Cardiac Arrhythmias Simulated by Concealed Bundle of His Extrasystoles in the Dog

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ABSTRACT
In 10 open-chest intact dog hearts, multiple close bipolar electrograms were obtained from various regions of both atria and the bundle of His. The bundle of His was also prematurely stimulated at varying coupling intervals following a sinus beat. At short coupling intervals, the bundle of His stimulus failed to propagate antegradely (no ventricular response) but did propagate retrogradely. Coupled bundle of His stimuli retrogradely concealed within the A-V node caused the next sinus impulse to be delayed or blocked. Types I and II second degree A-V block, 2:1 A-V block, and alternation of the P-R interval were simulated. An atrial (nonconducted) bigeminal rhythm was simulated when the bundle of His stimuli completely traversed the A-V node and completely (inverted P waves) or partially (fusion P waves) depolarized the atria.

KEY WORDS
- second degree A-V block
- coupled pacing
- alternation of P-R interval
- atrial electrograms
- concealed conduction
- retrograde conduction
- fusion P waves
- bigeminal rhythm

Concealed conduction refers to the incomplete or partial penetration of a cardiac impulse along the atrioventricular conducting system. Electrocardiographically, the effects of concealed impulses are reflected in the conduction and formation of subsequent impulses (1).

Studied on intact animal hearts and isolated cardiac tissue have demonstrated that concealment can occur within the A-V nodal and His-Purkinje systems (3-8). Studies in man have demonstrated that impulse propagation may be blocked proximal or distal to the bundle of His (9-11).

In 1947, Langendorf and Mehman described an unusual form of concealed conduction (12). In their analysis of two clinical electrocardiograms, the authors proposed that first and second degree A-V block was simulated by nonconducted (concealed) junctional premature systoles. In addition, it was proposed that when junctional premature systoles encountered antegrade block but were conducted retrogradely, blocked premature atrial systoles could be simulated. The purpose of the present report is to provide experimental evidence that His bundle extrasystoles can simulate types I and II second degree A-V block, high degree A-V block, nonconducted atrial extrasystoles and alternation of the P-R interval.

Methods
Thirty adult mongrel dogs weighing 15 to 35 kg were anesthetized with pentobarbital sodium, 30 mg/kg iv, and artificially ventilated. Each animal was placed on its left side and a thoracotomy was performed at the level of the fourth right intercostal space. A pericardiotomy was performed and the intact heart exposed. Close bipolar plunge wire electrodes were prepared by threading two fine Teflon-coated wires (0.005 inch diam) through a 22-gauge needle. The distal ends of wires were bent to form small hooks. Two sets of plunge wires were inserted into the bundle of His by a previously described technique (13). One set of wires was inserted...
used to record the electrical activity of the bundle of His, and the other set was used for electrical stimulation of the common bundle. Close bipolar atrial electrograms were also simultaneously recorded from the regions of the sinus node, Bachmann’s bundle, the right atrial appendage, the left atrial appendage, the posterior portion (body) of the left atrium and the coronary sinus vein near the os. All electrogram recordings were obtained at filter frequency settings of 40 to 500 Hz. A standard lead II electrocardiogram was simultaneously recorded. All records were taken on a multichannel oscillographic photographic recorder at paper speeds of 100 to 200 mm/sec. The bundle of His was stimulated with a battery-powered pacemaker that delivered impulses of 2-msec duration at approximately twice threshold. Coupled pacing of the bundle of His was achieved by triggering the impulse off the preceding sinus beat at varying coupling intervals.

**Results**

Bundle of His pacing above the sinus rate was accomplished in 30 different experiments. In all studies, bundle of His pacing was confirmed by noting that the interval between the stimulus artifact and the onset of the QRS complex (S-V interval) was the same as the interval from the His deflection to the onset of the QRS (H-V interval) of the sinus beats. In addition, the shape of the resulting QRS complexes was the same as the sinus beats. Similar criteria were applied when the bundle of His was paced in the coupled mode at long coupling intervals. As the coupling interval was progressively shortened, bundle of His stimulation resulted in aberrant ventricular conduction. In 10 of 30 studies, bundle of His pacing at the shortest coupling intervals resulted in failure of antegrade propagation of the impulse while retrograde conduction occurred. The results obtained in these ten studies form the basis of this report.

Figure 1 shows an experiment in which bundle of His stimulation simulated 2:1 A-V block. All atrial impulses originated from the region of the sinus node, as determined by the earliest point of atrial activation and the normal antegrade sequence of atrial activation. The A-A intervals were constant at 379 msec. The first, third, and fifth atrial beats were conducted to the ventricles with A-H and H-V intervals of 52 and 31 msec, respectively. Following each QRS complex, the bundle of His was prematurely stimulated at an H-S coupling interval of 223 msec. The bundle of His stimuli failed to propagate antegradely (no ventricular response). However, the premature His stimuli were conducted retrogradely and concealed in the A-V
Figure 2

A: Two sinus beats with A-H and H-V intervals of 80 and 33 msec, respectively.  
B: Constant bundle of His stimulation. The S-V interval is nearly the same as the sinus H-V interval and the resultant QRS complexes are the same as in A. During bundle of His pacing there is 1:1 retrograde conduction to the atria.

Same experiment as Figure 3. Coupled premature stimulation of the bundle of His at an H-S interval of 244 msec resulted in retrograde A-V nodal conduction and activation of the atria. Note the inverted P waves and altered sequence of atrial activation. SA denotes the retrograde conduction time from the stimulus artifact (S) to the low atrial septal electrogram (A). The vertical time lines represent 1000 msec.

node, which in turn caused block of the second and fourth atrial impulses. Continuous stimulation of the bundle of His at a coupling interval of 223 msec produced a constant 2:1 A-V block.

Figures 2 through 4, recorded from the same animal, demonstrate the variations in the sequence of atrial activation and the shape of the P waves resulting from premature stimulation of the bundle of His. Validation of His bundle pacing is presented in Figure 2. Panel A depicts two sinus beats with A-H and H-V intervals of 80 and 33 msec, respectively. In B, the bundle of His was paced at a constant rate. The S-V interval was approximately the same as the H-V interval of the sinus beats, and the shape of the QRS complexes was the same. Note the morphological and sequential changes in the atrial electrograms during retrograde conduction (B) as compared to antegrade conduction (A). Since the P wave occurred on the S-T segment of the standard ECG lead, its polarity cannot be easily determined.

Figure 3 is an example of an atrial (nonconducted) bigeminal rhythm simulated by bundle of His stimulation. The first, third, and fifth atrial impulses originated from the sinus node and were conducted to the ventricles with a constant A-H and H-V
Some experiment as Figures 2 and 3. The coupling interval for bundle of His stimulation was increased to 283 msec. The P waves are fusion P waves being activated in part by an impulse arising from the sinus node region and in part by the retrogradely conducted bundle of His stimulus. In this experiment, an atrial (nonconducted) bigeminal rhythm is simulated. The vertical time lines represent 1000 msec.

Bundle of His stimulation simulating type B second degree A-V block. All atrial impulses arise from the region of the sinus node and there is a normal sequence of atrial activation. The P-R intervals of the conducted beats are constant. Following the third QRS complex, a single premature bundle of His stimulus, delivered at an H-S interval of 165 msec causes retrograde concealed conduction and block of the fourth atrial impulse. The vertical time lines represent 1000 msec.

Note the antegrade sequence of atrial activation. Following each of these conducted beats, the bundle of His was prematurely stimulated at an H-S coupling interval of 244 msec. The premature stimulus failed to propagate antegraderly (no ventricular response) but was conducted retrogradely and depolarized the atria. Note the altered sequence of atrial activation and the inverted P waves. During retrograde activation of the atria, electrical activity was first recorded in the region of the low atrial septum (A), followed by the regions of the coronary sinus and Bachmann's bundle. In addition, the LAP electrogram preceded the RAA electrogram and there were morphological changes in most of the atrial electrograms. The ECG recording (lead II) reveals that the retrograde P waves were biphasic, consisting of a small positive component followed by a larger negative component.

In Figure 4, the H-S coupling interval was increased to 283 msec. At the longer coupling interval the atria were partially depolarized....
by the sinus node impulse and partially by the bundle of His impulse. The fusion P waves appear on the standard ECG as a deflection of very low amplitude. Note that for the fusion P waves the electrical activity recorded from the sinus node, Bachmann’s bundle, and right atrial appendage electrodes was the same as during sinus beats (A, Fig. 2), and there was an alteration in the sequence of activity from the low atrial septum (A) and coronary sinus region. The SN-SN intervals were constant at 495 msec, and the CS-CS intervals alternated between 462 and 528 msec.

Figure 5 demonstrates how a single properly timed bundle of His extrasystole can simulate (electrocardiographically) a type II second degree A-V block. In this example, the A-A (P-P) interval was constant at 323 msec. The P-R interval of the conducted P waves was constant as reflected in the constant A-H and H-V intervals of 40 and 30 msec, respectively. Stimulation of the bundle of His at an H-S interval of 171 msec following the third QRS complex caused the unexpected failure of conduction of the fourth atrial impulse.

Figure 6 is an example of type I second degree A-V block (Wenckebach) simulated by coupled premature bundle of His extrasystoles. There was sinus rhythm with a constant

FIGURE 6
Type I second degree A-V block simulated by coupled premature bundle of His stimuli. The P-P interval of the sinus beats is constant at 366 msec. The bundle of His is prematurely stimulated at an H-S coupling interval of 188 msec. The vertical time lines represent 1000 msec.

FIGURE 7
Alternation of the P-R interval due to premature bundle of His extrasystoles. The bundle of His was prematurely stimulated following every other beat at an H-S coupling interval of 240 msec. Retrograde concealed conduction of the premature stimulus caused the A-H interval of the subsequent sinus beat to increase to 147 msec. The H-V interval for all beats is constant at 35 msec.
P-P interval of 366 msec. The A-H and H-V intervals of the first sinus beat measured 49 and 30 msec, respectively. A bundle of His extrasystole (S) occurring 188 msec after the first His deflection (H) failed to propagate antegradely to the ventricles. Retrograde concealed conduction into the A-V node occurred, as reflected in the prolonged A-H interval of the second sinus beat (158 msec). A second bundle of His extrasystole at the same coupling interval caused failure of conduction of the third sinus beat, thereby simulating a type I second degree A-V block.

An example of alternation of the P-R interval caused by concealed bundle of His extrasystoles is illustrated in Figure 7. The atria were depolarized by impulses arising in the region of the sinus node. The SN-SN interval measured 615 msec. The first sinus beat had an A-H and H-V interval of 87 and 35 msec, respectively. Following the first sinus beat, the bundle of His was prematurely stimulated at an H-S coupling interval of 240 msec. The bundle of His stimulus failed to propagate antegradely (no ventricular response). However, concealed retrograde conduction of the His stimulus into the A-V node was reflected in the prolonged A-H interval (147 msec) of the next sinus beat. A continuous alternation of the P-R interval occurred when the bundle of His was prematurely stimulated after every other sinus beat.

Discussion

The bundle of His is one of the specialized conducting tissues of the heart which have been shown to have automaticity (spontaneous phase 4 depolarization) and therefore can serve as a pacemaker of the heart (14). Bundle of His rhythms have been studied clinically by an electrode catheter technique to record electrical activity of the common bundle (15). Junctional extrasystoles are clinically fairly common. Junctional extrasystoles that occur relatively late in the R-R cycle generally result in normal ventricular depolarization, whereas extrasystoles occurring relatively early in the R-R cycle may produce aberrant ventricular depolarization, depending on the state of recovery of excitability of the bundle branch-Purkinje system (16). The salient feature of the present communication concerns the observation that premature stimulation of the bundle of His at short coupling intervals may result in failure of antegrade propagation while retrograde propagation across the A-V node may be complete or incomplete. Complete retrograde A-V nodal conduction will result in either retrograde activation of the atria or fusion P waves (Figs. 3 and 4). This situation will simulate an atrial (nonconducted) bigeminal rhythm. In this study, retrograde depolarization of the atria as determined by the altered sequence of atrial activation is the same as previously described (17). Incomplete retrograde conduction of the bundle of His stimulus across the A-V node (i.e., it is concealed) may cause subsequent sinus impulses to be delayed or blocked, thus simulating types I and II second degree A-V block, high degree (2:1) A-V block and alternation of the P-R interval.

The results of this study can be explained on the basis of the differences in the refractory periods of the A-V nodal and His-Purkinje conduction systems. When the refractory period of the bundle branches and Purkinje fibers is longer than the refractory period of the A-V node, the bundle of His impulses will fail to elicit a ventricular response but will propagate in a retrograde direction (16). Our experimental observations confirm the clinical interpretation proposed by Langendorf and Mehlman (12). Sheiner and Stock (18) proposed that coupled bundle of His pacing with retrograde concealed conduction in the A-V node and simultaneous antegrade concealed conduction and block were the mechanisms for ventricular slowing in their case of atrial fibrillation. Recently, Rosen and co-workers (19) confirmed the clinical occurrence of these forms of arrhythmias in a patient in whom bundle of His electrograms were recorded by an electrode catheter technique.
References


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Circ Res. 1971;28:316-322
doi: 10.1161/01.RES.28.3.316

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7330. Online ISSN: 1524-4571

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