Atrioventricular Conduction
Physiology and Autonomic Influences

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KEYWORDS

• AV node • His-Purkinje system • Autonomic nervous system • AV node reentry • WPW reentry • Parasympathetic • Sympathetic • Conduction

KEY POINTS

- Changes in the autonomic nervous system can lead to substantial alterations of atrioventricular (AV) nodal conduction.
- The direct effects of increasing heart rate during activity that prolong AV nodal conduction are offset by vagal withdrawal and enhanced sympathetic tone resulting in minimal change in the PR interval.
- Termination of AV and atrioventricular node (AVN) reentry with vagal maneuvers relates to vagal effects on the vulnerable part of the AVN function curve, which is present during tachycardia.
- Heart block during activity is likely in the His-Purkinje system.

INTRODUCTION

Atrioventricular (AV) conduction typically starts with a sinus impulse that activates the atria and subsequently conducts through the atrioventricular node (AVN) and His-Purkinje system (HPS) before activation of the ventricles. The PR interval on the electrocardiogram (ECG) represents the total conduction time through these tissues (**Fig. 1**).[1] This article focuses mainly on AVN conduction, represented by the atrio-His (AH) interval in the figure, but also discusses important aspects of HPS conduction, represented by the His-ventricle (HV) interval in the figure. The influences of the autonomic nervous system (ANS) tone on AV conduction and AVN-dependent arrhythmias also are discussed in depth.

ATRIOVENTRICULAR NODE
Structure

Anatomically, the AVN is located in the right atrium anteriorly at the base of the interatrial septum in the apex of the triangle of Koch.[1–4] It is a complex structure anatomically and electrophysiologically. The compact node has right and left posterior extensions,[5] which may play a role in AVN reentry. Initial microelectrode studies of the AVN subdivided it into 3 functional zones: the atrionodal (AN), nodal (N), and nodo-His (NH) zones,[1] whereas more recent observations suggest 6 different cell types.[6] Cells in the N region seem to correlate with the compact AVN, where block in the AVN typically occurs. Action potentials in the AVN are mediated primarily by calcium channels (slow-channel-dependent) and have fewer intercalated disks, both of which lead to reductions in nodal conduction velocity.[7] Surrounding the compact AVN are transitional cell types, with intermediate histology between atrial myocardium and compact nodal cells. Thus, slow and decremental conduction through the AVN (**Fig. 2**) is multifactorial, depending on factors, such as complex anatomy, reduced electrical cellular coupling, and action potentials dependent on the slow inward calcium current.

There appears to be 2 distinct atrial inputs to the AVN, an anterior one via the interatrial septum, and posteriorly by the crista terminalis.[3] The anterior

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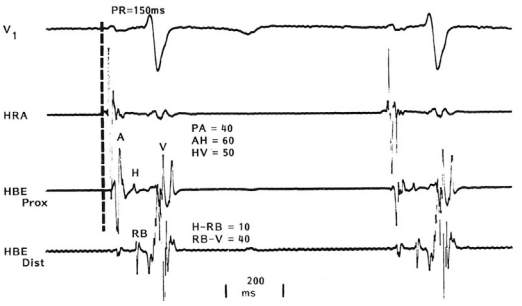

Fig. 1. Intracardiac conduction intervals during the PR interval. Simultaneous recordings from ECG lead V1, high right atrium (HRA), His bundle proximal (HBE prox), and distal (HBE dist) electrode pairs. Sinus impulses conduct to the AVN (PA interval), through the AVN measured as the AH interval, and then to the ventricles by way of the His and the right and left bundles, which comprise the HV interval. The PR interval represents the time it takes to conduct through all these tissues. H-RB, his to right bundle; RB-V, right bundle to ventricle. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

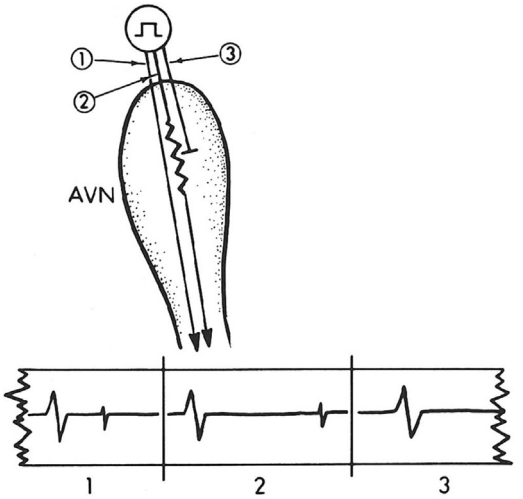

Fig. 2. Wenckebach AV nodal block at electrophysiologic study during incremental atrial pacing. (*top*) The AVN and the impulses conducting through it during pacing. (*bottom*)The AH interval for each beat. The AH interval in beat 1 is relatively short, but the second beat conducts with an increased AH interval. The third atrial paced complex blocks in the AVN. This progressive increase in the AH interval (decremental conduction) is the cause of the increase in PR interval when block occurs in the AVN. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

input seems to favor conduction over the "fast" AVN pathway, or the usual mode of AVN conduction, and the posterior input leads to conduction over the "slow" AVN pathway (Fig. 3). Although this is likely too simplistic, observations from catheter ablation of AVN reentry generally support this hypothesis.[3]

Induction of the usual form of slow/fast AVN reentry occurs with anterograde block over the fast AVN pathway, conduction over the slow AVN pathway, and retrograde conduction over the fast pathway that has recovered excitability (Fig. 4). The initial approach was to ablate the fast pathway inputs in the anterior septum, and this resulted in a marked prolongation of the AH interval supposedly via conduction through the AVN from the posterior atrial AVN inputs. Alternatively, ablation in the posterior right atrial septum cures AVN reentry without any significant change in the AH interval (assuming no damage to the AVN).

Autonomic Inputs

Autonomic innervation of the AVN has been well demonstrated and seems to change with age.[4,8] In a study of 24 human hearts, Chow and colleagues[8] used immunohistochemical and histochemical analysis to analyze the sympathetic and parasympathetic nerve inputs to the AVN. They found an initial sympathetic dominance in infancy, but a more balanced parasympathetic and sympathetic neural input in adulthood. Furthermore, there was a reduction in density of innervation with aging.

Parasympathetic and sympathetic tone exerts negative and positive dromotropic effects, respectively, on AVN conduction. Acetylcholine shortens nodal action potentials, but prolongs postrepolarization refractoriness, with a net effect to slow AVN conduction.[4] In contrast, catecholamine-mediated phosphorylation of L-type calcium channels has a marked effect to enhance inward calcium currents, which leads to an increase in AV nodal conduction velocity.[4] In humans, alterations in autonomic tone can either facilitate or impede AVN conduction (Fig. 5).

HIS-PURKINJE SYSTEM

Impulses leave the AVN and enter the HPS, a ventricular specialized conduction system composed of the His bundle, left and right bundle branches, and the peripheral network of Purkinje fibers.[1] The HPS has more rapid conduction properties, and the action potentials are initiated by the fast-acting sodium current. A normal HPS does not usually demonstrate decremental conduction as heart rate increases, because it has rapid

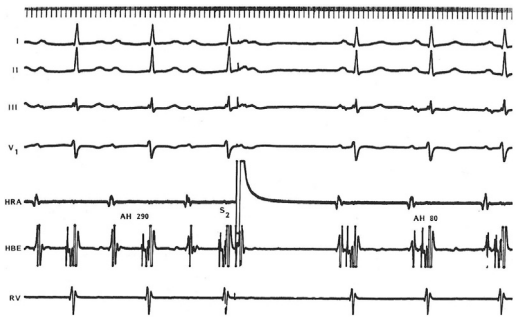

Fig. 3. Dual AV nodal conduction pathways. The ECGs and intracardiac tracings are recorded simultaneously. Note on the first 3 complexes the PR interval is long as is the AH interval (290 milliseconds) because of conduction over the slow AV nodal pathway. A premature atrial stimulus is given that blocks in the AVN. The fourth and subsequently conducted P waves now have normal PR intervals and AH intervals (80 milliseconds) because conduction is over the fast AV nodal pathway. RV, right ventricle. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

accommodation to changes in rate. Thus, when block in the HPS occurs during incremental atrial pacing, it is an abnormal response and signifies a diseased HPS[9] (Fig. 6). It is important that evaluation of HPS conduction be done with an incremental atrial pacing run, not by the sudden onset of atrial pacing that can lead to shortening of the atrial cycle length (CL), resulting in a "long-short" sequence with block below the HPS (Fig. 7). Block in the HPS in this context is a physiologic, not a pathologic event.[1]

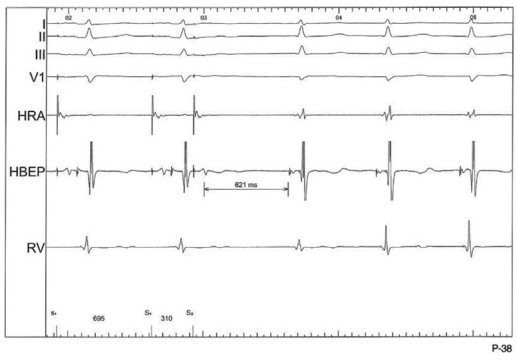

Fig. 4. Initiation of slow-fast AVN reentry at EPS. The atrium is paced, and the third paced beat is premature. There is block in the fast AVN pathway with conduction over the slow pathway (AH 621 milliseconds). The previously blocked anterograde fast pathway has recovered excitability for retrograde conduction allowing AVN reentry to occur. HBEP, proximal his bundle electrogram; RV, right ventricle.

Autonomic Inputs

Autonomic innervation of the HPS has been demonstrated,[8] although the direct effects of the ANS on HPS conduction are generally small in a normal HPS in humans.[1] Changes in autonomic tone can have a direct effect on sinus rate and thereby an indirect effect on HPS conduction, and which predominates is not always clear. Markel and colleagues[10] studied the effects of intravenous atropine, propranolol, or isoproterenol in 4 patients with documented Mobitz II block clinically and below the His at electrophysiologic study. In 2 of 3 patients, propranolol prolonged the atrial pacing cycle length (PCL) with block below the His compared with control; in contrast, in 3 of 4 patients, atropine in the presence of propranolol shortened the PCL of block below the His. Isoproterenol in 1 patient improved HPS conduction. Thus, it appears that beta-adrenergic blockers may worsen, whereas atropine can improve dynamic HPS conduction.

Clinical Correlates

Fig. 8 demonstrates the complex interaction of direct and indirect effects of changes in autonomic tone on HPS conduction. During sinus rhythm at rest, there is 1:1 conduction with a prolonged HV interval of 70 milliseconds (see Fig. 8A). Atropine 1 mg was given, and the sinus rate increases as does the HV interval with maintenance of 1:1 conduction (see Fig. 8B). The heart rate substantially increases with 1.5 mg of atropine, and 2:1 block occurs below the His potential (see Fig. 8C).

Maneuvers to alter heart rate may be used to aid in the diagnosis of intra-His or infra-His block. In Fig. 9, Mobitz II block is present in a patient who was recovering from cardiac surgery (see Fig. 9A). Carotid sinus massage slows the heart rate and restores 1:1 conduction. In Fig. 9B at electrophysiology study, block below the His potential is confirmed.

Exercise testing under careful observation can also aid in diagnosing HPS block. Fig. 10A shows an ECG with 2:1 AV block. A narrow QRS normally implies the level of block is in the AVN. However, note that the PR interval is normal at about 180 milliseconds. It is relatively rare for 2:1 block to occur in the AVN with a normal PR interval, so one must consider block in the His bundle in this circumstance. The patient was exercised, and the block worsened (Fig. 10B). Typically, the PR interval does not change much with exercise, where the effect of increased rate is countered by vagal withdrawal and increased sympathetic tone. At electrophysiology study, intra-His block was demonstrated (Fig. 10C), and the patient received a permanent pacemaker.

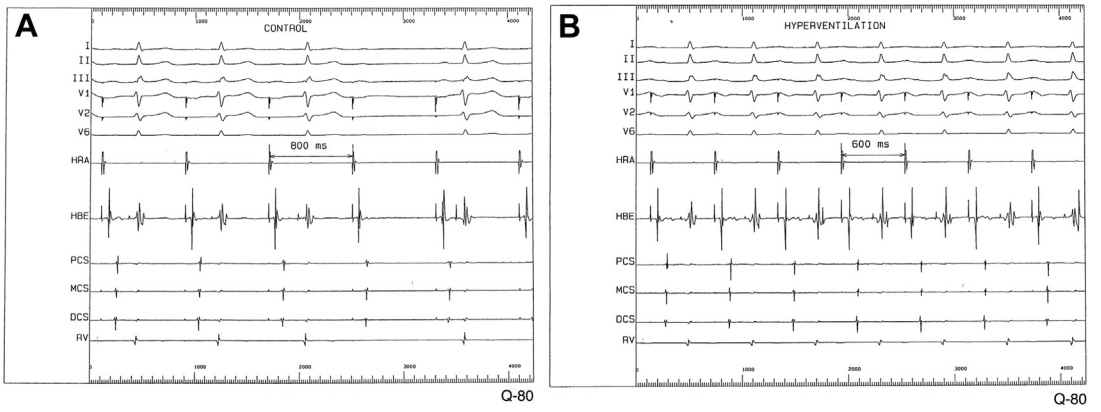

Fig. 5. Hyperventilation facilitates AV nodal conduction. (*A*) During atrial pacing at 800 milliseconds Wenckebach block occurs in the AVN. (*B*) Hyperventilation changes the autonomic inputs to the AVN to facilitate conduction, and even at 600 milliseconds 1:1 AV nodal conduction occurs.

ATRIOVENTRICULAR NODE CONDUCTION

Atrioventricular Nodal Function Curves

In the 1970s, the concept of enhanced AVN conduction was proposed for a subset of patients who had an AH interval during sinus rhythm of $\leq$60 milliseconds; 1:1 conduction during atrial PCL to $\leq$300 milliseconds; and at atrial PCL 300 milliseconds an AH interval $\leq$100 milliseconds longer than the AH during sinus rhythm.[11] Various theories were proposed as the mechanism of enhanced AVN conduction, including conduction over an atrio-Hisian pathway. The authors studied 160 patients to determine if such a subgroup of patients existed, or whether those with rapid AVN conduction characteristics were merely part of the overall spectrum of AVN behavior.[11] They concluded that patients with these rapid conduction criteria were not a unique subgroup, but rather the lower end of a continuous spectrum of normal AVN physiology.

An important observation on AVN conduction curves was identified by the study of Jackman and colleagues[11] (**Fig. 11**). For each patient, AH measurements were made at atrial PCLs 600, 500, 400, and 300 milliseconds, and at each of the 5- to 10-millisecond intervals before AVN block. The slopes of the segments of each curve were calculated. Importantly, regardless of the shortest PCL with 1:1 conduction, the shape of each curve was similar, as was the slope at the stressed end of each curve (labeled A). Thus, the shape of this AVN conduction curve during incremental atrial pacing represents a fundamental property of the AVN.

Autonomic Blockade and Atrioventricular Nodal Conduction

In humans, the parasympathetic nervous system predominates over the sympathetic nervous system on sinus rate.[12] Whether this is similar for AVN conduction was investigated by Prystowsky and colleagues.[13] In 13 patients, atrial pacing to assess 1:1 AVN conduction was evaluated in the control

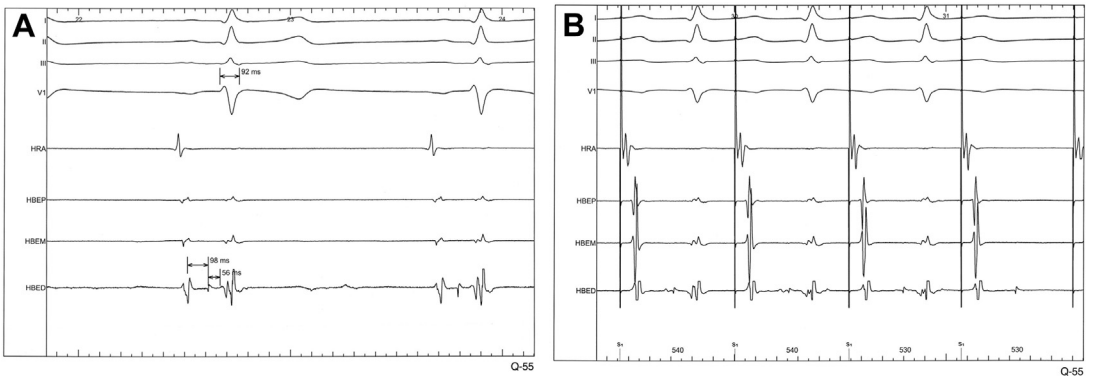

Fig. 6. Diseased HPS with block below the His during incremental atrial pacing. (*A*) HV interval is essentially normal during sinus rhythm. (*B*) During atrial pacing the fourth paced beat blocks below the His recording.

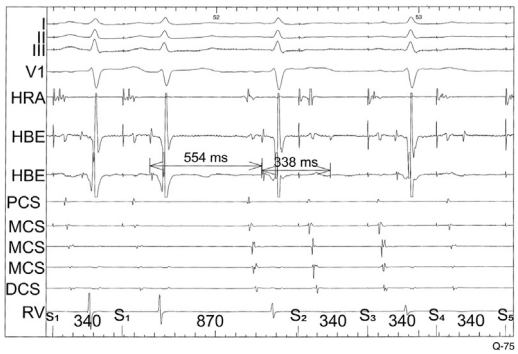

Fig. 7. Physiologic block in the HPS. The first 2 atrial paced beats (S_1) conduct to the ventricle. The stimulator is turned off to give a pause of 554 milliseconds. Then, pacing resumes at the same cycle as in the first 2 beats, but 2:1 block below the His recording occurs because of the long-short sequence (554 to 338 milliseconds); this is a physiologic response, not a pathologic one as seen in Fig. 6. CS, coronary sinus; DCS, distal CS, MCS, mid CS; PCS, proximal CS.

state, in the presence of either intravenous propranolol (0.15 mg/kg) or atropine (0.03 mg/kg) alone, and with both drugs (autonomic blockade). The doses of drugs used have been shown to block effectively

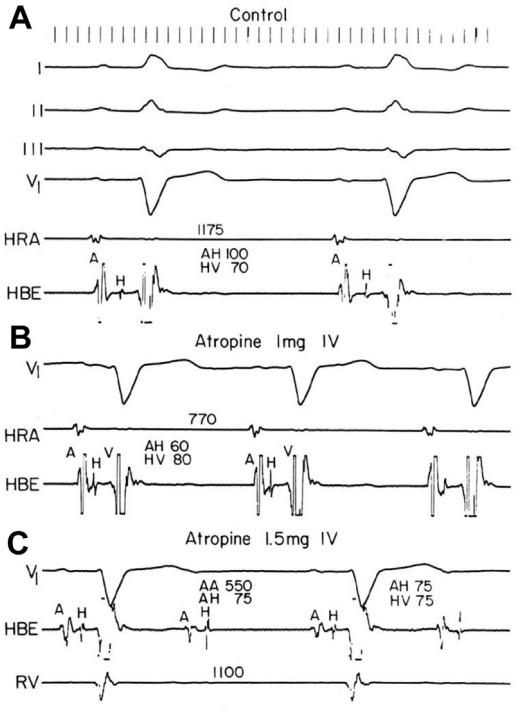

Fig. 8. The effects of atropine on the HPS with increased heart rate. IV, intravenous. See text for details. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

ANS influences on sinus nodal automaticity in humans.[12] As expected, propranolol increased and atropine decreased the shortest atrial PCL sustaining 1:1 AVN conduction. However, there was no significant difference in atrial PCL with 1:1 conduction at control versus propranolol plus atropine (386 ± 109 to 372 ± 74 milliseconds). Thus, it appears that in contrast to the prepotent effect of the parasympathetic nervous system on sinus nodal automaticity at rest, vagal and adrenergic tone have a more balanced effect on resting AV nodal conduction.

In a follow-up study, the authors evaluated the effect of autonomic blockade in patients with normal and abnormal AV nodal function.[14] To define a normal atrial PCL with 1:1 conduction, 168 patients without ECG AVN conduction abnormalities were studied. Using the 95th percentile, normal was defined as a shortest atrial PCL with 1:1 conduction less than 505 milliseconds. In 14 patients with normal AVN conduction, atrial PCL with 1:1 conduction did not change from control to autonomic blockade (361 ± 16 to 359 ± 14 milliseconds). However, in the 9 patients with abnormal AVN conduction, atrial PCL with 1:1 conduction shortened from control to autonomic blockade (610 ± 33 to 493 ± 20 milliseconds). If one considers AVN conduction in the presence of autonomic blockade as the intrinsic AV nodal conduction, then the patients with abnormal AVN conduction at rest also had significantly longer atrial PCL with 1:1 conduction versus those in the normal AVN conduction group. There was a clear predominance of vagal tone on AVN conduction in patients with intrinsically abnormal AV nodal conduction.

All patients had normal PR intervals, so there would be no way of knowing which ones had an intrinsic abnormality of AVN conduction. This has several potential clinical consequences. It may explain why some people are more prone to vagal-mediated heart block during sleep. Furthermore, patients with an abnormal intrinsic AVN may demonstrate exaggerated responses to drugs, such as beta-adrenergic blockers or slow-channel blockers, especially during atrial fibrillation. Further research is needed in this area.

Isoproterenol and Atrioventricular Nodal Conduction

Increased sympathetic tone can accelerate sinus rate and improve AV nodal conduction. It is important to keep the heart rate constant to determine the effects of increased adrenergic tone on AV nodal conduction. Because AV nodal function curves do not depend on the shortest atrial PCL with 1:1 conduction,[11] one can study the effects

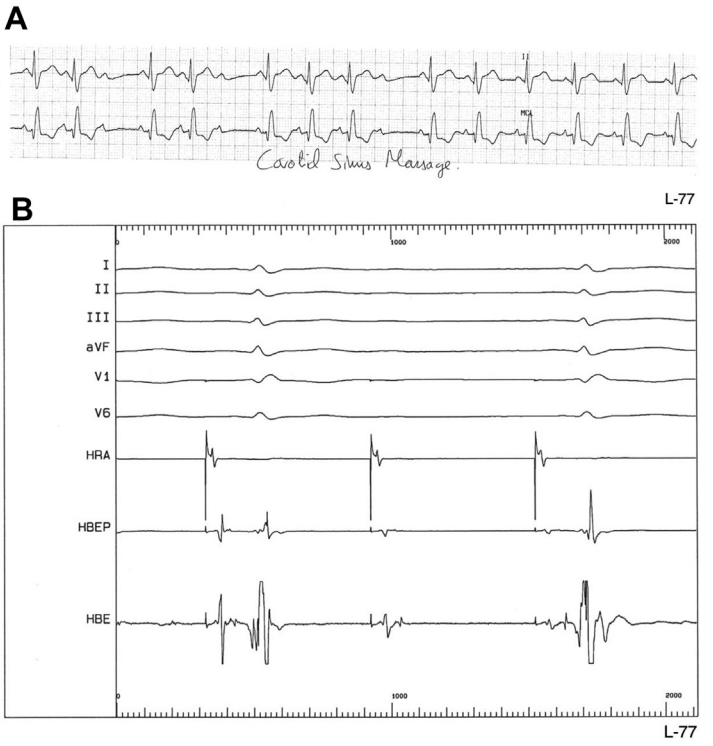

Fig. 9. Slowing of the heart rate with carotid sinus massage (CSM) improves AV conduction. (*A*) Mobitz II block occurs on the left side of the figure, but CSM slows the sinus rate and restores 1:1 conduction on the right side of the figure. (*B*) Block below the His bundle deflection is noted at EPS.

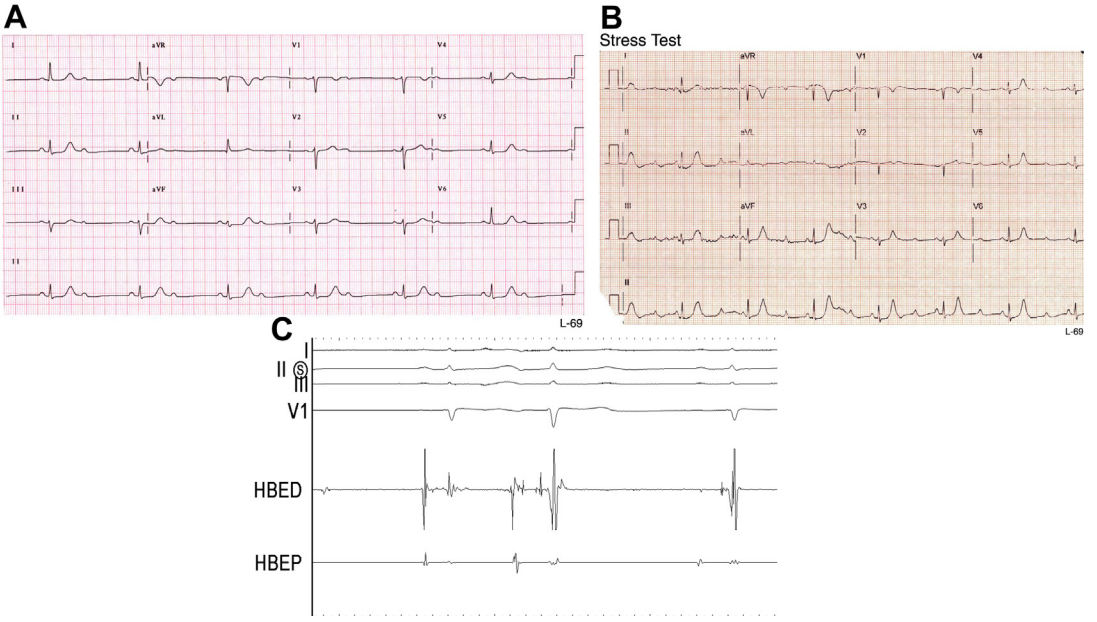

Fig. 10. Block in the His bundle. (*A*) 2:1 AV block. (*B*) AV block worsens during exercise. (*C*) Second complex shows a split His potential, and block would always occur after the first His recording. See text for details. ([*A*, *C*] *From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

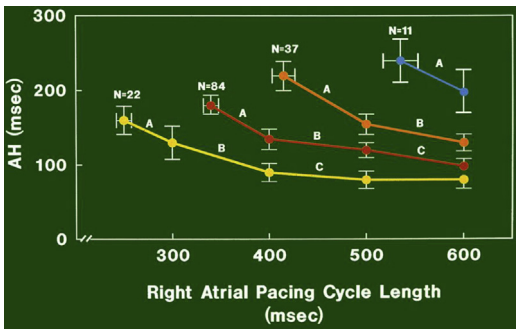

Fig. 11. Family of AV nodal function curves at EPS. See text for details. (*From* Jackman WM, Prystowsky EN, Naccarelli GV, et al. Reevaluation of enhanced atrioventricular nodal conduction: evidence to suggest a continuum of normal atrioventricular nodal physiology. Circulation 1983;67:441-448; with permission).

of isoproterenol in patients by comparing the same parts of the curve before and after isoproterenol infusion. Fig. 12 shows the results from such a study in patients with normal PR intervals (Eric N. Prystowsky, MD, unpublished data). Atrial pacing was performed before and after isoproterenol was given at 1 ug/min constant infusion. At the longest mean atrial PCL of 650 milliseconds, the AH interval shortened by a mean of 34 milliseconds. However, there was a significant and marked 63-millisecond shortening of the AH interval at the atrial PCL (414 milliseconds) near the steep slope of the curve. This was the authors' first observation that alterations in autonomic tone appear to have a differential effect on AV nodal conduction depending on whether they occur

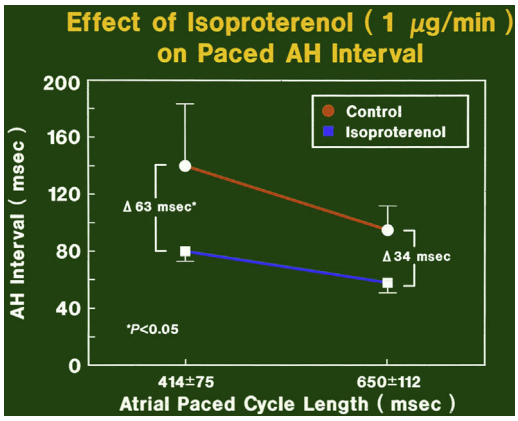

Fig. 12. Effect of isoproterenol on paced AH interval at different points on the AVN function curve. See text for details. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

during the flat or stressed part of the functional AV nodal curve.

Enhanced Vagal Tone and Atrioventricular Node Conduction

Page and colleagues[15] investigated the effect of enhanced vagal tone on AV nodal conduction and sinus nodal automaticity. To augment reflex vagal tone, a constant intravenous infusion of phenylephrine (0.74 ± 0.41 ug/kg/min) was given to 10 patients. The mean diastolic blood pressure increased during the infusion from 76 to 89 mm Hg. This technique allowed the authors to study the enhanced vagal effects in a new steady state. Incremental atrial pacing was performed before and during the infusion, and AH intervals for each patient were measured at the long (845 ± 132 milliseconds) and short (575 ± 209 milliseconds) atrial PCLs (Fig. 13). The AH interval during sinus rhythm was not significantly prolonged with enhanced vagal tone. The shortest atrial PCL with 1:1 conduction significantly increased during phenylephrine infusion from 412 ± 120 to 575 ± 211 milliseconds. There was a significant increase in the mean AH interval at both the longer and the shorter atrial PCLs. However, the mean increase in AH interval of 59 milliseconds at the shorter PCL was significantly greater than the 18 milliseconds at the longer PCL. Thus, the effect of enhanced vagal tone was greater on the stressed or steeper part of the functional AV nodal curve.

A comparison was done of the magnitude of changes in sinus nodal automaticity with AV nodal conduction during phenylephrine infusion. Importantly, although enhanced vagal tone significantly increased sinus CL and the shortest atrial PCL with 1:1 conduction, there was a lack of correlation between the two. This has important clinical implications, because one cannot judge the magnitude of enhanced vagal tone on the AVN, and likely other cardiac tissues, by the degree of sinus slowing.

Combined heart rate and autonomic nervous system effects on atrioventricular nodal conduction

The above data demonstrate that in a resting state, increasing the heart rate with atrial pacing will yield a progressive lengthening of the AH interval until AV nodal block occurs. However, during normal daily activity, increases in heart rate are accompanied by predictable changes in autonomic tone, with enhanced sympathetic and reduced parasympathetic effects on the AVN. Fig. 14 illustrates how these opposing changes affect the AH interval and therefore the PR interval in a person without HPS disease.

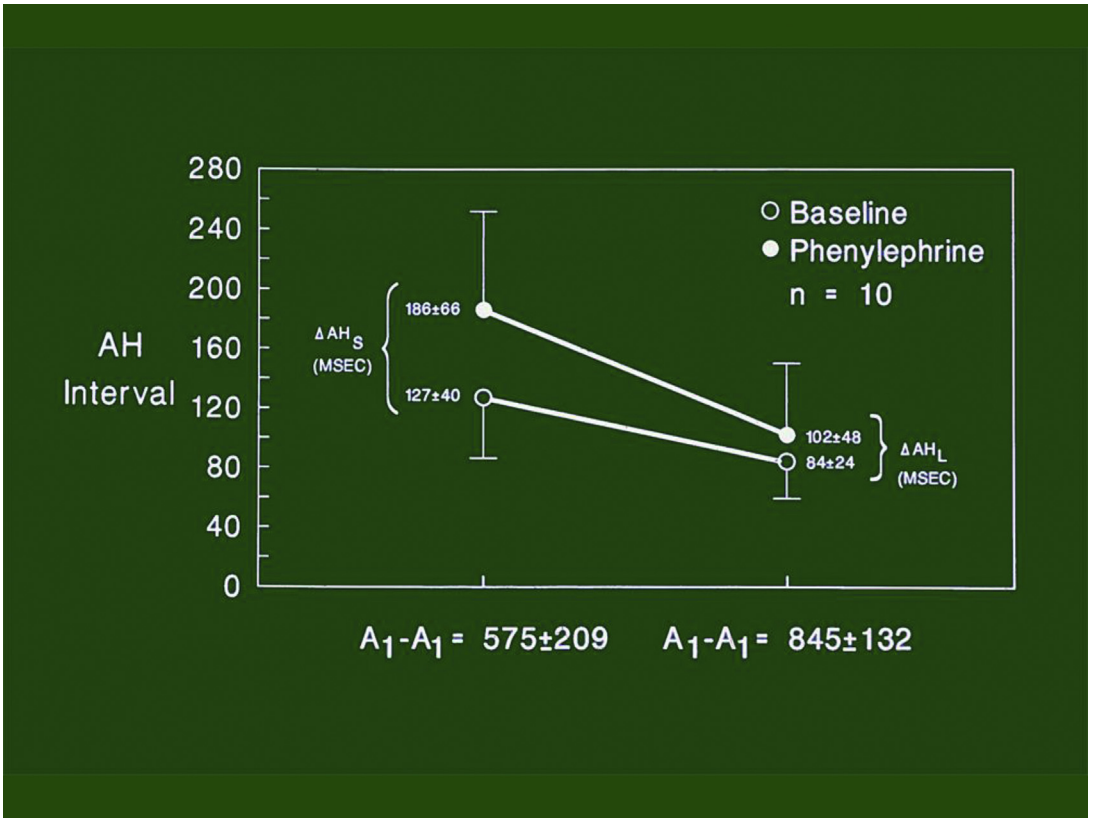

Fig. 13. Effect of enhanced reflex parasympathetic tone during intravenous phenylephrine infusion on AH interval at different points of the AV node function curve. See text for details. (*From* Page RL, Tang AS, Prystowsky EN. Effect of continuous enhanced vagal tone on atrioventricular nodal and sinoatrial nodal function in humans. Circulation Research 1991;68:614-620; with permission).

Note that the resulting PR interval is nearly the same as the heart rate increases, and one need merely measure the PR interval during a treadmill examination to confirm this observation. If there is a marked increase in the PR interval, or block occurs, consider disease in the HPS, even if the QRS is normal (see **Fig. 10**). A constant PR interval improves hemodynamics, and if the PR increased enough that the P wave fell within the T wave at faster heart rates, a pacemaker-like syndrome may occur. Thus, the system works amazingly well!

A clinical pearl from all of this is to measure the PR interval on rhythm strips when trying to decide whether an atrial tachycardia or sinus tachycardia is present. An atrial tachycardia is like pacing the atrium without the advantage of the autonomic changes that occur with sinus tachycardia. Thus, if the PR during sinus rhythm is shorter than during the tachycardia, consider the possibility of an atrial tachycardia; if it is the same, sinus tachycardia is usually present.

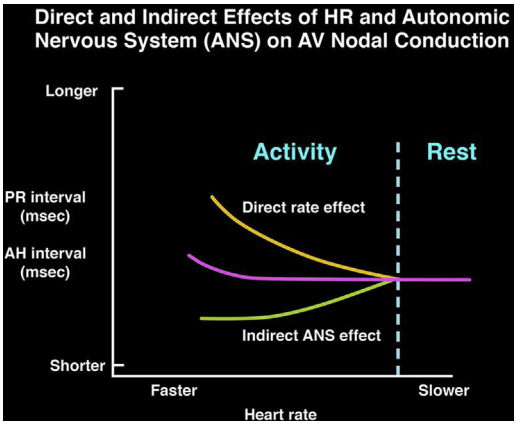

Fig. 14. Direct and indirect effects of heart rate and ANS on AV nodal conduction and the PR interval. See text for details.

SUPRAVENTRICULAR TACHYCARDIA AND AUTONOMIC NERVOUS SYSTEM

Atrioventricular Reentry

Atrioventricular reentry (AVRT) comprises several tissue types in its circuit (**Fig. 15**). However, the CL of tachycardia is usually decided by the anterograde properties of the AVN, a dramatic example of which is the change in AVRT CL when anterograde conduction over the fast AV nodal pathway switches to the slow AV nodal pathway.[16]

Increased adrenergic tone can shorten atrial and ventricular refractoriness to some degree, as well as the accessory pathway (AP),[17] but the effects on the AVN usually predominate. Enhanced vagal tone shortens atrial refractoriness,[18] whereas resting vagal tone increases ventricular refractoriness,[13] but has minimal effect on AP conduction and refractoriness.[19] As noted above, changes in vagal tone can have marked effects on AV nodal refractoriness and conduction. Thus, alterations in ANS tone primarily affect AVRT CL by its effect on the AVN.

Autonomic Changes and Atrioventricular Reentry Cycle Length

As described above, changes in autonomic tone have their greatest effect on the stressed part of the AV nodal function curve. The authors (Eric N. Prystowsky, MD, unpublished data) studied a group of patients with AVRT using a concealed AP for retrograde conduction to determine if AV nodal conduction during AVRT was at the stressed part of the curve. They further evaluated the effects of vagal withdrawal and adrenergic enhancement on the AVRT circuit (**Fig. 16**). The term "electrophysiologic reserve" is used to calculate how close the 1:1 conduction over the AP and AVN are to the AVRT CL.

Patients were studied first in the control state; then, after constant intravenous infusion of isoproterenol to increase sinus rate by about 20%, and after washout of isoproterenol, intravenous atropine was given in graded doses to approximate the sinus rate during isoproterenol infusion. The authors recognized that the changes in sinus rate by both agents do not necessarily mirror

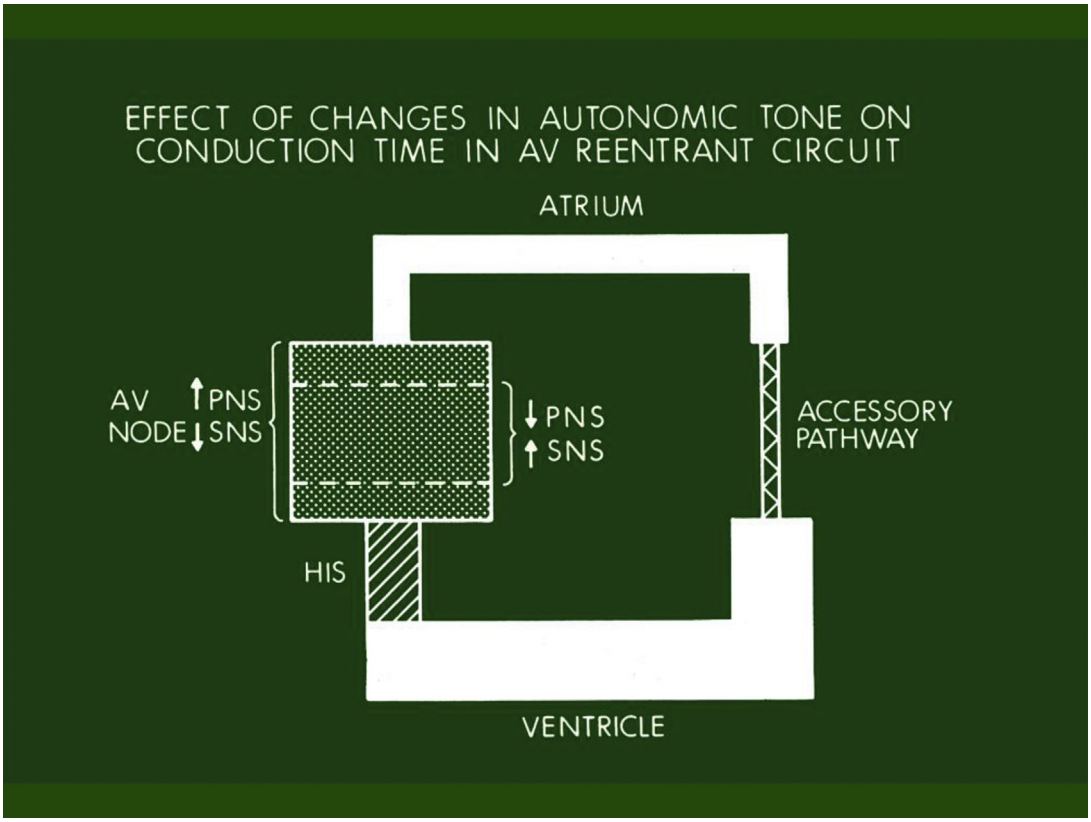

Fig. 15. The components of the AV reentry circuit, and the effects of changes in autonomic tone on it. Changes in CL are mainly due to ANS effects on AV nodal conduction. The AVN acts like an accordion "opening and closing" with alterations of parasympathetic (PNS) and sympathetic (SNS) nervous system tone on it. See text for details.

alterations of AV nodal conduction. At control and ANS perturbations, atrial and ventricular pacing were performed to assess 1:1 conduction over the AVN and AP, and AVRT was induced.

At control, the 1:1 AVN conduction was typically about 30 milliseconds shorter than the AVRT CL, placing it on the stressed area of the AVN function curve. Note that there was more "reserve" with retrograde conduction over the AP. Both isoproterenol and atropine shorted the AVRT CL. Retrograde 1:1 conduction over the AP shortened with isoproterenol, but unexpectedly also with atropine. Note that the 1:1 AVN conduction still was within 30 milliseconds of the AVRT CL, again on the stressed part of the AVN conduction curve. The more pronounced effect of vagal withdrawal and adrenergic enhancement on AV nodal conduction lessened the electrophysiologic reserve of the AVRT circuit, as 1:1 AP conduction was now closer to the AVRT CL.

These observations demonstrate the AVRT CL "finds" its fastest rate at various levels of autonomic tone. The AH interval during AVRT is on the steep slope of its curve, and at faster rates would lengthen the AVRT CL.

Clinical Correlates

AV nodal conduction is most vulnerable at the stressed part of its function curve, and this explains why enhanced vagal tone can terminate AVRT yet exert minimal effect on AVN conduction in sinus rhythm. **Fig. 17** shows an example of enhanced vagal tone during breath-holding in a patient with AVRT induced at electrophysiologic study. Note that it terminates tachycardia, yet the returning sinus impulse conducts with a normal AH interval along with preexcitation. Similar examples are seen with carotid sinus massage, and this also explains why intravenous verapamil and adenosine can terminate paroxysmal supraventricular tachycardias but minimally prolong PR interval during sinus rhythm.

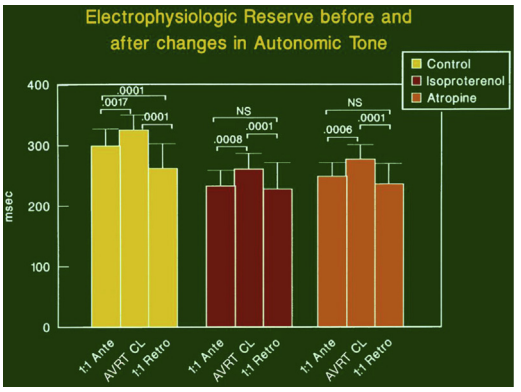

Fig. 16. Electrophysiologic reserve before and after changes in autonomic tone. Ante, anterograde; Retro, retrograde. NS, non significant. See text for details.

Autonomic Changes and Atrioventricular Nodal Reentry

Changes in ANS can affect AV nodal reentry. At electrophysiologic study, isoproterenol or epinephrine may be needed to facilitate induction of AVN reentry by exerting positive effects on AV nodal conduction and refractoriness.[20] In contrast, enhanced vagal tone has a negative dromotropic effect on AV nodal conduction. Chiou and colleagues[19] studied 10 patients with AVN reentry at control and during enhanced parasympathetic tone using constant phenylephrine infusion. Enhanced vagal tone prolonged 1:1 conduction time over the anterograde fast and slow pathways, and retrograde fast pathway. However, phenylephrine prolonged the effective and functional refractory periods of the anterograde fast pathway but had no effect on the refractoriness of the anterograde slow or retrograde fast pathway. Such disparate results in vagal-induced refractoriness on these pathways may explain the common occurrence of AVN reentry occurring at rest and during sleep. One could imagine a premature atrial complex during increased vagal tone blocking over the fast AVN pathway but being able to conduct over both the anterograde slow pathway and the retrograde fast pathway, allowing AVN reentry to occur.

Clinical Correlate

Hyperventilation can have substantial effects on autonomic tone, with vagal withdrawal and sympathovagal imbalance.[21] Chen and colleagues[21]

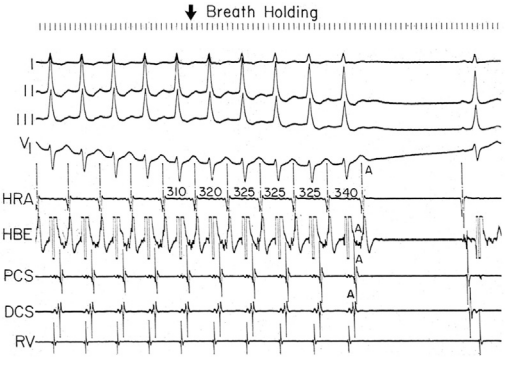

Fig. 17. Increased vagal tone during breath holding terminates AVRT at electrophysiologic study. See text for details. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

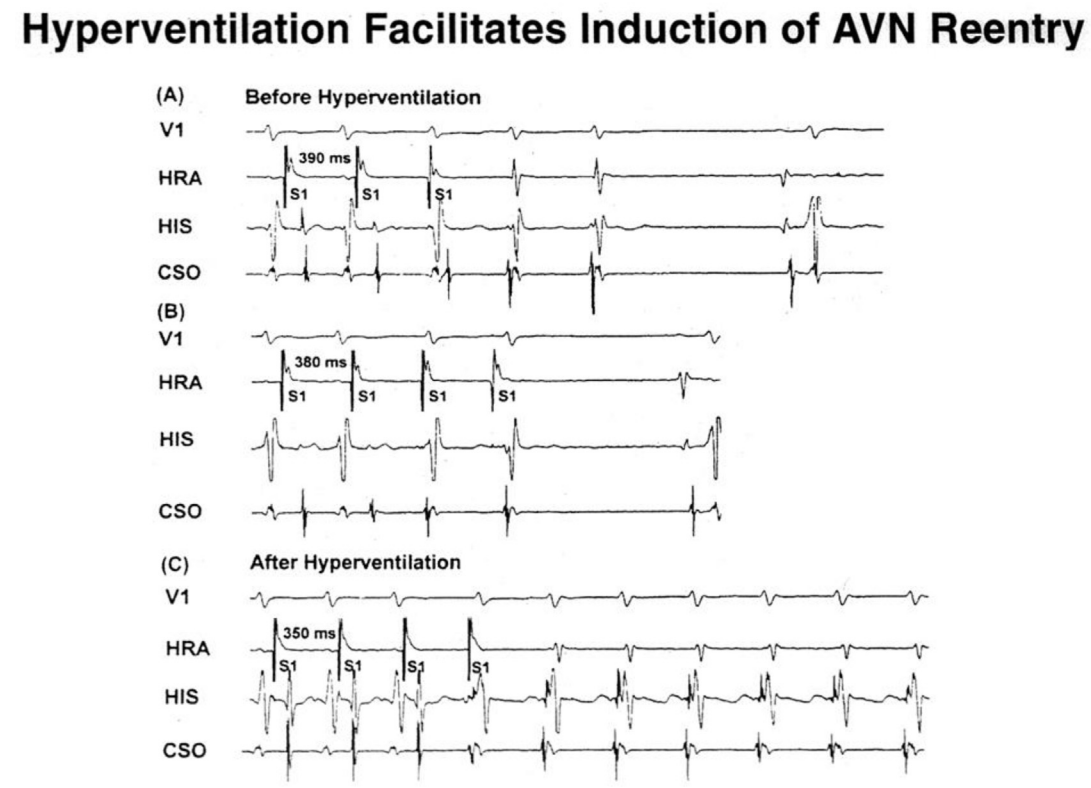

Fig. 18. Hyperventilation facilitates induction of AV nodal reentry at electrophysiologic study. See text for details. (*From* Chen CC, Chen SA, Tai CT, et al. Hyperventilation facilitates induction of supraventricular tachycardia: a novel method and the possible mechanism. J Cardiovasc Electrophysiol 2001;12:1242-1246. doi:10.1046/j.1540-8167.2001.01242.x; with permission).

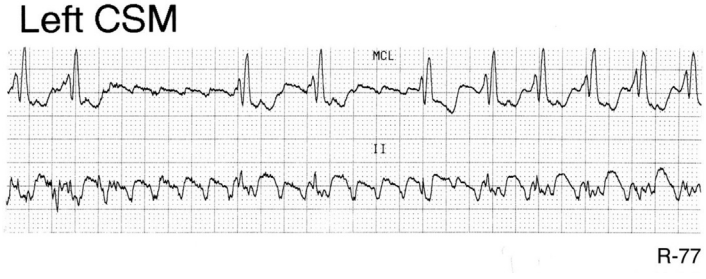

Fig. 19. Left CSM increases level of block in atrial flutter. See text for details.

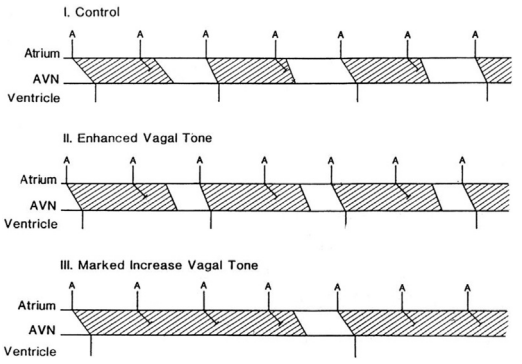

Fig. 20. Enhanced vagal tone as a possible mechanism for 4:1 AV block in atrial flutter. (*top*) 2:1 AV block occurs, and the blocked flutter complex occurs near the end of AVN refractoriness (shaded area). (*middle*) Increased vagal tone that prolongs AVN refractoriness, and the blocked beat is now further away from the end of refractoriness. (*bottom*) Marked vagal tone that causes such an increase in refractoriness that the third beat is blocked, and the concealed conduction from that beat prolongs refractoriness even more, resulting in block of the fourth beat, with a 4:1 conduction pattern in the AVN. (*From* Page RL, Wharton, JM, Prystowsky EN. Effect of continuous vagal enhancement on concealed conduction and refractoriness within the atrioventricular node. Am J Cardiol 1996;77:260-265. doi:10.1016/s0002-9149(9789390-3) with permission)

studied the effects of hyperventilation on AV nodal function in patients with AVRT and AVN reentry. In patients with slow-fast AVN reentry, hyperventilation significantly improved 1:1 conduction over the anterograde fast and slow pathways, and over the retrograde fast pathway. In 7 of 9 patients without AVNRT induced at baseline state, initiation occurred during hyperventilation (Fig. 18). Patients diagnosed with panic disorders can have PSVT that is undiagnosed.[22] It is possible that hyperventilation, which is common in this disorder, can help to initiate AVNRT or AVRT in these individuals.

Atrial Flutter

Fig. 19 demonstrates increased AVN block in atrial flutter during left carotid massage. Concealed conduction occurs during atrial flutter, and Page and colleagues[23] evaluated the effect of vagal enhancement on concealed conduction in the AVN.

Enhanced reflex vagal tone was produced using constant intravenous phenylephrine infusion. Page and colleagues[23] found that enhanced vagal tone could magnify the effects of concealed AVN conduction. They further hypothesized that the common occurrence of 4:1 block during atrial flutter often seen during times of increased vagal tone, such as sleep, might be explained by augmentation of concealed conduction (Fig. 20).

Clinical Examples of Autonomic Nervous System Effects on Atrioventricular Node Conduction

Fig. 21 shows heart block during sleep. Note that the third PP interval suddenly lengthens and is associated with the first nonconducted P wave. When there is a concomitant increase in the PP interval and heart block, the mechanism is increased parasympathetic tone. Remember, the magnitude of the vagal effect may be different on the sinus and AV nodes, and thus the degree of PP increase is not as important as the fact that it does lengthen.

Fig. 22 is taken during an episode of sleep apnea in a patient with an implantable loop recorder. As in Fig. 21, the PP interval lengths but the effect on AV nodal conduction is more pronounced. Treating the sleep apnea eliminated the heart block in this patient.

Fig. 23 occurred during swallowing in a patient with deglutition syncope. There is more than a 7-second pause of all electrical activity. In the absence of high vagal tone, one would have expected a junctional escape complex sooner. This demonstrates that extremely high levels of vagal tone can suppress not only the sinus and AV nodes, but also lower subsidiary pacemakers.

Fig. 24 occurred in a patient with atrial tachycardia. Fig. 24A is during rest with 3:1 conduction. Fig. 24B was during activity and now shows 1:1 conduction. The increase in ventricular response results from vagal withdrawal and enhanced sympathetic tone. Such changes commonly occur during atrial fibrillation, and

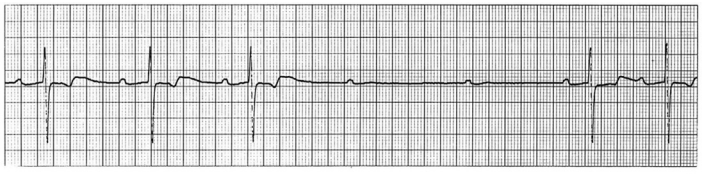

Fig. 21. Heart block during sleep owing to enhanced vagal tone. See text for details.

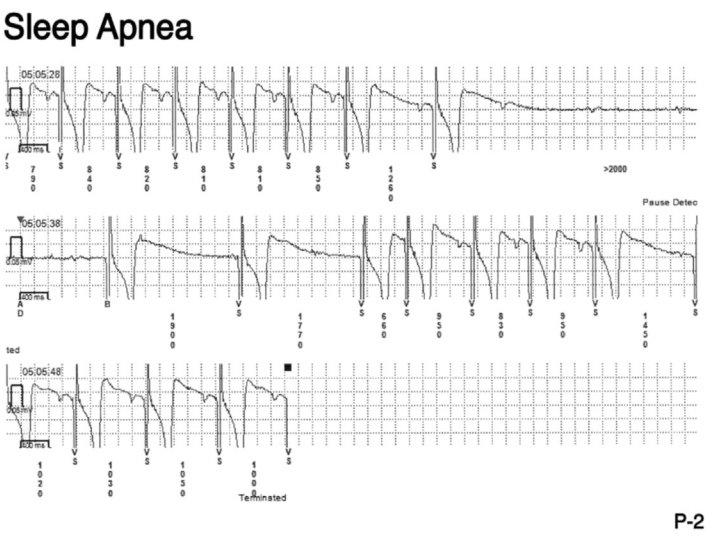

Fig. 22. Heart block during an episode of sleep apnea. See text for details.

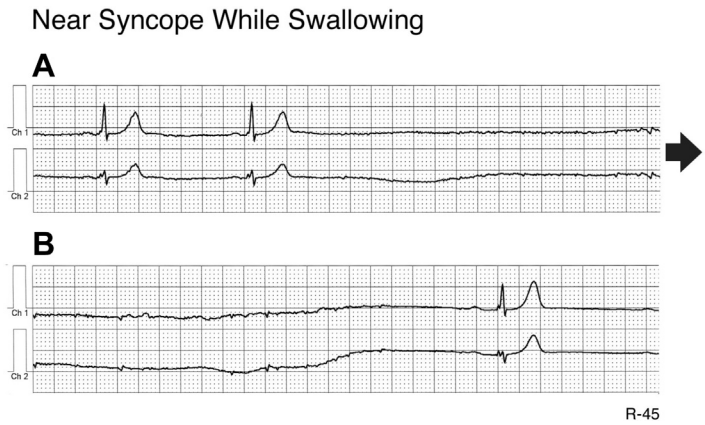

Fig. 23. Deglutation syncope. See text for details.

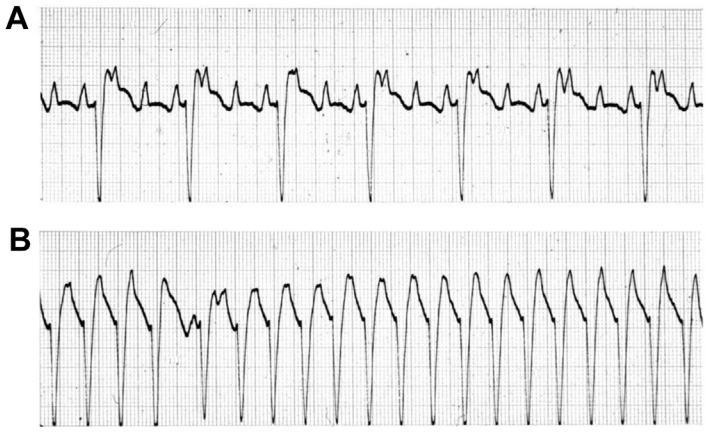

Fig. 24. Improvement in AVN conduction during atrial tachycardia from rest (*A*) to activity (*B*). See text for details. (*From* Prystowsky EN, Klein GJ, Daubert JP. Cardiac Arrhythmias: Interpretation, Diagnosis, and Treatment, 2nd edition. New York: McGraw Hill; 2020; with permission).

rate control should be assessed throughout the day to be sure adequate control is achieved.

DISCLOSURE

None.

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