Digitalis-Induced Bundle-Branch Ventricular Tachycardia Studied by Electrode Catheter Recordings of the Specialized Conducting Tissues of the Dog

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ABSTRACT
Electrode catheter recordings of the bundle of His (H), the right bundle branch (RB) and the left bundle branch (LB) were obtained in 15 dogs without thoracotomy during sinus rhythm and digitalis-induced ventricular tachycardia. During sinus rhythm an H-RB-LB sequence was recorded. This sequence was unchanged during atrial stimulation at rapid rates or during cardiac slowing by vagal stimulation. In 10 of 15 cases of digitalis-induced ventricular tachycardia, the LB potential preceded the onset of ventricular depolarization (QRS), and an LB-H-RB sequence was recorded. These findings indicated that during ventricular tachycardia the pacemaker was located in the left bundle branch and the bundle of His was retrogradely depolarized. In 5 of 15 cases of digitalis-induced ventricular tachycardia the H, LB and RB potentials were recorded after the onset of ventricular depolarization. These findings suggested that the pacemaker was located in the Purkinje fibers.

KEY WORDS bundle-branch pacemaker His-Purkinje system bundle of His potentials bundle of His potentials left bundle-branch potentials right bundle-branch potentials retrograde intraventricular conduction

Methods
Fifteen adult mongrel dogs were anesthetized with pentobarbital sodium (30 mg/kg body weight) and artificially ventilated. The animals were secured in the supine position. Bipolar electrograms were obtained with trilopolar catheters composed of ring electrodes 2 mm wide. One electrode was at the distal tip of the catheter and the other two were 1 and 2 cm back from the tip. A bipolar electrode catheter was introduced into a femoral vein and fluoroscopically advanced into the right ventricle. The catheter was slowly withdrawn to the region of the tricuspid valve. Bipolar recordings of the bundle of His and right bundle branch were obtained as previously described (1, 2). A bipolar electrode catheter was introduced into the right carotid artery and fluoroscopically advanced into the left ventricle. The recording electrodes were positioned high along the interventricular septum beneath the aortic valve. This catheter was used to record electrical activity of the left bundle branch (9). Using a distribution switch box, the bipolar electrodes from both catheters were led into the a-c input of ECG preamplifiers. Bundle of His and
Bundle of His recordings during normal sinus rhythm (panel A), A-V junctional rhythm (panel B), and digitalis-induced ventricular tachycardia (panel C). In each panel, ECG is standard lead II, and HBE is the His bundle electrogram recorded by plunge wire technique. Lower five tracings are close bipolar electrograms were recorded from the regions of Bachmann's bundle (BB), the right atrial appendage (RA), the left atrial appendage (LAA), the posterior portion of the left atrium (LAP) and the coronary sinus (CS). A denotes activation of the low atrial septum, H is the bundle of His deflection, and V is the ventricular electrogram. The vertical time lines represent 1000 msec.

Right and left bundle-branch activities were recorded at filter frequency settings of 40 and 500 Hz. All records were taken on an oscilloscopic photographic recorder at paper speeds of 200 mm/sec. A bipolar electrode catheter was introduced into a jugular vein and positioned in the right atrium at the junction with the superior vena cava. This catheter was used to pace the right atrium with a battery-powered pacemaker which delivered impulses of 2 msec at approximately twice threshold. Atrial pacing was performed in both the single and coupled modes. The right cervical vagus nerve was isolated and sectioned. The distal portion of the vagus nerve was stimulated by a stimulator which delivered impulses of 2 msec at 40/sec and between 7 and 15 v. A standard electrocardiographic lead II or V1 was simultaneously recorded. Electrode catheter recordings of the bundle of His and right and left bundle branches were obtained during single atrial pacing, coupled atrial pacing, vagal stimulation, and digitalis toxicity. Digitalis-induced ventricular tachycardia was produced by injecting intravenously a loading dose of ouabain, 7.5 \( \mu g/kg \) body weight, followed by a constant infusion at a rate of 2.5 \( \mu g/kg \) • min.\(^{-1}\).

In 10 animals, a right lateral thoracotomy was performed along the fourth intercostal space. The pericardium was opened and the intact heart exposed. Close bipolar atrial electrograms were recorded from the regions of the sinus node, Bachmann's bundle, the right atrial appendage, the left atrial appendage, the posterior portion of the left atrium, and the coronary sinus according to a method previously described (10). Electrode catheter recordings of the bundle of His and the right and left bundle branches were obtained during single atrial pacing, coupled atrial pacing, vagal stimulation, and digitalis toxicity. Digitalis-induced ventricular tachycardia was produced by injecting intravenously a loading dose of ouabain, 7.5 \( \mu g/kg \) body weight, followed by a constant infusion at a rate of 2.5 \( \mu g/kg \) • min.\(^{-1}\).

Results

Figure 1 illustrates the results from earlier experiments in which only bundle of His electrograms were recorded in the open-chest animal by the plunge wire technique during sinus rhythm (panel A), junctional rhythm (panel B), and digitalis-induced ventricular tachycardia (panel C). In panel A, the sequence of the atrial electrograms is that which is normally seen for sinus rhythm. Electrogram recordings from the sinus node region, which are not shown in this figure, precede the Bachmann's bundle electrogram during sinus rhythm and follow it during retrograde conduction. In panel A, the His bundle (H) deflection appears as a sharp spike between the atrial (A) and ventricular (V) electrograms, and occurs within the P-R interval. The A-H interval measures 72 msec and the H-V interval measures 33 msec. In
this example, the H-V interval is measured from the onset of the H deflection to the onset of the Q wave of the QRS complex. Panel B depicts a junctional beat. The H deflection precedes the onset of ventricular depolarization, and the H-V interval again measures 33 msec. The atria are retrogradely depolarized as determined by the sequence of the atrial electrogram recordings (10). Panel C demonstrates a ventricular tachycardia induced by a constant infusion of digitalis. The H deflection, which has changed in form, is recorded after the onset of ventricular depolarization; the bundle of His has been retrogradely depolarized. The atrial electrograms reveal that there is an A-V dissociation with a slow atrial rate and an antegrade sequence of atrial activation.

In Figure 2, a digitalis-induced ventricular tachycardia was converted to normal A-V conduction by pacing the right atrium at a rate faster than the idioventricular rate. In panel A, a retrograde H deflection (plunge wire technique) was recorded during the ventricular tachycardia. The H deflection appeared after the onset of the QRS complex in all but the last beat. The retrograde H deflection appeared slightly before the onset of the fifth QRS complex. In panel B, normal 1:1 A-V conduction was established by right atrial pacing. The antegrade H deflection appears within the P-R segment. Normal ventricular depolarization occurs and is associated with a normal H-V interval of 42 msec. The A-H interval of 100 msec is longer than during normal sinus rhythm because of the increased frequency of stimulation or the effect of digitalis on A-V nodal conduction or both.

Figure 3 illustrates electrode catheter recordings of the bundle of His during sinus rhythm (panel A) and during atrial pacing (panel B) in the closed-chest dog. In each panel the top tracing is a lead V1 recording and the next three tracings are electrode catheter recordings from the right and left
Electrode catheter records of the bundle of His (H), right bundle branch (RB), and left bundle branch (LB), during sinus rhythm (panel A) and during atrial pacing (panel B) in the closed-chest dog. Standard electrocardiographic lead V1 is recorded. A denotes the atrial electrogram and V the ventricular electrogram. In panel B, S denotes the stimulus artifact delivered to the right atrium. In panel A the interval from the atrial electrogram to the onset of the H deflection (A-H interval) is 80 msec. The S-H interval during atrial pacing (panel B) is 110 msec.

The RB is 10 msec, and the H-LB interval, 13 msec. The longer H-LB interval probably reflects the fact that the LB recording was...
obtained at a point more distal to the common bundle. The stability of the recording technique is demonstrated in panel B. During atrial pacing the H-RB-LB sequence is maintained.

In Figure 4, an escape beat arising from the right side of the heart during vagal stimulation results in a pattern resembling an incomplete block. The escape beat has an RB potential that precedes the onset of the QRS complex and is of the same polarity as the antegrade deflection. The LB potential is recorded after the onset of ventricular depolarization. The H deflection is obscured by the ventricular electrogram.

The results of the studies of digitalis-induced ventricular tachycardia can be divided into two groups. In group A (10 of 15 cases), the LB potential preceded the onset of ventricular depolarization. In group B (5 of 15 cases), muscular depolarization preceded the electrical activities of the right and left bundle branches and bundle of His.

Figures 5 and 8 are representative of our findings in group A (10 cases) during digitalis-induced ventricular tachycardia. In all 10 cases the LB potential preceded the onset of ventricular depolarization.

In panel A of Figure 5 are electrode catheter recordings of the bundle of His, right bundle branch and left bundle branch during control sinus rhythm. The recordings obtained in the same dog during digitalis-induced ventricular tachycardia are illustrated in panel B. There is a normal H-RB-LB sequence during sinus rhythm. During ventricular tachycardia, initial electrical activity is recorded from the left bundle branch, and the LB potential precedes the onset of the QRS complex. The LB potential is followed by the H deflection, which in turn is followed by the RB potential. The latter two deflections occur at about the time of the upstroke of the R wave. The QRS complex itself is of the type of a right bundle-branch block.

Another example of electrode catheter recordings during ventricular tachycardia...
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(group A) is depicted in Figure 6. A representative sinus beat demonstrates an H-RB-LB sequence. During digitalis-induced ventricular tachycardia, the LB potential precedes the onset of the QRS complex. There is an LB-H-RB sequence. During the third beat in panel B, the RB potential is probably delayed and recorded within the ventricular electrogram. Delayed conduction in the right bundle branch is associated with an alteration of the QRS complex.

Figure 7 is representative of the remaining five cases of ventricular tachycardia (group B). In these cases electrical activity of the His bundle and the right and left bundle branches was recorded within the ventricular electrogram. Often the responses of the bundles could not be clearly distinguished from the ventricular electrograms except for capture beats. In no case did the H, RB, or LB potentials precede the onset of ventricular depolarization. The relationship of these findings to the pacemaker site during ventricular tachycardia will be discussed. In Figure 7, the first, second, and fourth beats are ventricular ectopic beats. The third complex is a captured beat in which the normal H-RB-LB relationship is recorded.

Discussion

The technique and validation of electrode catheter recordings of left bundle-branch activity in the intact dog heart have recently been reported by Lau and associates (9). The results of the present study are in agreement with our previous observations.

None of our cases demonstrated a ventricular tachycardia which originated on the right side of the heart, that is, an RB potential preceding ventricular depolarization. These findings are probably fortuitous. However, it is not known whether there exists a higher degree of automaticity of specialized conducting fibers of the left side of the heart as compared to the right in the intact dog heart. Likewise, it is not known whether left-sided structures are more sensitive to digitalis.

The results of group A suggest that during ventricular tachycardia the pacemaker for the ventricles is located within the left bundle branch. Our recordings demonstrate that there is an interval between the LB potential and the onset of ventricular depolarization. In some of our cases the polarity of the bundle-branch potential during ventricular tachycardia was the same as during normal sinus rhythm. There are two possible explanations for these findings. If, during ventricular tachycardia, the pacemaker was located within the bundle branch and proximal to the recording electrodes, then the recorded potential would appear the same as during normal sinus rhythm. An alternative explanation concerns the positional relationship of the bipolar pair of electrodes to the bundle branch itself. If the bipolar electrodes "straddle" the bundle branch and are perpendicular to it, antegrade and retrograde impulses cannot be easily distinguished. In such a case, the pacemaker could be located at a more distal point along the left bundle branch, and the retrograde LB potential would be the same as during antegrade conduction. A change in polarity would be expected if the bipolar pair of electrodes were in a parallel or oblique relationship to the bundle branch.

In contrast, our findings in group B suggest that the pacemaker was located within the peripheral Purkinje system. In these five cases, electrogram recordings of the bundle of His and bundle branches occurred after the onset of ventricular depolarization. It would be expected that a pacemaker located within the peripheral Purkinje system would result in almost immediate muscular depolarization. It is unlikely that our findings in group B can be ascribed to catheter movement, since, as illustrated in Figure 8, intermittent atrial capture resulted in a normal sequence of electrogram recordings.

The His-Purkinje system, including the right and left bundle branches, is composed of specialized cardiac cells which can function as latent pacemakers of the heart (12). Using microelectrode techniques, Vassalle and coworkers demonstrated that during ouabain toxicity spontaneous depolarization occurred in the specialized Purkinje fibers and not in
Preliminary studies in our laboratory using a bundle branch and Purkinje-muscle preparation showed that during ouabain toxicity spontaneous phase 4 depolarization occurs within the bundle branch (unpublished observations). These preliminary studies in the isolated canine cardiac tissue support the observations of the present study. Thus, the specialized fibers of the bundle branches, as well as the Purkinje fibers, can serve as pacemakers of the heart.

In group A, the sequence of LB-H-RB during ventricular tachycardia indicates that the pacemaking impulse arose on the left side of the heart and was retrogradely conducted to the bundle of His and then antegradely conducted to the right bundle branch. A similar conduction pattern could be predicted for impulses arising from the right side of the conduction system. This proposed pathway of conduction from the left side of the heart to the right side is supported by the fact that the LB-H-RB potentials are recorded before and during the initial portions of the QRS complex. One would expect that if activation of the RB occurred retrogradely through the anastomosing peripheral Purkinje system, the RB potential would be more delayed and, in all likelihood, obscured within the ventricular electrogram, since a significant amount of muscular depolarization would have already begun.

References
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