Concealed Intraventricular Conduction in the His Bundle Electrogram

HOWARD C. COHEN, M.D., IVAN D’CRUZ, M.D., AND ALFRED PICK, M.D.

SUMMARY Multiple areas of concealed intraventricular conduction are deduced on the basis of aftereffects observed in His bundle recordings. Electrocardiograms and His bundle recordings are presented from two patients with unstable bilateral bundle branch block, the instability of which depended on the interval at which ventricular depolarization was initiated by sinus or paced impulses. This circumstance allows postulation of 1) concealed transseptal retrograde penetration of the left bundle branch system; 2) concealed transseptal retrograde penetration of the right bundle branch system; 3) alternate beat Wenckebach phenomenon with two areas of block in the bundle branch system with concealed penetration of the proximal area; 4) concealed re-entry in the right bundle branch system during an H-V Wenckebach cycle with resetting of the sequence of 2:1 H-V block and return of the re-entry wave to the A-V node causing subsequent A-H block; 5) proximal 2:1 block and distal Wenckebach block producing only two consecutively blocked beats; and 6) infrahisian Wenckebach block with changes both in A-V conduction and QRS contour.

INTRAVENTRICULAR CONDUCTION that is concealed in the surface electrocardiogram (ECG) may also not be apparent in the His bundle electrogram (HBE), but can be recognized in the HBE, as in the ECG, by its aftereffects. The HBE permits localization of multiple areas of concealment with complex aftereffects within the His-Purkinje system.

From the Cardiovascular Institute, Department of Medicine, Michael Reese Hospital and Medical Center, and the University of Chicago, Pritzker School of Medicine, Chicago, Illinois. Supported by funds contributed by the Helen Fay Hunter Trust Fund, the Michael Reese Medical Research Institute Council, and the NHLBI Grant 17648, SCOR — Ischemic Heart Disease. Address for reprints: Howard C. Cohen, M.D., Chief, Heart Station, Cardiovascular Institute, Michael Reese Hospital and Medical Center, 29th Street and Ellis Avenue, Chicago, Illinois 60616.

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Concealed intraventricular conduction each time the \textit{P}-\textit{R} interval, left bundle branch block, and occasional blocked \textit{P} waves in leads \textit{V}_1, \text{V}_2, and \text{V}_3. Below a rhythm strip in lead \textit{II} shows 2:1 \textit{A}-\textit{V} block, at a sinus rate of 80.

The interval of 0.16 sec on a 12-lead ECG. At a rate of 75 beats/min, occasional blocked \textit{P} waves are evident in the leads \textit{V}_1, \text{V}_2, and \text{V}_3. At a faster sinus rate of 80 beats/min (bottom strip), a continuous 2:1 block develops, without change in the \textit{P}-\textit{R} interval (0.16 sec) or in the QRS-T configuration.

The record illustrated in figure 2 was obtained on the same day, when the sinus rate was 86 beats/min. Persistent 2:1 \textit{A}-\textit{V} block is present with the \textit{P}-\textit{R} interval now prolonged to 0.26 sec. QRS complexes show right bundle branch block (RBBB) and left anterior fascicular block (LAFB), which indicates that conduction is now via the main left bundle and its posterior fascicle. Figure 2 demonstrates, therefore, that the left bundle is capable of conducting, in contrast to figure 1, which suggests "complete" LBBB. Consequently, some postulation must be made for the persistent LBBB during the slower rate in figure 1. The most likely explanation is that the left bundle branch is maintained in a refractory state because of transseptal retrograde concealed conduction each time antegrade conduction occurs via the right bundle branch to the ventricles. Similarly, figure 1 shows that the right bundle branch can conduct despite the presence of persistent RBBB when the heart rate is faster, as shown in figure 2. Concealed conduction, either transseptal retrograde, or slow antegrade, must produce the persistent refractoriness of the right bundle branch seen in figure 2.

A portion of the HBE recorded from this patient is shown in figure 3, during atrial pacing (\textit{S} = pacing spikes). This record demonstrates a change from LBBB to RBBB with LAFB as the rate is increased. 2:1 H-V block manifests itself by conduction to the ventricles in beats numbered 1, 3, and 5, but block below the site of recording of the His bundle electrogram (H) in beats 2, 4, and 6. When the pacing rate is increased after beat 4 so that the H-H interval between conducted beats decreases from 1205 msec to 1190 msec, the H-V interval increases from 70 msec to 156 msec, and the ventricular contour changes from LBBB to RBBB with LAFB. The tracing suggests, therefore, that the right bundle branch, which becomes blocked as the cycle length shortens, has a longer refractory period than the left bundle branch system. However, the left bundle branch system has a longer

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{A 12-lead ECG shows sinus rhythm at a rate of 75 beats/min, a normal \textit{P}-\textit{R} interval, left bundle branch block, and occasional blocked \textit{P} waves in leads \textit{V}_1, \text{V}_2, and \text{V}_3. Below a rhythm strip in lead \textit{II} shows 2:1 \textit{A}-\textit{V} block, at a sinus rate of 80.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{At a rate of 86 beats/min, more rapid than in figure 1, 2:1 block persists, \textit{P}-\textit{R} intervals are long, and right bundle branch block and left anterior fascicular block are present.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Surface lead \textit{II} above and a His bundle electrogram below. \textit{H} = His bundle potentials, \textit{S} = atrial pacing spikes. 2:1 block below the bundle of His is present. As the pacing rate increases, sudden prolongation of H-V interval in beat 5 and a QRS contour change occur.}
\end{figure}
conduction time as manifested by the longer H-V interval of the last conducted beat.

A similar phenomenon occurs in a different manner in figure 4. The pacing rate is increased further with S-S intervals starting at 545 msec and finally reaching 440 msec. As the pacing rate increases, the conduction ratio changes from 2:1 to 3:1, so that beats numbered 1, 3, and then 6 are conducted, whereas 2, 4, and 5 are blocked below H. The increased ratio of block is a result of the more rapid pacing rate, such that two successive beats fall into the absolute refractory period of one or more areas of the His-Purkinje system. However, the 3:1 ratio allows a long interval between successively conducted beats 3 and 6, which enables the right bundle branch to recover. It then conducts more rapidly (H-V = 60 msec in beat 6) than the left bundle branch system (H-V = 180 msec in beats 1 and 3), again suggesting a longer refractory period but a shorter conduction time of the right bundle branch. As a result of these alterations in conduction, the ventricular contour changes from RBBB with LAFB back to LBBB.

A third mode of change of conduction, again from RBBB with LAFB to LBBB during 2:1 block, was recorded in an HBE (fig. 5), but now at a fixed atrial pacing rate of 110 beats/min. With each of the six consecutively numbered paced atrial impulses, a His bundle deflection follows the stimulus at a constant S-H interval, although the second, fourth, and fifth are not followed by ventricular complexes. The first and third impulses are conducted with a pattern of RBBB with LAFB and lengthening H-V intervals of 180 and 220 msec, respectively. Thus, two sites of infrahisian block might be present, one producing a 2:1 block (beats 2 and 4) and the other a 3:2 Wenckebach block of alternate beats, 1, 3, and 5. If beat 5 is blocked in a more distal area of Wenckebach type H-V block, concealed penetration must have occurred in this beat in the other, more proximal area of 2:1 H-V block. The sixth beat should be blocked, were the 2:1 pattern to continue. However, if both areas of block are in the left bundle branch system, the sixth beat could be conducted because it uses an alternate pathway, the right bundle branch, which has recovered after a long pause. In the first beat, conduction occurs through the proximal and distal left bundle branch. After reaching the ventricles, concealed transseptal retrograde conduction back into the right bundle branch takes place. Antegrade right bundle branch conduction in beat 1 is blocked because of a prolonged refractory state produced by a preceding concealed retrograde penetration into two cycles before, indicated by the dotted arrow at the left. Concealed retrograde conduction in beat 1 causes RBBB in beat 2, while the left bundle branch does not conduct because of a 2:1 antegrade block in a more proximal area. Beat 3 has antegrade block in the right bundle branch just as beat 1 did, because of a refractory period produced by concealed retrograde conduction two beats before (in beat 1). The proximal left bundle branch allows conduction, and the distal portion of the left bundle branch conducts with a delay as Wenckebach block progresses. Once again, concealed retrograde conduction into the right bundle branch occurs. The fourth beat is similar to the second. In the fifth beat both bundle branches are blocked, the right by the prolonged aftereffects of its earlier retrograde penetration in beat 3, the left because of completion of the Wenckebach cycle in a distal portion of the left bundle branch system, though concealed penetration of the proximal portion of the left bundle branch system still occurs. In the sixth beat, conduction through the right bundle branch becomes possible because concealed retrograde conduction into this bundle has not occurred for two successive cycles. The recovered right bundle branch conducts with a much shorter H-V in-

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**Figure 4.** Surface lead II above and His bundle electrogram below. As the pacing rate increases, 2:1 block below the bundle of His changes to 3:1 block, and QRS contour changes.

**Figure 5.** Surface lead II above, His bundle electrogram next, and ladder diagram below. H = bundle of His, BB = bundle branches, V = the ventricles, R = right bundle branch system, LP = proximal area of the left bundle branch system, and LD = distal area of the left bundle branch system. 2:1 block occurs in the LP (beats 2 and 4) and Wenckebach phenomenon in the LD (beats 1, 3, and 5).
terval than the left bundle branch system, so that LBBB pattern is in evidence (now with retrograde concealed conduction into the left BB).

At least four alternative interpretations of the rhythm strip in figure 5 are conceivable, and three of these are diagrammed in figure 6. In panel A, only one area of block, located in the distal bundle of His (intrahisian), is responsible for both the 2:1 block and the Wenckebach block. \(^1\) Beasts 2 and 4 fall into the markedly prolonged absolute refractory period (ARP) of this area, whereas beats 1 and 3 fall into the markedly prolonged relative refractory period and demonstrate progressive Wenckebach delay. A 3:2 Wenckebach cycle is completed with no conduction into the abnormal area of the His bundle in beat 5, so that beat 6 may conduct “out of turn” with reference to the 2:1 pattern. Intraventricular conduction proceeds through the right bundle branch which has recovered after the long pause.

In panel B, a similar explanation prevails except that the single area of block is in the left bundle branch system either in the main left bundle branch or in the posterior fascicle, with the anterior fascicle being constantly blocked. Again, beats 2 and 4 fall into the markedly prolonged absolute refractory period, and beats 1 and 3 into the markedly prolonged relative refractory period. The 3:2 Wenckebach cycle is completed with no conduction into the abnormal area of the left bundle branch system in beat 5, and resumption of conduction, “out of turn,” occurs in beat 6 via the recovered right bundle.

A third possible interpretation is depicted in panel C. Here, two areas of block are postulated. The proximal area is within the His bundle and is of a Wenckebach type, with a conduction ratio of 5:4. The second area of block is in the left bundle branch system where the conduction ratio is 2:1. In beat 6, conduction resumes because the Wenckebach series has been completed in the proximal area in beat 5, and has, thereby, protected the more distal area of 2:1 block, allowing it to recover “out of turn.” Finally, (not diagrammed) a similar circumstance would prevail if both the proximal Wenckebach type block and the distal 2:1 block were within the left bundle branch.

Another variant of concealed intraventricular conduction in the same patient is diagrammed in figure 7. All conducted beats now show LBBB and we postulate a single area of block with longitudinal dissociation located in the right bundle to explain the findings. In beat 1, conduction occurs through the right bundle branch, reaches the ventricles with

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**Figure 6.** Alternative diagrammatic analyses of the arrhythmia in figure 5. The abbreviations, the broken arrow to the left and the upward pointing arrows are the same as in figure 5. ARP = absolute refractory period. A and B each show one area of conduction abnormality responsible for 2:1 H-V block and the Wenckebach structure. In C, two areas of block are proposed.

**Figure 7.** The ladder diagram shows a 2:1 and a Wenckebach type block in the right bundle branch with re-entry occurring in beat 3.
an H-V of 55 msec, and causes transseptal retrograde depolarization of a portion of the left bundle branch. Antegrade block occurs in the left bundle branch because of a refractory period produced by transseptal retrograde penetration of this bundle branch two beats before, as indicated by the dotted arrow to the left.

In beat 2, block of the left bundle occurs as a result of the refractory period produced by retrograde penetration associated with beat 1. The right bundle branch is blocked because the abnormal area of conduction is still in the absolute refractory period. In the third beat, the left bundle branch is blocked for the same reason as in the first beat. Conduction now takes place through the right bundle branch in its markedly prolonged relative refractory period with progression of the Wenckebach cycle, producing a longer H-V of 198 msec. Thus, a type I H-V block on alternate beats is combined with 2:1 H-V block. The slow conduction represented by the H-V of 198 msec, longitudinal dissociation, and unidirectional block allow re-entry to occur in the right bundle branch (R') which proceeds back through the bundle of His and into the A-V node. This concealed retrograde re-entry produces a refractory period in the A-V node so that in beat 4 antegrade conduction does not reach the bundle of His, and thus, no H is seen in the HBE. The re-entrant His potential of beat 3 is lost in the ventricular deflection. In beat 5, the left bundle branch is blocked for the same reason as in beats 3 and 1. The right bundle branch is blocked because of completion of the Wenckebach cycle or as a part of the 2:1 block sequence that has been "moved up" by the re-entry in beat 3. Resumption of right bundle branch conduction in beat 6 is possible because of recovery after two cycles without penetration of this pathway.

**Patient 2**

A 62-year-old man was admitted with chest pain and the routine ECG disclosed right bundle branch block with posterior fascicular block. To delineate further his conduction abnormalities, we recorded an HBE, at rest and during atrial pacing. In figure 8, the atrial pacing rate is 171 beats/min (S-S = 350 msec). Each pacing spike is followed by an A wave, but only alternate A waves are followed by His bundle potentials and QRS complexes. Thus, 2:1 block occurs above the H. The contour of QRS complexes in leads I, II, and V1 is compatible with right bundle branch block and possibly left posterior fascicular block. S-H intervals are long (330 msec), but H-V intervals are normal (50 msec). The bifascicular block pattern suggests that impulses arrive at the ventricles via only the anterior fascicle of the left bundle branch, which is capable of conducting at a normal velocity.

When the atrial pacing rate was decreased to 136 beats/min (S-S = 440 msec) (fig. 9), S-H block changes from the previous 2:1 to a Wenckebach type so that S-H intervals increase progressively from 340 msec in beat 1 to 590 msec in beat 6. His bundle potentials are associated with beats 1 through 6, whereas beat 7 is blocked above the bundle of His. The H following the A wave of beat 7 actually belongs to beat 6. Beat 8 again conducts to the His bundle. A-V block is also present below the bundle of His so that beat 1 is conducted to the ventricles, but beats 2 and 3 are not. The H of beat 3 occurs at a greater interval from the H of beat 1 than any H-H interval in figure 8, yet beat 3 of figure 9 does not conduct to the ventricles. This finding suggests that the depolarization of beat 2 not only reaches the bundle of His, but proceeds in a concealed fashion into the bundle branch system, being blocked at a relatively distal point. This concealed conduction produces block in beat 3 at a more proximal point. Block at this more proximal point allows recovery of the distal area so that beat 4 again conducts to the ventricles. Thus, 3:1 H-V block is present. Beat 5 is blocked but the 3:1 sequence is disturbed because beat 6 has such a long S-H interval that recovery of the bundle branch system occurs. However, it is the right bundle branch that recovers first so that the last QRS complex in this tracing has a pattern of left bundle branch block. The long H-V interval (240 msec) indicates that although the right bundle branch has a shorter refractory period, it has a longer conduction time than the left bundle branch system. Conduction via the right bundle branch also indicates that this pathway can be used when it is no longer refractory, and thus, it must have been kept regularly in a refractory state in figure 8, either by concealed slow antegrade conduction or concealed transseptal retrograde conduction.

When the pacing rate was slowed further to 119 beats/min (S-S = 505 msec) (fig. 10), S-H intervals become constant at 285 msec. However, H-V intervals increase from 215 msec in beat 1 to 300 msec in beat 3. Beat 2 is blocked below H. Thus, these observations suggest the presence of a 2:1 block and an alternate beat Wenckebach sequence involving beats 1, 3, and 5, the last of which is blocked below H, ending the Wenckebach series. Also, the long H-V interval of beat 3 (300 msec) is followed by block above the bundle of His in beat 4. When paced at this rate, S-H block occurs only after markedly prolonged H-V intervals. This block can be accounted for by concealed re-entry below the bundle of His.
which ascends into the A-V node causing S-H block of the next beat. In this tracing constant left bundle branch block is present. Nevertheless, other tracings show conduction through this bundle. Therefore, it must be kept refractory in figure 10 by concealed slow antegrade or concealed transseptal retrograde conduction. Also, just as in patient 1, the Wenckebach structure, or the subhisian re-entry, or both, disturb the 2:1 H-V sequence of block, i.e., beats 2 and 4 are blocked, but beat 6 is conducted. This figure duplicates, almost exactly, the finding in patient 1 (fig. 7), and demonstrates long refractory periods, longitudinal dissociation, concealed re-entry in the right bundle branch causing subsequent block above the bundle of His, and concealed transseptal retrograde or concealed slow antegrade conduction in the left bundle branch.

Discussion
Concealed A-V conduction in the heart has been studied for at least 81 years, was named by Langendorf in 1948, and was systematized by Langendorf and Pick in 1965. The concept of concealed intraventricular conduction was probably considered by Wilson and Herrmann in 1921, who suggested that conduction is manifest in electrophysiologic studies should not be termed “concealed,” even though it may be concealed in the surface electrocardiogram. If truly concealed, it reveals itself only by its effects upon subsequent events.

We have encountered several of the general forms of concealed intraventricular conduction outlined by Langendorf and Pick, including concealed transseptal retrograde intraventricular conduction (figs. 1–10), and concealed antegrade conduction into the bundle branch system (figs. 5, 6, and 9). In addition, we have suggested several specific variations not categorized by them, including antegrade concealed conduction through one of two areas of block within the intraventricular conduction system (fig. 5) and infrahisian re-entry occurring after long H-V intervals causing subsequent block above H. This re-entry ended infrahisian Wenckebach sequences and possibly reset the sequences of 2:1 infrahisian block, (figs. 7, 10). We also propose the possibility (figs. 6A, 6C) that intra-hisian block may explain several of our findings.

Concealed antegrade conduction of sinus beats into a proximal portion of the intraventricular conduction system must be postulated if antegrade block of a distal portion manifests itself, as in figure 5, by the change from 2:1 to 3:1 intraventricular block, or when expected conduction does not occur as in beat 3 of figure 9. Other reported indications of concealed antegrade intraventricular conduction include left bundle branch block dependent upon a specific time relationship to apparently blocked sinus P waves, and discharge of subsidiary ventricular pacemakers by apparently blocked impulses from above. Also, prevention of expected aberrant ventricular conduction when a short cycle follows a
long one, and exceptions to the "rule of bigeminy" may occur because of concealed shortening of the apparently long cycle.15

On the other hand, concealed retrograde intraventricular conduction may occur in the form of concealed transseptal retrograde conduction (figs. 1–10), re-entry after long H-V intervals (figs. 7, 10), or retrograde conduction with block secondary to concealed junctional and ventricular impulses,20–24 indicating parasystolic ones.25

The location of the pacemaker and the presence or absence of re-entry determine the direction of the concealed conduction. Thus, apparently blocked sinus beats are likely to produce antegrade concealed conduction, and apparently blocked ventricular beats are likely to produce retrograde concealed conduction. For example, Cohen et al.26 showed concealed retrograde conduction into the His bundle from paced ventricular beats in complete A-V block. However, re-entry reverses the direction of concealed conduction. Gupta and Haft27 showed re-entry to the His bundle associated with delay of retrograde conduction from spontaneous ectopic ventricular beats. The site of reflection for the re-entry was supraventricular, so that concealed His bundle re-entry was antegrade. Concealed retrograde re-entry occurring via the Purkinje-bundle branch system has been demonstrated a) after early paced HB beats that conducted aberrantly to the ventricles,4 b) after artificially premature atrial beats that produce functional RBBB,28 c) during tachycardias with functional right or left bundle branch block in patients with Wolf-Parkinson-White syndrome;29 d) in association with infranodal Wenckebach as reported here. His-Purkinje re-entry has been documented previously by atrial echoes30 rather than by the aftereffects of concealed conduction. The re-entry in our cases may terminate the infranodal Wenckebach series by a mechanism similar to that previously suggested for termination of Wenckebach series in the A-V node.31 Block of the final beat (fig. 7, beat 4 and fig. 10, beat 5) occurs because of collision of the antegrade and retrograde waves of depolarization in a common pathway.

The Wenckebach phenomenon below the His bundle32, 33 is ordinarily recognized by 1) changing QRS contour34, 35 or 2) changes in A-V conduction if an exclusive pathway to the ventricle is involved,48 such as the His bundle or a single conducting fascicle. In our figure 5, both of these occur because the "exclusive" pathway to the ventricles changes after the long pause, thereby producing the opposite bundle branch block pattern. This special circumstance has additional implications. The alternate beat Wenckebach phenomenon in figure 5 displays a maximum of two consecutively blocked beats. We are able to postulate a proximal 2:1 block and a distal Wenckebach block, which is contrary to the suggestion of Halpern et al.37 who indicated that the occurrence of two consecutively blocked beats is more compatible with a proximal Wenckebach block and a distal 2:1 block. Moreover, our analysis adds another dimension to the study of Besoain-Santander et al. of two areas of block during atrial flutter48 in which they postulated that a proximal 2:1 block and a distal Wenckebach block usually produce three consecutively blocked beats. The use of an alternate pathway (which does not contain the area of 2:1 block) by the final conducted beat (indicated by the change in QRS contour) gives credence to our postulation. Thus, ordinarily, the blocked beat ending a Wenckebach series is the second consecutively blocked beat when 2:1 block is also present. If the area of the Wenckebach block is proximal, it protects the distal area of 2:1 block, so that the third of three consecutive impulses is conducted, limiting the consecutively blocked series to two. If the Wenckebach block is distal, the more proximal area of 2:1 block in combination with a 3:2 distal block results in three consecutively blocked beats (proximally due to 2:1 block, distally due to Wenckebach, and again proximally due to 2:1 block). However, if this third beat can be conducted via a pathway not containing the 2:1 block, such as the right bundle branch in our case, the number of consecutively blocked beats may still be limited to two.

The changing QRS pattern seen in figures 3, 5, and 9, which represents the switching of exclusive pathways to the ventricles, also proves that apparently blocked pathways are capable of conduction and indicates that concealed transseptal retrograde penetration of the bundle branch system35, 36, 39–43 or slow antegrade conduction may keep apparently blocked bundle branches in a refractory state. The QRS pattern of complete bundle branch block frequently means only that the transseptal conduction time44 from the contralateral bundle branch is shorter than the conduction time of the apparently blocked bundle branch. The term complete bundle branch block, therefore, may frequently be a misnomer.

Thus, we have presented data that 1) support the concept of concealed transseptal retrograde penetration of the bundle branch system; 2) suggest concealed antegrade penetration of one of two areas of infranodal block; 3) allow postulation of proximal 2:1 block and distal 3:2 Wenckebach block with a maximum of two consecutively blocked beats; 4) suggest resetting of the sequence of 2:1 block by concealed intraventricular re-entry; 5) indicate that under special circumstances an infranodal Wenckebach sequence may display changes in A-V conduction as well as changes in QRS contour; and 6) show that infranodal delay of sinus or atrial paced beats may produce re-entry which causes A-H block. His bundle recordings contribute to the differentiation between concealed supraventricular and infranodal conduction, especially when the aftereffects of this conduction are multiple and complex.

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Correction

Nagaora and Katori: Circulation 52: 325, 1975. On page 329, line 14, the dosage 10^4 KIU/kg trasyol should read 10^4 KIU/kg. In figure 6, page 330, the signs of inequality at end circulation are reversed and should represent greater than 60 min.

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