Manifest and Concealed Reentry
A Mechanism of A-V Nodal Wenckebach in Man

By John J. Gallagher, M.D., Anthony N. Damato, M.D.,
P. Jacob Varghese, M.D., and Sun H. Lau, M.D.

SUMMARY
In five patients, bundle of His electrograms were recorded during right ventricular pacing at various cycle lengths. In all patients, as the cycle length of stimulation was decreased, the pattern of retrograde conduction proceeded from 1:1 retrograde conduction, to retrograde Wenckebach with or without manifest reentry, to retrograde Wenckebach cycles with concealed reentry. The requisite condition for reentry was a critical retrograde A-V nodal delay. During retrograde Wenckebach cycles, reentry could be either concealed or manifest. Concealed reentry resulted in typical or ordinary Wenckebach cycles on the surface electrocardiogram and manifest reentry resulted in ventricular echo beats. Depending upon the cycle length of stimulation, reentry could be concealed on the surface electrocardiogram but manifest on the His bundle electrogram recording. Concealed reentry could be manifest by turning off the stimulator at the appropriate time in the cardiac cycle while manifest reentry could be concealed by changing the cycle length of stimulation. Reentry with collision of wavefronts within the A-V node or proximal His-Purkinje conduction system explains why the last ventricular impulse is not conducted to the atria during ordinary Wenckebach cycles.

Additional Indexing Words:
Critical A-V nodal delay Ventricular stimulation Type I second-degree A-V block
His bundle electrograms Collision of wavefronts

The A-V nodal Wenckebach phenomenon (type I second-degree A-V block) is electrocardiographically characterized by a progressive prolongation of the P-R interval, followed by a nonconducted atrial impulse. Previous electrophysiologic studies in man have demonstrated that the area of conduction delay and block is proximal to the bundle of His in most cases. The exact mechanism for the A-V nodal delay and block is not well understood. Previous explanations have centered around the concept of decremental conduction. Recent animal studies from this laboratory have demonstrated that block of the nonconducted beat during retrograde Wenckebach cycles is the result of manifest and concealed reentry. In addition, it was suggested that manifest and concealed reentry may be the basis of the progressive prolongation of conduction seen during Wenckebach cycles. The present study was undertaken to investigate whether similar phenomena are present in man.

Methods
Nine men and one woman underwent right heart catheterization in the postabsorptive, nonsedated state for evaluation of nondiagnostic chest pain. The patients were not taking any cardioactive drugs at the time of the study. The nature of the procedure was explained and a signed consent obtained. Using a tripolar electrode catheter introduced percutaneously into a femoral vein, His bundle recordings (HBE) were obtained according to methods previously described. In addition, a quadripolar electrode catheter was percutaneously introduced into an antecubital vein and fluoroscopically positioned against the lateral wall of the high right atrium, near its junction with the superior vena cava. The distal pair of electrodes was connected to a battery-powered pacemaker (Medtronic no. 5847) which delivered impulses of 2-msec duration at approximately twice diastolic threshold. The proximal pair of electrodes was used to record a high right atrial (HRA) electrogram. A bipolar catheter was also introduced percutaneously into another antecubital vein.
and positioned at the right ventricular apex for ventricular pacing at a milliamperage ≤ 1. Care was taken to insure proper grounding of all equipment.

During all stimulation sequences, the surface electrocardiogram (ECG), intracardiac electrograms, and time lines generated at intervals of 10 and 100 msec were displayed on a multichannel switched-beam oscilloscope and recorded via a universal matching amplifier onto magnetic tape. Records were subsequently reproduced at paper speeds of 150 mm/sec. All patients tolerated the procedure without complication.

Results

During ventricular pacing, retrograde conduction was observed in eight of 10 patients. The criteria for retrograde conduction and activation of the atria were similar to those used by Castillo and Castellanos. In five of these eight patients retrograde A-V nodal Wenckebach periodicity occurred at cycle lengths sufficiently slow to permit further study. The findings in these five patients constitute the basis of this report.

In all studies, retrograde A-V nodal conduction time during ventricular pacing was longer than antegrade A-V nodal conduction time at comparable paced atrial rates. In addition, the Wenckebach phenomenon appeared at slower rates during ventricular pacing than during atrial pacing. As the cycle length of ventricular stimulation was decreased, the pattern of retrograde conduction proceeded from 1:1 retrograde conduction to retrograde Wenckebach cycles with or without manifest reentry, to retrograde Wenckebach cycles with concealed reentry.

Figures 1–4 depict typical responses to decreasing the cycle length of ventricular stimulation. In this patient, reentry occurred whenever retrograde conduction time exceeded 325 msec. Figure 1 demonstrates that at a paced cycle length of 850 msec, 1:1 retrograde conduction occurred. Decreasing the cycle length to 540 msec, as shown in figure 2, resulted in retrograde Wenckebach cycles. Manifest reentry, as noted on both the surface electrocardiogram and HBE recording occurred following the fourth ventricular beat which was associated with a retrograde conduction time of 330 msec. The last ventricular stimulus occurred 60 msec after the antegrade His deflection of this reentrant impulse and contributed little, if at all, to ventricular depolarization. In figure 3, a further decrease in the cycle length of stimulation to 460 msec resulted in ordinary 3:2 retrograde Wenckebach cycles in which reentry concealed on the surface electrocardiogram. However, reentry was manifest on the HBE recording. The second

![Figure 1](http://circ.ahajournals.org/)

**Figure 1**

Ventricular pacing at cycle length (CL) of 850 msec with 1:1 retrograde conduction. The recordings from top to bottom are standard ECG leads I, II, and III, V₁, a high right atrial electrogram (HRA), His bundle electrogram (HBE), and time lines (T) generated at 10 and 100 msec. A = atrial electrogram; H = His bundle electrogram; V = ventricular electrogram; S = stimulus artifact. The first beat is a sinus beat and the sequence of atrial depolarization is from HRA to the low right atrium. Ventricular pacing results in 1:1 retrograde conduction to the atria with a V-A conductive time of 160 msec. Note that atrial activation is from the low right atrium to the high right atrium. The above abbreviations will be used for subsequent figures.
Figure 2

Retrograde Wenckebach terminated by a manifest reentrant beat (same patient as fig. 1). The panel to the left depicts a single sinus beat with a high-to-low sequence of atrial activation. Ventricular pacing at a CL of 540 msec results in an increasing V-A conduction time from 280 to 330 msec. The fourth retrograde impulse reenters within the A-V node and antegradely depolarizes the bundle of His (H) 60 msec prior to the fifth stimulus artifact (S). Reentry is manifest on both the ECG and HBE tracings.

The retrograde impulse of each Wenckebach cycle reentered within the A-V node as evidenced by the appearance of an antegrade His deflection 25 msec after the third ventricular stimulus. The reentrant impulse collided with the retrograde impulse within the bundle-branch system, thereby resulting in failure of the third ventricular impulse to propagate retrogradely to the atria. The reentrant impulse contributed little if at all to ventricular depolarization.

Figure 4 is a recording at the same cycle length as figure 3 and demonstrates how manifest reentry can be produced by turning off the stimulator at the appropriate time in the Wenckebach cycle. Following the second ventricular beat which was associated with the requisite A-V nodal delay (350 msec) the stimulator was turned off and manifest reentry terminated the Wenckebach cycle. Reentry was not demonstrated when the stimulator was turned off at earlier points in the Wenckebach cycle, that is, prior to the point of requisite A-V nodal delay.

Figure 5 is an example of a spontaneous episode of ventricular tachycardia in which there was an ordinary 4:3 Wenckebach cycle with concealed

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Figure 3

Same patient as figures 1 and 2. Decreasing the CL to 460 msec results in ordinary 3:2 retrograde Wenckebach in which reentry is concealed on the ECG tracings but manifest on the HBE tracing.

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Figure 4

Same patient as figures 1–3. Concealed reentry is made manifest by turning off the stimulator at the appropriate time in the cardiac cycle. Same cycle length of stimulation as in figure 3. Following a V-A conduction time of 350 msec, the stimulator is turned off and reentry occurs. The arrows indicate the point at which the omitted stimulus would have been delivered.

Reentry on the surface electrocardiogram and manifest reentry on the HBE recording.

Discussion

Reentry within the A-V node is an accepted electrophysiologic event which has been extensively studied in both the experimental animal and man.7, 9–23

The results of this clinical study are in agreement with our previous experimental observations in dogs.7 In both studies, it has been demonstrated that reentry within the A-V node occurred whenever a requisite A-V nodal delay was attained during the Wendkebach cycle. In this regard our findings in both man and experimental animals are in agreement with those of Moe and Mendez who stated that reciprocal responses can be so readily induced in normal animal hearts that their occurrence must be considered a normal physiologic response.10 This reentry can be either manifest or concealed. Indeed, manifest reentry can be concealed by changing the cycle length of stimulation, and concealed reentry can be made manifest by turning off the stimulator at the appropriate time in the cardiac cycle. Oftentimes, reentry is concealed on the surface electrocardiogram (resulting in an ordinary or typical retrograde Wenckebach cycle) but manifest on the His bundle electrogram recording. Reentry in its concealed or manifest form explains why, during Wenckebach cycles, the last ventricular impulse fails to retrogradely conduct to the atria. During ordinary or typical retrograde Wenckebach cycles there is a collision of the reentrant impulse and the last ventricular impulse within the A-V node or proximal His-Purkinje system. Collision of the two impulses may also occur within the common bundle itself.7

It should be emphasized that the most important determinant of A-V nodal reentry is a critical degree of A-V nodal delay.10–11 This fact explains why reentry was not observed when the stimulator was turned off at earlier times in the cardiac cycle.

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The fact that reentry is responsible for the failure of the last ventricular impulse of the Wenckebach cycle to retrogradely conduct to the atria raises the interesting possibility that an abortive form of reentry is continuously occurring throughout and that this abortive reentry may explain the progressive prolongation of the P-R interval.\(^7\)

Except for quantitative aspects, antegrade and retrograde A-V nodal conduction are quite similar.\(^13\)

However, in both clinical and experimental studies, echo beats (manifest reentry) are less commonly seen terminating antegrade Wenckebach cycles than retrograde Wenckebach cycles. One possible explanation for this discrepancy centers about the relationship between antegrade and retrograde A-V nodal conduction times and the cycle length of stimulation. Since retrograde A-V nodal conduction time is generally longer than antegrade conduction time, the requisite A-V nodal delay for manifest reentry can be achieved at longer ventricular cycle lengths relative to atrial cycle lengths. The shorter atrial cycle lengths needed to achieve the requisite delay for reentry favors the possibility that the atrial pacemaker will depolarize the atria prior to the arrival of the reentrant impulse. Under these circumstances collision of atrial and reentrant impulses will occur in the A-V node and reentry will be concealed. Furthermore, concealed reentry during antegrade Wenckebach cycles may be more common due to the fact that, once the requisite antegrade A-V nodal delay is achieved, the reentrant impulse must return to the atria in a retrograde direction. Since retrograde conduction is slower than antegrade conduction the possibility that the atrial pacemaker will capture the atria in advance of the reentrant impulse is again greater.

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