Significance of His and Left Bundle Recordings from the Left Heart in Man

By Onkar S. Narula, M.D., Roger P. Javier, M.D., Philip Samet, M.D., and Lamberto C. Maramba, M.D.

SUMMARY

Eight patients were studied by simultaneous intracardiac recordings of the specialized conduction system from left and right heart. Five patients had normal A-V conduction, one had left axis deviation (LAD), and two had bundle-branch block. Bundle of His (BH) and right bundle (RB) recordings from the right heart were obtained and validated as previously described. In addition a bipolar electrode catheter was introduced into the root of the aorta and left ventricle via the right brachial artery. BH and left bundle (LB) electrograms were recorded at the level of the aortic cusps and just below the aortic valve, respectively. BH recordings from both sides could be temporally superimposed and were similar in onset and duration. In patients with normal A-V conduction the duration of these deflections was BH 15 to 20, LB 15, and RB 10 msec. The conduction time from the proximal LB to ventricular (V) activation (LB-V) ranged from 20 to 25 msec. The LB-V and RB-V conduction times from comparable points were similar and support the previous observations that interventricular septal activation occurs almost simultaneously on both sides. In the patient with right bundle-branch block (RBBB) and LAD with a slightly prolonged H-V time (50 msec), the delay was localized distal to the main LB (LB-V = 30 msec). During ectopic "ventricular," probably left bundle rhythm, retrograde activation of the BH was demonstrated. Aberration (RBBB) of the supraventricular impulse resulting from invasion of the RB by the preceding interpolated premature "ventricular" beat is suggested.

Additional Indexing Words:
Atrial pacing Bundle-branch block Bundle electrograms Electrocardiograms Left axis deviation Premature atrial beats Premature ventricular beats

RECENTLY several reports1–5 have described intracardiac recordings from the specialized conducting system of man during right heart catheterization. These studies have been very helpful in the analysis of A-V conduction by expanding and confirming some of the conclusions reached from the standard electrocardiogram. Some of the inherent limitations in the surface electrocardiogram have also been revealed.6–8

The purpose of the present study was to obtain electrograms of the specialized conduction system in man during left heart catheterization thereby expanding our understanding of A-V conduction in patients with normal A-V conduction and with various conduction defects.

Methods

Eight patients (ranging in age from 18 to 68 years) were studied during diagnostic right and left heart catheterization. Five patients exhibited normal atrioventricular and intraventricular conduction (table 1), one had left axis deviation,
### Table 1

**Summary of Data on the Eight Cases**

<table>
<thead>
<tr>
<th>No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>ECG interpretation</th>
<th>QRS duration (msec)</th>
<th>Heart rate (beats/min)</th>
<th>P-R (msec)</th>
<th>P-A (msec)</th>
<th>A-H (msec)</th>
<th>H-V* (msec)</th>
<th>L-V (msec)</th>
<th>R-V (msec)</th>
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<td>7</td>
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<td>110</td>
<td>70</td>
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<td>30 Digoxin, 0.25 mg/day</td>
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*H-V times from both right and left sides were essentially identical.

Abbreviations: LAD = left axis deviation; RBBB = right bundle-branch block; LBBB = left bundle-branch block; AS = aortic stenosis; AI = aortic insufficiency; MS = mitral stenosis; MI = mitral insufficiency.
HIS AND LEFT BUNDLE RECORDINGS

Anteroposterior views. (A) Usual positions of catheters for His bundle recordings during right (R) and left (L) heart catheterizations. RA = right atrial pacing catheter. Note the proximity of BH recording catheters from the two sides of the heart.

(B) Catheter (L) position during recordings from the left bundle. His bundle recording catheter (R) is in the right heart.

and two had bundle-branch block. Only one patient (case 8) was receiving cardiac medication. All patients were studied in the postabsorptive state and were premedicated with 100 mg of pentobarbital (Nembutal) administered intramuscularly 30 minutes prior to the study. Right bundle (RB) and His bundle (BH) electrograms were obtained during right heart catheterization as described previously. BH electrograms recorded from the right side were validated by BH pacing. The right brachial artery was isolated by cutdown in the antecubital area. A number 5 bipolar pacing catheter with ring electrodes (each 1 mm wide and 1 cm apart) was introduced into the brachial artery and placed in the root of the aorta, at the level of the aortic cusps, under fluoroscopic control and electrographic monitoring. The catheter tip was directed toward the right or posteriorly adjacent to the tip of the BH recording catheter in the right heart or to both sites (fig. 1A). A slight rotatory movement of the catheter tip, in the region of the aortic valve, enhanced the BH recordings from the left heart. Three standard ECG leads were recorded simultaneously with the bipolar electrograms (BE) from both left and right heart. The bipolar electrograms from both sides were recorded at filter settings of 40 to 200 Hz. All recordings were made at paper speeds of 100 and 200 mm/sec.

The BH electrogram from the left side was validated by atrial pacing and induced premature atrial beats in all patients in order to demonstrate lengthening of the A-H time, as the P-P interval was shortened. In addition, the recorded BH electrogram from the left side was validated by simultaneously recording the BH electrogram from the right heart (fig. 2).

The BH recording catheter from the left side was then advanced across the aortic valve into the left ventricle. A left bundle (LB) electrogram was obtained as the catheter tip was directed toward the interventricular septum just below the aortic valve (fig. 1B).

Definition of Terms

A-H time is the interval from the first rapid deflection of the A wave (recorded from the area of the A-V junction) to the first rapid deflection of the BH bipolar electrogram. His bundle to ventricular activation (H-V) time was measured from the BH deflection to the earliest ventricular depolarization recorded on either the intracardiac electrograms or the three standard ECG leads. Three ECG leads were recorded simultaneously with intracardiac recordings in an effort to delineate the earliest ventricular activation. LB-V and RB-V time are the intervals from the recording site of the LB and RB, respectively, to the earliest ventricular activation. The H-V time represents His bundle to ventricular activation time. The simultaneous recordings of BH, LB, and RB electrograms permit a further breakdown of the H-V time into its subdivisions. No major or minor complications were noted following this procedure for intracardiac electrographic recordings.

Results

His Bundle

BH electrograms from the left side were obtained at the level of the aortic cusps in all but one patient (case 8). In the latter, BH
recordings from the left side were obtained just across (below) the aortic valve.

The BH electrograms recorded from the two sides of the heart were similar in shape and duration and could be temporally superimposed (fig. 2). The time of onset of the BH deflection as well as the H-V time from both sides was usually identical. In an occasional instance, the onset of BH electrogram from the left side was delayed by 2 to 3 msec. This difference is within the range of error of measurement and is probably insignificant. The polarity of the BH electrogram from each side could be reversed by altering the polarity of the recording electrodes.

**Left Bundle**

Left bundle (LB) electrograms (fig. 3) were recorded in all patients except for patient 8 (fig. 4), a patient with left bundle-branch block (LBBB). The LB electrograms were obtained about 1.5 cm below the aortic valve with the catheter tip directed medially toward the interventricular septum. The LB electrograms ranged from 10 to 15 msec in duration and consisted of a rapid biphasic or triphasic deflection. The LB-V time ranged from 20 to 25 msec in all the five patients with normal A-V conduction and one with left axis deviation (LAD). In case 7 with right bundle-branch block (RBBB) and LAD, the LB-V time was 30 msec (fig. 5). Right bundle (RB) electrograms were obtained from the right side at corresponding sites to that of the LB. In the cases studied, the LB-V time was

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Figure 2

Bilateral His bundle (BH) recordings during atrial pacing (AP) at 160/min. Simultaneous recordings of bipolar electrograms (BE) from right (R) and left (L) heart and two ECG leads (L-1 and L-3) show Wenckebach type of A-V block. Following the dropped (first) A wave, the atrial impulses are conducted with progressive lengthening of the A-H interval from 180 to 260 msec before the next atrial impulse is blocked. The H-V time (40 msec) remains constant throughout in the conducted beats. The time of onset of BH deflections is identical and constant on both BE (right and left). PI = pacing impulse. BH is the bipolar His bundle electrogram. A and V are the bipolar atrial and ventricular electrograms, respectively, from the area of the A-V junction. P-P = the time interval between the two consecutive P waves. P-R = P-R interval. A-H = the time interval from the A wave to the BH deflection. H-V = the time interval from the onset of BH to the earliest ventricular (V) activation. Time lines = 1 sec in this and subsequent figures.
identical to the RB-V time recorded from a comparable site (fig. 6).

**Atrial Pacing**

As the heart rate was progressively increased by atrial pacing, there was progressive lengthening of the A-H time. The BH electrograms from both sides responded in a similar fashion and maintained their identical temporal relationship (fig. 2). At all observed heart rates the H-V, LB-V, and RB-V times as well as the shape of the QRS complexes, remained unchanged.

**Premature Beats**

**Premature Atrial Beats**

With shortening of the P-P interval (range, 500 to 300 msec) by induced premature atrial beats the A-H time lengthened while the H-V, LB-V, and RB-V times remained constant (fig. 5). Premature atrial beats in these cases did not result in aberration of the shape of the QRS complex.

**Premature Ventricular Beats**

Two interesting cases were studied. One patient (case 4) exhibited premature beats arising at or proximal to the recording site of the left bundle. The premature beats were possibly mechanically induced by the catheter. In figure 7, the third QRS complex is an interpolated premature "ventricular" beat as evidenced by the absence of a preceding atrial activity. The ventricular activation is preceded by an LB deflection at an interval of 25 msec (identical to the control LB-V time), indicating origin of the ectopic beat at or proximal to the recording site of the LB. The ECG (L-1)

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**Figure 3**

Case 5: His bundle and left bundle recordings. The 12 standard ECG leads are shown above. Simultaneous recordings of BE from right (R) and left (L) heart are shown together with three ECG leads (aVR, L-2, and aVF). The left bundle (LB) deflection precedes the V at an interval (LB-V) of 25 msec. The H-V time (50 msec) is measured from the BH recordings on the BE from the right (R) heart. A-A = the interval between two consecutive A waves.
Recordings from a patient (case 8) with left bundle-branch block (LBBB). The 12-lead ECG is shown above.

(A) Simultaneous recordings of BE from the aortic root (L) and right (R) heart with two ECG leads (L-1 and aVF). The time of onset of BH deflections on both right (R) and left (L) BE is identical. As the A-A interval is shortened by an induced (P1) premature atrial beat from 940 to 440 msec, the A-H time lengthened from 110 to 200 msec.

(B) Simultaneous recordings of BE from the left (L) heart in the region of the LB and BH from the right (R) heart. The absence of LB deflections on the BE (L) indicates that the LBBB is located proximal to the recording site. Note the marked diminution of A wave on the BE (L) due to catheter position in the region of the LB. The H-V time (70 msec) remains constant throughout on the BE (R).

shows absence of a Q wave and the presence of an S wave in the ectopic QRS complex which is 100 msec in duration. The atrial activity (second A wave) following the premature beat is probably sinus in origin and is not the result of retrograde conduction because the A-A interval is relatively constant. This second A wave is then conducted to the ventricles producing the fourth QRS complex with a right bundle-branch block (RBBB) pattern (QRS complex = 120 msec). The constant A-A, A-V and LB-V intervals suggest that the fourth QRS complex is a sinus conducted beat and is not a premature ventricular beat. The RBBB pattern is due to refractoriness of the RB caused by the preceding premature (third QRS complex) beat.

In case 5 simultaneous recordings of BH from right heart and LB from left heart showed the sequence of activation during A-V and ventriculo-atrial impulse transmission.
Figure 5

Case 7: His bundle and left bundle (LB) recordings in a patient with right bundle-branch block and left axis deviation. The H-V time is minimally prolonged, and the delay is localized distal to the recording site of the LB. The 12 standard ECG leads are shown on top. Simultaneous bipolar (BE) recordings of BH and LB from the right (R) and left (L) heart, respectively, together with three ECG leads (L-1, aVF, and V1). The H-V time (50 msec) is minimally prolonged and this prolongation is due to increased LB-V (30 msec) time with a normal conduction time from the BH to the proximal LB (20 msec). As the P-P interval was shortened from 1030 to 350 msec by an induced (PI) premature atrial beat, the A-H time lengthened from 90 to 160 msec. The LB-V and H-V times remained unchanged.

Discussion

Previous studies9,11 have described intra-cardiac recordings of the specialized conduction system from the right heart and permitted breakdown of the P-R interval into three segments, that is, (1) intra-atrial conduction time (P-A), (2) conduction time through the A-V node (A-H), and (3) conduction time from the onset of the His bundle deflection to the earliest onset of ventricular activation (H-V). The H-V interval represents the sum total of conduction time through the BH, both bundle branches, and peripheral Purkinje network. In patients with abnormal H-V time further localization of conduction delay within the His-Purkinje system (HPS) has been limited to only a few cases during right heart recordings. For example, recording of a “split
Figure 6

Case 4: Recordings of LB and right bundle (RB) from comparable areas in the left and right heart, respectively.

(A) Simultaneous recordings of BE from right (R) side and three ECG leads (L-1, L-2, and L-3). RB deflection precedes the ventricular activation at an interval (RB-V) of 25 msec.

(B) Simultaneous recordings of BE from left (L) side and three ECG leads show LB electrogram preceding the V at an interval (LB-V) of 25 msec identical to RB-V time.

BH" or an abnormally prolonged BH deflection in patients with a narrow QRS complex has helped to localize the defect to the main BH. However, in the majority of the patients with abnormal QRS complexes and prolonged H-V time, precise localization of delay in the HPS (BH, bundle branches, and peripheral Purkinje network) has not been possible. In this study the intracardiac recordings from both sides of the heart permit the measurement of conduction time from the BH to the proximal left (probably main stem) and right bundle branches, as well as from the bundle branches to the ventricle.* Conduction defects within the HPS can thus be localized in the BH, proximal or distal to mainstem LB (fig. 4), and proximal or distal to the recording site of RB.

A prolonged H-V time in some patients with RBBB and LAD8 may be due to a delay localized within the BH, mainstem LB, in the two subdivisions of LB, or even more distally in the peripheral Purkinje network along with RBBB. In patients with complete heart block localized distal to the BH by right heart

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*It should be added that the positive differentiation between recordings from the anterior and posterior division of the LB is not possible in man at this time. Differentiation based on the position of the recording catheter tip is not valid in view of variations of size, position, and rotation of the heart.

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Figure 7

Case 4: Invasion of the right bundle branch by a premature "ventricular" beat producing aberration (right bundle-branch block) in the succeeding supraventricular impulse. The 12 standard ECG leads are shown above. Simultaneous recordings of BE from the left (L) side in the region of the LB and right (R) side at the A-V junction with three ECG leads (L-1, L-2, and L-3). BE (L) shows that each V is preceded by a LB deflection with a LB-V time of 25 msec. The BE (R) reveals that the third V deflection is premature and is not preceded by an A wave indicating its infra-atrial origin. In this beat (third) the duration of the QRS is abnormal (100 msec). The absence of a Q wave and presence of S wave in ECG lead L-1, control LB-V time (25 msec), and the absence of a prolonged atrioventricular time (A-V = 170 msec) in the succeeding beat, all indicate its infra-nodal origin proximal to the recording site of LB, probably in the LB at the bifurcation of the BH. The following supraventricular impulse (fourth QRS complex) is conducted with aberration of the right bundle-branch block type. This beat is probably not reciprocal because the A-A interval is relatively unchanged and the A-V time is not prolonged.

recordings, the recorded deflection labelled as BH may in reality be an RB electrogram. In these cases, the potential error may be revealed by simultaneous left heart recordings. This error may be demonstrated by an earlier recording of either the BH from the root of the aorta, or the LB from the left ventricle than the "labelled BH" deflection in the right heart recordings. During induced premature atrial beats with aberrant conduction or block, the delay, or block, or both, may be localized in different segments of the HPS by simultaneous recordings of BH, LB, and RB. Likewise, refractory periods of the individual bundle branches may be evaluated (fig. 7).

Descriptions of the normal sequence of activation of the interventricular septum vary. According to Sodi-Pallares and Calder12 the first area to be depolarized is the middle part of the left septal surface followed by a spread of activation from left to right in an anterior direction. This view12 is accepted by the majority of the electrophysiologists with few
exceptions.\textsuperscript{13, 14} Scher\textsuperscript{14} has described the simultaneous arrival of activation at two sites of the septal surface. These two sites correspond to the distal portions of the superior and inferior divisions of the left bundle branch. A study in isolated human heart describes the onset of right ventricular septal surface 10 msec after the onset on the left side.\textsuperscript{15} Amer and co-workers\textsuperscript{16} have studied the sequence of activation of the right and left septal surfaces, under direct vision from multiple selected points, and have demonstrated that the arrival of earliest activity is almost simultaneous on both sides of the septum. Our results confirm the findings of the latter study\textsuperscript{16} by showing that the RB-V and LB-V times from comparable points are identical. This would therefore suggest together with previous observations\textsuperscript{17} that impulse arrival and ventricular activation occur simultaneously on the right and left sides.

We\textsuperscript{17} have observed that the H-V time remains constant in patients with normal QRS complex who intermittently develop left or right bundle-branch block. The absence of any delay in the earliest ventricular activation despite the transient development of bundle-branch block (especially left) indicates virtually simultaneous arrival of the impulse on both sides, that is, via the right and left bundle branches. Under these circumstances, a theoretical possibility may be considered, namely, that the fibers activating the two sides of the septum simultaneously originate directly from the main BH instead of from the bundle branches. The presence of a normal Q wave in standard ECG lead (L-1) may be predicted on the basis of a larger septal muscle mass supplied by the left side than the right, resulting in an initial rightwardly directed vector. During LBBB the dominant initial septal vector from the left side is absent, abolishing the Q wave in lead L-1. Previous electrocardiographic observations\textsuperscript{18, 19} in patients with Wenckebach type of block within the left bundle branch and a constant P-R interval, indirectly support the presented concept that simultaneous ventricular activation occurs from both bundle branches.

Utilization of His bundle stimulation for validation of BH recordings from the right side has been described previously by us.\textsuperscript{10} Similarly BH stimulation from the left heart (at the recording site of the BH) is theoretically possible and has actually been done in an experimental study from this laboratory.\textsuperscript{20} However, this was not attempted in the present study in order to shorten the duration of the procedure.

Figure 8 shows premature ventricular beats arising at, or proximal to the recording site of the LB, suggestive of left bundle rhythm. Simultaneous BH recordings from the right heart exhibit retrograde activation of the His bundle with reversed sequence of activation. In these ectopic beats the BH electrogram follows the LB deflection but precedes the ventricular activation. The spread of activation of the ectopic impulse from the proximal portion of the LB simultaneously in two directions, that is, to the BH and the ventricle, is demonstrated. This illustration further emphasizes the fallacy of interpretations based on intracardiac recordings from the right heart alone in patients with tachycardia and aberrant QRS complexes preceded by BH deflection. Such records may be misinterpreted as being supraventricular in origin.\textsuperscript{21}

Aberrant conduction of the supraventricular impulse, due to retrograde invasion in one of the bundle branches during supraventricular tachycardia, has been described in experimental\textsuperscript{22} and clinical studies.\textsuperscript{23} The longer functional refractory period in the RB as compared to the LB explains the greater frequency of RBBB pattern and transmission failure in the RB.\textsuperscript{24} Our findings are in agreement with the above observations and suggest invasion of the right bundle branch by a premature “ventricular” beat, rendering it functionally refractory. The interpolated premature “ventricular” beat in figure 7 arises at or proximal to the recording site of the LB probably in the upper portion of the LB. This ectopic impulse invades the RB in any of the three manners: (1) at its lower portion in a retrograde fashion; (2) at its upper end via retrograde transmission in the proximal LB.
and across the BH, and (3) by lateral transmission to the RB from the ectopic origin. The following sinus impulse arriving at the bundle branches, without any compensatory pause, finds RB functionally refractory and is conducted down the LB. The resultant QRS complex shows an RBBB pattern.

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