic, particularly in patients with acute MI.

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2. Beta-adrenergic agonists such as isoproterenol, dopamine, dobutamine, and epinephrine exert direct effects to enhance atrioventricular nodal and, to a lesser degree, His-Purkinje conduction. These drugs may also enhance automaticity of subsidiary atrioventricular junctional and ventricular pacemakers in the setting of complete atrioventricular block. Clinical efficacy of dopamine was shown to be equivalent to transcutaneous pacing in 1 small randomized trial of patients with unstable bradycardia unresponsive to atropine in the prehospital setting (S6.3.2-7). Isoproterenol was shown to elicit an escape rhythm in 68% of pacemaker-dependent patients undergoing generator replacement (S6.3.2-4). Other data come from cohort studies of limited design (S6.3.2-3, S6.3.2-5, S6.3.2-6). Adverse effects of beta-adrenergic agonists may include elicitation of ventricular arrhythmias and induction of coronary ischemia, particularly in the setting of acute MI or unstable coronary artery disease. In addition, isoproterenol may exacerbate hypotension because of the vasodilatory effects.
3. Aminophylline is a methylxanthine compound that is a nonselective adenosine receptor antagonist and phosphodiesterase inhibitor. It is used clinically as a bronchodilator and as a reversal drug for dipyridamole, adenosine, and regadenoson in pharmacologic nuclear stress testing. Experimental evidence suggests a role of increased adenosine production in development of atrioventricular block in acute inferior MI. Several small case series of up to 8 patients have shown prompt reversal of atrioventricular block in this clinical setting without adverse effects (S6.3.2-8–S6.3.2-11). Larger cohort studies and randomized trials in hospitalized patients are lacking. A large randomized trial and a systematic review showed no benefit for aminophylline in resuscitation for out-of-hospital brady-asystolic cardiac arrest (S6.3.2-12).

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6.3.3. Temporary Pacing for Atrioventricular Block

Recommendations for Temporary Pacing for Bradycardia Attributable to Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplements 29 and 30.		
COR	**LOE**	**Recommendations**
IIa	**B-NR**	**1. For patients with second-degree or third-degree atrioventricular block associated with symptoms or hemodynamic compromise that is refractory to medical therapy, temporary transvenous pacing is reasonable to increase heart rate and improve symptoms (S6.3.3-1–S6.3.3-7).**
IIa	**B-NR**	**2. For patients who require prolonged temporary transvenous pacing, it is reasonable to choose an externalized permanent active fixation lead over a standard passive fixation temporary pacing lead (S6.3.3-8–S6.3.3-14)**.
IIb	**B-R**	**3. For patients with second-degree or third-degree atrioventricular block and hemodynamic compromise refractory to antibradycardic medical therapy, temporary transcutaneous pacing may be considered until a temporary transvenous or PPM is placed or the bradyarrhythmia resolves (S6.3.3-15–S6.3.3-20).**

Synopsis

Temporary transvenous pacing techniques have been used for nearly 60 years but have remarkably little data to guide their appropriate use. Early literature suggests a high rate of complications and dislodgement that has prompted some authors to advise very limited use (S6.3.3-2, S6.3.3-4). More recent case series and trials with balloon flotation catheters suggest better safety profile (S6.3.3-6). The cause of atrioventricular block must be taken into account when considering the timing and necessity of temporary pacing. For example, in the setting of an MI, initial focus on primary reperfusion rather than temporary pacing for rate support may be associated with improved outcomes (S6.3.3-21). The safety of prolonged temporary pacing with an externalized active fixation permanent pacing lead has been demonstrated over the past 10 years (S6.3.3-8–S6.3.3-14). Transcutaneous pacing, devised >60 years ago, has a limited role in the acute treatment of atrioventricular block because of the painful nature of the stimulation and difficulty in ascertaining reliable myocardial capture (S6.3.3-22). Figure 5 provides an algorithm for choosing specific pacing strategy once temporary pacing is thought to be clinically necessary.

Recommendation-Specific Supportive Text

1. Temporary transvenous pacing was introduced in 1959 and is now widely available. Use of semirigid fixed curve catheters were associated with high complication rates, particularly in the acute MI setting and when placed by less-experienced operators (S6.3.3-1, S6.3.3-2, S6.3.3-7). One randomized trial showed faster placement and lower complication rates with balloon-tipped catheters (S6.3.3-6). Nonrandomized data suggest lower complication rates using internal jugular vein access and fluoroscopic or echocardiographic guidance (for venous access and lead position) for placement (S6.3.3-4, S6.3.3-5, S6.3.3-23). Complications for transvenous pacing wires are greater when left in place for longer duration (>48 hours), which may delay placement of a PPM (S6.3.3-3). Temporary transvenous pacing should therefore be used for the minimum duration necessary to provide hemodynamic support or back-up pacing to prevent asystole and should be placed by the most

experienced available operator. If atrioventricular block is felt to be irreversible, and the means to place a permanent pacing system is available, it may be best for the patient to avoid temporary pacing and proceed directly to permanent system implantation.

2. Use of an active fixation permanent pacing lead externalized and connected to a reusable PPM generator (sometimes referred to as a "temporary PPM") has been introduced as a means of allowing more prolonged temporary pacing for pacemaker-dependent patients who have a contraindication to PPM implantation, such as infection. A primary use is for bridging therapy in patients who have undergone CIED extraction for infection and require prolonged antibiotic treatment (S6.3.3-11). Patients receiving long-term antibiotics who will be receiving a new pacemaker benefit from externalized devices during the course of therapy (S6.3.3-24). Non-RCTs and cohort studies suggest that this form of temporary pacing is associated with much lower dislodgment rates and lower complication rates overall (S6.3.3-8–S6.3.3-14). Other advantages include ability to mobilize patients who would otherwise be confined to bedrest in an intensive care unit setting. One study suggested that this form of pacing is cost saving after 1 to 2 days, despite the higher lead cost because of ability to care for the patient in a lower intensity/lower cost setting (S6.3.3-9). No infections have been reported with the use of reusable sterilized pacemakers (S6.3.3-8–S6.3.3-14).
3. Transcutaneous pacing was reported in 1952 and became commercially available in the early 1980s (S6.3.3-20). It is now universally available in combination with external defibrillators. Numerous trials have not shown any improvement in survival to hospital discharge when used in the prehospital phase of bradyasystolic cardiac arrest (S6.3.3-16–S6.3.3-19). Its use appears to be greater when applied to patients with a perfusing rhythm or early in the course of cardiac arrest (S6.3.3-15, S6.3.3-17). There are no controlled trials of transcutaneous pacing outside the setting of prehospital cardiac arrest. Use of transcutaneous pacing may be limited by high capture thresholds and patient discomfort, which may require sedation. Assessment of myocardial capture by ECG alone may be difficult and should be confirmed by assessment of pulse or intra-arterial pressure. Because prolonged use of transcutaneous pacing may be unreliable and poorly tolerated, it should generally serve as a short-term bridge to temporary or permanent transvenous pacing or resolution of bradycardia. However, prophylactic placement of pads for rapid institution of temporary pacing, if necessary, is reasonable in patients who are thought to be at future risk for significant bradycardia (S6.3.3-25).

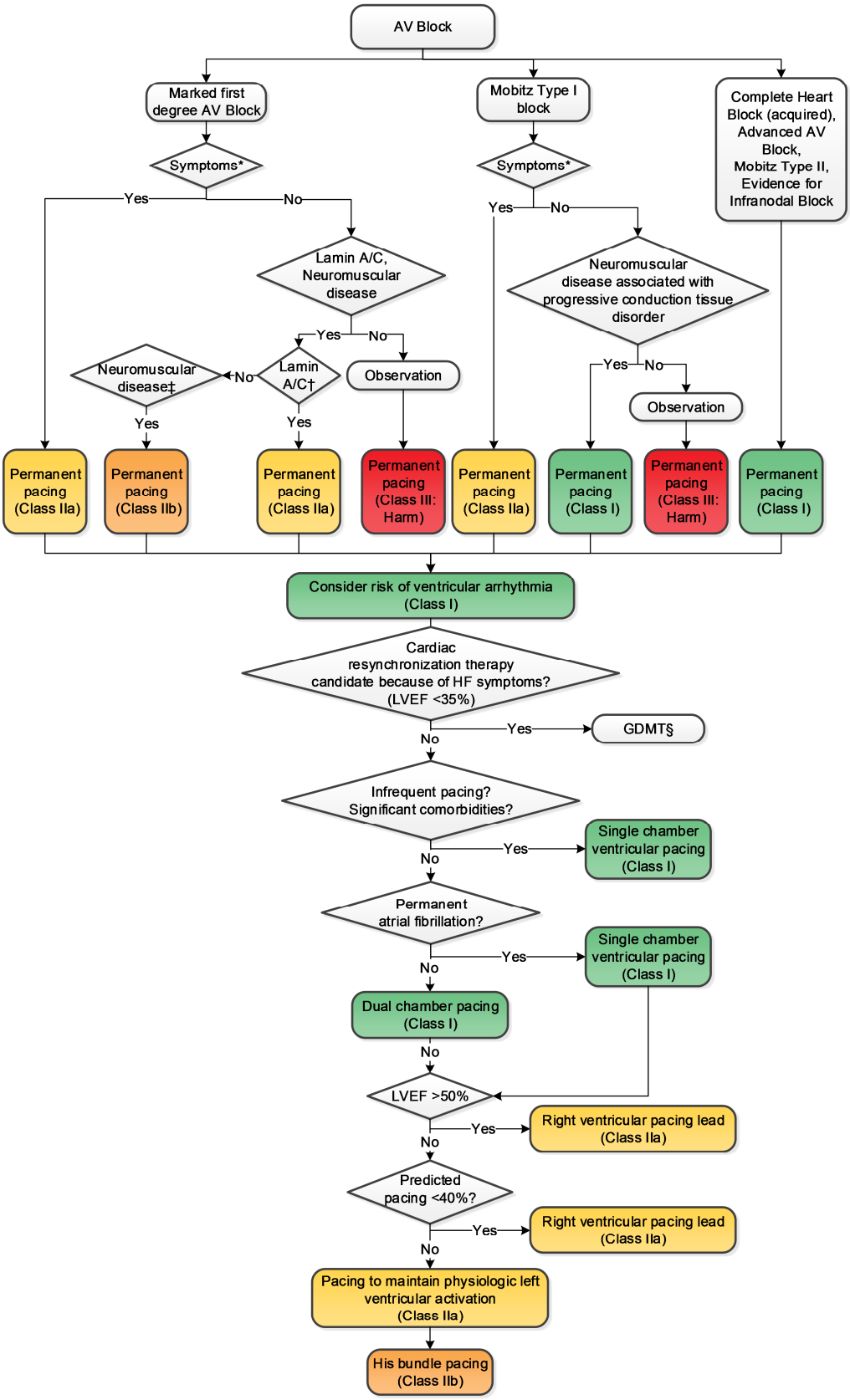
6.4. Chronic Therapy/Management of Bradycardia Attributable to Atrioventricular Block

An algorithm for the management of bradycardia or pauses attributable to chronic atrioventricular block is provided in Figure 7. Specific subsections address general principles, transient or potentially reversible causes, additional testing, and permanent pacing for chronic atrioventricular block.

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Figure 7. Management of Bradycardia or Pauses Attributable to Chronic Atrioventricular Block Algorithm

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AV Block
Marked first degree AV Block
Mobitz Type I block
Complete Heart Block (acquired), Advanced AV Block, Mobitz Type II, Evidence for Infranodal Block
Symptoms*
Symptoms*
Yes
No
Yes
No
Lamin A/C, Neuromuscular disease
Neuromuscular disease associated with progressive conduction tissue disorder
Yes
No
Yes
No
Neuromuscular disease‡
No
Lamin A/C†
Observation
Observation
Yes
Yes
Permanent pacing (Class IIa)
Permanent pacing (Class IIb)
Permanent pacing (Class IIa)
Permanent pacing (Class III: Harm)
Permanent pacing (Class IIa)
Permanent pacing (Class I)
Permanent pacing (Class III: Harm)
Permanent pacing (Class I)
Consider risk of ventricular arrhythmia (Class I)
Cardiac resynchronization therapy candidate because of HF symptoms? (LVEF <35%)
Yes
GDMT§
No
Infrequent pacing? Significant comorbidities?
Yes
Single chamber ventricular pacing (Class I)
No
Permanent atrial fibrillation?
Yes
Single chamber ventricular pacing (Class I)
No
Dual chamber pacing (Class I)
No
LVEF >50%
Yes
Right ventricular pacing lead (Class IIa)
No
Predicted pacing <40%?
Yes
Right ventricular pacing lead (Class IIa)
No
Pacing to maintain physiologic left ventricular activation (Class IIa)
His bundle pacing (Class IIb)

Colors correspond to Class of Recommendation in Table 2.
Refer to Section 6.4. for discussion.
*Symptoms correlate with AV block.
†PR interval >240 ms, LBBB.
‡PR interval >240 ms, QRS >120 ms or fascicular block.
§Refer to heart failure guidelines (S6.4-1, S6.4-2).
AV indicates atrioventricular; GDMT, guideline-directed management and therapy; HF, heart failure; LBBB, left bundle branch block; and LVEF, left ventricular ejection fraction.

6.4.1. General Principles of Chronic Therapy/Management of Bradycardia Attributable to Atrioventricular Block

Recommendations for General Principles of Chronic Therapy/Management of Bradycardia Attributable to Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplements 31, 32, 33, and 34.		
COR	**LOE**	**Recommendations**
III: Harm	**C-LD**	**1. In patients with first-degree atrioventricular block or second-degree Mobitz type I (Wenckebach) or 2:1 atrioventricular block which is believed to be at the level of the atrioventricular node, with symptoms that do not temporally correspond to the atrioventricular block, permanent pacing should not be performed (S6.4.1-1–S6.4.1-7).**
III: Harm	**C-LD**	**2. In asymptomatic patients with first-degree atrioventricular block or second-degree Mobitz type I (Wenckebach) or 2:1 atrioventricular block which is believed to be at the level of the atrioventricular node, permanent pacing should not be performed (S6.4.1-4–S6.4.1-10).**

Synopsis

The presence or absence of symptoms is a major determinant on whether permanent pacing will be required in the setting of bradycardia associated with atrioventricular block. In addition to symptoms, there are 3 additional clinical issues that must be considered when deciding on the use of permanent pacing in patients with atrioventricular block. First, the site of atrioventricular block is critical because patients with infranodal disease who then later develop complete heart block will be dependent on unreliable ventricular escape rhythms. Second, significant amounts of right ventricular pacing are potentially deleterious. Finally, patients with atrioventricular block may have an associated systemic disease that leads to progressive atrioventricular block or has additional risk for ventricular arrhythmias.

Recommendation-Specific Supportive Text

1. In patients who have second-degree Mobitz type I (Wenckebach) or 2:1 atrioventricular block but with symptoms of dizziness or presyncope or even syncope that do not temporally correspond to the episode of atrioventricular block, it is unclear whether permanent pacing will improve symptoms or alleviate them. If the level of the block is at the atrioventricular node, then sudden progression to a higher degree of atrioventricular block is unlikely (S6.4.1-1, S6.4.1-3). If the symptoms do not correlate with the episodes of first-degree or second-degree Mobitz type I atrioventricular block, the episodes would be considered unrelated and a pacemaker would not be indicated (S6.4.1-1, S6.4.1-3). Given the procedural and long-term risks of PPMs, in the absence of mitigating circumstances,

for patients with first-degree or second-degree Mobitz type I (Wenckebach) atrioventricular block that does not clearly correspond to symptoms, further monitoring and follow up should be implemented (S6.4.1-4–S6.4.1-7).

2. First- and second-degree Mobitz type I (Wenckebach) atrioventricular blocks (or 2:1 atrioventricular block, if the level of block is at the atrioventricular node), are typically benign in that they do not progress suddenly to complete heart block (S6.4.1-1, S6.4.1-3). Treatment of these conduction disorders with a pacemaker are typically reserved for significant symptoms that affect QOL. Occasionally second-degree Mobitz type I (Wenckebach) atrioventricular block is in fact infranodal, and in those instances a pacemaker may be considered even in the absence of symptoms (S6.4.1-1). Although a narrow QRS complex suggests that the block is at the level of the atrioventricular node, there are instances where it has been determined to be infranodal during an EPS. Symptoms may be difficult to correlate but ambulatory electrocardio

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atrioventricular block is useful or even consideration for permanent pacing after the offending medication has been discontinued. Although PPM implantation is a relatively low-risk cardiac procedure, procedural complications and death directly related to implant can occur, and implanted leads have long-term management implications (S6.4.2-6–S6.4.2-9).

3. Vagally mediated atrioventricular block observed with ambulatory electrocardiographic monitoring may be an incidental finding that occurred while the patient was sleeping or in other cases be associated with syncope. Vagally mediated atrioventricular block is felt to be attributable to neural reflexes, which result in simultaneous bradycardia and hypotension (S6.4.2-14). There is typically sinus rate slowing in conjunction with the onset of atrioventricular block and the atrioventricular block can be high grade or complete (S6.4.2-10). Atrioventricular block attributable to high vagal tone, such as during sleep, is almost always asymptomatic (S6.4.2-15). The level of the block is at the atrioventricular node, and there is normal atrioventricular nodal function when tested at EPS (S6.4.2-16). If asymptomatic, medical treatment or pacemaker implantation is not warranted for atrioventricular block attributable to high vagal tone or vagally mediated atrioventricular block. If the patient is having frequent syncopal episodes, treatment may be warranted if bradycardia appears to be the dominant factor in these episodes (S

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ventricular (HV) interval or induced infranodal atrioventricular block with procainamide challenge was considered abnormal and possibly indicative of underlying infra-Hisian block (S6.4.3-11). The sensitivity of a procainamide challenge for distal conduction disease is low. However, it could be potentially useful in cases where the HV interval is borderline or atrioventricular block cannot be induced (S6.4.3-11, S6.4.3-17). Atropine shortens the refractoriness of the atrioventricular node but has little effect on infranodal conduction tissues (S6.4.3-10). Atropine will improve or have no change in atrioventricular conduction block if the block is at the level of the atrioventricular node but will worsen atrioventricular conduction block in the presence of intra-His or distal conduction disease (S6.4.3-8, S6.4.3-18). Isoproterenol can also be used to unmask underlying pathologic His-Purkinje disease by enhancing atrioventricular nodal and sinus conduction and precipitating heart block with faster heart rates (S6.4.3-12, S6.4.3-19). Similar to atropine, worsening atrioventricular block with isoproterenol infusion would be suggestive of infranodal block. Conversely, improvement of atrioventricular conduction with carotid sinus massage may be observed in patients with infranodal atrioventricular block (S6.4.3-10). All provocative testing should be done with careful monitoring, particularly when using a drug, because the pharmacologic effects can be prolonged.

6.4.4. Permanent Pacing

Recommendations for Permanent Pacing for Chronic Therapy/Management of Bradycardia Attributable to Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplements 34, 39, and 40.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients with acquired second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or third-degree atrioventricular block not attributable to reversible or physiologic causes, permanent pacing is recommended regardless of symptoms (S6.4.4-1–S6.4.4-7).**
I	**B-NR**	**2. In patients with neuromuscular diseases associated with conduction disorders, including muscular dystrophy (e.g., myotonic dystrophy type 1) or Kearns-Sayre syndrome, who have evidence of second-degree atrioventricular block, third-degree atrioventricular block, or an HV interval of 70 ms or greater, regardless of symptoms, permanent pacing, with additional defibrillator capability if needed and meaningful survival of greater than 1 year is expected, is recommended (S6.4.4-8–S6.4.4-15).**
I	**C-LD**	**3. In patients with permanent AF and symptomatic bradycardia, permanent pacing is recommended (S6.4.4-2, S6.4.4-16, S6.4.4-17).**
I	**C-LD**	**4. In patients who develop symptomatic atrioventricular block as a consequence of guideline-directed management and therapy for which there is no alternative treatment and continued treatment is clinically necessary, permanent pacing is recommended to increase heart rate and improve symptoms (S6.4.4-18–S6.4.4-24).**
IIa	**B-NR**	**5. In patients with an infiltrative cardiomyopathy, such as cardiac sarcoidosis or amyloidosis, and second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or third-degree atrioventricular block, permanent pacing, with additional defibrillator**

		capability if needed and meaningful survival of greater than 1 year is expected, is reasonable (S6.4.4-25–S6.4.4-30).
IIa	**B-NR**	**6. In patients with lamin A/C gene mutations, including limb-girdle and Emery Dreifuss muscular dystrophies, with a PR interval greater than 240 ms and LBBB, permanent pacing, with additional defibrillator capability if needed and meaningful survival of greater than 1 year is expected, is reasonable (S6.4.4-31–S6.4.4-33).**
IIa	**C-LD**	**7. In patients with marked first-degree or second-degree Mobitz type I (Wenckebach) atrioventricular block with symptoms that are clearly attributable to the atrioventricular block, permanent pacing is reasonable (S6.4.4-34–S6.4.4-37).**
IIb	**C-LD**	**8. In patients with neuromuscular diseases, such as myotonic dystrophy type 1, with a PR interval greater than 240 ms, a QRS duration greater than 120 ms, or fascicular block, permanent pacing, with additional defibrillator capability if needed and meaningful survival of greater than 1 year is expected, may be considered (S6.4.4-9–S6.4.4-13, S6.4.4-15).**

Synopsis

Similar to SND, symptoms are an important factor when determining whether permanent pacing is indicated. If the patient is symptomatic, regardless of the level of atrioventricular block and the likelihood of future progression of atrioventricular block, permanent pacing is indicated. However, unlike SND, infranodal atrioventricular block regardless of the presence or absence of symptoms warrants a pacemaker because the patient could suffer from sudden onset complete atrioventricular block resulting in syncope and subsequent harm (Figure 7).

Recommendation-Specific Supportive Text

1. Older observational studies have documented the natural history of untreated patients with second-degree Mobitz type II and third-degree atrioventricular block, and they demonstrated that these patients have recurrent symptoms including syncope and heart failure (S6.4.4-1, S6.4.4-4). There are also observational studies that have demonstrated a mortality benefit with pacing therapy. One study from the 1970s showed that despite having other cardiac comorbidities such as prior MI and heart failure, there was an improvement in survival compared with similar patients who did not receive a pacemaker (S6.4.4-6). A 5-year survival benefit was also shown in a study from the 1980s evaluating patients with second-degree Mobitz type II and 2:1 atrioventricular block. Importantly, in patients with high-grade atrioventricular block, although those with symptoms had a worse prognosis than those without symptoms, the prognosis was poor overall for both groups if left untreated (S6.4.4-3, S6.4.4-5).
2. Patients with certain neuromuscular disorders such as one of the muscular dystrophies or Kearns-Sayre syndrome often develop cardiac involvement; those with certain myotonic dystrophies such as myotonic dystrophy type 1, Emery-Dreifuss, and limb-girdle type 1B have a high incidence of conduction abnormalities (S6.4.4-10). Up to 20% of patients with myotonic dystrophy type 1 have evidence of atrioventricular block on their ECG or intermittent second-degree or third-degree atrioventricular block on 24-hour ambulatory electrocardiographic monitoring (S6.4.4-9, S6.4.4-12). More than 50% of patients with a normal ECG may have evidence of infra-Hisian block at EPS demonstrating the clinical use of the EPS in these patients. One study found that 46.7% of patients with an HV interval ≥70 ms, developed high-grade atrioventricular block (S6.4.4-14). Although there are no randomized trials assessing whether pacing reduces sudden cardiac death or all-cause

mortality, a large retrospective study showed a 75% lower risk of sudden death in those with a pacemaker (S6.4.4-15). Some of the patients will have concomitant ventricular arrhythmias or systolic dysfunction requiring implantable cardioverter defibrillator (ICD) therapy in addition to pacing support (S6.4.4-8, S6.4.4-11). Serial ECGs in these patients can be performed in follow-up to assess for development of conduction abnormalities (S6.4.4-13).

3. Diagnosing atrioventricular block in the setting of AF can be less straightforward than evaluating patients in sinus rhythm. atrioventricular block should be suspected if a slow regular ventricular response is observed, and a wide QRS might indicate the presence of infranodal block. Retrospective studies using ambulatory electrocardiographic monitoring have had conflicting results; in 1 study, pauses >3 seconds even when they occurred in the setting of AF, were mostly asymptomatic, while in the other 2 studies, most pauses >3 seconds were symptomatic. All 3 of these studies had a mix of patients with AF and sinus rhythm and subgroup analyses were not done (S6.4.4-2, S6.4.4-16, S6.4.4-17). If the pauses are causing symptoms or if the pauses are attributable to infranodal block, the recommendation is similar to patients who are in normal sinus rhythm. In the asymptomatic patient, there is specific pause duration that warrants permanent pacing.
4. Beta blockers have been recommended as guideline-directed medical therapy for heart failure and after MI (S6.4.4-18, S6.4.4-19). Atrioventricular block was usually an exclusion criterion for large trials that demonstrated the benefit of beta blockers in these patient populations (S6.4.4-20–S6.4.4-22). Atrioventricular block can develop secondary to drugs such as amiodarone or sotalol that may be important for the management of AF. The benefit of any medication that exacerbates atrioventricular block must be balanced with potentially deleterious effects of right ventricular pacing (S6.4.4-23, S6.4.4-24).
5. Cardiac sarcoidosis is an infiltrative cardiomyopathy that is known to predispose patients to both bradycardia and tachyarrhythmias. Systemic corticosteroids have been shown in small case studies to resolve atrioventricular block in some patients although the response rate has been reported to be in the 30% to 60% range (S6.4.4-25, S6.4.4-27, S6.4.4-29). In 1 study of 30 patients with cardiac sarcoid, 5 had atrioventricular block and 2 of the 3 patients who received corticosteroids within 30 days of the initial diagnosis had complete resolution of atrioventricular block, while both of the 2 patients who received corticosteroids >30 days of the initial diagnosis had persistent atrioventricular block (S6.4.4-38). However, even if atrioventricular block resolves, the recurrence rate of atrioventricular block and future risk of ventricular arrhythmias remains unclear (S6.4.4-39). In patients with type I AL cardiac amyloidosis, there appears to be a high incidence of bradycardia and atrioventricular block. One small study showed that all 25 patients referred for biopsy proven AL cardiac amyloidosis had evidence of conduction disease on the baseline ECG and almost all had a prolonged HV interval (>55 ms) despite a narrow QRS (S6.4.4-26, S6.4.4-28).
6. Patients with mutations in the lamin A/C gene can present with atrioventricular block, atrial arrhythmias, and ventricular arrhythmias (S6.4.4-31, S6.4.4-33, S6.4.4-40–S6.4.4-45). Lamin A/C genetic defects have been linked to dilated cardiomyopathy, limb girdle muscular dystrophy, and an autosomal dominant variant of Emery Dreifuss (S6.4.4-31). Case series in patients with lamin A/C cardiomyopathy have found some form of atrioventricular block in approximately 50% of patients and may be attributable to intramyocardial fibrosis that can be seen on cardiac MRI with gadolinium enhancement (S6.4.4-32, S6.4.4-40). Lamin A/C affected patients with evidence of atrioventricular block, with or without symptoms, are at an increased risk of sudden death (S6.4.4-46). One study showed that a first-degree atrioventricular block may be predictive of future ventricular arrhythmias (S6.4.4-33) Because of the high risk of ventricular arrhythmias and sudden cardiac death in these patients, devices with pacing as well as defibrillator capabilities are typically implanted (S6.4.4-42, S6.4.4-47–S6.4.4-49).

7. First-degree atrioventricular block and second-degree Mobitz type I (Wenckebach) atrioventricular block, when above or at the level of the atrioventricular node, are not concerning for progression to a higher degree atrioventricular block. They are also typically asymptomatic. However, in some patients, severe first-degree atrioventricular block can cause symptoms similar to pacemaker syndrome, as well as heart failure, and exertional intolerance (S6.4.4-34, S6.4.4-37). If the PR interval is very long, atrial contraction occurs when the atrioventricular valves are closed which can lead to an increase in wedge pressure and a decrease in cardiac output (S6.4.4-50). This phenomenon has been referred to as "pseudo-pacemaker syndrome" and has also been reported in patients with dual pathway physiology of the atrioventricular node (S6.4.4-51, S6.4.4-52). In patients with second-degree atrioventricular block Mobitz type I, frequently dropped QRS complexes can lead to symptoms attributable to loss of atrioventricular synchrony even in the absence of bradycardia (S6.4.4-52).
8. In patients with neuromuscular diseases that can affect the cardiac conduction system, such as myotonic dystrophy 1, the degree of the conduction abnormality can vary from mild first-degree atrioventricular block to complete heart block and it often progresses over a variable period of time (S6.4.4-10, S6.4.4-53–S6.4.4-55). Serial ambulatory electrocardiographic monitoring and EPSs have been done to determine whether paroxysmal atrioventricular block is present or for identifying a prolonged HV interval (i.e., >70 ms) (S6.4.4-9). In a single center study of 211 myotonic dystrophy type 1 patients, 45 patients were categorized as having a severe electrocardiographic abnormality (PR interval >240 ms, QRS >120 ms, second-degree or third-degree atrioventricular block, or a nonsinus rhythm) and 29 (65%) underwent pacemaker or ICD implantation (S6.4.4-12). Over 90% of the patients were asymptomatic at initial implant and at 5-year follow-up 13% of patients were pacemaker dependent (S6.4.4-12). In a multicenter prospective registry of patients with type 1 diabetes mellitus, this definition for severe electrocardiographic abnormalities had a sensitivity of 74% and a negative predictive value of 97.1% for predicting sudden death (rhythm at death unknown) (S6.4.4-11). In this study, sudden death accounted for 33% of deaths while 40% of deaths were attributable to progressive neuromuscular respiratory failure, emphasizing that use of a CIED and type of CIED chosen should be based on arrhythmia risk profile, patient preference, and overall prognosis (S6.4.4-11). Data for other types of less common neuromuscular disorders (without lamin A/C involvement) is limited to case reports. Although neuromuscular disorders are a heterogeneous group with different cardiac effects, in the presence of severe conduction disorders the recommendations are similar, while acknowledging the limited evidence base.

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6.4.4.1. Permanent Pacing Techniques and Methods for Chronic Therapy/Management of Bradycardia Attributable to Atrioventricular Block

Recommendations for Permanent Pacing Techniques and Methods for Chronic Therapy/Management of Bradycardia Attributable to Atrioventricular Block Referenced studies that support recommendations are summarized in Online Data Supplements 39 and 40 and the Systematic Review.		
COR	**LOE**	**Recommendations**
I	**A**	**1. In patients with SND and atrioventricular block who require permanent pacing, dual chamber pacing is recommended over single chamber ventricular pacing (S6.4.4.1-1–S6.4.4.1-7).**
I	**A**	**2. In select patients with atrioventricular block who require permanent pacing in whom frequent ventricular pacing is not expected, or who have significant comorbidities that are likely to determine clinical outcomes and that may limit the benefit of dual chamber pacing, single chamber ventricular pacing is effective (S6.4.4.1-1–S6.4.4.1-6, S6.4.4.1-8–S6.4.4.1-10).**
I	**B-R**	**3. For patients in sinus rhythm with a single chamber ventricular pacemaker who develop pacemaker syndrome, revising to a dual chamber pacemaker is recommended (S6.4.4.1-1, S6.4.4.1-2, S6.4.4.1-5, S6.4.4.1-8–S6.4.4.1-10).**
IIa	**B-R^{SR}**	**4. In patients with atrioventricular block who have an indication for permanent pacing with a LVEF between 36% and 50% and are expected to require ventricular pacing more than 40% of the time, it is reasonable to choose pacing methods that maintain physiologic ventricular activation (e.g., cardiac resynchronization therapy [CRT] or His bundle pacing) over right ventricular pacing (S6.4.4.1-7, S6.4.4.1-11–S6.4.4.1-19).**
IIa	**B-R**	**5. In patients with atrioventricular block who have an indication for permanent pacing with a LVEF between 36% and 50% and are expected to require ventricular pacing less than 40% of the time, it is reasonable to choose right ventricular pacing over pacing methods that maintain physiologic ventricular activation (e.g., CRT or His bundle pacing) (S6.4.4.1-15, S6.4.4.1-16, S6.4.4.1-20, S6.4.4.1-21).**
IIb	**B-R^{SR}**	**6. In patients with atrioventricular block at the level of the atrioventricular node who have an indication for permanent pacing, His bundle pacing may be considered to maintain physiologic ventricular activation (S6.4.4.1-19, S6.4.4.1-22–S6.4.4.1-25).**
III: Harm	**C-LD**	**7. In patients with permanent or persistent AF in whom a rhythm control strategy is not planned, implantation of an atrial lead should not be performed (S6.4.4.1-26, S6.4.4.1-27).**

SR indicates systematic review.

Synopsis

Refer to "Systematic Review for the 2018 ACC/AHA/HRS Guideline on the Evaluation and Management of Patients With Bradycardia and Cardiac Conduction Delay" for the complete systematic evidence review (S6.4.4.1-19), and the Online Data Supplement

(http://jaccjacc.acc.org/Clinical_Document/Bradycardia_GL_Online_Data_Supplement.pdf) for additional data and analyses. The results from the question "Impact of Physiologic Versus Right Ventricular Pacing Among Patients With Left Ventricular Ejection Fraction Greater Than 35%" and the writing committee's review of the totality of the literature were used to frame recommendations. Recommendations that are based on a body of evidence that includes the systematic review conducted by the evidence review committee are denoted by the superscript SR (e.g., LOE: B-R^{SR}). The effects of pacing mode on outcomes in patients with atrioventricular block have also been reviewed in a recent expert consensus statement (S6.4.4.1-28).

In older observational studies, patients with high-grade atrioventricular block often had syncope and heart failure symptoms prompting pacemaker implantation, although sudden death attributable to atrioventricular block was not commonly reported (S6.4.4.1-29–S6.4.4.1-31). There are several RCTs that looked at the possible benefits of dual chamber pacing for atrioventricular block compared with ventricular pacing but neither improvements in all-cause mortality nor cardiovascular mortality were demonstrated (S6.4.4.1-1–S6.4.4.1-5, S6.4.4.1-8). However, regardless of pacing technique, patients with atrioventricular block will require ventricular pacing for rate support. Specialized pacing modalities, such as biventricular pacing or His bundle pacing may alleviate the deleterious effects of right ventricular pacing in these patients. When determining the type of pacemaker (single, dual, biventricular), many patient factors should be considered including the projected percent of ventricular pacing and the LVEF. As addressed in the 2013 ACCF/AHA guideline for the management of heart failure, biventricular pacing can be useful for the patient on guideline-directed management and therapy who has an LVEF of ≤35% with an anticipated requirement for significant ventricular pacing (>40%) (S6.4.4.1-32).

Recommendation-Specific Supportive Text

1. PASE (Pacemaker Selection in the Elderly), MOST (Mode Selection Trial in Sinus Node Dysfunction), and CTOPP (Canadian Trial of Physiologic Pacing) were RCTs that enrolled subjects indicated for a pacemaker with SND or atrioventricular block, or both, and compared dual chamber pacing or pacing modes that maintained atrioventricular synchrony with single chamber ventricular pacing (S6.4.4.1-1–S6.4.4.1-4, S6.4.4.1-6). These trials did not demonstrate a reduction in all-cause mortality or stroke. The PASE investigators did a subgroup analysis and found no difference in functional status or QOL life for the atrioventricular block patients but did find that the SND patients with dual chamber pacing had improved functional status after 18 months of pacing therapy compared with single chamber ventricular pacing patients. These RCTs also showed a lower incidence of AF in the dual chamber patients (S6.4.4.1-28). A comprehensive Cochrane review looking at pacing mode and outcomes concluded that dual chamber pacing is preferred because of a smaller incidence of AF and because of the prevalence of pacemaker syndrome with single chamber ventricular pacing (S6.4.4.1-5). Clinical situations where it may be reasonable to implant a single chamber ventricular pacing device include patients with frailty or significant comorbidities, advanced age, a very sedentary lifestyle, difficulty placing the atrial lead and very infrequent episodes where pacing would be needed.
2. UKPace (United Kingdom Pacing and Cardiovascular Events), an RCT that only enrolled elderly patients with atrioventricular block and compared dual chamber with single chamber ventricular pacing did not show a mortality benefit or a lower incidence of AF or heart failure in the patients with dual chamber pacing. For the combined outcome of stroke, transient ischemic attack, and other thromboembolism, the mean annual rate was not different between the 2 groups (S6.4.4.1-8, S6.4.4.1-33). Furthermore, there was a significantly higher risk of procedural complications in the dual chamber group (7.8% versus 3.5%; $p<0.001$). Similarly, the MOST and CTOPP studies did not show any all-cause mortality or cardiovascular death reduction in the dual chamber group (S6.4.4.1-

2–S6.4.4.1-4, S6.4.4.1-8). Therefore, although dual chamber devices provide atrioventricular synchrony and are generally preferable, it is reasonable to implant a single chamber ventricular pacing system in patients who do not need the chronotropic support from atrial pacing and who have significant comorbidities or limited mobility.

In addition, for patients who will only require intermittent pacing support, single chamber ventricular pacing can be a reasonable option. Patients who require intermittent or occasional pacing are less likely to develop symptoms of pacemaker syndrome such as exertional intolerance and hypotension (S6.4.4.1-1).

3. Patients who are in sinus rhythm with single chamber ventricular pacing can develop symptoms of pacemaker syndrome such as exertional intolerance and hypotension. Patients with a high burden of ventricular pacing and intact ventriculoatrial conduction are more likely to develop symptoms of pacemaker syndrome (S6.4.4.1-9, S6.4.4.1-10). If the risk of pacemaker syndrome seems likely because of frequent sinus bradycardia and a high likelihood of frequent pacing, then a ventricular lead only device will probably be inadequate. Pacemaker syndrome was diagnosed in >18% of patients with the single chamber ventricular pacing mode in the MOST trial; however, ultimately a total of 31.4% had crossed over to dual chamber pacing (S6.4.4.1-2, S6.4.4.1-9). Predictors included a lower intrinsic sinus rate and a higher programmed pacing rate (S6.4.4.1-9). Similarly, a 26% crossover rate from the VVI to DDD pacing mode was seen in the PASE trial with predictors of pacemaker syndrome including decreased systolic blood pressure during pacing and use of beta blockers (S6.4.4.1-1, S6.4.4.1-10). Although there was a lower crossover rate in CTOPP and UKPace (approximately 3%), these patients would have required a system revision to a dual chamber system rather than reprogramming the pacing mode (S6.4.4.1-3, S6.4.4.1-8). Therefore, in patients likely to develop pacemaker syndrome symptoms, a dual chamber device is preferred to avoid an additional procedure to revise the device in the future.
4. The deleterious effects of chronic RV pacing have been demonstrated in various studies, although only a minority of chronically RV paced individuals will develop ventricular dysfunction or heart failure symptoms (S6.4.4.1-7, S6.4.4.1-34–S6.4.4.1-36). The DAVID (Dual Chamber and VVI Implantable Defibrillator) trial, a defibrillator trial comparing dual chamber pacing at 70 bpm to “back-up” pacing at 40 bpm, found that ICD patients without a pacing indication had an increased combined endpoint of death and hospitalization with dual chamber pacing (S6.4.4.1-7). Some studies have suggested that the risk of RV pacing induced cardiomyopathy increases when RV pacing exceeds 40% or perhaps as low as 20% (S6.4.4.1-6, S6.4.4.1-34, S6.4.4.1-37). The BLOCK HF trial (Biventricular Versus Right Ventricular Pacing in Heart Failure Patients With Atrioventricular Block), which compared CRT and RV pacing in patients with an LVEF of ≤50% and atrioventricular block, showed a significant reduction in the combined primary endpoint of an increase in left ventricular end-systolic volume index by 15%, a heart failure urgent visit, or death. Although some patients had an LVEF ≤35%, most CRT-P subjects had an LVEF of >35% with a mean LVEF of 42.9% (approximately 60% of the total cohort). A mortality benefit was not shown, but there was a significant reduction in HF hospitalizations (HR: 0.68; 95% CI: 0.49–0.94). Subsequent studies have also shown a reduction of left ventricular end-systolic volume and an improvement in LVEF with CRT compared with RV pacing in patients with relatively preserved LVEF (S6.4.4.1-15, S6.4.4.1-19, S6.4.4.1-21, S6.4.4.1-36). In patients with AF who undergo atrioventricular node ablation to control rapid ventricular rates, physiologic pacing (CRT or His bundle) was associated with significant improvements in patient-centered outcomes such as 6-minute walk distances and QOL compared with RV pacing (S6.4.4.1-19). An analysis by the evidence review committee suggests that there may be some benefit associated with physiologic ventricular activation by CRT or His bundle pacing (S6.4.4.1-19).
5. Predictors of RV pacing cardiomyopathy include a lower baseline LVEF and a higher percentage of RV pacing (S6.4.4.1-34, S6.4.4.1-37). Some studies showed that the risk of RV pacing induced

cardiomyopathy increases when RV pacing exceeds 40% or perhaps as low as 20% (S6.4.4.1-6, S6.4.4.1-34, S6.4.4.1-37). The MOST study (Multicenter Osteoarthritis Study), an RCT looking at dual chamber pacing in SND patients, showed that RV pacing at least 40% of the time led to a 2.6-fold increase in HF hospitalizations (S6.4.4.1-6). Although not directly comparable because it enrolled patients with an LVEF <40%, an analysis of the DAVID trial also found the cutoff of 40% pacing as a predictor of increased HF adverse events (S6.4.4.1-38). Although there is unlikely a precise value for RV pacing burden where adverse remodeling occurs in all pacemaker patients, a cutoff of at least 40% RV pacing is where increases in left ventricular end-systolic volume index and decreases in LVEF have been demonstrated (S6.4.4.1-11, S6.4.4.1-13, S6.4.4.1-18, S6.4.4.1-39, S6.4.4.1-40). In patients with an LVEF of >50%, CRT has not been associated with increased exertional capacity or improved QOL compared with RV pacing (S6.4.4.1-15, S6.4.4.1-16, S6.4.4.1-20, S6.4.4.1-21, S6.4.4.1-36). Although the BLOCK-HF trial demonstrated benefit with CRT compared with RV pacing, the benefit was attributable to improved LV function with CRT rather than worsened LV function with RV paving and algorithms that minimize ventricular pacing were unavailable (S6.4.4.1-41).

6. His bundle pacing is another promising pacing option because it prevents or mitigates the ventricular dyssynchrony and mechanical adverse remodeling observed with RV pacing (S6.4.4.1-23). Two small crossover studies showed mixed results in terms of improvement in New York Heart Association class, 6MHW, and LVEF but overall seem to show a reduction in left ventricular end-systolic volume index and improvement in LVEF (S6.4.4.1-22, S6.4.4.1-25). One nonrandomized study did show a reduction in HF hospitalizations compared to RV pacing in the group pacing >40% (S6.4.4.1-24). A recent study found that His bundle pacing was associated with a significant decrease in heart failure hospitalizations particularly in those patients with ventricular pacing >20% compared with RV pacing (S6.4.4.1-42). Although a progressive increase in thresholds was identified in a small number of patients His bundle pacing has been shown to be feasible in patients after atrioventricular nodal ablation (S6.4.4.1-42, S6.4.4.1-43). More studies are needed to better characterize His bundle pacing and compare it to RV and CRT pacing in atrioventricular block patients.
7. In patients with permanent AF with no plans to attempt rhythm control, there is no need to pace the atrium and no benefit to sensing the atrial activity. Given that dual chamber systems have a higher peri-operative complication rate as well as a higher, long-term complication rate (S6.4.4.1-8, S6.4.4.1-26, S6.4.4.1-27), exposing the patient to the risk of an additional lead without any potential benefit does not make clinical sense. In a large Dutch pacemaker registry looking at pacemaker implants from 2003 to 2007, and complications within 2 months of implant, a HR of 3.09 for dual chamber pacemakers compared with single chamber was seen (S6.4.4.1-27). In contrast to new implants, if the patient already has an existing dual chamber system, and subsequently develops persistent AF, it may be reasonable to use another dual chamber device at the subsequent generator change as an alternative to capping the atrial lead to allow future attempts for rhythm control and because of the sparse data on the safety of MRI in the setting of abandoned leads (S6.4.4.1-44).

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7. Conduction Disorders (With 1:1 Atrioventricular Conduction)

This section focuses on QRS abnormalities caused by fascicular blocks and bundle branch blocks caused by delayed or blocked conduction within ≥1 of the branches of the His-Purkinje system, which consists of the division of the His bundle into left and right bundle branches, followed by division of the left bundle into anterior and posterior fascicles. The combination of delayed or blocked conduction of the right bundle branch and 1 of the left bundle's fascicles is denoted bifascicular block (which also includes LBBB). Although first-degree atrioventricular block is more accurately a conduction disorder rather than atrioventricular block, for historical reasons full discussion and recommendations on this condition are provided in the section on atrioventricular block.

7.1. Pathophysiology

The normal conduction axis consists of the sinus node, atrial muscle, atrioventricular node, His bundle, bundle branches, fascicles, Purkinje fibers, and ventricular muscle. The pathophysiology involved in conduction disease may be developmental, hereditary/genetic, metabolic, infectious, inflammatory, infiltrative, traumatic, ischemic, malignant, or degenerative. In general, it may be helpful to characterize the process as static or progressive.

7.2. Etiology/Classification

There are a number of possible etiologies for conduction disorders with 1:1 atrioventricular condition that the clinician should consider (Table S3 in Web Supplement).

7.3. Clinical Presentation

Isolated fascicular and bundle branch blocks are rarely associated with symptoms on their own although their presence may be a marker for underlying structural heart disease and cardiac dyssynchrony from LBBB may cause symptoms particularly in the setting of reduced left ventricular function. The presence or absence of symptoms potentially referable to intermittent bradycardia will usually guide evaluation of the patient with fascicular or bundle branch block.

7.4. Evaluation of Conduction Disorders

Recommendations for Evaluation of Conduction Disorders (With 1:1 Atrioventricular Conduction and Normal PR Interval) Referenced studies that support recommendations are summarized in Online Data Supplements 41 and 42.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients with newly detected LBBB, a transthoracic echocardiogram to exclude structural heart disease is recommended (S7.4-1–S7.4-3).**
I	**C-LD**	**2. In symptomatic patients with conduction system disease, in whom atrioventricular block is suspected, ambulatory electrocardiographic monitoring is useful (S7.4-4–S7.4-11).**
IIa	**B-NR**	**3. In selected patients presenting with intraventricular conduction disorders other than LBBB, transthoracic echocardiography is reasonable if structural heart disease is suspected (S7.4-3, S7.4-12, S7.4-13).**

IIa	**B-NR**	**4. In patients with symptoms suggestive of intermittent bradycardia (e.g., lightheadedness, syncope), with conduction system disease identified by ECG and no demonstrated atrioventricular block, an EPS is reasonable (S7.4-14).**
IIa	**C-LD**	**5. In selected patients with LBBB in whom structural heart disease is suspected and echocardiogram is unrevealing, advanced imaging (e.g., cardiac MRI, computed tomography, or nuclear studies) is reasonable (S7.4-15).**
IIb	**C-LD**	**6. In selected asymptomatic patients with extensive conduction system disease (bifascicular or trifascicular block), ambulatory electrocardiographic recording may be considered to document suspected higher degree of atrioventricular block (S7.4-4, S7.4-6).**
IIb	**C-LD**	**7. In selected asymptomatic patients with LBBB in whom ischemic heart disease is suspected, stress testing with imaging may be considered (S7.4-2).**

Synopsis

Ambulatory electrocardiographic monitoring can help establish a symptom-rhythm correlation or document previously unknown pathologic atrioventricular block. Cohort studies have generally demonstrated an association between LBBB, but not RBBB, presence and the development of coronary disease and heart failure (S7.4-1–S7.4-3, S7.4-16). Nonspecific intraventricular conduction delay was a marker for poorer prognosis in 1 study but in another study was not found to be an independent predictor of mortality in the absence of coronary artery disease (S7.4-17, S7.4-18). Thus, the threshold for further imaging or functional study is lower in patients with LBBB and echocardiogram, cardiac MR, and stress testing may be potentially useful. An EPS has a low specificity and sensitivity overall but may be helpful in selected patients with demonstrated conduction abnormalities in whom other testing has been unrevealing. A proposed algorithm for evaluating patients with conduction disorders is shown in Figure 8.

Recommendation-Specific Supportive Text

1. In patients in whom structural heart disease is suspected, an echocardiogram may uncover treatable disease, or impact management decisions such as cardiac resynchronization device placement. The presence of LBBB on ECG markedly increases the likelihood that left ventricular systolic dysfunction will be diagnosed by echocardiogram (S7.4-3).
2. Electrocardiography is the primary method of diagnosing potential conduction disorders. Recording duration may vary from a 10-second ECG through continuous ambulatory recordings of various (24-, 48-, 72-hour) durations to event monitors or implantable loop recorders, aiming to uncover a symptom-rhythm correlation for patients with fatigue, dizziness, or syncope suspected of having atrioventricular block or SND in addition to their manifest conduction system disease (S7.4-19). Such devices are also often capable of automated detection and storage of bradycardic or tachycardic events, although these detections are influenced by recording quality (artifacts). In addition to prescribed medical devices, direct-to-consumer devices are becoming increasingly available, particularly in association with personal electronics.
3. Patients with RBBB or intraventricular conduction delay on ECG also have increased risk of left ventricular systolic dysfunction compared with those with completely normal ECGs, yet the yield is lower than those patients with LBBB (S7.4-12). Echocardiography can identify various structural cardiac abnormalities underlying conduction disturbance, including cardiomyopathy, valvular heart

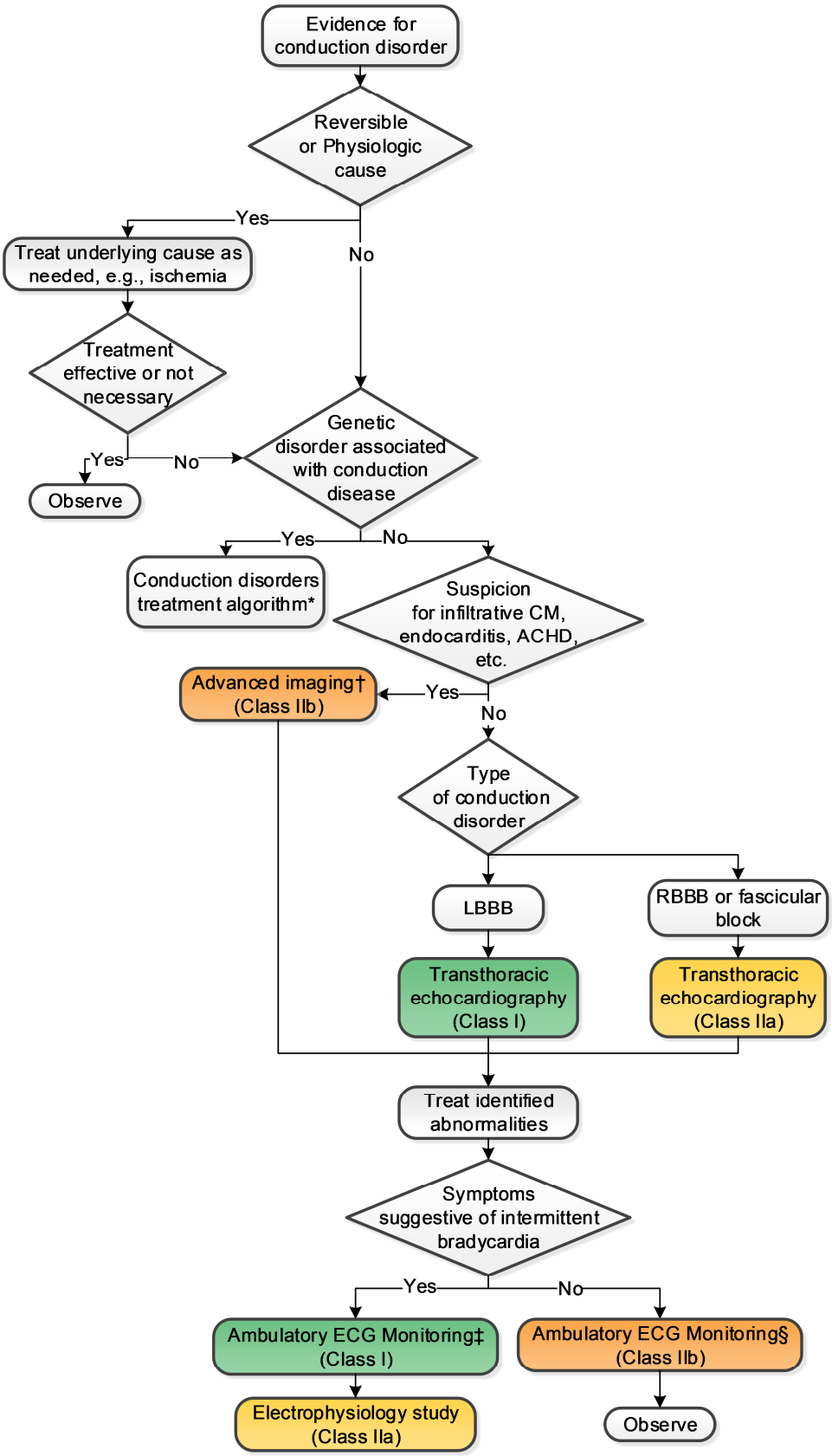
disease, congenital anomalies, tumors, infections, infiltrative processes, immunologically mediated conditions, and diseases of the great vessels and pericardium (S7.4-13).

4. An EPS may provide acute diagnostic information, avoiding the potential risks of delayed diagnosis with outpatient monitoring strategies, but has variable sensitivity depending on the presentation and does impart a small procedural risk. In patients with fascicular or bundle branch block, a prolonged HV interval at EPS predicts a higher risk for complete heart block (S7.4-14). In another study, first-degree atrioventricular block or bundle branch block were markers for abnormal EPS findings in patients with syncope (S7.4-20).
5. Cardiac MRI may be considered in selected patients with LBBB and normal left ventricular function by echocardiography where sarcoidosis, connective tissue disease, myocarditis, or other dilated cardiomyopathies are suspected on clinical grounds. In 1 study, cardiac MRI detected subclinical cardiomyopathy in one-third of patients with asymptomatic LBBB and a normal echocardiogram (S7.4-15). In another study of patients with connective tissue disease, new onset LBBB, and normal transthoracic echocardiograms, cardiac MRI identified significant abnormalities in 42% of patients (S7.4-21).
6. Ambulatory electrocardiographic monitoring can be used to document clinically significant arrhythmias in asymptomatic patients as well. Most current monitoring systems will automatically store clinically abnormal rhythms in addition to patient-triggered recordings. Selected patients with conduction system disease may benefit from such screening, even in the absence of significant symptoms such as syncope (S7.4-4, S7.4-6). However, progression of LBBB and bifascicular block to atrioventricular block and bradycardia is low, approximately 1% per year, with approximately half of the patients presenting with syncope and the other half with a constellation of symptoms including fatigue, chest pain, or dyspnea (S7.4-14). Most studies have reported that LBBB is associated with higher mortality than other forms of conduction disorders (S7.4-2, S7.4-22).
7. The threshold to consider stress testing is lower in patients with LBBB and concern for ischemia as well, given the higher probability of associated cardiac disease (S7.4-23–S7.4-27). If LBBB is present, ischemic electrocardiographic changes are more difficult to interpret, and an imaging component is necessary (S7.4-2). Rate related LBBB has also been reported as a possible cause of nonischemic chest pain (S7.4-28). Exercise induced LBBB, but not exercise induced RBBB, has been associated with increased risk of death and cardiac events (S7.4-29, S7.4-30).

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Figure 8. Evaluation of Conduction Disorders Algorithm

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Evidence for conduction disorder
Reversible or Physiologic cause
Yes
No
Treat underlying cause as needed, e.g., ischemia
Treatment effective or not necessary
Yes
No
Observe
Genetic disorder associated with conduction disease
Yes
No
Conduction disorders treatment algorithm*
Suspicion for infiltrative CM, endocarditis, ACHD, etc.
Advanced imaging† (Class IIb)
Yes
No
Type of conduction disorder
LBBB
RBBB or fascicular block
Transthoracic echocardiography (Class I)
Transthoracic echocardiography (Class IIa)
Treat identified abnormalities
Symptoms suggestive of intermittent bradycardia
Yes
No
Ambulatory ECG Monitoring‡ (Class I)
Ambulatory ECG Monitoring§ (Class IIb)
Electrophysiology study (Class IIa)
Observe

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Colors correspond to Class of Recommendation in Table 2.
See Section 7.4. for discussion.
*Refer to Section 7.5., Figure 9.
†Advanced imaging could include magnetic resonance imaging, computed tomography, or transesophageal echocardiography.
‡Monitor choice based on the frequency of symptoms.
§Extensive conduction disease (e.g., first-degree atrioventricular block combined with LBBB).
ACHD indicates adult congenital heart disease; CM, cardiomyopathy; ECG, electrocardiogram/electrocardiographic; LBBB, left bundle branch block; and RBBB, right bundle branch block.

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7.5. Management of Conduction Disorders (With 1:1 Atrioventricular Conduction)

Recommendations for Management of Conduction Disorders (With 1:1 Atrioventricular Conduction and Normal PR Intervals) Referenced studies that support recommendations are summarized in Online Data Supplements 41, 42, and 43.		
COR	**LOE**	**Recommendations**
I	**C-LD**	**1. In patients with syncope and bundle branch block who are found to have an HV interval 70 ms or greater or evidence of infranodal block at EPS, permanent pacing is recommended (S7.5-1, S7.5-2)**
I	**C-LD**	**2. In patients with alternating bundle branch block, permanent pacing is recommended (S7.5-3).**
IIa	**C-LD**	**3. In patients with Kearns-Sayre syndrome and conduction disorders, permanent pacing is reasonable, with additional defibrillator capability if appropriate and meaningful survival of greater than 1 year is expected (S7.5-4, S7.5-5).**
IIb	**C-LD**	**4. In patients with Anderson-Fabry disease and QRS prolongation greater than 110 ms, permanent pacing, with additional defibrillator capability if needed and meaningful survival of greater than 1 year is expected, may be considered (S7.5-6, S7.5-7).**
IIb	**C-LD**	**5. In patients with heart failure, a mildly to moderately reduced LVEF (36%-50%), and LBBB (QRS ≥150 ms), CRT may be considered (S7.5-8, S7.5-9).**
III: Harm	**B-NR**	**6. In asymptomatic patients with isolated conduction disease and 1:1 atrioventricular conduction, permanent pacing is not indicated (in the absence of other indications for pacing) (S7.5-10–S7.5-15).**

Synopsis

Management of conduction disorders with 1:1 atrioventricular conduction with a normal PR interval requires a patient-centered approach with assessment of any known underlying heart disease, symptomatology and the baseline ECG (bundle branch block, nonspecific intraventricular delay, fascicular block in isolation or in combination) (Figure 9). Pacing therapy can be considered in the presence or absence of symptoms if an underlying disorder associated with progressive disease is present such as Emery-Dreifuss muscular dystrophy or Kearns-Sayre syndrome. True alternating bundle branch block (QRS complexes with alternating LBBB and RBBB morphologies) is evidence for significant infranodal disease and a high likelihood for developing sudden onset of complete heart block with a slow or absent ventricular escape rate.

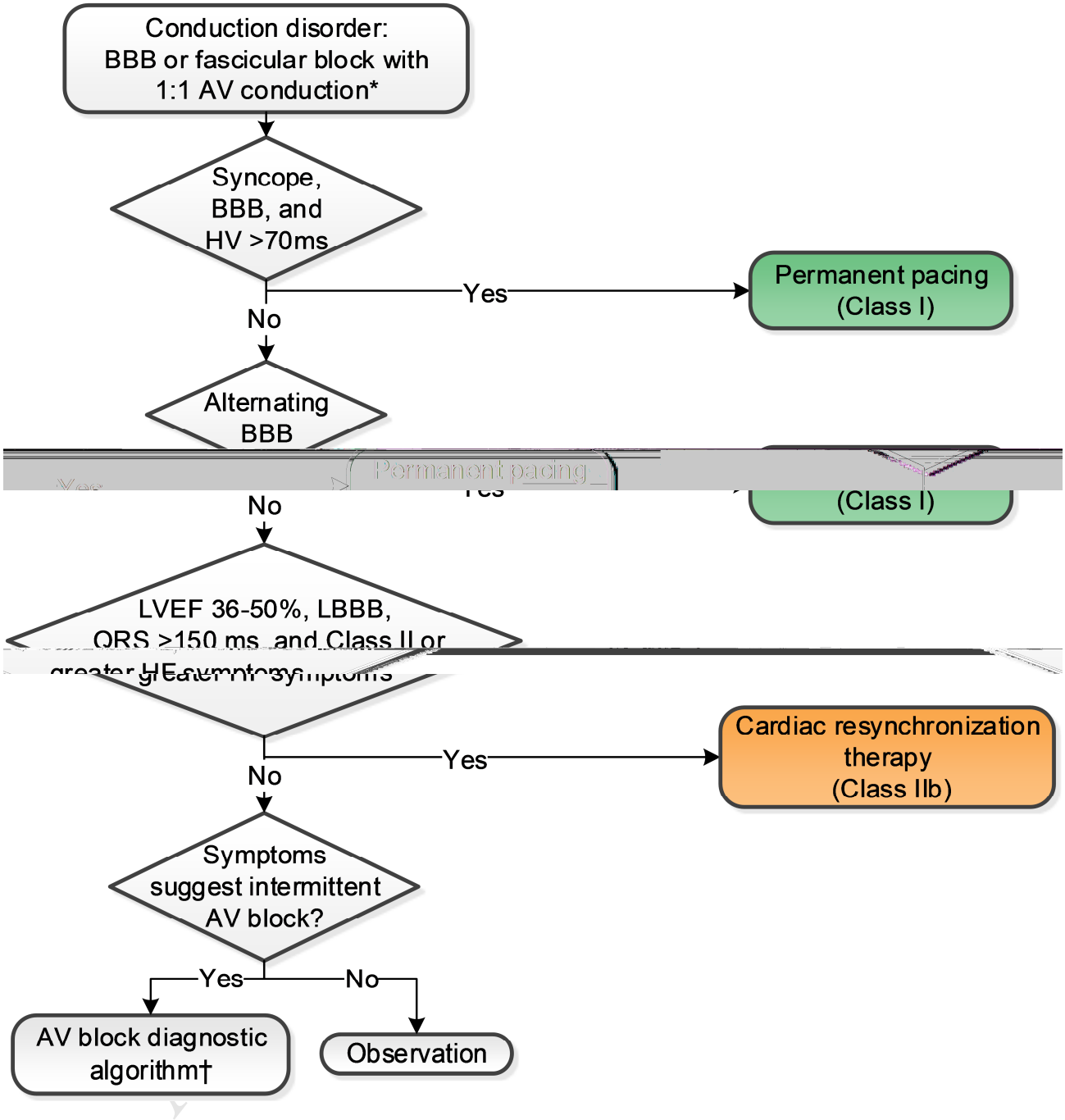
Recommendation-Specific Supportive Text

1. In a patient with syncope, the presence of bundle branch block on ECG is a predictor for abnormal conduction properties identified at EPS (S7.5-16). However, for patients with bundle branch block, the underlying cause for syncope may be related to vasodepressor mechanisms rather than heart block mediated bradycardia. An EPS can be used to evaluate atrioventricular conduction and identify the presence and extent of infranodal disease. Permanent pacing has been recommended for patients with syncope and HV intervals ≥70 ms or frank infranodal block (S7.5-17).

2. Alternating bundle branch block (QRS complexes with alternating LBBB and RBBB morphologies) implies unstable conduction disease in both conduction bundles, and patients with this electrocardiographic pattern should receive a pacemaker because of high risk of developing complete atrioventricular block (S7.5-3).
3. In Kearns-Sayre syndrome, a mitochondrial genetic disorder with progressive external ophthalmoplegia and myopathy, there is a high incidence of atrioventricular block and sudden cardiac death (S7.5-4, S7.5-5). In a series of 35 patients with Kearns Sayre syndrome, 66% had conduction delays, and 4 patients had sudden cardiac death (S7.5-4).
4. Anderson Fabry disease is an X-linked lysosomal storage disorder. In 1 cohort study of 189 patients 6.3% of patients had permanent pacing for bradycardia attributable to atrioventricular block or SND and an additional 2.6% of patients underwent ICD implantation (S7.5-6, S7.5-7). A QRS duration of >110 ms was an independent predictor for requiring pacing therapy (HR: 1.05; 95% CI: 1.02–1.09; p=0.001; c=0.726). Myocardial scarring and sudden death have been reported in patients with Anderson Fabry disease (S7.5-18, S7.5-19).
5. In 1 retrospective study of 1,436 patients with and LVEF of 36% to 50% and LBBB who were matched to a group of patients without conduction disease, LBBB was associated with significantly worse mortality (HR: 1.17; 95% CI: 1.00–1.36) and a decrease in LVEF to ≤35% (HR: 1.34; 95% CI: 1.09–1.63) (S7.5-8). PROSPECT (Predictors of Response to CRT Trial) enrolled patients with LVEF of ≤35%, QRS interval >130 ms and Class III/IV heart failure. In a post hoc analysis, patients with an LVEF of >35% (when assessed by the core laboratory) had similar clinical and echocardiographic responses to CRT compared with patients with an LVEF of ≤35% (S7.5-9). In the REVERSE (Resynchronization Reverses Remodeling in Systolic Left Ventricular Dysfunction) trial, patients could be enrolled if they had New York Heart Association class I/II heart failure symptoms and an LVEF of <40% (although mean LVEF was 27%). Patients with QRS prolongation and LBBB morphology were markers for a clinical benefit with CRT (S7.5-20).
6. Several studies from the 1970s demonstrated no benefit from prophylactic pacing in asymptomatic patients with conduction disorders (combined RBBB and left anterior fascicular block, or bundle branch block) even in the presence of infranodal disease S7.5-10, S7.5-11). Although PPM implant is a relatively low-risk cardiac procedure, complications including death range from 3% to 7% and there are significant long-term implications for pacing systems that use transvenous leads (S7.5-12–S7.5-15).

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Figure 9. Management of Conduction Disorders Algorithm



Colors correspond to Class of Recommendation in Table 2.
*For severe first-degree atrioventricular block or first-degree atrioventricular block with an accompanying neuromuscular disease, also refer to Section 6.4., Figure 7, the atrioventricular block algorithm.
†See Section 4.3.2., Figure 3.
AV indicates atrioventricular; BBB, bundle branch block; HF, heart failure; LBBB, left bundle branch block; and LVEF, left ventricular ejection fraction.

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8. Special Populations

8.1. Perioperative Management

Management of bradycardia after cardiac surgery is primarily based on historical surgical practice. Typically, all patients receive temporary epicardial pacing wires at the time of cardiac surgery. These are suture-sized wires placed on the atrial and/or ventricular epicardium with the proximal end brought out through the skin. The temporary wires are used if necessary for rate support or for maintaining atrioventricular synchrony and later removed by pulling them out from their exit at the skin. Bleeding from the removal of temporary wires can occasionally be the cause of cardiac tamponade, late surgical exploration, and even death (S8.1-1). The need for temporary pacing after cardiac surgery is highly variable (between 0.8% and 24%) and primarily depends on the type of cardiac surgery, as well as a number of risk factors such as: older age, AF, prior surgery, preoperative renal failure, and active endocarditis (S8.1-2–S8.1-4).

8.1.1. Patients at Risk for Bradycardia During Noncardiac Surgery or Procedures

Recommendations for Patients at Risk for Bradycardia During Noncardiac Surgery or Procedures Referenced studies that support recommendations are summarized in Online Data Supplements 42, 44, and 45.		
COR	**LOE**	**Recommendations**
IIa	**B-NR**	**1. In patients who are thought to be at high risk for the development of intraoperative or periprocedural bradycardia because of patient characteristics or procedure type, placement of transcutaneous pacing pads is reasonable (S8.1.1-1–S8.1.1-3).**
III: Harm	**B-NR**	**2. In patients with LBBB who require pulmonary artery catheterization for intraoperative monitoring, routine prophylactic temporary transvenous pacing should not be performed (S8.1.1-4, S8.1.1-5).**

Synopsis

The development of significant bradycardia during surgery can be attributable to both patient-related and procedure related factors. Several retrospective studies have identified age (>60-65 years of age), comorbidities (American Society of Anesthesia Class III or IV), lower heart rates (<60 bpm) or blood pressure (<110/60 mm Hg) at baseline, and use of concomitant drugs such as beta blockers or drugs that block the renin angiotensin system as risk factors for the development of intraoperative bradycardia and hypotension in patients undergoing non-cardiac surgery (S8.1.1-6–S8.1.1-8). Because the right bundle branch is located near the endocardial surface of the RV, transient RBBB can occur during placement of pulmonary artery catheters for use during intraoperative monitoring (S8.1.1-1, S8.1.1-4, S8.1.1-5).

A number of case reports and small series have identified several non-cardiac procedures that are more likely to be associated with bradycardia. In particular, procedures that could potentially activate the trigeminal cardiac reflex or vagus nerve, for example, maxillofacial surgeries or carotid endarterectomy or stenting, or other neurosurgical procedures that involve manipulation of the spine or dura mater have been reported to cause bradycardia (S8.1.1-3, S8.1.1-9–S8.1.1-12). Others have identified peritoneal insufflation as a possible critical period during abdominal surgery associated with significant bradycardia (S8.1.1-13, S8.1.1-14).

Recommendation-Specific Supportive Text

1. Older patients with comorbidities (American Society of Anesthesia Class III or IV) and low heart rates at baseline are at higher risk for the development of intraoperative bradycardia (S8.1.1-6–S8.1.1-8). In the setting of non-cardiac surgery, intraoperative bradycardia is most commonly attributable to SND and only rarely attributable to worsening atrioventricular conduction (S8.1.1-1, S8.1.1-8, S8.1.1-15). Certain surgical procedures such as carotid artery endarterectomy or stenting have been associated with periods of bradycardia (S8.1.1-3, S8.1.1-9–S8.1.1-12). Additionally, critical periods during surgery such as abdominal insufflation during laparoscopic surgeries or manipulation of regions innervated by the trigeminal nerve have been reported to be associated with bradycardia (S8.1.1-13, S8.1.1-14). In a study of 30 patients undergoing carotid angioplasty and stenting who underwent prophylactic transcutaneous pacing because of a high risk for angioplasty-related bradycardia, temporary transcutaneous pacing was used in 23 patients and was effective for eliminating bradycardia in all patients (S8.1.1-2). However, routine placement of transcutaneous pacing pads in patients solely for the presence of conduction disorders does not provide additional benefit (S8.1.1-15).
2. Although complete heart block can occur in the setting of pulmonary artery catheter placement in a patient with underlying LBBB, the incidence is low (S8.1.1-4, S8.1.1-5). Several studies have reported increased risk of ventricular arrhythmias with temporary pacing (S8.1.1-16, S8.1.1-17). Prophylactic transvenous pacing is not recommended, but the clinician should consider the likelihood of complete heart block if a pulmonary artery catheter is required for intraoperative monitoring and be prepared to manage this complication with rapid initiation of transvenous pacing or immediate transcutaneous pacing if sustained rate support is required.

8.1.2. Postoperative Bradycardia and Conduction Disorders After Cardiac Surgery

The risks of bradycardia after cardiac surgery are largely related to the type of cardiac surgery and the anatomical relationship to the conduction system. Because of this, this section has been subdivided by specific cardiac surgeries and conditions: coronary artery bypass, open valve surgery, including aortic, tricuspid and mitral valves, transcatheter aortic valve placement; congenital heart surgery; heart transplant, surgical myectomy, alcohol septal ablation, and postsurgical sequelae of medical AF treatment. Recovery of atrioventricular conduction after surgery occurs in approximately 12% to 13% of patients within 6 months and depends on the surgery, preoperative conduction abnormalities, presence of endocarditis, and whether transient postoperative atrioventricular conduction is observed (S8.1.2-1, S8.1.2-2) (Online Data Supplement 46).

8.1.2.1. Coronary Artery Bypass

Recommendations for Pacing After Isolated Coronary Artery Bypass Surgery Referenced studies that support recommendations are summarized in Online Data Supplement 47.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients who have new postoperative SND or atrioventricular block associated with persistent symptoms or hemodynamic instability that does not resolve after isolated coronary artery bypass surgery, permanent pacing is recommended before discharge (S8.1.2.1-1–S8.1.2.1-9).**

IIa	**B-NR**	**2. In patients undergoing isolated coronary artery bypass surgery, routine placement of temporary epicardial pacing wires is reasonable (S8.1.2.1-5, S8.1.2.1-10, S8.1.2.1-11).**
IIb	**C-EO**	**3. In patients undergoing coronary artery bypass surgery who will likely require future CRT or ventricular pacing, intraoperative placement of a permanent epicardial left ventricular lead may be considered.**

Synopsis

The incidence of conduction defects after isolated coronary artery bypass graft has ranged from 2% to 58% and has been related to factors such as chronic degenerative disease of the heart, direct surgical damage to the conduction system, myocardial ischemia or inadequate myocardial protection. Advances in surgical practice may be decreasing the incidence of conduction defects but has been unable to eliminate it in any series (S8.1.2.1-1–S8.1.2.1-4, S8.1.2.1-6–S8.1.2.1-9, S8.1.2.1-12).

Recommendation-Specific Supportive Text

1. The frequency with which patients develop conduction abnormalities needing permanent pacing after isolated coronary artery bypass surgery has varied and may be decreasing over time (S8.1.2.1-1–S8.1.2.1-7, S8.1.2.1-9, S8.1.2.1-12). If conduction abnormalities resulting in symptomatic bradycardia are already present preoperatively, they will generally not resolve with coronary artery bypass grafting (S8.1.2.1-8). In part to help facilitate postoperative recovery (e.g., moving out of the intensive care setting, ambulation and the initiation of anticoagulation when necessary), patients in whom new onset SND or advanced primary atrioventricular block develops and does not improve should undergo permanent pacer placement after isolated coronary artery bypass surgery. Specific timing of pacemaker implant has not been formally studied and will always depend on the individual clinical situation but 5 to 7 days after surgery is reasonable (S8.1.2.1-1).
2. The routine placement of temporary epicardial pacing wires at the time of isolated coronary artery bypass has been standard surgical practice. There is a very small risk of significant bleeding leading to morbidity and even mortality after their removal, but this risk is offset by the frequent and unpredictable need for the use of temporary pacing (S8.1.2.1-5, S8.1.2.1-10, S8.1.2.1-11). Some patients are at very low risk for needing temporary pacing after isolated coronary artery bypass. In 1 retrospective analysis, patients without diabetes mellitus, preoperative arrhythmia, or the requirement for pacing while coming off cardiopulmonary bypass had only a 2.6% need for postsurgical temporary pacing compared with 8.6% of patients in the entire cohort (S8.1.2.1-10). Patients undergoing off-pump coronary artery bypass grafting may also warrant special consideration for a strategy that does not use temporary pacing wires (S8.1.2.1-13). However, no large study has clearly identified a benefit to this approach. Temporary cardiac resynchronization using right atrial, right ventricular, and left ventricular pacing wires has been proposed for improving cardiac hemodynamic parameters in the immediate postoperative period in patients with severe left ventricular dysfunction with mixed results though may provide benefits in patients with accompanying LBBB (S8.1.2.1-14–S8.1.2.1-16).
3. Surgical left ventricular lead placement is performed as a stand-alone procedure when placement via coronary sinus is unsuccessful (S8.1.2.1-17). If a patient has an indication for cardiac resynchronization before cardiac surgery, epicardial placement of a nonapical, lateral left ventricular lead at the time of cardiac surgery may offer future benefit without significant risk of harm. Although traditionally considered a contraindication, it may be that MRI can be performed safely in selected patients with abandoned leads under the auspices of specialized protocols (S8.1.2.1-18–

S8.1.2.1-20). At the time of a future CRT procedure, the operator can implant a coronary sinus lead or use the capped epicardial lead if necessary.

8.1.2.2. Surgery for Atrial Fibrillation

Recommendations for Pacing After Surgery for Atrial Fibrillation Referenced studies that support recommendations are summarized in Online Data Supplement 48.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients undergoing surgery for AF, routine placement of temporary epicardial pacing wires is recommended (S8.1.2.2-1–S8.1.2.2-4).**
I	**B-NR**	**2. In patients who have new postoperative SND or atrioventricular block associated with symptoms or hemodynamic instability that does not resolve after surgery for AF, permanent pacing is recommended before discharge (S8.1.2.2-1–S8.1.2.2-4).**
IIb	**C-EO**	**3. In patients undergoing surgery for AF who will likely require future CRT or ventricular pacing, intraoperative placement of a permanent epicardial left ventricular lead may be considered.**

Synopsis

AF is present in 30% to 50% of patients undergoing valve surgery and is associated with reduced survival and increased risk of stroke (S8.1.2.2-2). Successful surgical correction of AF is associated with improved patient survival compared with patients who have recurrent AF (S8.1.2.2-5). Up to 65% of patients undergoing mitral surgery with AF undergo surgery directed toward management of AF (S8.1.2.2-6). A recent single center study found reported that 11% of patients undergoing a Cox Maze IV procedure in addition to mitral valve surgery required postoperative PPM implantation (S8.1.2.2-4).

The data on whether surgery for AF is associated with an increased risk for postoperative bradycardia and PPM implant are mixed, in part caused by the significant evolution in the lesion set and surgical technique (S8.1.2.2-1–S8.1.2.2-4). An analysis of the STS registry and an RCT found that adding ablation for AF was associated with an increased likelihood of PPM implantation (S8.1.2.2-1, S8.1.2.2-2). However, a meta-analysis of 16 RCTs found no difference in need for permanent pacer in patients randomized to additional surgery for AF (OR: 0.88; 95% CI: 0.51–1.51; p=0.64) (S8.1.2.2-3).

Recommendation-Specific Supportive Text

1. Placement of temporary epicardial pacing wires at the time of surgery for AF is routine practice. The risk of postsurgical bradycardia is relatively frequent, and no study has advocated a selective approach to temporary pacing wire placement (S8.1.2.2-1–S8.1.2.2-4).
2. The need for PPM placement is common after surgery for AF usually for SND because atrioventricular block is uncommon (S8.1.2.2-1–S8.1.2.2-4). In part to facilitate recovery after surgery (e.g., moving out of the intensive care setting, ambulation and the initiation of anticoagulation), patients in whom new onset SND (and in rare cases atrioventricular block) develops and does not improve should undergo permanent pacer placement before discharge. Specific timing of pacemaker implant has not been formally studied and will always depend on the individual clinical situation but 5 to 7 days after surgery is probably reasonable.
3. Surgical left ventricular lead placement is performed as a stand-alone procedure when placement via coronary sinus is unsuccessful (S8.1.2.2-7). If a patient has an indication for cardiac resynchronization before cardiac surgery, an epicardial placement of a left ventricular lead at the

time of surgery for AF may offer future benefit without significant risk of harm. In addition, placement of a nonapical, lateral epicardial lead will allow more pacing options if the patient undergoes a future atrioventricular nodal ablation. Although traditionally considered a contraindication, it may be that MRI can be performed safely in selected patients with abandoned leads under the auspices of specialized protocols (S8.1.2.2-8–S8.1.2.2-10). At the time of a future CRT procedure the operator can implant a coronary sinus lead or use the capped epicardial lead if necessary.

8.1.2.3. Valvular Surgery

There are many types of valve surgeries. In adult cardiac surgery, the most commonly affected valves are the aortic, the mitral and the tricuspid. The pulmonary valve is rarely a target of intervention and when it is, does not usually disturb cardiac conduction. Approximately 5% of the roughly 100,000 patients annually undergoing valve surgery in North America have required pacemaker implantation before hospital discharge (S8.1.2.3-1). Several papers have identified a myriad of risk factors associated with PPM implant after valve surgery and include: preoperative RBBB, multivalve surgery particularly those that included the tricuspid valve, preoperative LBBB, preoperative PR interval >200 ms, prior valve surgery, age >70 years, reoperations, longer cumulative cross-clamp times, and absence of preoperative sinus rhythm (S8.1.2.3-2, S8.1.2.3-3). The rates of PPM implant after valve surgery vary widely and depend on the operation. Pacemaker implantation rates for single and multiple valves were as follows: mitral alone 3.5%, aortic alone 5.1%, tricuspid alone 12%, aortic plus mitral 10%, mitral plus tricuspid 16%, and combined aortic, mitral, and tricuspid 25% (S8.1.2.3-2, S8.1.2.3-4).

8.1.2.3.1. Surgical Aortic Valve Replacement or Repair

Recommendations for Pacing After Aortic Valve Surgery Referenced studies that support recommendations are summarized in Online Data Supplement 48.		
COR	**LOE**	**Recommendations**
I	**C-LD**	**1. In patients undergoing surgical aortic valve replacement or repair, routine placement of temporary epicardial pacing wires is recommended (S8.1.2.3.1-1–S8.1.2.3.1-3).**
I	**B-NR**	**2. In patients who have new postoperative SND or atrioventricular block associated with persistent symptoms or hemodynamic instability that does not resolve after aortic valve replacement, permanent pacing is recommended before discharge (S8.1.2.3.1-1–S8.1.2.3.1-5).**
IIb	**C-EO**	**3. In patients undergoing aortic valve surgery who will likely require future CRT or ventricular pacing, intraoperative placement of a permanent epicardial left ventricular lead may be considered.**

Synopsis

The most common injury to the conduction system after surgical aortic valve replacement is injury to the common bundle from edema, removal of calcium, or deeply placed sutures.

The requirement for pacemaker after aortic valve replacement is common, ranging between 3% and 8.5%: the highest risk is likely in patients with preoperative conduction disturbance (S8.1.2.3.1-1–S8.1.2.3.1-3). Available data suggest that most patients do not recover atrioventricular conduction

(S8.1.2.3.1-4, S8.1.2.3.1-6). One study found that patients who received a pacemaker within 30 days after aortic valve replacement had a higher, long-term risk of death (S8.1.2.3.1-5).

Recommendation-Specific Supportive Text

1. Placement of temporary epicardial pacing wires at the time of aortic valve surgery is routine practice. The risk of postsurgical bradycardia is high, and no study has advocated a selective approach to temporary pacing wire placement (S8.1.2.3.1-1–S8.1.2.3.1-3). Temporary cardiac resynchronization using right atrial, right ventricular, and left ventricular pacing wires has been proposed for improving cardiac hemodynamic parameters in the immediate postoperative period in patients with severe left ventricular dysfunction with mixed results though may provide benefits in patients with accompanying LBBB (S8.1.2.3.1-4–S8.1.2.3.1-9).
2. The need for PPM placement is frequent after aortic valve replacement (S8.1.2.3.1-1–S8.1.2.3.1-3). Because the aortic valve is anatomically located near the bundle of His, while the mitral valve is close to the atrioventricular node, atrioventricular block after aortic valve surgery has a lower threshold for recommending pacing compared with the mitral valve, and conduction is less likely to resume (S8.1.2.3.1-4, S8.1.2.3.1-6). This suggests that patients who have new atrioventricular block which does not resolve or SND should undergo PPM implantation before discharge for persistent symptomatic or hemodynamically significant bradycardia. Specific timing of pacemaker implant has not been formally studied and will always depend on the individual clinical situation but 3 to 5 days after surgery is probably reasonable.
3. Surgical left ventricular lead placement is performed as a stand-alone procedure when placement via coronary sinus is unsuccessful (S8.1.2.3.1-10). If a patient has an indication for cardiac resynchronization before cardiac surgery, an epicardial placement of a nonapical, lateral left ventricular lead at the time of cardiac surgery may offer future benefit without significant risk of harm. Although traditionally considered a contraindication, it may be that MRI can be performed safely in selected patients with abandoned leads under the auspices of specialized protocols (S8.1.2.3.1-11–S8.1.2.3.1-13). At the time of a future CRT procedure, the operator can implant a coronary sinus lead or use the capped epicardial lead if necessary.

8.1.2.3.2. Mitral Valve Surgery

Recommendations for Pacing After Mitral Valve Surgery Referenced studies that support recommendations are summarized in Online Data Supplement 48.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients who have new postoperative SND or atrioventricular block associated with persistent symptoms or hemodynamic instability that does not resolve after mitral valve repair or replacement surgery, permanent pacing is recommended before discharge (S8.1.2.3.2-1, S8.1.2.3.2-2).**
IIa	**C-LD**	**2. In patients undergoing mitral valve surgery, routine placement of temporary epicardial pacing wires is reasonable (S8.1.2.3.2-1–S8.1.2.3.2-3).**
IIb	**C-EO**	**3. In patients undergoing surgical mitral valve repair or replacement who will likely require future CRT or ventricular pacing, intraoperative placement of a permanent epicardial left ventricular lead may be considered.**

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Synopsis

Incidence of new atrioventricular block has been reported in as high as 23.5% of patients undergoing mitral valve replacement or ring repair (S8.1.2.3.2-1). In 1 pathologic study, 55 hearts from patients who had not undergone surgery were examined to evaluate the relationship between the atrioventricular node, atrioventricular nodal artery and mitral annulus (S8.1.2.3.2-1). In the dissected hearts, 23% had an atrioventricular nodal artery that ran close to the mitral valve, suggesting that damage to the artery may play a role in the development of atrioventricular block after mitral valve surgery. The need for a PPM after mitral surgery h ranges from 1% to 9% (S8.1.2.3.2-1, S8.1.2.3.2-2, S8.1.2.3.2-4). The cause may be influenced by type surgery and may be lower in the repair population in whom an incomplete annuloplasty band could avoid injury to the atrioventricular nodal artery (S8.1.2.3.2-2, S8.1.2.3.2-4) .

Recommendation-Specific Supportive Text

1. The need for PPM placement is common after mitral valve surgery (S8.1.2.3.2-1, S8.1.2.3.2-2, S8.1.2.3.2-5). In part to facilitate postsurgical recovery (such as moving out of the intensive care setting, ambulation and the initiation of anticoagulation), patients in whom new onset atrioventricular block or SND develops and does not improve should undergo permanent pacer placement before discharge for persistent symptomatic or hemodynamically significant bradycardia. Because mitral valve surgery involves injury of the atrioventricular node region rather than the His bundle injury associated with aortic valve surgery, the threshold for pacemaker implant is higher. Specific timing of pacemaker implant has not been formally studied and will always depend on the individual clinical situation but 5 to 7 days after mitral valve surgery is probably reasonable.
2. Placement of temporary epicardial pacing wires at the time of mitral valve surgery is routine practice. The risk of postsurgical bradycardia is relatively frequent, and no study has advocated a selective approach to temporary pacing wire placement (S8.1.2.3.2-1, S8.1.2.3.2-2). However, alternative pacing strategies using pacing pulmonary artery catheters have been described for patients undergoing minimally invasive mitral valve surgery (S8.1.2.3.2-3). Temporary cardiac resynchronization using right atrial, right ventricular, and left ventricular pacing wires has been proposed for improving cardiac hemodynamic parameters in the immediate postoperative period in patients with severe left ventricular dysfunction with mixed results though may provide benefits in patients with accompanying LBBB (S8.1.2.3.2-6–S8.1.2.3.2-8).
3. Surgical left ventricular lead placement is performed as a stand-alone procedure when placement via coronary sinus is unsuccessful (S8.1.2.3.2-9). If a patient has an indication for cardiac resynchronization before cardiac surgery, an epicardial placement of a nonapical, lateral left ventricular lead at the time of cardiac surgery may offer future benefit without significant risk of harm. Although traditionally considered a contraindication, it may be that MRI can be performed safely in selected patients with abandoned leads under the auspices of specialized protocols (S8.1.2.3.2-10–S8.1.2.3.2-12). At the time of a future CRT procedure, the operator can implant a coronary sinus lead or use the capped epicardial lead if necessary.

8.1.2.3.3. Tricuspid Valve Surgery

Recommendations for Pacing After Tricuspid Valve Surgery Referenced studies that support recommendations are summarized in Online Data Supplement 48.		
COR	**LOE**	**Recommendations**
I	**C-LD**	**1. In patients undergoing tricuspid valve surgery, routine placement of temporary epicardial pacing wires is recommended (S8.1.2.3.3-1–S8.1.2.3.3-4).**
I	**B-NR**	**2. In patients who have new postoperative SND or atrioventricular block associated with symptoms or hemodynamic instability that does not resolve after tricuspid valve surgery, permanent pacing is recommended before discharge (S8.1.2.3.3-1–S8.1.2.3.3-4).**
IIa	**C-LD**	**3. In patients who are undergoing tricuspid valve replacement or tricuspid repair with high risk for postoperative atrioventricular block, intraoperative placement of permanent epicardial leads at the time of cardiac surgery is reasonable (S8.1.2.3.3-1–S8.1.2.3.3-5).**

Synopsis

The atrioventricular node is intimately related to the tricuspid valve, located between its anterior and septal leaflets; this makes the atrioventricular node particularly susceptible to injury with any tricuspid valve intervention. Surgeons have developed numerous repair techniques to avoid nodal injury, including the design of several incomplete tricuspid rings that have gaps between the anterior and septal leaflets. These techniques avoid suture placement in the area of the atrioventricular node, and thus its injury. The need for pacemaker after repair has been reported to be as low as 2.3% (S8.1.2.3.3-1). However, because isolated tricuspid surgery is rare in the adult population, the exact incidence of conduction disorders attributable to isolated tricuspid intervention is difficult to ascertain. Several series report a much higher incidence, up to 22% (S8.1.2.3.3-2, S8.1.2.3.3-4). Managing conduction abnormalities in this population are additionally complicated by an inability to use transvenous pacing leads in mechanical valves and their interference in the closure of bioprosthetic valves or native valves that have been repaired. Even in native valves, nearly one-quarter of patients suffer significant tricuspid regurgitation associated with placement of an endovascular right ventricular lead (S8.1.2.3.3-5). In patients who need a pacemaker after repair, incidence of moderate to severe or severe tricuspid regurgitation is 42% (S8.1.2.3.3-3).

Recommendation-Specific Supportive Text

1. Placement of temporary epicardial pacing wires at the time of tricuspid valve surgery is routine practice. The risk of postsurgical bradycardia is relatively frequent, and no study has advocated a selective approach to temporary pacing wire placement (S8.1.2.3.3-1–S8.1.2.3.3-4).
2. The need for PPM placement is frequent after tricuspid valve surgery (S8.1.2.3.3-1–S8.1.2.3.3-4). In part to facilitate postsurgical recovery (such as moving out of the intensive care setting, ambulation and the initiation of anticoagulation), patients in whom new onset advanced primary atrioventricular block or SND develops and does not improve should undergo permanent pacer placement after open tricuspid valve surgery. Specific timing of pacemaker implant has not been formally studied and will always depend on the individual clinical situation but 3 to 5 days after surgery is probably reasonable. To minimize valve impingement in the setting of a repaired tricuspid valve, a transvalvular endocardial ventricular lead is ideally placed at the commissure between the anterior and septal tricuspid leaflets.

3. The need for PPM placement is frequent after tricuspid valve surgery (S8.1.2.3.3-1–S8.1.2.3.3-4). After repair or replacement, transvalvular endocardial ventricular lead placement can be successfully placed after tricuspid valve repair or bioprosthetic valve replacement but may cause severe tricuspid regurgitation (S8.1.2.3.3-3, S8.1.2.3.3-5, S8.1.2.3.3-6). Transvalvular, endocardial ventricular leads cannot be placed across mechanical valves in the tricuspid position. Patients who are undergoing tricuspid valve replacement or tricuspid repair with high risk for postoperative atrioventricular block should be strongly considered for permanent epicardial pacing leads at the time of cardiac surgery (S8.1.2.3.3-7). Because epicardial leads can fail and subsequent placement of a right ventricular endocardial lead may be problematic in patients after tricuspid valve replacement, at the time of initial tricuspid valve surgery, if possible, intraoperative implantation of several leads (nonapical, lateral left ventricular, right ventricular, and atrial leads) should be considered. Although traditionally considered a contraindication, it may be that MRI can be performed safely in selected patients with abandoned leads under the auspices of specialized protocols (S8.1.2.3.3-8–S8.1.2.3.3-10). If a PPM is required in the future, the operator can implant a coronary sinus lead or use the capped epicardial lead if necessary.

8.1.2.4. Transcatheter Aortic Valve Replacement

Recommendations for Conduction Disturbances After Transcatheter Aortic Valve Replacement Referenced studies that support recommendations are summarized in Online Data Supplement 49.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients who have new atrioventricular block after transcatheter aortic valve replacement associated with symptoms or hemodynamic instability that does not resolve, permanent pacing is recommended before discharge (S8.1.2.4-1–S8.1.2.4-4).**
IIa	**B-NR**	**2. In patients with new persistent bundle branch block after transcatheter aortic valve replacement, careful surveillance for bradycardia is reasonable (S8.1.2.4-5, S8.1.2.4-6).**
IIb	**B-NR**	**3. In patients with new persistent LBBB after transcatheter aortic valve replacement, implantation of a PPM may be considered (S8.1.2.4-4, S8.1.2.4-7–S8.1.2.4-10).**

Synopsis

At time of writing, the literature on conduction disturbance after transcatheter aortic valve replacement (TAVR) is replete with thousands of case series, multiple reports from larger registries, a few meta-analyses, and no prospective RCTs of PPM implantation. Before TAVR predictors for PPM implant include preexisting RBBB, increased prosthesis to left ventricular outflow tract ratio, and increased left ventricular end-diastolic diameter (S8.1.2.4-8).

After TAVR, new LBBB occurs in 19% to 55% of patients (S8.1.2.4-1, S8.1.2.4-3, S8.1.2.4-11) and new high-degree atrioventricular block in approximately 10% of patients (S8.1.2.4-12). Up to half of new bundle branch block (S8.1.2.4-1) and complete heart block (S8.1.2.4-7) can be expected to resolve before discharge. Further, only half of patients with a new PPM after TAVR will be pacer dependent at follow-up although that does not necessarily imply that pacing is not needed, as intermittent atrioventricular block may be present (S8.1.2.4-13). The likelihood of new conduction disturbances depends on patient and procedural factors (S8.1.2.4-7, S8.1.2.4-8).

After TAVR, new RBBB is associated with increased risk of PPM implantation and increased late all-cause mortality and cardiac mortality independent on whether a new PPM was implanted (S8.1.2.4-5, S8.1.2.4-8, S8.1.2.4-14, S8.1.2.4-15). Although most studies show that new LBBB after TAVR (S8.1.2.4-4, S8.1.2.4-9, S8.1.2.4-10) is associated with a higher risk of new PPM, studies are mixed as to whether new LBBB is a predictor of late mortality. What is clear is that early PPM for new LBBB is not protective against the increased mortality (S8.1.2.4-4, S8.1.2.4-16, S8.1.2.4-17). Although it may be considered, at the time of this writing, it is unclear whether patients with new bundle branch block that persists when the patient is ready for discharge, will benefit from pacer implantation during the index hospitalization (S8.1.2.4-4, S8.1.2.4-7–S8.1.2.4-10).

Recommendation-Specific Supportive Text

1. High-degree atrioventricular block is most commonly observed in the immediate periprocedural period but will persist beyond 48 hours in 2% to 20% of patients (S8.1.2.4-1, S8.1.2.4-7, S8.1.2.4-8). In older studies, rates of PPM implant after TAVR ranged from 2% 51%, but with rapidly evolving technology and newer implant strategies, there has been a general decrease in the requirements for pacemaker implantation after TAVR (S8.1.2.4-2–S8.1.2.4-4, S8.1.2.4-7). In 1 study, at follow-up, 52% of patients were continuously paced, but 22% of patients had recovery of atrioventricular conduction and no longer required pacing for rate support (S8.1.2.4-3). Specific timing of pacemaker implant has not been formally studied and will always depend on the individual clinical situation. In published reports, the range for pacemaker implantation after TAVR has varied from 2 days to several weeks with a median of approximately 3 days (S8.1.2.4-2–S8.1.2.4-4, S8.1.2.4-7).
2. Patients with new bundle branch block after TAVR may be at risk for syncope and development of atrioventricular block. In 29% of patients with new LBBB the first episode of high-degree atrioventricular block occurs after discharge with associated potential risk for syncope (S8.1.2.4-6). Careful surveillance for bradycardia is appropriate. Although different monitoring modalities, durations and intervals are available, to date no specific method or protocol has been proven to be superior. Further investigation in this area is needed. Institutions should choose the monitoring modality and protocol according to availability and expertise at the individual institution.
3. New LBBB occurs in approximately 10% of patients after TAVR and will resolve in approximately 50% at 6 to 12 months (S8.1.2.4-8). Patients with new persistent LBBB after TAVR are at increased risk for needing a PPM both perioperatively and after discharge (S8.1.2.4-4, S8.1.2.4-10). Studies have been inconsistent on the implications of new LBBB after TAVR with some studies showing lower survival and others reporting no increased risk of death or repeat hospitalization (S8.1.2.4-4, S8.1.2.4-18). Preprocedural conduction abnormalities, particularly RBBB are associated with increased risk of PPM after TAVR (S8.1.2.4-19, S8.1.2.4-20). In 1 study an HV interval ≥65 ms after TAVR was modestly predictive for the development of high-grade atrioventricular block in the setting of new left bundle branch block after TAVR (sensitivity, 80%; specificity, 79%) (S8.1.2.4-21).

8.1.2.5. Heart Transplant, Surgical Myectomy, and Alcohol Septal Ablation

8.1.2.5.1. After Heart Transplant

With the adoption of bicaval heart transplant anastomoses rather than biatrial anastomoses the pacemaker rate has decreased from 10% to 14% to 2% to 4% (S8.1.2.5.1-1–S8.1.2.5.1-4). SND remains the most common cause for bradycardia accounting for approximately 80% of cases (S8.1.2.5.1-1–S8.1.2.5.1-4). A pathology study has identified individual patients in whom the conduction system was affected preferentially during allograft rejection, but a relationship between bradycardia and allograft rejection has not been found more generally in analyses of large databases (S8.1.2.5.1-1–S8.1.2.5.1-5). Guidelines for the use of permanent pacing are the same for those that apply generally for SND and

atrioventricular block, and in particular careful evaluation for the presence of symptomatic SND (Data Supplement 50).

8.1.2.5.2. Surgical Myectomy and Alcohol Septal Ablation for Hypertrophic Cardiomyopathy

Recommendations for Patients Undergoing Surgical Myectomy or Alcohol Septal Ablation for Hypertrophic Cardiomyopathy Referenced studies that support recommendations are summarized in Online Data Supplements 51 and 52.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients with second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or persistent complete atrioventricular block after alcohol septal ablation or surgical myectomy, permanent pacing is recommended before discharge (S8.1.2.5.2-1–S8.1.2.5.2-4).**
IIa	**B-NR**	**2. In selected patients with hypertrophic cardiomyopathy who require permanent pacing for rate support after alcohol septal ablation or surgical myectomy and are at high risk for sudden cardiac death and meaningful survival of greater than 1 year is expected, selecting a device with defibrillator capabilities is reasonable (S8.1.2.5.2-5–S8.1.2.5.2-7).**
IIb	**C-LD**	**3. In patients with hypertrophic cardiomyopathy who undergo alcohol septal ablation and who are at risk for developing late atrioventricular block, prolonged ambulatory electrocardiographic monitoring may be considered (S8.1.2.5.2-1, S8.1.2.5.2-2, S8.1.2.5.2-4, S8.1.2.5.2-7, S8.1.2.5.2-8).**
IIb	**C-LD**	**4. In patients with hypertrophic cardiomyopathy, evaluation of ventriculoatrial conduction by EPS at the time of alcohol septal ablation may be considered for identifying future risk of atrioventricular block (S8.1.2.5.2-9).**

Synopsis

In patients with hypertrophic cardiomyopathy and symptoms attributable to left ventricular outflow tract obstruction, surgical myectomy or alcohol septal ablation may be used to reduce septal thickness and improve symptoms (S8.1.2.5.2-10). Risk of abnormal atrioventricular conduction varies widely among observational studies with estimates of 10% to 33% for alcohol septal ablation and 3% to 4% for surgical myectomy (S8.1.2.5.2-10–S8.1.2.5.2-15). The wide reported range is in part attributable to differences in baseline conduction properties. For example, in patients undergoing surgical myectomy requirement for permanent pacing was 2% but increased to 10% if baseline conduction abnormalities were present (S8.1.2.5.2-13). A meta-analysis of observational studies suggests that the risk of abnormal atrioventricular conduction requiring permanent pacing is higher with alcohol septal ablation relative to myectomy (10% versus 4.4%) (S8.1.2.5.2-11). However, a recent analysis of the National Inpatient Sample Database found similar 9% to 14% requirements for PPM for both alcohol septal ablation and surgical myectomy (S8.1.2.5.2-16). Development of RBBB is observed in approximately 60% of patients after alcohol septal ablation and up to 90% of patients develop LBBB after surgical myectomy (S8.1.2.5.2-13, S8.1.2.5.2-15).

Recommendation-Specific Supportive Text

1. Transient atrioventricular block after alcohol septal ablation is observed in approximately 15% to 50% of patients and usually resolves within 24 hours (S8.1.2.5.2-1–S8.1.2.5.2-4, S8.1.2.5.2-11–S8.1.2.5.2-15). The development of intraprocedural atrioventricular block is more likely in patients with preexisting LBBB, older patients, women, and the use of larger doses of ethanol (S8.1.2.5.2-17). Protocols for implantation of a PPM varied from study to study, but most implanted a PPM if complete atrioventricular block was present >24 hours after alcohol septal ablation although actual time of implant varied with a range of 2 to 7 days. In some studies, patients with persistent complete atrioventricular block >24 hours commonly required permanent pacing for rate support at 2 weeks while, in other studies, recovery of atrioventricular conduction was observed in most patients (S8.1.2.5.2-2–S8.1.2.5.2-4, S8.1.2.5.2-13). PPMs are implanted in 2% to 10% of patients after septal myectomy usually for persistent complete heart block (S8.1.2.5.2-15, S8.1.2.5.2-18).
2. Selected patients with hypertrophic cardiomyopathy are at risk for sudden cardiac death. The 2011 ACCF/AHA guidelines for the diagnosis and treatment of hypertrophic cardiomyopathy and the 2017 AHA/ACC/HRS ventricular arrhythmias and sudden cardiac death guidelines have identified several risk factors for sudden cardiac death including prior history of ventricular arrhythmias, a family history of sudden cardiac death, unexplained syncope, and a maximal left ventricular wall thickness ≥30 mm (S8.1.2.5.2-5–S8.1.2.5.2-7, S8.1.2.5.2-10, S8.1.2.5.2-19). Surgical myectomy has been associated with decreased risk of sudden death in 1 large cohort (S8.1.2.5.2-20).
3. Late heart block with initial identification >48 hours has been observed in some but not all studies after alcohol septal ablation. Potential risk factors for persistent atrioventricular block have not been consistent from study to study and have included preprocedure first-degree atrioventricular block (S8.1.2.5.2-1) or LBBB (S8.1.2.5.2-2), transient atrioventricular block and new RBBB after the procedure (S8.1.2.5.2-4). In 1 study, the first manifestation of atrioventricular block occurred between 2 days and 3 years in 9% of patients after alcohol septal ablation (S8.1.2.5.2-21). In another study, outpatient rhythm monitoring with implantable loop recorders was initiated after alcohol septal ablation (S8.1.2.5.2-8). Although there were episodes of ventricular fibrillation associated with complete heart block in the immediate periprocedural period, no episodes of heart block were identified after discharge (S8.1.2.5.2-8). Late development of atrioventricular block after surgical myectomy has not been reported with limited follow-up (S8.1.2.5.2-7, S8.1.2.5.2-15).
4. In 1 study of 172 patients who underwent simultaneous alcohol septal ablation and EPS, those patients with intact retrograde ventriculoatrial conduction did not develop late complete heart block regardless of changes in anterograde atrioventricular conduction properties associated with the alcohol septal ablation (S8.1.2.5.2-9).

8.1.2.6. Managing Episodes of Bradycardia Associated With Postoperative AF

AF occurs commonly after cardiac surgery in adults, with a peak incidence 2 to 4 days postoperatively and an overall incidence ranging from 10% to 65% (S8.1.2.6-1). Postoperative AF occurs more frequently in patients undergoing valve surgery than in those undergoing isolated coronary artery bypass graft (S8.1.2.6-2). Bradycardia may take several forms in these patients, including slow ventricular response during AF and prolonged sinus pauses after sinus rhythm is restored. A slow and regular ventricular response during AF usually indicates complete heart block, and pacing may be required if resolution does not occur (S8.1.2.6-3). The assessment of bradyarrhythmias in this setting is often complicated by the coexistence of atrial tachyarrhythmia; transient and time-dependent postoperative effects on sinus and atrioventricular node function, and the potential presence of antiarrhythmic drugs (S8.1.2.6-4). In general, bradyarrhythmias in the setting of postoperative AF should be treated similarly to those occurring in the nonoperative setting, and a period of watchful waiting rather than early PPM implantation is generally used. In occasional patients with refractory AF with rapid ventricular responses

associated with significant SND limiting rate control drugs, a PPM may be required for adequate AF management.

8.2. Bradycardia Management for Adult Congenital Heart Disease

Recommendations for Management of Bradycardia in Adults With Adult Congenital Heart Disease Referenced studies that support recommendations are summarized in Online Data Supplement 53.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In adults with adult congenital heart disease (ACHD) and symptomatic SND or chronotropic incompetence, atrial based permanent pacing is recommended (S8.2-1–S8.2-6).**
I	**B-NR**	**2. In adults with ACHD and symptomatic bradycardia related to atrioventricular block, permanent pacing is recommended (S8.2-7–S8.2-9).**
I	**B-NR**	**3. In adults with congenital complete atrioventricular block with any symptomatic bradycardia, a wide QRS escape rhythm, mean daytime heart rate below 50 bpm, complex ventricular ectopy, or ventricular dysfunction, permanent pacing is recommended (S8.2-10, S8.2-11).**
I	**B-NR**	**4. In adults with ACHD and postoperative second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, or third-degree atrioventricular block that is not expected to resolve, permanent pacing is recommended (S8.2-12, S8.2-13).**
IIa	**B-NR**	**5. In asymptomatic adults with congenital complete atrioventricular block,**

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these patients should be referred to dedicated centers with multimodality experience in managing this type of patient.

Recommendation-Specific Supportive Text

1. Permanent pacing can alleviate symptoms from SND in adults with ACHD. In adults with ACHD, SND is associated with higher mortality and a higher rate of atrial flutter although there is no randomized trial evaluating whether permanent pacing prevent these sequelae (S8.2-1–S8.2-6). Given the younger median age of presentation of sinus node disease in this group of patients, they remain at higher risk for multiple transvenous leads over their lifetime. Single-lead atrial-based pacing is an established strategy for this type of patient and pathophysiology and is recommended for patients with isolated sinus nodal disease and preserved atrioventricular conduction. Single lead atrial-based pacing aims to limit the number of leads and potentially preserve vascular patency (S8.2-19–S8.2-23).
2. Atrioventricular block at any level is associated with a higher mortality in the ACHD patient, yet no randomized studies exist to compare treatment strategies for the asymptomatic patient. The degree of atrioventricular block from first-degree to complete atrioventricular block is relevant as far as reliability of an escape rhythm or unexpected syncope is concerned, yet patients may develop symptoms, regardless of the level block. As an example, patients with significant prolongation of atrioventricular conduction (without block) can develop atrioventricular dyssynchrony to such a degree that pacemaker syndrome can develop. Certain congenital anomalies (e.g., ccTGA and the endocardial cushion defects) are inherently associated with a more fragile atrioventricular conduction system, and more rigorous scrutiny of these patient groups is necessary (S8.2-7–S8.2-9).
3. Certain clinical features have been identified as high-risk markers for adverse outcomes including death in patients with congenital complete heart block (S8.2-10, S8.2-11, S8.2-24). These reflect a deterioration or unreliability of the escape rate; and an increased propensity to develop bradycardia-related ventricular arrhythmias including torsades de pointes (S8.2-10, S8.2-11, S8.2-24).
4. The incidence and natural history of postoperative heart block in adults with ACHD varies by underlying anatomy, surgery performed, and genetic effects (S8.2-25). The optimal duration the clinician should wait before permanent pacing is not well defined given the multiple mechanisms at play including direct traumatic injury, ischemia, infarction, autonomic tone, stunned myocardium and differences in reperfusion that all influence recovery of conduction. Recent investigations suggest that waiting 7 to 9 days is likely unnecessary, but the clinician is urged to carefully consider and generally avoid early implantation <72 hours, so as to avoid unnecessary implantation of pacemakers (S8.2-12, S8.2-13). One study has shown that patients are at high risk for permanent heart block if conduction has not resumed within 72 hours postoperatively (S8.2-13).
5. Patients with congenital complete heart block have a high incidence of late sudden death at any age, and although the supporting literature is somewhat conflicting, there is sufficient concern for unpredictability of disease progression that the clinician can consider permanent pacing in the asymptomatic individual (S8.2-7–S8.2-11).
6. The reentrant nature of the most common atrial arrhythmias in adults with ACHD will potentially allow for effective and reliable pace termination. This is distinctly different from managing the most common atrial arrhythmia in normal hearts and those with acquired disease, where AF predominates and cannot be consistently pace-terminated (S8.2-14, S8.2-15).
7. Long-term longitudinal observational studies have consistently demonstrated that endocardial leads retain better longevity and are less likely to fail. This is likely related to epicardial fibrosis in patients who have undergone prior pericardiotomy (S8.2-26, S8.2-27). However, given the low-risk in placing epicardial leads at the time of cardiac surgery, it is recommended that this opportunity be used for

lead placement—before the development of more epicardial fibrosis/adhesions in this patient group who are likely to undergo repeat operation and are at significant risk of sinus and atrioventricular node disease. In patients with single-ventricle anatomy who have undergone orthoterminal correction by some version of a Fontan procedure, there is likely not to be transcutaneous access for atrial pacing, because the atria have been excluded from the systemic venous pathway. These patients will require epicardial atrial electrodes to atrial pacing, and in general, will need both atrial and ventricular permanent epicardial leads. Although traditionally considered a contraindication, it may be that MRI can be performed safely in selected patients with abandoned leads using specialized protocols (S8.2-28–S8.2-30).

8. Atrial arrhythmias are observed in approximately 40% to 45% of patients with congenital heart disease. Large randomized trials such as CTOPP and MOST have shown a decrease in atrial arrhythmias with atrial based pacing in the general population compared with ventricular based pacing modes (S8.2-31, S8.2-32). However, a recent nonrandomized study from a large registry of patients with congenital heart disease found no beneficial effect with atrial based pacing for preventing atrial arrhythmias (S8.2-33).
9. Lead thrombus and/or vegetations can develop on endocardial pacing leads and have also been identified despite full anticoagulation (S8.2-34). Systemic thromboembolism can therefore occur from these sources by crossing from the venous system and subpulmonic chambers into the systemic circulation. Shunts can exist in various forms such as atrial or ventricular septal defects, or baffle leaks, and can result in distal embolism and brain and peripheral infarction. Nonconventional approaches for pacing therapy should be individualized, and multiple strategies can be considered. In patients in whom epicardial lead placement is not feasible or high risk; open or percutaneous shunt/leak closure may be considered; and rarely, the utilization of higher levels of anticoagulation to prevent lead thrombus (S8.2-17, S8.2-18).

8.3. Management of Bradycardia in Patients With an Acute MI

Recommendations for Management of Bradycardia in the Context of Acute MI Referenced studies that support recommendations are summarized in Online Data Supplement 54.		
COR	**LOE**	**Recommendations**
I	**B-NR**	**1. In patients presenting with an acute MI, temporary pacing is indicated for medically refractory symptomatic or hemodynamically significant bradycardia related to SND or atrioventricular block (S8.3-1–S8.3-4).**
I	**B-NR**	**2. Patients who present with SND or atrioventricular block in the setting of an acute MI should undergo a waiting period before determining the need for permanent pacing (S8.3-1, S8.3-4–S8.3-7).**
I	**B-NR**	**3. In patients presenting with an acute MI with second-degree Mobitz type II atrioventricular block, high-grade atrioventricular block, alternating bundle-branch block, or third-degree atrioventricular block (persistent or infranodal), permanent pacing is indicated after a waiting period (S8.3-7, S8.3-8).**
IIa	**B-NR**	**4. In patients with an acute MI with symptomatic or hemodynamically significant sinus bradycardia or atrioventricular block at the level of the atrioventricular node, the administration of atropine is reasonable (S8.3-9–S8.3-11).**

III: Harm	**B-NR**	**5. In patients with an acute MI and transient atrioventricular block that resolves, permanent pacing should not be performed (S8.3-1, S8.3-4, S8.3-7, S8.3-12–S8.3-16).**
III: Harm	**B-NR**	**6. In patients with an acute MI and a new bundle-branch block or isolated fascicular block in the absence of second-degree or third-degree atrioventricular block, permanent pacing should not be performed (S8.3-17–S8.3-19).**

Synopsis

Although transient SND may occur in the context of an acute MI, nonreversible injury to the atrioventricular conduction system accounts for most pacing indications. The transient nature of the effects conduction issues in this setting must be considered. For example, SND and atrioventricular block in the setting of an inferior wall MI may be attributable to a transient increase in vagal tone or decreased blood supply to the atrioventricular node or less commonly the sinus node. Temporary pacing does not by itself constitute an indication for permanent pacing. The long-term prognosis for survivors of MI who have had atrioventricular block is related primarily to the extent of myocardial injury and the character of intraventricular conduction disturbances rather than the atrioventricular block itself (S8.3-20, S8.3-21). A major caveat in guiding current therapy is that there have been no RCTs comparing pacing approaches in atrioventricular block complicating an MI. Regardless of whether the infarction is anterior or inferior, the development of an intraventricular conduction delay reflects extensive myocardial damage rather than an electrical problem in isolation (S8.3-22).

Recommendation-Specific Supportive Text

1. All types of conduction disturbances can occur in the context of an acute MI, and these are influenced by multiple mechanisms (often concomitant) including ischemia, extent and location of MI, reperfusion and autonomic effects affecting electrical conduction or the sinus or atrioventricular node (S8.3-1–S8.3-4). Hemodynamic compromise secondary to significant bradycardia can have deleterious effects on organ perfusion, which can complicate recovery and negatively impact survival (through renal, hepatic or cerebral ischemia). Given the difficulty in assessing reliable myocardial capture with transcutaneous pacing, this method should only be used if other temporary methods are delayed or not available.
2. Given that regions of myocardium may not be irreversibly infarcted, and adequate reperfusion will improve electrical conduction, temporary atrioventricular block is common. The outcome is therefore determined primarily by the clinical presentation, location of infarct, and associated myocardial damage (S8.3-6, S8.3-7, S8.3-9–S8.3-11, S8.3-23). Anterior MI with associated atrioventricular conduction impairment generally confers a worse prognosis with a higher mortality than an inferior MI with a similar initial presentation (S8.3-1, S8.3-4, S8.3-6, S8.3-12, S8.3-24). Indications, therefore, for PPM implantation in the setting of an acute MI are based on the clinical situation, and adequate observation to allow for recovery of atrioventricular conduction, and to avoid unnecessary pacemaker implantation. Again, the clinician should carefully consider and generally avoid early permanent pacing (<72 hours), so as to potentially avoid unnecessary implantation of pacemakers (S8.3-10, S8.3-23). It may be reasonable to consider CIED with defibrillator capacity in patients with pacing requirement and low LVEF as indicated in other scientific society statements S8.3-25, S8.3-26).
3. Persistent evidence of infranodal conduction impairment is associated with more severe myocardial injury, and a worse prognosis. In the context of infranodal conduction block maintenance of ventricular systole depends on the presence of less reliable ventricular escape rhythms. It may be

reasonable to consider CIED with defibrillator capacity in patients with pacing requirement and low LVEF as indicated in other scientific society statements (S8.3-25, S8.3-26).

4. Autonomic derangements during an acute MI are common, and small case series suggest that atropine can be used to increase heart rate (S8.3-27). Atropine appears to be safe in those patients with atrioventricular nodal block in the absence of infranodal conduction system disease (S8.3-9, S8.3-28, S8.3-29). In contrast, it is important to recognize that the use of atropine in patients with infranodal conduction disease or block can be associated with exacerbation of block and is potentially of harm. Aminophylline/theophylline has also been examined in this setting, and in the context of very limited data appears likely to be safe if atropine is ineffective (S8.3-10, S8.3-11, S8.3-30, S8.3-31).
5. Given that the natural course of a MI with conduction system abnormalities is frequently associated with recovery of conduction – early and unnecessary pacing should be avoided (S8.3-1, S8.3-4, S8.3-7, S8.3-12). Although PPM implantation is a relatively low risk cardiac procedure, complications including death range from 3% to 7% and there are significant long-term implications for pacing systems that use transvenous leads (S8.3-13–S8.3-16).
6. Although injury to the fascicular system in the context of an acute MI indicates substantial myocardial injury (commonly through an anterior infarction), patients with injury to single bundle branches or fascicles have not been shown to benefit from permanent pacing (S8.3-1, S8.3-4, S8.3-6, S8.3-12, S8.3-24).

8.4. Neurologic Disorders

A number of neurologic disorders can be associated with bradycardia, for example increased intracranial pressure (often called Cushing's reflex) (S8.4-1). In these settings, bradycardia can be treated as described in the acute management sections (Sections 5.4. and 6.3.) if heart rate support is required. During chronic management of neurologic disorders, bradycardia can be observed in several settings. General recommendations for the management of cardiac involvement in patients with neuromuscular disorders including recommendations on surveillance and medical management have been provided in a recent AHA scientific statement (S8.4-2). Specific recommendations for permanent pacing in the setting of progressive neurologic disorders that affect atrioventricular and intraventricular conduction has been discussed in Sections 6.4.4. and 7.5. in this document and special considerations for permanent pacing in patients with neuromuscular disease is summarized in Table S4 in the Web Supplement. Traumatic spinal cord injury above the sixth thoracic spinal cord can result in autonomic dysreflexia characterized by sympathetic impairment and preserved parasympathetic responses via the vagus nerve. Profound bradycardia can be triggered by noxious stimuli such as bladder catheterization (S8.4-3). In a prospective multicenter study of 315 patients with spinal cord injury, bradycardia accounted for approximately 50% of the observed cardiovascular complications (S8.4-4). Because bradycardia resolves after either a few weeks or removal of the noxious stimulus, conservative therapy is generally successful for managing the bradycardia. However, in some cases where symptomatic bradycardia cannot be avoided by conservative measures permanent pacing can be considered using the standard recommendations for implantation outlined in sections 5.5.4 and 6.4.4.

8.4.1. Epilepsy

Recommendation for Patients With Epilepsy and Symptomatic Bradycardia Referenced studies that support the recommendation are summarized in Online Data Supplement 55.		
COR	**LOE**	**Recommendation**
IIa	**C-LD**	**1. In patients with epilepsy associated with severe symptomatic bradycardia (ictal bradycardia) where antiepileptic medications are ineffective, permanent pacing is reasonable for reducing the severity of symptoms (S8.4.1-1–S8.4.1-4).**

Synopsis

In approximately 0.15% to 0.3% of patients with seizures, profound bradycardia can be observed and is often referred to as ictal asystole (S8.4.1-1–S8.4.1-3). Bradycardia can be attributable to either sinus node arrest or complete heart block and is most commonly associated with temporal lobe source of seizures (S8.4.1-1–S8.4.1-4). Rate support in patients with profound bradycardia during seizures could theoretically attenuate the severity of associated syncope.

Recommendation-Specific Supportive Text

1. Permanent pacing has been evaluated in small numbers of patients with significant bradycardia associated with seizures identified from large databases (S8.4.1-1–S8.4.1-3). Although bradycardia is most commonly defined as a pause >3 seconds and a 2-fold increase in the preceding R-R interval, in practice the pauses have been much longer, commonly with durations >10 seconds, and 1 study found that syncope only occurred with asystole >6 seconds. In these studies with limited follow-up pacing appears to be beneficial for reducing syncope symptoms associated with seizures (S8.4.1-1–S8.4.1-4). Effective treatment of seizures with antiepileptic medications or surgery also appears to reduce the likelihood of bradycardia-induced syncope and should be considered before implanting a PPM (S8.4.1-4, S8.4.1-5). Rate support with a PPM will not affect any accompanying vasodepressor effect associated with the seizure.

9. Evaluation of the Risks for Ventricular Arrhythmias in Patients Who Require Permanent Pacing

Recommendation for Management of Bradycardia and Conduction Tissue Disease in Patients Who Require Pacing Therapy and May Also Be at Risk for Ventricular Arrhythmias Referenced studies that support the recommendation are summarized in Online Data Supplement 56.		
COR	**LOE**	**Recommendation**
I	**B-NR**	**1. In patients who require permanent pacing therapy, before implantation, an assessment of the risk of future ventricular arrhythmias and need for an ICD should be performed (S9-1–S9-7).**

Synopsis

Some patients who require or may benefit from pacing therapy may also be at risk for ventricular arrhythmias and should be considered for a device that provides treatment for bradycardia and/or

conduction tissue disease and also ICD therapies (S9-8, S9-9). For example, patients with symptomatic bradycardia caused by atrioventricular block who also have heart failure symptoms and an LVEF of ≤35%, myotonic dystrophy, lamin A/C cardiomyopathy, cardiac sarcoidosis, or hypertrophic cardiomyopathy are at increased risk of ventricular arrhythmias and sudden cardiac death and might benefit from a device that has antitachycardia pacing or defibrillation capabilities (S9-1, S9-5–S9-9). Although an ICD is designed for treatment of sustained ventricular arrhythmias, ICDs are associated with increased risk of complications compared with PPMs and in some cases the prognosis is dominated by nonarrhythmia-related sequelae of the underlying disease (S9-2–S9-4, S9-6).

Recommendation-Specific Supportive Text

1. Some patients who require or may benefit from pacing therapy may also be at risk for ventricular arrhythmias and an ICD should be considered (S9-1–S9-7). Before implantation of a cardiac device for treatment of symptoms associated with bradycardia or conduction tissue disease, a separate evaluation for potential risk of sudden cardiac death attributable to ventricular arrhythmias should be performed. Final device choice should be made after comprehensive discussion of the relative benefits and risks and an individualized choice based on shared decision-making principles (S9-9).

10. Cost and Value Considerations

Pacemaker costs can be challenging to characterize, because of variability in both charges, reimbursement, and device type (single versus dual chamber, presence of ICD or CRT capabilities); the Center for Medicare & Medicaid Services reports by state that charges vary from $20,753 to $78,140, and reimbursement varies from $11,411 to $19,577 in the United States, and systems with >1 lead are more expensive than simpler single-chamber systems (S10-1). Calculation of the incremental cost-effectiveness of dual chamber pacing systems over single-chamber systems varies both by the specific estimates of benefit in terms of cost and the quality-adjusted life years gained (S10-2–S10-6). In the United States, based on data from the MOST trial, the short-term incremental cost-effectiveness ratio (difference in cost between 2 therapies divided by the difference in their effect or incremental cost-effectiveness ratio for a dual chamber pacemaker over a single-chamber device was $53,000, but considered over a lifetime, the incremental cost-effectiveness ratio was $6,800 per quality-adjusted life year (S10-6). In large part driven by data from the DANPACE (The Danish Multicenter Randomised Study on AAI Versus DDD Pacing in Sick Sinus Syndrome) trial (S10-7), dual chamber devices in another study were found to be more cost effective than single-chamber devices across a range of “willingness to pay” thresholds and in most scenarios, especially in elderly patients with greater burden of comorbidity (S10-8), primarily because of a >20% risk of reoperation for pacemaker syndrome among patients with single-chamber devices.

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11. Shared Decision-Making

Recommendations for Shared Decision-Making for Pacemaker Implantation in the Setting of Guideline-Based Indications for Bradycardia Pacing		
COR	**LOE**	**Recommendations**
I	**C-LD**	**1. In patients with symptomatic bradycardia or conduction disorder, clinicians and patients should engage in a shared decision-making approach in which treatment decisions are based not only on the best available evidence, but also on the patient's goals of care, preferences, and values (S11-1–S11-6).**
I	**C-LD**	**2. Patients considering implantation of a pacemaker or with a pacemaker that requires lead revision or generator change should be informed of procedural benefits and risks, including the potential short and long-term complications and possible alternative therapy, if any, in light of their goals of care, preferences, and values (S11-1–S11-6).**
III: No Benefit	**C-LD**	**3. In patients with indications for permanent pacing but also with significant comorbidities such that pacing therapy is unlikely to provide meaningful clinical benefit, or if patient goals of care strongly preclude pacemaker therapy, implantation or replacement of a pacemaker should not be performed (S11-1–S11-6).**

Synopsis

The decision to implant a pacemaker should be shared between the patient and clinicians, using the principles of shared decision-making, and based on the clinical indications, consideration of individualized risks and benefits based on comorbidities and overall prognosis, and the patient's preferences and goals of care. The potential consequences and potential future lead management issues (if applicable) should be discussed with the patient and family along with potential considerations at end of life (S11-7, S11-8).

Recommendation-Specific Supportive Text

1. Consideration of patient preferences is essential for management decisions. Patient preferences for and acceptance of procedural and long-term risks and benefits of invasive therapies vary and may evolve throughout the course of their illness. The bradycardia guideline writing committee endorses shared decision-making as part of the general care for patients with symptomatic bradycardia. A commonly accepted definition of shared decision-making (S11-9) includes 4 components: 1) at least 2 participants, the clinician and patient; 2) both participants share information with each other; 3) both parties build a consensus about the preferred treatment; and 4) an agreement is reached on the treatment to implement. Sharing a decision does not mean giving a patient a list of risks and benefits and telling them to make a decision—a practice some authors have called "abandonment" (S11-10). If time permits the patient should be directed to trusted material which supports and itemizes appropriate considerations which should be factored into their decision-making. Notably, a recommendation based on evidence or guidelines alone is not shared decision-making. Rather, a recommendation based both on the evidence as well as an understanding of the patients' health goals, preferences and values is essential to achieving true shared decision-making.
2. Pacemaker implantation or revision are commonly performed heart procedures and are not typically associated with high procedural risk in most patients. Nevertheless, because pacemaker implantation or revision is frequently performed in elderly patients with multiple comorbidities,

frailty, and competing risks of mortality, adverse events such as pneumothorax and cardiac tamponade can complicate the procedure. A thorough discussion should take place with the patient before the procedure outlining the potential individualized, patient-specific benefits and risks, including the implications of living with an implantable electrophysiology device that includes a discussion of a patient's health goals, preferences, and values. For some patients, pacemaker therapy may affect usability.

3. Patients with significant comorbid conditions may not derive the intended benefit of pacing support or an improved QOL. Similarly, in patients who are expected to have a shortened life span because of a terminal progressive illness (including advanced dementia, metastatic cancer with anticipated death in the immediate future, or similar situations with poor prognosis), the benefits of pacing support may not be realized and are unlikely to positively impact the overall outcome. Although the risks of pacemaker implantation are relatively low, the benefit-risk ratio is not favorable if the probable benefit is also quite low (S11-11). These pros and cons can be discussed with the patient, with patient permission a discussion of the process and patient decision needs to be facilitated with the family, or the patient's family or surrogate if the patient does not have capacity.

12. Quality of Life

Among patients with indications for PPM implantation for either shared decision-making or atrioventricular block, QOL improves substantially after pacemaker implantation (S12-1–S12-5), but the benefits of different pacing modes (such as dual chamber pacing versus single chamber pacing) are inconsistent. In the CTOPP trial, for example, there was no significant difference in improvement in QOL between patients with dual chamber and single chamber pacing (S12-4). In the PASE trial, however, although there were no overall benefits of dual chamber over single chamber pacing in terms of QOL, dual chamber pacing did appear to result in better QOL in the subgroup with shared decision-making (S12-3). In the MOST trial, in addition to the benefits of less AF and heart failure, dual chamber pacing was associated with modest improvements in some QOL indices, especially among younger patients (S12-1, S12-2). In small crossover studies, improvements in measures of QOL were found with dual chamber pacing in some (S12-6–S12-9), but not all studies (S12-10). In the nonrandomized FOLLOWPACE observational study, over a mean follow-up of 7.5 years, pacing was associated with long-term improvement in QOL, but there were no apparent differences based on mode of pacing (S12-5).

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13. Discontinuation of Pacemaker Therapy

Recommendation for Discontinuation of Pacemaker Therapy		
COR	**LOE**	**Recommendation**
IIa	**C-LD**	**1. In patients who present for pacemaker pulse generator replacement, or for management of pacemaker related complications, in whom the original pacing indication has resolved or is in question, discontinuation of pacemaker therapy is reasonable after evaluation of symptoms during a period of monitoring while pacing therapy is off (S13-1, S13-2).**

Synopsis

Prior recommendations have been provided for implantation of PPMs (S13-3). Yet, the decision to not replace a pacemaker is more difficult. No guidelines previously existed for the removal of PPMs and the termination of long-term cardiac pacing.

In general, most patients with pacemakers at end of battery life or with lead or device malfunction undergo replacement or revision without questioning the need for continued pacing. However, physicians occasionally encounter patients referred for pacemaker surgery or with pacemaker related complications that do not appear to have a persistent need for pacing because the original indication is unclear, questionable, or appears to have resolved (S13-4, S13-5). Furthermore, several studies have estimated that approximately 30% of pacemakers have been implanted for other than Class I and IIa indications (S13-4, S13-6). In this group of patients, in whom the continued need for pacing is questioned, the process required to discontinue pacing therapy is unclear. Although the decision of not replacing a pacemaker is a difficult one, especially because the natural history of bradycardia can be unpredictable, it has to be balanced against the risk of long-term pacemaker related complications over a lifetime. In such patients, options for discontinuation of pacemaker therapy could include programming the pacemaker “off,” elective nonreplacement of a device approaching end of battery service life, explant of the pulse generator alone, and in some cases, pulse generator explant and extraction of the lead(s).

Recommendation-Specific Supportive Text

1. In 1 study, 5 patients referred for pacemaker replacement or a pacemaker related complication in which the original indication for pacing appeared to have resolved, intrinsic rhythm was documented and 2 underwent EPS (S13-1).The pacemakers were removed from all 5 patients and none had symptomatic bradycardia after 18 to 48 months of follow-up (S13-1). One group of investigators developed a protocol that was used to discontinue pacing therapy in 70 patients without a clear initial or persistent indication. The protocol included clinical evaluation, echocardiogram, exercise testing, and tilt table testing. If these tests were negative, the pulse generator energy was turned to off, with periodic 24-hour ambulatory electrocardiographic monitoring for up to 1 year, after which an EPS was conducted. Of the 70 patients, 35 had their pacemaker explanted; after a mean follow-up of 30.3 months all patients remained asymptomatic, except for 1 patient who died of a non-cardiac cause (S13-2). In a retrospective study of patients who underwent lead extraction without device replacement, mortality appeared to be dependent on comorbid conditions, and arrhythmia related death was rare (S13-7).

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14. End-of-Life Considerations

Healthcare professionals frequently face questions about pacemaker deactivation in patients nearing end of life. Although patients and families often fear that pacemakers will prolong the process of death, studies show that many physicians report uneasiness with conversations related to device management at the end of life, with many physicians feeling more uncomfortable deactivating pacemakers than defibrillators (S14-1). Therefore, understanding the legal, ethical, and practical issues related to pacemaker deactivation is imperative. This topic has been addressed extensively in an HRS consensus statement; therefore, only a summary of the most important issues is provided here (S14-2).

From the legal and ethical standpoint, a patient with decision-making capacity or his/her legally defined surrogate, has the right to refuse or request withdrawal of any medical treatment or intervention, including pacemakers, regardless of whether the treatment prolongs life and its withdrawal would result in death. Withdrawal of a life sustaining medical intervention with the informed consent of a patient or legal surrogate should not be considered physician-assisted suicide, and honoring these requests should be considered to be an integral aspect of patient-centered care (S14-3). As with decisions surrounding implantation of pacemakers, these decisions should be undertaken by patients or legally defined surrogate and physicians together using the principles of shared decision-making.

Physicians should clarify for patients or their legally defined surrogates and their families the expected consequences of pacemaker deactivation. Patients and their families may wrongly assume that pacemakers may prolong the process of dying and thus prolong suffering. However, in general, pacemakers do not keep dying patients alive, because terminal events are often caused by various of other clinical conditions, such as cancer and, at the time of death, the pacemaker will ultimately fail to capture myocardial muscle rendering it irrelevant. Because pacemaker pulses are painless, in most cases pacemaker deactivation is unnecessary and reassurance of patients and family in addition to turning off cardiac monitoring may be all that is needed. If the decision is made to deactivate a pacemaker, patient death may follow immediately after the cessation of pacing therapy if the patient is completely pacemaker dependent. However, in those who are not pacemaker dependent, the process of death may be unpredictable. It is possible that turning off a pacemaker may lead to additional discomfort; therefore, patients must be monitored closely for potential symptoms, such as respiratory distress, which may require intensification of comfort care measures.

Pacemaker deactivation requires a written order from the responsible physician, which should be accompanied by a do-not-resuscitate order as well. Additional documentation in the medical record should include confirmation that the patient (or legal surrogate) has requested device deactivation, capacity of the patient to make the decision or identification of the appropriate surrogate and documentation that alternative therapies as well as documentation that the consequences of deactivation have been discussed (S14-2). Palliative care and medical support should be provided to the patient and family in order to provide comfort in view of potential symptoms that may arise. Access to clergy (or chaplain) should be offered and provided according to the patient's individual religious beliefs. If the clinician asked to deactivate a device has religious or ethical beliefs that prohibit him or her from carrying out device deactivation, he or she should not be forced to do so, and instead the patient should be referred to a different physician who is capable and willing.

Ideally, providers and healthcare systems that care for pacemaker patients should have processes in place for device deactivation when the time comes. Conversation related to end-of-life issues ideally should begin either at the time of device implant, or early during the early stages of the terminal illness. Clinicians should encourage patients undergoing device implantation to complete advanced directives and specifically address the matter of device management and deactivation if the patient is terminally ill.

15. Knowledge Gaps and Future Research

Gaps in the understanding of the management of bradycardia persist, particularly in the evolving role and developing technology for pacing. His bundle pacing is an emerging area of interest and is particularly relevant in patients who require significant amounts of ventricular pacing, but the long-term outcomes for this approach in large populations of patients remain uncertain (S15-1, S15-2). The role of pacing among patients with transient bradycardia with reflex-mediated syncope beyond those with documented transient asystole is also uncertain (S15-3, S15-4). Although cardiac resynchronization pacing is associated with improvement in outcomes among patients with atrioventricular block and heart failure in general (S15-5, S15-6), the role of cardiac resynchronization in the subgroup of patients with an LVEF of >35% remains incompletely understood. The relative merits of His bundle pacing, cardiac resynchronization, or other pacing strategies for maintaining or improving left ventricular function in patients with atrioventricular block is unknown. In addition, pacing with entirely leadless devices is also an emerging area of interest (S15-7, S15-8), but the roles of these new devices in real-world practice, and their potential interaction with other cardiac devices is not yet clear. Regardless of technology, for the foreseeable future, pacing therapy requires implantation of a medical device and future studies will be required to focus on the long-term implications associated with lifelong therapy.

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Appendix 1. Author Relationships With Industry and Other Entities (Relevant)—2018 ACC/AHA/HRS Guideline on the Evaluation and Management of Patients With Bradycardia and Cardiac Conduction Delay (July 2018)

Committee Member	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section*
Fred M. Kusumoto *(Chair)*	Mayo Clinic—Professor of Medicine	None	None	None	None	None	None	None
Mark H. Schoenfeld *(Vice Chair)*	Yale University School of Medicine—Clinical Professor of Medicine	None	None	None	None	None	None	None
Coletta C. Barrett	American Heart Association—Chairman of the Board	None	None	None	None	None	None	None
James R. Edgerton	The Heart Hospital Baylor—Director of Education	None	None	None	None	None	None	None
Kenneth A. Ellenbogen	VCU Medical Center—Director, Clinical Electrophysiology	• Biotronik† • Boston Scientific† • Janssen Pharmaceuticals • Medtronic† • Pfizer† • St. Jude Medical†	• Biosense Webster† • Biotronik† • Boston Scientific† • Medtronic† • St. Jude Medical†	None	• Biosense Webster† • Boston Scientific† • Medtronic† • Sanofi-Aventis† • Medtronic (DSMB)†	• Biosense Webster† • Boston Scientific† • Medtronic† • Sanofi-Aventis	None	4.3.1, 4.3.2, 5, 6, 7, 8, 9, 11, 13
Michael R. Gold	Medical University of South Carolina—Director, Division of Cardiology and Professor of Medicine	• Boston Scientific† • Medtronic • St. Jude Medical	None	None	• Boston Scientific‡ • St. Jude Medical‡	None	None	4.3.1, 5, 6, 7, 8, 9, 11, 13
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Annemarie Thompson	Duke University School of Medicine—Professor of Anesthesiology and Medicine	None	None	None	None	None	None	None
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This table represents the relationships of committee members with industry and other entities that were determined to be relevant to this document. These relationships were reviewed and updated in conjunction with all meetings and/or conference calls of the writing committee during the document development process. The table does not necessarily reflect relationships with industry at the time of publication. A person is deemed to have a significant interest in a business if the interest represents ownership of ≥5% of the voting stock or share of the business entity, or ownership of ≥$5,000 of the fair market value of the business entity; or if funds received by the person from the business entity exceed 5% of the person's gross income for the previous year. Relationships that exist with no financial benefit are also included for the purpose of transparency. Relationships in this table are modest unless otherwise noted.

According to the ACC/AHA, a person has a *relevant* relationship IF: a) the *relationship or interest* relates to the same or similar subject matter, intellectual property or asset, topic, or issue addressed in the *document;* or b) the *company/entity* (with whom the relationship exists) makes a drug, drug class, or device addressed in the *document* or makes a competing drug or device addressed in the *document*; or c) the *person or a member of the person's household*, has a reasonable potential for financial, professional or other personal gain or loss as a result of the issues/content addressed in the *document*.

*Writing committee members are required to recuse themselves from voting on sections to which their specific relationships with industry and other entities may apply.
†Significant relationship.
‡No financial benefit.

CMS reported payments from Cardiofocus to Dr. Kusumoto in 2016 and 2017. Dr. Kusumoto has established that the study he participated in ended in 2014 and was published in 2015.
CMS reported consulting payments to Dr. Lee from Abbott, Cryolife and Maquet in 2016. Dr. Lee has established that his participation with the companies ended in January 2015.
CMS reported research payments from Medtronic to Dr. McLeod in 2016 and 2017. Dr. McLeod is disputing the payments.

ACC indicates American College of Cardiology; AHA, American Heart Association; DSMB, data safety monitoring board; HRS, Heart Rhythm Society; UT, University of Texas; VA, Veterans Affairs; and VCU, Virginia Commonwealth University.

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Appendix 2. Abbreviated Reviewer Relationships With Industry and Other Entities—2018 ACC/AHA/HRS Guideline on the Evaluation and Management of Patients With Bradycardia and Cardiac Conduction Delay (August 2018)*

Reviewer	Representation	Employment	Comprehensive RWI?
Yong-Mei Cha	Official Reviewer—AHA	Mayo Clinic, Division of Cardiovascular Diseases	No
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Richard J. Kovacs	Official Reviewer—ACC Science and Quality Committee	Indiana University School of Medicine, Krannert Institute of Cardiology—Professor of Clinical Medicine	Yes
Kevin F. Kwaku	Official Reviewer—AHA	Dartmouth-Hitchcock Medical	No
Daniel M. Philbin Jr	Official Reviewer—ACC Board of Governors	New England Heart Institute	Yes
Peter A. Brady	Organizational Reviewer—HRS	Mayo Clinic, Mayo Foundation	No
Ratika Parkash	Organizational Reviewer—HRS	Dalhousie University and Nova Scotia Health Authority—Professor of Medicine, Division of Cardiology (Arrhythmia); Director of Research, Division of Cardiology	Yes
Jonathan Philpott	Organizational Reviewer—STS	Mid-Atlantic Cardiothoracic Surgeons	Yes
Kevin Shannon	Organizational Reviewer—PACES	Mattel Children's Hospital at UCLA—Clinical Professor, Division of Pediatric Cardiology	Yes
Gus J. Vlahakes	Organizational Reviewer—AATS	Harvard Medical School and Massachusetts General Hospital—Professor of Surgery	No
Nazem Akoum	Content Reviewer	University of Washington	No
Sana M. Al-Khatib	Content Reviewer—ACC/AHA Task Force on Clinical Practice Guidelines	Duke Clinical Research Institute—Professor of Medicine	Yes
Joshua A. Beckman	Content Reviewer—ACC/AHA Task Force on Clinical Practice Guidelines	Vanderbilt University Medical Center—Director, Section of Vascular Medicine	Yes
Kim K. Birtcher	Content Reviewer—ACC/AHA Task Force on Clinical Practice Guidelines	University of Houston College of Pharmacy—Clinical Professor	Yes
Mitchell I. Cohen	Content Reviewer—PACES	Pediatric Cardiology Associates	No
Freddy Del-Carpio Munoz	Content Reviewer—ERC Member	Mayo Clinic	No
Bernard Dennis	Content Reviewer—ACC/AHA Lay Reviewer	Dennis Associates, LLC	No
Anita Deswal	Content Reviewer—ACC/AHA Task Force on Clinical Practice Guidelines	Michael E. DeBakey VA Medical Center—Chief, Cardiology; Baylor College of Medicine—Professor of Medicine	Yes
Andrew E. Epstein	Content Reviewer	The Hospital of the University of Pennsylvania—Professor of Medicine	Yes

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Michael E. Field	Content Reviewer	University of Wisconsin School of Medicine and Public Health—Director, Clinical Electrophysiology and Cardiac Arrhythmia Service	No
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AATS indicates American Association for Thoracic Surgery; ACC, American College of Cardiology; AHA, American Heart Association; CCEP, Clinical Cardiac Electrophysiology; ERC, evidence review committee; HRS, Heart Rhythm Society; NYU, New York University; PACES, Pediatric & Congenital Electrophysiology Society; STS, Society of Thoracic Surgeons; UCLA, University of California, Los Angeles; UT, University of Texas; and VA, Veterans Affairs.

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6. Bradycardia Attributable to Atrioventricular Block

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