



poor efficacy and side effect profiles of available antiarrhythmic drugs. Radiofrequency ablation (i.e., applying radiofrequency-range energy) and cryoablation (i.e., administering freezing temperatures, to produce localized cellular and tissue injury) are commonly used.

Focal and reentrant arrhythmias are defined and localized, permitting targeted delivery of ablation energy to eliminate the tachyarrhythmia. Ablation is associated with varied success and complication rates, depending on the mechanism and location of the arrhythmogenic focus. Cure rates for tricuspid and caval isthmus–dependent atrial flutter, AV nodal reentry tachycardia (AVNRT), and accessory pathway–mediated tachycardias exceed 95%, with low complication rates of about 2%. Although an important therapeutic option in the treatment of AF and VT, success rates are lower and procedural risks are higher.

 For a deeper discussion on this topic, please see Chapter 62, “Approach to the Patient with Suspected Arrhythmia,” in Goldman-Cecil Medicine, 25th Edition.

BRADYCARDIA

Bradycardia, defined as a heart rate of less than 60 beats per minute, may occur as a consequence of physiologic adaptations or pathology. Bradycardia always results from failure of sinus node function or AV conduction disturbances, or both processes. Clinically significant bradycardia or pauses may result from autonomic disturbances, drugs, chronic intrinsic conduction system disease, or acute cardiac damage as occurs with endocarditis or infarction.

Normal Conduction System: Anatomy and Physiology

Because of the normal gradient of intrinsic automaticity, heart rate usually is determined by intrinsic automaticity of the sinus node. The sinus node is a complex of cells that extends from the superior vena cava and along the upper right atrial free wall in the sulcus terminalis. Blood supply is derived from the sinus node artery, which arises from the right coronary in 66% or left coronary in 34% of patients.

Activation proceeds through the right atrium to the AV node, which is located in the low interatrial septum adjacent to the tricuspid annulus. The AV node is a complex structure with at least three preferential atrial insertions. The anterior atrial insertion has a short conduction time and usually determines the normal AV conduction time in sinus rhythm. The posterior right and left atrial insertions have long conduction times. Because they do not normally mediate AV conduction in humans, they are functionally vestigial. However, the posterior slowly conducting insertions become important in mediating paroxysmal supraventricular tachycardia (PSVT). The AV node derives its blood supply from the AV nodal artery, which is supplied by the right coronary artery in 73% or the left coronary artery in 27% of patients.

After entry into the AV node, conduction proceeds to the His bundle through the fibrous annulus and along the membranous septum before splitting into a leftward Purkinje branch, which ramifies over the left ventricular endocardium, and a rightward branch, which similarly ramifies over the RV endocardium. The

leftward branch may be damaged proximally, resulting in full left bundle branch block, or damaged more distally in its anterior or posterior divisions, resulting in fascicular hemiblock patterns.

Normal Autonomic Regulation of Heart Rate

Normal heart rate is a consequence of tonic and phasic autonomic modulation of intrinsic sinus node automaticity. The intrinsic heart rate in the absence of autonomic modulation ranges from 85 to 110 beats per minute and is somewhat faster than normal resting heart rates. That the normal heart rate is slower than the intrinsic rate is a consequence of the dominance of parasympathetic tone over adrenergic tone in the resting state.

Based on a review of Holter recordings in a normal population, the normal resting heart rate is 46 to 93 beats per minute in men and 51 to 95 beats per minute in women. It has been proposed that 50 to 90 is a clinically more accurate working definition of normal heart rate for adults than the traditional 60 to 100 beats per minute commonly used by consensus. However, heart rates well below these estimates may be seen in normal people, especially during hours of sleep. For these reasons, defining a cutoff value for pathologic bradycardia in the absence of symptoms is problematic for an otherwise healthy patient.

The maximal stress-induced heart rate (HR_{max}) is related to maximal sympathetic stimulation, accompanied by withdrawal of parasympathetic tone. This is commonly estimated as $HR_{max} = (220 - \text{age})$.

Sinus Node Dysfunction

Sick sinus syndrome, also called *sinus node dysfunction*, is a common clinical syndrome that increases in prevalence with age. The estimated prevalence is 1 case per 600 patients older than 65 years of age, and it accounts for about one half of all pacemaker implantations. Sinus node dysfunction is a consequence of two distinct processes: failure of intrinsic automaticity and failure of propagation of sinus node impulses to the surrounding atrial tissue, also referred to a *sinus node exit block*.

Sinus node dysfunction manifests clinically as one of several patterns: persistent or episodic sinus bradycardia, inability to appropriately augment rate with exercise (i.e., chronotropic incompetence), sinus pauses, or commonly a combination of these patterns. The sinus node is at the top of a cascade of automaticity and is normally backed up by a competent AV junctional escape mechanism. Severe bradycardia and associated symptoms due to sinus node dysfunction always imply sinus node dysfunction and simultaneous failure of normal subsidiary escape mechanisms. In the setting of a competent escape mechanism, even severe sinus node dysfunction may be completely asymptomatic, clinically well tolerated, and require no specific therapy.

Resting Sinus Bradycardia

Sinus bradycardia is frequently observed during routine clinical practice. Modest sinus bradycardia in the high 40s in men and 50s in women is normal and called *bradycardia* only because of the conventional choice of 60 beats per minute as the lower limit of normal rates. Because there is no set rate at which sinus bradycardia can be labeled as pathologic, pathologic sinus node