Intraventricular Reentry with Narrow QRS Complex

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SUMMARY  Reentry within the His-Purkinje system (V₃ phenomenon) where the reentry pathway incorporates both bundle branches and the bundle of His is a frequent phenomenon during ventricular refractory period studies. In this form of reentry, both divisions of the left bundle branch function as a single limb and the reentrant beats (V₃) have either left bundle branch block or right bundle branch block pattern. In this report, we describe in three patients the occurrence of a new type of reentrant beat (V₃) whose characteristics suggested reentry within a circuit in which the retrograde limb of the reentrant circuit was constituted by one of the two divisions of the left bundle branch and the antegrade limb(s) by right bundle branch and the remaining division of the left bundle branch; i.e., the two divisions of the left bundle branch functioned as two separate limbs. We reached this conclusion because 1) reentry occurred within a narrow range of V₃, V₄ intervals and was dependent upon critical retrograde His-Purkinje conduction (V₃H₄) delays; 2) reentry did not occur when the V₃ impulse blocked retrogradely within the His-Purkinje system below the site of His bundle recording; 3) the QRS duration of V₃ was less than 90 msec; and 4) in two-thirds of the patients, the HV interval of V₃ was the same as that of sinus beats.

THE PHENOMENON of macroreentry within the His-Purkinje system wherein both bundle branches, the His bundle and the ventricular muscle are incorporated in the reentrant circuit has been described in the intact human heart.¹ In this form of reentry, during a constant paced ventricular drive a closely coupled premature ventricular complex (V₃) blocks retrogradely in the right bundle branch and propagates to the His bundle via the left bundle branch. If conduction of the V₃ impulse to the His bundle is sufficiently delayed, adequate time is available for recovery of the right bundle branch, which permits antegrade conduction resulting in reexcitation of the ventricles manifested by another ventricular complex, V₄, which has a left bundle branch block (LBBB) pattern.¹ ² ³ This means that the left bundle branch constitutes the retrograde limb and the right bundle branch the antegrade limb of the reentrant circuit. Recently, Akhtar et al.⁴ reported another type of reentrant beat, V₅, with a right bundle branch block (RBBB) pattern, in which the retrograde limb of the reentrant circuit was formed by the right bundle branch and the antegrade limb by the left bundle branch.

In this report, we describe in three patients the occurrence of a third type of reentrant beat whose characteristics suggested reentry in a circuit in which the retrograde limb of the reentrant circuit was constituted by one of the two divisions of the left bundle branch and the antegrade limb(s) by the right bundle branch and the remaining division of the left bundle branch.

Methods

Right-heart catheterization was performed with patients in the postabsorptive, nonedated state after informed consent was obtained. All cardiovascular drugs were discontinued at least 48 hours before the study. His bundle electrograms were recorded as previously reported using a tri- or quadrupolar electrode catheter.⁵ Additional electrode catheters were positioned in the high right atrium and right ventricle for recording local electrograms and for electrical stimulation. Atrial and ventricular stimulation was performed using a programmed digital stimulator that delivered rectangular, 1.5-msec pulses at twice diastolic threshold. Intracardiac electrograms were simultaneously displayed with ECG leads I, II and V₁ on a multichannel oscilloscope and recorded at a paper speed of 100 mm/sec.

Antegrade and retrograde refractory periods were determined at one or more basic cycle lengths (A₁A₁ or V₁V₁) using the extrastimulus methods.⁵ QRS duration of V₃ complexes was measured in all three recorded electrocardiographic leads and the longest of the three was taken as the representative measurement. The measurements were made and confirmed independently by each author.

Definition of Terms

S₄, V₄, H₁, and A₁ represent the stimulus artifact, ventricular electrogram, His bundle electrogram and atrial electrogram of the basic drive beat, respectively.

S₅, V₅, H₅, and A₅ represent the stimulus artifact, ventricular electrogram, His bundle electrogram and atrial electrogram of the premature complex, respectively.

Antegrade conduction intervals and refractory periods have been defined previously.⁷ Retrograde conduction intervals.⁵ The stimulus artifact (S) marked the onset of induced ventricular depolarization, and the SH interval was measured from S to the onset of the His bundle electrogram. The HA interval was measured from the onset of the His bundle electrogram to the beginning of low atrial electrogram. When S₅ resulted in more than one ventricular complex, the HV interval of subsequent complexes (H₅V₅) was measured from the onset of the His bundle electrogram to the earliest point of ventricular
activation on the ECG or the ventricular electrogram.

Critical $S_2H_2$ interval is defined as the shortest $S_2H_2$ required for reentry.

Zone of reentry refers to the range of $S_2S_2$ coupling intervals during which reentry occurs consistently.

Zone of $S_2H_2$ block is defined as the range of $S_1S_2$ intervals during which retrograde block of the $S_2$ impulse occurs proximal to the His bundle recording site. Such zones can be identified only if $H_2$ is clearly identified at longer $S_1S_2$ intervals before the blocked complex.

Retrograde refractory period measurements. The retrograde His deflection for both the basic drive complex ($V_1$) as well as premature complexes ($V_2$) introduced at long coupling ($S_2S_2$) intervals were obscured within their respective ventricular electrograms and could not be identified. Data from experimental studies indicate that for the basic ventricular drive complexes, the interval between the stimulus artifact and the retrograde His deflection is constant. Thus, $H_1$ was taken from the onset of ventricular activation of the last complex of the basic drive ($V_1$). During ventricular premature stimulation, retrograde conduction delay caused the $H_2$ deflection to emerge from the ventricular electrogram. $H_2$ was identified by its morphology and expected physiologic behavior. For comparison, $V_1H_2$ ($S_1H_2$) can be used interchangeably with $H_1H_2$ interval, because the previous interval always exceeds the latter by a constant amount.

Effective refractory period (ERP) of ventricular muscle is the longest $S_1S_2$ at which $S_2$ fails to evoke a ventricular response.

Functional refractory period (FRP) of the His-Purkinje system is the shortest $V_1H_2$ in response to any $V_1V_2$ intervals.

Results

Case 1

A 39-year-old man with mitral valve prolapse and paroxysmal atrial fibrillation and sinus pauses was referred for electrophysiologic studies. Cardiac findings were consistent with the diagnosis of mitral valve prolapse, which was confirmed by echocardiogram. The ECG and chest x-ray were normal.

Electrophysiologic Data

The AH and HV intervals, which measured 90 msec and 45 msec, respectively, were normal. No split His potentials were recorded. During incremental atrial pacing, atroventricular (AV) nodal Wenckebach block occurred at a rate of 170 beats/min. The corrected sinus node recovery time measured 720 msec, which was longer than the upper limit of normal (525 msec). During antegrade refractory period studies, the ERP of the atrium exceeded the ERP of the AV node and the His-Purkinje system. No atrial echo beats occurred during atrial refractory period studies.

During ventricular refractory period studies at a cycle length of 600 msec, retrograde conduction to the atria was present (fig. 1). A premature ventricular complex ($V_2$) delivered at a coupling ($S_1S_2$) interval of 370 msec (fig. 1A) conducted retrogradely to the atria, with a His-Purkinje conduction time ($S_2H_2$) of 155 msec and an AV nodal conduction time ($H_2A_2$) of 60 msec. At a closer coupling interval of 360 msec (fig. 1B), the $V_2$ impulse conducted to the bundle of His ($H_2$) with a longer $S_2H_2$ interval of 290 msec and resulted in a single reentrant beat ($V_3$). In this beat, the QRS duration measured in surface electrocardiographic leads was 90 msec and there was right-axis deviation. The HV interval of the reentrant beat ($H_2V_3$) measured 60 msec. $V_3$ also occurred at a shorter $S_2S_2$ interval of 350 msec (fig. 1C). At coupling intervals of 340–320 msec, the $V_2$ impulse blocked retrogradely below the His bundle recording site ($S_2H_2$ block) and was not followed by either $H_2$ or $V_3$ (fig. 1D). However, on further shortening the $S_2S_2$ interval to 310 msec (fig. 1E), $V_3$ resumed conduction to the His bundle with an $S_3H_3$ interval of 310 msec and again resulted in a reentrant beat ($V_3$). However, the QRS configuration of $V_3$ became that of complete LBBB pattern and the QRS duration was 150 msec. $V_3$ with LBBB pattern occurred at shorter $S_2S_2$ intervals and longer $S_2H_2$ delays up to the onset of ventricular muscle refractoriness.

Comment

$V_3$ caused by reentry within a circuit incorporating both bundle branches and the His bundle (bundle branch system) is expected to have a LBBB or RBBB pattern. A $V_3$ with a narrow QRS and right-axis deviation that occurred within a narrow range of $S_2S_2$ intervals and was dependent upon critical retrograde His-Purkinje conduction delays may be explained as follows: The $V_2$ impulse encounters retrograde block in both the right bundle branch and the anterior division of the left bundle branch and conducts retrogradely via the posterior division of the left bundle branch with subsequent reexcitation of the ventricles (antegrade) simultaneously via the right bundle branch and anterior division of the left bundle branch. This sequence of activation would result in a posterior hemiblock pattern in which Q waves in leads 2 and 3 would be expected. The absence of a Q wave in lead 2 in this patient may be due to a slight conduction delay in the left anterior division of the left bundle branch with respect to the right bundle branch, which can alter the initial QRS vector but still produce a nearly simultaneous activation of both ventricles via right bundle branch and the anterior division of the left bundle branch. The prolonged HV interval of the reentrant beats may be explained by incomplete recovery of the right bundle branch and the anterior division of the left bundle branch. The LBBB pattern ($V_3$) seen in figure 1E is due to reentry within the bundle branch system where both fascicles of the left bundle branch function as a single limb.

Case 2

A 52-year-old man with mitral valve prolapse and paroxysmal atrial tachycardia was referred for evalu-
tion. Cardiac physical findings were consistent with the diagnosis of mitral valve prolapse. The ECG and chest x-ray were normal.

Electrophysiologic Study

The AH and HV intervals, which measured 115 and 45 msec, respectively, were within normal limits. No split His potentials were recorded. On incremental atrial pacing, AV nodal Wenckebach block occurred at 130 beats/min. During antegrade refractory period studies, the ERP of the AV node exceeded the ERP of the atrium and that of the His-Purkinje system. Short bursts of sinus node reentrant tachycardia were induced during atrial refractory period studies.

During ventricular refractory period studies at a cycle length of 650 msec, retrograde conduction to the atria was absent during the basic drive (fig. 2). A premature ventricular complex (V₂) introduced at a coupling (S₁S₂) interval of 340 msec (fig. 2A) conducted retrogradely to the His bundle (H₃) with an S₁H₄ interval of 240 msec and resulted in a reentrant beat (V₃) with a LBBB pattern. The H₂V₃ interval measured 70 msec. At an S₁S₂ interval of 330 msec, the V₂ impulse encountered S₂H₂ block and V₃ was not followed by either H₄ or V₄ (not shown in the figure). However, on further shortening the S₁S₂ to 320 msec (fig. 2B), V₃ resumed conduction to the His bundle with a longer S₂H₂ interval of 320 msec and was followed by V₄ with a QRS duration of 85 msec and right-axis deviation. The H₃V₄ interval measured 45 msec. At a shorter coupling interval of 310 msec, the V₂ impulse blocked retrogradely in the His-Purkinje system (not shown in the figure). However, on further decreasing the S₁S₂ interval to 300 msec (fig. 2C), V₃ resumed conduction to the His bundle and again resulted in a V₄ that had a LBBB pattern. The S₂H₂ and H₁V₃ intervals measured 335 and 55 msec, respectively. The LBBB pattern V₃ continued to occur at shorter S₁S₂ intervals until the onset of the ERP of the ventricular muscle.

Comment

The mechanism of V₃ with narrow QRS and right-axis deviation is the same as in the preceding case. The H₁V₃ interval of 45 msec, which is the same as the HV interval of sinus beats, is consistent with this type of reentry because reexcitation of the ventricles by the V₂ impulse begins while it is on its way to the His bundle.

![Figure 1. Intraventricular reentry with narrow QRS complex. The records are organized in each panel from top to bottom: ECG leads 1, 2 and V₁, and electrograms from the high right atrium (HRA) and the His bundle (HBE). Time lines (T) are 40 msec apart. The right ventricle is paced from the outflow tract at a basic cycle length (BCL) of 600 msec. During the basic drive, retrograde conduction to the atria is present. A) A premature beat (V₂) introduced at an S₁S₂ interval of 370 msec conducts to the atria (A₁) with an S₂H₂ interval of 155 msec and an H₆A₂ interval of 60 msec and a sinus escape beat follows. B) At a shorter S₁S₂ interval of 360 msec, the V₂ impulse propagates to the bundle of His with a longer S₁H₃ interval of 290 msec, and V₃ is followed by another beat of ventricular origin (V₄) that has a QRS duration of 90 msec. The H₄V₅ interval is 60 msec. C) Narrow QRS V₅ occurred at a shorter S₁S₂ and longer S₂H₂ interval. D) On further shortening the S₁S₂ interval to 340 msec, the V₅ impulse blocks retrogradely below the site of His bundle recording (S₂H₂ block). S₂H₂ block continued to occur up to an S₁S₂ interval of 320 msec. E) At an S₁S₂ interval of 310 msec, the V₅ impulse resumes conduction with a longer S₂H₂ interval and again results in V₆. However, the QRS configuration of V₆ is now that of left bundle branch block (LBBB) pattern. LBBB pattern V₆ occurred at shorter coupling intervals up to the point of ventricular muscle refractoriness.](http://circ.ahajournals.org/content/64/4/643.f1)
and right bundle branch. The LBBB pattern V₃ seen in figures 2A and 2C is due to reentry within the bundle branch system, as previously described.¹⁻⁴

Case 3

A 51-year-old man with persistent sinus bradycardia and dizzy spells was referred for electrophysiologic studies. Physical examination, ECG and chest x-ray were normal.

Electrophysiologic Data

The AH and HV intervals were normal and measured 105 and 40 msec, respectively. No split His potentials were recorded. During incremental atrial pacing, AV nodal Wenckebach block was observed at a rate of 140 beats/min. Sinus node recovery times were normal. During antegrade refractory period studies, the ERP of the AV node exceeded the ERP of the atrium and the His-Purkinje system. No atrial echo beats were noted during atrial refractory period studies.

During ventricular refractory period studies at a cycle length of 800 msec, retrograde conduction to the atria was present (fig. 3). A premature ventricular complex (V₃) introduced at an S₁S₂ interval of 300 msec (fig. 3A) conducted retrogradely to the His bundle with an S₂H₂ of 260 msec, and V₂ was followed by a reentrant beat (V₄) in which the QRS complex duration was 85 msec and the axis was deviated superiorly. The HV interval of V₃ measured 40 msec. The V₂ impulse encountered S₂H₂ block between S₁S₂ intervals of 290–270 msec (not shown in the figure). At a shorter coupling interval of 260 msec (fig. 3B), the V₂ impulse resumed conduction to the His bundle with an S₂H₂ of 260 msec and resulted in a reentrant beat (V₄) that had a LBBB pattern. The H₂V₃ measured 50 msec. V₃ was followed by an AV nodal reentrant beat. LBBB pattern V₃ continued to occur at shorter coupling intervals up to the point of ERP of the ventricle.

Comment

In contrast to the previous two cases, the V₂ impulse in this case retrogradely conducted via the anterior division of the left bundle branch with subsequent antegrade activation of the ventricles simultaneously via the right bundle branch and posterior division of the left bundle branch, resulting in V₃ with narrow QRS and left-axis deviation. The LBBB pattern V₃ is due to reentry within the bundle branch system as previously described.¹⁻⁴

Discussion

Reentry within the His-Purkinje system as originally reported is usually limited to a single ven-
atrial beat with a LBBB configuration. Recently, Akhtar et al. described both LBBB and RBBB pattern reentrant beats in two of 13 patients who had reentry within the His-Purkinje system. Using simultaneous recordings of the His and right bundle, these workers analyzed the sequence of His bundle and right bundle activation preceding both types of reentrant beats and reported that the His bundle was activated earlier than the right bundle preceding V₃, displaying a LBBB pattern. The reverse sequence of His-right bundle activation was observed preceding V₃, displaying a RBBB pattern (i.e., R₅ preceded H₂). The QRS duration of both types of reentrant beats was greater than 120 msec and the HV intervals were longer than those of sinus beats.

The findings in our patients show the occurrence of reentrant beats with a narrow QRS complex (≤ 90 msec). Because only three electrocardiographic leads were recorded simultaneously we cannot exclude the possibility that other leads may have shown a wider QRS complex. In addition to the narrow QRS V₃, LBBB pattern V₃ was elicited in all three patients. The zone of reentry ranged from 10–20 msec for narrow QRS V₃ and 30–100 msec for LBBB pattern V₃. The narrow QRS V₃ either preceded or occurred within the reentry zone of LBBB pattern V₃. As with other types of His-Purkinje reentrant beats, the occurrence of narrow QRS V₃ in the present study was dependent upon critical V₁V₂ and V₂H₂ intervals. However, in contrast to the LBBB and RBBB pattern V₃, where the HV interval is always longer than that of sinus beats, the HV interval of narrow QRS V₃ was the same as that of sinus beats.

The following observations suggested reentry within a circuit where one of the two divisions of the left bundle branch functioned as the retrograde limb and the right bundle branch and the remaining division of the left bundle branch functioned as the antegrad limt(s) as the basis of narrow QRS V₃:

1) Reentry consistently occurred within a narrow range of V₁V₂ intervals and was dependent upon critical His-Purkinje conduction (V₂H₂) delays.

2) Reentry did not occur when the V₂ impulse blocked retrogradely within the His-Purkinje system below the site of His bundle recording.

3) The QRS duration of V₃ was less than 90 msec in all three patients. This observation excludes reentry within the bundle branch system where both divisions of the left bundle branch function as a single limb because V₃ resulting from reentry within such a circuit must have a wide QRS.

4) V₃ displayed either right- or left-axis deviation, suggesting that, in addition to the right bundle branch, antegrad activation of ventricles occurred via one of the two divisions of the left bundle branch.

5) In two of three patients, the HV interval of V₃ was the same as that of sinus beats. As a rule, the HV interval of V₃ resulting from reentry within the bundle branch system where both fascicles of the left bundle branch function as a single limb is longer than that of sinus beats. In contrast, relatively short H₂V₃ intervals are consistent with the proposed reentrant circuit, because in this type of circuit, reentry to the ventricles is initiated while the V₃ impulse is on its way to the His bundle and right bundle branch.

Alternative but less likely possibilities that could explain our findings include reentry within the His bundle due to functional longitudinal dissociation of con-
duction,\textsuperscript{11-13} ventricular echoes due to AV nodal reentry,\textsuperscript{16,20} and fusion beats resulting from fusion between the His-Purkinje reentrant beat (LBBB or RBBB pattern V$_2$) and a ventricular premature complex originating in the left or right ventricle.\textsuperscript{21} On the basis of histologic studies of the human His bundle and deductive analysis of surface ECGs, James and Sherf suggested that functional longitudinal dissociation of conduction may occur in the His bundle.\textsuperscript{13,16} Normalization of chronic bundle branch block patterns by distal His bundle pacing suggested longitudinal dissociation in the His bundle as a basis of bundle branch block pattern on the surface ECG.\textsuperscript{22-26} However, in most patients with bundle branch block pattern secondary to longitudinal dissociation in the His bundle, the studies showed prolonged HV intervals or split His potentials or both.\textsuperscript{24,25} Although the possibility of intrahisian reentry due to functional longitudinal dissociation of conduction cannot be entirely excluded, it is unlikely because HV intervals were normal in all three patients and none had low amplitude or split His potentials.\textsuperscript{27,28} Further, the His bundle, which is remote from the stimulation site, will be an unlikely area of conduction delay in the absence of preexisting local conduction abnormalities.

AV nodal reentry is an unlikely mechanism of narrow QRS V$_2$ because the His bundle activation preceding V$_3$ occurred only once, while in AV nodal reentry, the activation of the His bundle would have to occur twice before the inscription of AV nodal reentrant ventricular echo. Further, the occurrence of narrow QRS V$_3$ in the absence of intact ventriculoatrial conduction and delayed AV nodal conduction makes AV nodal reentry a less likely mechanism. Fusion complexes giving rise to narrow QRS V$_3$ are also unlikely, because ventricular premature complexes were not noted in any of the patients before or during the electrophysiologic studies.

Figure 4 is a diagram of the proposed mechanisms for the occurrence of V$_2$ with both narrow and wide QRS complex. In panel A, the S$_2$ impulse conducts retrogradely via the posterior division of the left bundle branch and reexcites the ventricles via the right bundle branch and the anterior division of the left bundle branch. In panel B, the S$_2$ impulse conducts retrogradely via the anterior division of the left bundle branch and initiates reentry to the ventricles via the right bundle branch and the posterior division of the left bundle branch. Panels C and D show the mechanisms of V$_2$ with LBBB pattern.

The occurrence in the same patient of both narrow QRS and LBBB pattern V$_2$ dependent upon critical V$_2$/H$_3$ delays supports the concept that V$_2$ phenomenon represents a form of macroreentry where the bundle of His is an essential part of the reentrant circuit.\textsuperscript{1} However, the observations made in this study do not explain why V$_2$ with narrow QRS does not occur more frequently. In previous reports of reentry within the bundle branch system, the left bundle branch was treated as a single limb. We do not know whether the V$_2$ impulse reaches the His bundle by simultaneous conduction via both divisions of the left bundle branch (fig. 4C), or via only one of the two divisions of the left bundle branch with concealed conduction into the remaining division of the left bundle branch (fig. 4D). However, the former possibility is less likely, because
to function as a single limb, the two divisions of left bundle branch must have very similar refractory periods and recovery characteristics, an unlikely possibility. In contrast, if the $V_1$ impulse reaches the His bundle via only one division of the left bundle branch with different degrees of concealed conduction into the remaining division, the resulting $V_2$ could have a wide or narrow QRS complex with different axis orientation. Which division of the left bundle branch allows preferential propagation of $V_2$ to the bundle of His will depend, among other things, on the site of ventricular pacing.

The incidence of intraventricular reentry with a narrow QRS complex during ventricular refractory period studies is not known. The three cases reported in this article belong to a series of 45 patients who had reentry within the bundle branch system. This type of reentry may be missed because of narrow zones of reentry.

**Clinical Implications**

Sustained intraventricular reentry with narrow QRS complex would result in ventricular tachycardia that closely simulates the supraventricular tachycardia with aberrant conduction, because in both instances a His bundle deflection will precede the QRS complex by HV intervals that are equal to or longer than those of sinus beats. During such a tachycardia, if the atrial and His bundle activation are dissociated, intraventricular reentry is more likely. On the other hand, absence of AV dissociation during such an arrhythmia does not necessarily exclude ventricular tachycardia. As suggested by Wellens, termination of such an arrhythmia by a blocked premature atrial complex would be diagnostic of ventricular tachycardia. Because tachycardias caused by reentry within the bundle branch system require a critical degree of His-Purkinje conduction delay, the antiarrhythmic drugs that prolong the HV interval could possibly facilitate the initiation or maintenance of such an arrhythmia.

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**References**

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