The Gap Phenomena During Retrograde Conduction in Man

By Masood Akhtar, M.D., Anthony N. Damato, M.D., Antonio R. Caracta, M.D., William P. Batsford, M.D., and Sun H. Lau, M.D.

SUMMARY

Ventricular refractory period studies were performed in 12 consecutive and unselected patients using the ventricular extrastimulus method \( V_2 \) at basic ventricular cycle lengths \( V_1, V_3 \). In six of 12 patients two types of retrograde gaps occurred. At relatively long \( V_1, V_3 \) intervals, ventriculo-atrial (V-A) conduction failed and then resumed at shorter \( V_1, V_3 \) intervals. The initial sites of retrograde block were the A-V node in two patients and the His-Purkinje system in four patients. In both groups, resumption of V-A conduction at shorter \( V_1, V_3 \) intervals occurred because of retrograde delay within the His-Purkinje system. Retrograde gaps differ from previously described antegrade gaps in A-V conduction: The site of initial block in A-V gaps is the His-Purkinje system and resumption of A-V conduction occurs at shorter \( A_1, A_2 \) intervals because of proximal delay in the A-V node (type I) or delay in the proximal His-Purkinje system (type II). In V-A gaps the site of initial block may be either the A-V node or the His-Purkinje system and resumption of V-A conduction always occurs due to delay within the distal His-Purkinje system. A common feature of both A-V and V-A gaps is the fact that delay of the more premature impulses allows time for previously refractory areas to recover excitability and both can be functional in nature. Only one of the 12 patients had both A-V and V-A gaps in conduction. Retrograde gaps in V-A conduction are more commonly observed than A-V gaps.

Additional Indexing Words:

- Atrioventricular node
- His-Purkinje system
- Purkinje myocardial junction

The GAP PHENOMENON in atrioventricular (A-V) conduction has been previously described in both canine and human hearts. As originally described by Moe et al., the term "gap" was used to define a zone within the cardiac cycle during which premature atrial impulses failed to evoke ventricular responses. Atrial impulses outside that zone, however, maintained conduction to the ventricles. Clinically, two types of antegrade gap phenomena (arbitrarily designated as types I and II) have been described and characterized electrophysiologically. Common to both types of gap phenomena are the following features: 1) within the "gap" zone premature atrial impulses (A2) block within some portion of the His-Purkinje system (HPS) and 2) resumption of A-V conduction results when more premature atrial impulses encounter sufficient conduction delay proximal to the site of initial block.

The A-V node is the site of proximal delay in type I gap as indicated by longer \( H_1, H_2 \) intervals of the conducted beats during resumed A-V conduction compared to prior blocked beats. In type II gap, however, the \( H_1, H_2 \) intervals of the conducted beats are shorter than previously blocked beats, indicating that the site of delayed conduction is below the recording site in the His bundle. The longer \( H_3, V_4 \) intervals of the conducted beats are consistent with delay of the premature impulse within the proximal HPS. The purpose of this report is to describe the occurrence of gap phenomena during retrograde conduction, to illustrate some differences between the antegrade and retrograde forms of these phenomena, and to further emphasize that gaps in conduction are seen in a setting in which a distal site of refractoriness exists and conduction is resumed when more premature impulses are delayed at any site proximal to the initial site of the block.

Methods

Right heart catheterization was performed in 12 patients in the nonsedated, postabsorptive state. All patients were...
advised of the nature of the study, and a signed consent was obtained. After administering local anesthesia, a tripolar electrode catheter was percutaneously introduced into a femoral vein and fluoroscopically positioned in the region of the tricuspid valve. Electrical activity of the low interatrial septum, His bundle, and ventricle was recorded as previously described. The extrastimulus method, was used to determine the functional properties of the atroventricular conduction system. Using a digital stimulator capable of delivering rectangular impulses of 1.5 msec duration and adjustable milliamperage, the right atrium or right ventricle was paced at a basic cycle length (A1, A2, or V1, V2) and following every eighth basic driven beat a premature impulse (A2 or V2) was introduced at progressively decreasing (5-10 msec) intervals until refactoriness was encountered in either the atrial or ventricular muscle. During retrograde refractory period studies the minimum milliamperage (< 1 ma) which allowed reliable ventricular capture was used. Refractory period studies during antegrade and retrograde conduction were compared at the same basic cycle lengths.

**Definition of Terms**

**Antegrade Conduction**

The A-H interval, measured from the beginning of low atrial electrogram to the beginning of the His bundle deflection, was taken as an approximation of A-V nodal conduction time (normal A-H for our laboratory is 60–140 msec). The H-V interval represented His-Purkinje conduction and was measured from the onset of the His deflection to the onset of ventricular activation (normal for our laboratory 30-55 msec).

**Antegrade refractory periods**

See reference 11.

**Effective refractory period (ERP) of the atroventricular (A-V) conduction system**

The longest A1, A2 interval where A2 fails to evoke a ventricular response.

**ERP of the atrium**

The longest S1, S2 interval where S2 does not cause an atrial depolarization.

**ERP of the A-V node**

The longest A1, A2 interval at which A2 does not conduct to the bundle of His.

**ERP of the His-Purkinje system (HPS)**

The longest H1, H2 interval where A2 blocks within the HPS.

**Functional refractory period (FRP) of the atroventricular (A-V) conduction system**

The shortest V1, V2 interval in response to a given range of A1, A2 intervals.

**FRP of the A-V node**

The shortest H1, H2 interval in response to two successive atrial impulses both propagated through the A-V node.

**FRP of the His-Purkinje system**

The shortest V1, V2 interval in response to two successive atrial impulses, both propagated through the bundle of His.

**Retrograde conduction**

The onset of induced ventricular depolarization was measured from the corresponding stimulus artifact. Ventriculo-atrial intervals were measured from the corresponding stimulus artifact to the onset of low atrial electrogram.

**Retrograde refractory period measurements**

The retrograde His deflection for the basic drive beats during 1:1 V-A conduction was obscured by the ventricular electrogram and could not be identified. Data from experimental studies indicate that for the basic ventricular drive beats the interval between the stimulus artifact and the retrograde His deflection is constant. Thus, H1 was taken from the onset of ventricular activation of the last beat of the basic drive (V1). During ventricular premature stimulation, the retrograde His deflection emerged from the ventricular electrogram and was identified by its morphology and expected physiologic behavior. For purposes of comparison, V1, H1 can be used interchangeably with H1, H2 intervals, since the former interval always exceeds the latter by a constant amount. The following definition of terms during retrograde refractory period studies applies to conduction through the normal pathways in the absence of functional bypass tracts.

**Effective Refractory Period (ERP) of the Ventriculo-atrial (V-A) Conduction System**

The longest V1, V2 interval at which V2 fails to propagate to the atria.

**ERP of the A-V Node**

The longest V1, V2 interval at which the retrograde His bundle deflection of the premature beat (H2) is not followed by atrial depolarization.

**ERP of the HPS**

The longest V1, V2 interval at which the premature impulse blocks within the HPS. This can be determined only if the retrograde His bundle deflection of the premature beat is clearly identifiable prior to the blocked beats.

**ERP of the Ventricular Myocardium**

Longest S1, S2 interval at which S2 does not evoke a ventricular response.

**Functional Refractory Period (FRP) of the V-A Conduction System**

The minimum interval between two successive atrial responses (A1, A2), both propagated from the ventricle.

**FRP of the A-V node**

The shortest A1, A2 interval in response to two successive retrograde impulses, both propagated from the His bundle.

**FRP of the HPS**

The shortest V1, V2 interval in response to any V1, V2 intervals.
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Results

Twelve patients were studied, all of whom demonstrated 1:1 ventriculo-atrial conduction at one or more ventricular paced cycle lengths. During programmed premature ventricular stimulation studies, retrograde gap phenomena were consistently seen in six of the 12 patients. Only one of these six patients also demonstrated a gap during antegrade conduction. The remaining six patients did not demonstrate gap phenomena during either antegrade or retrograde conduction. Essential clinical and electrophysiologic data on all patients who demonstrated retrograde gaps are presented in table 1. During retrograde refractory period studies no significant effect from sympathetic stimulation occurred, as indicated by lack of appreciable changes in sinus escape intervals, sinus rates, or conduction time of sinus beats (A-H interval), when ventricular pacing was periodically interrupted. In patients with retrograde gaps, as the V1 V2 intervals were progressively decreased, a zone was encountered during which premature ventricular depolarization failed to evoke a retrograde atrial response. Ventriculo-atrial (V-A) conduction was re-established when the V1 V2 intervals were shortened further. In all instances it was possible to define the site of the block of the premature ventricular beats.

The following results from three patients are representative of our findings. Figures 1 and 2 are taken from the same patient and demonstrate the characteristic features of V-A conduction which underlie the retrograde gap phenomenon. Figure 1 shows sinus rhythm (panel A) and 1:1 retrograde conduction (panel B) during ventricular pacing at a cycle length of 500 msec. Note the high to low sequence of atrial activation during sinus rhythm and the low to high relationship of atrial activation during 1:1 retrograde conduction.

Figure 2 illustrates the effects which retrograde conduction delay within the HPS has upon retrograde A-V nodal conduction during progressive premature stimulation of the ventricles. The basic ventricular cycle length (V1 V1) is 550 msec in all panels and at a V1 V4 interval of 280 msec (panel A), V2 conducts retrogradely to the atrium and encounters delay below the His bundle (V2 H2 : 170 msec) as well as in the A-V node (H2 A2 : 180 msec). The arrival time of V2 at the A-V node relative to preceding activation of the A-V node as measured from V1 (V1 H2 interval) is 450 msec. On decreasing the V1 V2 interval to 250 msec (panel B), V2 reaches the A-V node earlier (V1 H2 : 425 msec) and delays further within the A-V node (H2 A2 : 230 msec). An even earlier premature impulse (panel C) results in marked delay below the His bundle (V2 H2 : 220 msec). This infra-His bundle conduction delay results in the later arrival of the premature ventricular impulse at the A-V node (V1 H2 : 450 msec) compared to panel B. The V1 H2 and H2 A2 intervals in panels A and C are the same in spite of the fact that V1 V2 interval in panel C measures 50 msec less.

Although no gap in V-A conduction was seen in this patient, the tracings in figure 2 emphasize the way in which proximal retrograde conduction delay encountered by a premature impulse facilitates distal conduction simply due to its late arrival at that area.

Figure 3 illustrates one type of gap in retrograde conduction in which the site of initial retrograde block was within the A-V node and upon decreasing the ventricular coupling interval resumption of V-A conduction occurred because of proximal retrograde delay within the His-Purkinje system. In panels A-E, the V1 V4 interval is progressively decreased. At a V1 V4 interval of 360 msec (panel B) V2 fails to conduct to the atria. The site of retrograde block, as will be evident subsequently, was the A-V node. Upon further decreasing the V1 V2 interval (panel C) the retrograde

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<th>Age</th>
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<th>Gap in V-A conduction</th>
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Table 1

Abbreviations: ASHD = atherosclerotic heart disease; NHD = no heart disease; A-V = atrioventricular; V-A = ventriculo-atrial; MI = myocardial infarction; RBBB = right bundle branch block.

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Panel A shows high to low sequence of atrial activation during sinus rhythm. The A-H and H-V intervals are 95 and 50 msec respectively. Panel B demonstrates 1:1 retrograde conduction when the right ventricle is paced at a cycle length (CL) of 500 msec. Activation of the atrium occurred in a retrograde fashion (low to high); ventriculo-atrial (V-A) time is constant and measures 135 msec. All values are in milliseconds. Tracings are standard leads I, II, III and V1, high right atrial electrogram (HRA), His bundle electrogram (HBE), and timelines recorded at 10, 100, and 1000 msec. S denotes stimulus artifact. The same abbreviations will be used in subsequent figures.

His bundle deflection emerges. At a V1 H2 interval of 440 msec or less retrograde block of V2 continued to occur within the A-V node. As shown in panel D, V-A conduction resumes when the V1 V2 interval was decreased to 310 msec. Because of retrograde His-Purkinje delay, the V1 H2 interval (445 msec) falls outside the ERP of the A-V node. Upon further decreasing the V1 V2 interval (panel E), retrograde A-V nodal block again occurred. Despite the additional retrograde delay within the His-Purkinje system (V2 H2 of 195 msec), the resultant V1 H2 interval of 435 msec is within the ERP of the A-V node.

Figure 4 is an example of a gap in retrograde conduction in which the initial site of retrograde block was within the His-Purkinje system and resumption of V-A conduction at shorter V1 V2 intervals occurred because of increasing delay in retrograde conduction within the His-Purkinje system.

Discussion

The period of gap in A-V conduction describes a zone in which early premature atrial impulses (A2) fail to conduct to the ventricles, whereas, at still closer coupling intervals A2 successfully propagates and evokes a ventricular response. In the two types of gap phenomena described in man (type I and II), the ERP of some portion of the HPS exceeds the FRP of the A-V node so that A2 initially blocks within the HPS at shorter A1 A2 intervals. Resumption of A-V conduction results from delay of A2 in the A-V node (type I gap) or within the proximal HPS (type II gap), allowing time for previously refractory tissue to recover excitability.

The results of this study show that gap phenomena can occur during V-A conduction as well. V2 may initially block in the A-V node when the ERP of the latter exceeds that of HPS. A-V nodal block of V2 is recognized when a retrograde His deflection (H2) is not followed by an atrial depolarization (A2). At even
shorter V1 V2 intervals, resumption of V-A conduction may occur if V2 encounters sufficient infra-His bundle delay such that it arrives at the A-V node when the latter is not effectively refractory. In this form of retrograde gap the V1 H2 intervals of blocked beats are shorter than those of conducted beats. Figure 3 demonstrates this form of gap phenomenon in V-A conduction. Schuilenberg and Durrer4 and Castillo and Castellanos18 have described similar zones where no V-A conduction occurred at a certain range of V1 V2 intervals while at shorter and longer coupling intervals V2 successfully propagated to the atria. The proposed site of block in these cases was the A-V node.

The second form of retrograde gap phenomenon was seen when the ERP of some portion of the HPS was longer than that of the A-V node. At shorter V1 V2 intervals conduction delay between the site of stimulation and area of initial block enables conduction of V2 through previously refractory tissue. The exact site of initial retrograde block within the HPS is difficult to determine in the intact human heart. Results of experimental studies have indicated that any one of several areas may be the site of maximum refractoriness and block, e.g., at the Purkinje-myocardial junction, within the distal HPS, within any portion of bundle branches, or within the bundle of His itself.16-22 Resumption of V-A conduction occurs with V2 of greater prematurity because conduction is delayed between the ventricular muscle and the initial area of block.

The gap phenomenon in retrograde conduction

Figure 3

Gap phenomenon in V-A conduction. The basic ventricular cycle length is constant at 500 msec, panels A through E, and the ventriculo-atrial (V-A) conduction time during the basic drive (V1, A1) measures 175 msec. Panel A demonstrates successful propagation of V2 to the atria. At a V1 V2 interval of 360 msec (panel B) V2 fails to evoke an atrial response. Due to insufficient infra-His bundle delay encountered by V2, the His bundle deflection is still buried within the ventricular electrogram. At closer V1 V2 intervals (panel C), the retrograde His bundle deflection (H2) is identifiable and is not followed by atrial activation, suggesting the A-V node as the site of retrograde block. Still shorter V1 V2 intervals (panel D) result in reestablishment of V-A conduction. Infra-His bundle conduction delay of V2 was sufficient to allow recovery of excitability by the A-V node by the time V2 arrived. At very close coupling intervals (panel E) V2 again blocks in the A-V node. Note the V1 H2 interval of conducted beat (panel D) is longer than the blocked beats (panel C and E). Panel E also shows a reference sinus beat with high to low sequence of atrial activation.

Figure 4

Gap phenomenon in retrograde conduction. As shown in panel A during a basic cycle length (V1, V2) of 700 msec, V2 conducts retrogradely to the atria with marked conduction delay below the His bundle (V2 H2; 235 msec). Further increasing the prematurity of ventricular depolarization to 350 msec causes the V2 to fail to depolarize the bundle of His. Retrograde block of the V2 within the HPS persisted up to a V1 V2 interval of 325 msec. At a V1 V2 interval of 320 msec, however (panel D), V-A conduction resumes. V2 H2 interval of 270 msec during resumed V-A conduction suggests further delay within the HPS.
differences from its antegrade counterpart in the following respects:

1) In both types of gap in A-V conduction the initial site of block of premature atrial impulses is within some portion of the HPS; in V-A gaps the initial site of block of premature ventricular impulses may be either above or below the His bundle.

2) During periods of resumed A-V conduction the site of delay of the conducted premature atrial impulses is within the A-V node in type I gap and within the proximal HPS in type II gap. In both forms of retrograde gap, the site of proximal delay, which allows resumption of V-A conduction, is within the His-Purkinje system.

Thus, the designation of type I and type II gap in atrioventricular conduction is not strictly applicable to retrograde forms of gap because the initial sites of block as well as the area of proximal delay during resumed conduction are different. It is apparent that unless areas of conduction delay and block are specifically defined, classification of gaps by numerical designations limits the broad concept of these phenomena. The basic underlying mechanism responsible for demonstration of gap phenomena is that the premature impulses initially block in some area and then resume conduction at shorter coupling intervals as a result of conduction delay more proximal to the area of initial block.

In this series of 12 patients, retrograde gaps were more commonly demonstrated (six of 12) than antegrade gaps (one of 12). There are several reasons for this difference:

1) An essential requirement for the demonstration of both type I and type II gaps in A-V conduction is that the ERP of the HPS exceed the ERP and FRP of the A-V node. In most patients this requirement during antegrade conduction is not achieved because a) the ERP of the A-V node exceeds that of the HPS (six of 12 patients in this study) or b) the ERP of the HPS is never reached due to progressive increase in A-H interval with progressive decrease in A1 A2 interval (five of 12 patients in this study). In contrast some retrograde gaps (two of five in this study) occurred when the ERP of the A-V node exceeded that of the HPS. Thus a long ERP of the A-V node favors the demonstration of retrograde gaps but limits the demonstration of antegrade gaps.

2) Some patients may demonstrate initial block within the HPS during antegrade conduction but neither type of gap can be elicited because the ERP of the A-V node is quickly reached on further increasing the atrial prematurity (i.e., the ERP of the A-V node and the HPS are nearly equal). In four of six retrograde gaps in this series where the site of initial block was within the HPS, the likelihood of achieving a delay proximal to the site of block was increased because the premature ventricular impulse was delivered almost directly into the HPS without an intervening A-V node.

3) Although not a limiting factor in this series of patients, atrial refractoriness may limit the demonstration of antegrade gaps in some patients by limiting the achievement of closer A1 A2 intervals. During retrograde conduction, however, refractoriness of ventricular muscle very rarely exceeds that of the HPS or the A-V node. Following the initial block of relatively late V2 in the HPS or the A-V node, a wider range of coupling intervals (V1 V2) is still available where V2 may delay more proximally (i.e., in the most distal parts of the HPS) and consequently conduct through previously refractory area.

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