

Recent Studies in the Pre-Excitation Syndrome*

E. NEIL MOORE, D.V.M., Ph.D., F.A.C.C.

Professor of Physiology, The School of Veterinary Medicine, University of Pennsylvania, and Professor of Physiology in Medicine, Department of Medicine, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania

The Wolff-Parkinson-White syndrome has held an unusual fascination for cardiologists ever since its original description in 1930. Over 60 different theories have been postulated to describe the mechanism of pre-excitation. The recent development of epicardial mapping techniques to define the sequence of ventricular activation, and the introduction of His bundle electrocardiography have provided valuable procedures for studying pre-excitation. This presentation will discuss some of the insights into the mechanism of pre-excitation that have been derived from these two electrophysiological procedures.

Epicardial Mapping. Epicardial mapping of the sequence of ventricular activation is usually accomplished in the following way. First, a monopolar recording electrode is fixed within the ventricular cavity, or else bipolar electrodes are attached to the ventricular free wall. This permits recording of a consistent activation time which remains stable at a fixed time during ventricular activation and the inscription of the QRS complex. The standard ECG cannot be used as an indication of onset of ventricular activation due to the variations that result from moving the heart within the chest cavity to facilitate mapping both the right and left ventricular free walls. In addition to a fixed reference electrode, a second bipolar electrode (roving electrode) is placed at multiple sites on the ventricular epicardium; the time for onset of activation at each site is measured against the activation time of the fixed reference electrogram. By determining

the activation times at many epicardial sites, for example, 40 sites would be very minimal for constructing an activation map of the right ventricle, it is possible to construct a map of the sequence of epicardial activation. Detailed methods for determining the sequence of cardiac activation have been reported previously (1).

Figure 1 presents an ECG and bipolar electrograms recorded from a dog having spontaneous WPW. The Lead II ECG has a prominent delta wave without a visible isoelectric P-R segment. The uppermost electrogram labeled "Bipolar Electrograms Post. RV" was recorded from the earliest site on the ventricular epicardium where activation was recorded. Note that this ventricular electrogram occurs at the end of the P wave and before the initiation of the delta wave. In any normal heart, ventricular activation at the posterior right ventricular base would occur at least 50 msec later than shown in figure 1. In addition to the epicardial electrode, multipolar intramural electrodes were used to record from the right and left ventricular septum, in this case of spontaneous WPW in a dog. Purkinje spikes (labeled P) were recorded at the beginning of both septal electrograms. In a normal heart, septal Purkinje activation develops just before, or at the initiation of the QRS complex. In this WPW heart, early activation in the right ventricle began before the end of the P wave and preceded activity in the right Purkinje system by 10 msec. The right Purkinje system was activated prematurely by retrograde spread from the adjacent pre-excited myocardium. The impulse that spread over the normal A-V pathway was recorded in the left Purkinje network 30 msec after the onset of activity in the right Purkinje system and occurred 40 msec after pre-excitation of the posterior right ventricle. Since

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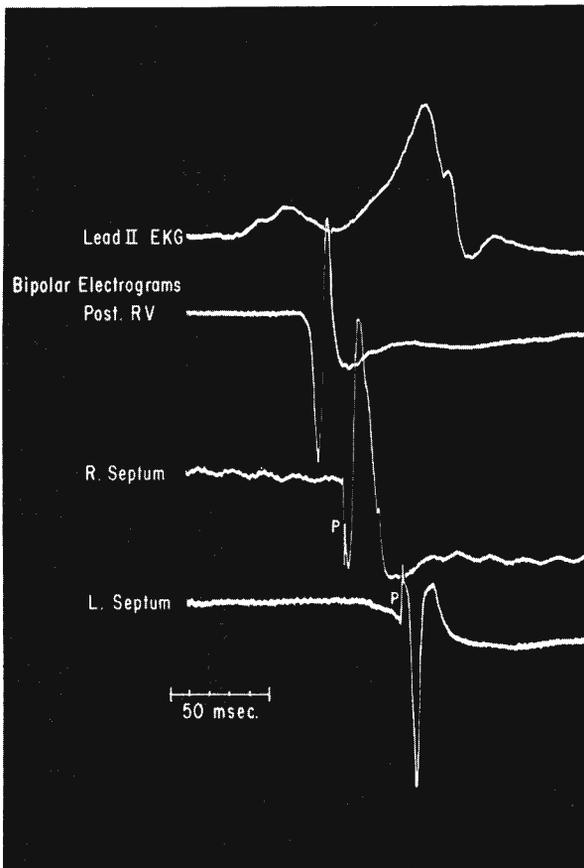


Fig. 1—The degree of ventricular fusion during activation in a dog with spontaneous WPW. Bipolar electrograms recorded from the site of pre-excitation in the posterior right ventricle and from the right and left septal surfaces are shown in relationship to the lead II ECG. P denotes Purkinje potentials. Pre-excitation begins in the posterior right ventricle during the P wave and before onset of the delta wave in the ECG. The pre-excitation wave spreads to the right septum and activates the right Purkinje system prematurely. The left Purkinje system is activated normally over the A-V conduction system. (Modified from J. P. Boineau and E. N. Moore, "Evidence for Propagation of Activation Across an Accessory Atrioventricular Connection in Types A and B Pre-excitation," *Circulation* 41:386, 1970. Reproduced by permission of The American Heart Association, Inc.)

the QRS duration was 65 msec, 60% of ventricular activation must have occurred due to activation over the accessory pathway before the impulse was propagated over the normal A-V conduction system to the left Purkinje system.

Figure 2 presents the sequence of ventricular epicardial excitation and the lead II ECG recorded at the time of surgery in a patient with type B

Wolff-Parkinson-White syndrome. It was decided to perform surgery since this patient had recurrent bouts of tachycardia and had to be resuscitated from a bout of ventricular fibrillation while in the hospital for evaluation. The subject's preoperative ECG (left tracing labeled "Pre-excitation") shows the absence of a P-R segment, the presence of a delta wave, and a marked prolongation of QRS. The initial or delta forces are oriented toward the left, and the principal QRS forces are directed posteriorly, superiorly, and to the left. The time sequence key below the maps of the heart indicates the times in milliseconds that the various areas of the heart were activated during the inscription of the ECG. Earliest activity at time 0 was recorded from the region of the sinus node. The atrial activation wave spread radially to the lateral right ventricular free wall with earliest activity being recorded at 100 msec at the A-V sulcus. The spread of ventricular activation then progressively spread radially from the right lateral A-V sulcus towards the apex. Once the sequence of ventricular activation was mapped in this WPW patient, the region of pre-excitation was sectioned along the right A-V sulcus. Following sectioning of this region, pre-excitation disappeared. Postoperatively, the ventricular activation sequence became completely normal, with activation occurring first at the medial aspect of the right ventricle near the anterior descending coronary artery. Activity then spread toward the A-V groove and into the pulmonary conus region in a normal manner. The patient's ECG has remained normal and no further bouts of tachycardia have been recorded since interruption of the presumed lateral accessory bypass tract.

The surgical interruption of a region of pre-excitation resulting in normalization of the ECG is strong supportive indirect evidence for the existence of a lateral accessory bypass tract (bundle of Kent). However, direct proof that lateral accessory bypass tracts actually can conduct and pre-excite the ventricles resulting in pre-excitation in the ECG was obtained in the dog with spontaneous WPW. Rather than surgically section the region where pre-excitation was demonstrated by electrophysiological activation mapping procedures, the region was removed for serial histological sectioning. An atrioventricular accessory bundle was demonstrated histologically at the precise location where pre-excitation was found by activation mapping procedures. This study provided the first direct demonstration that a lateral

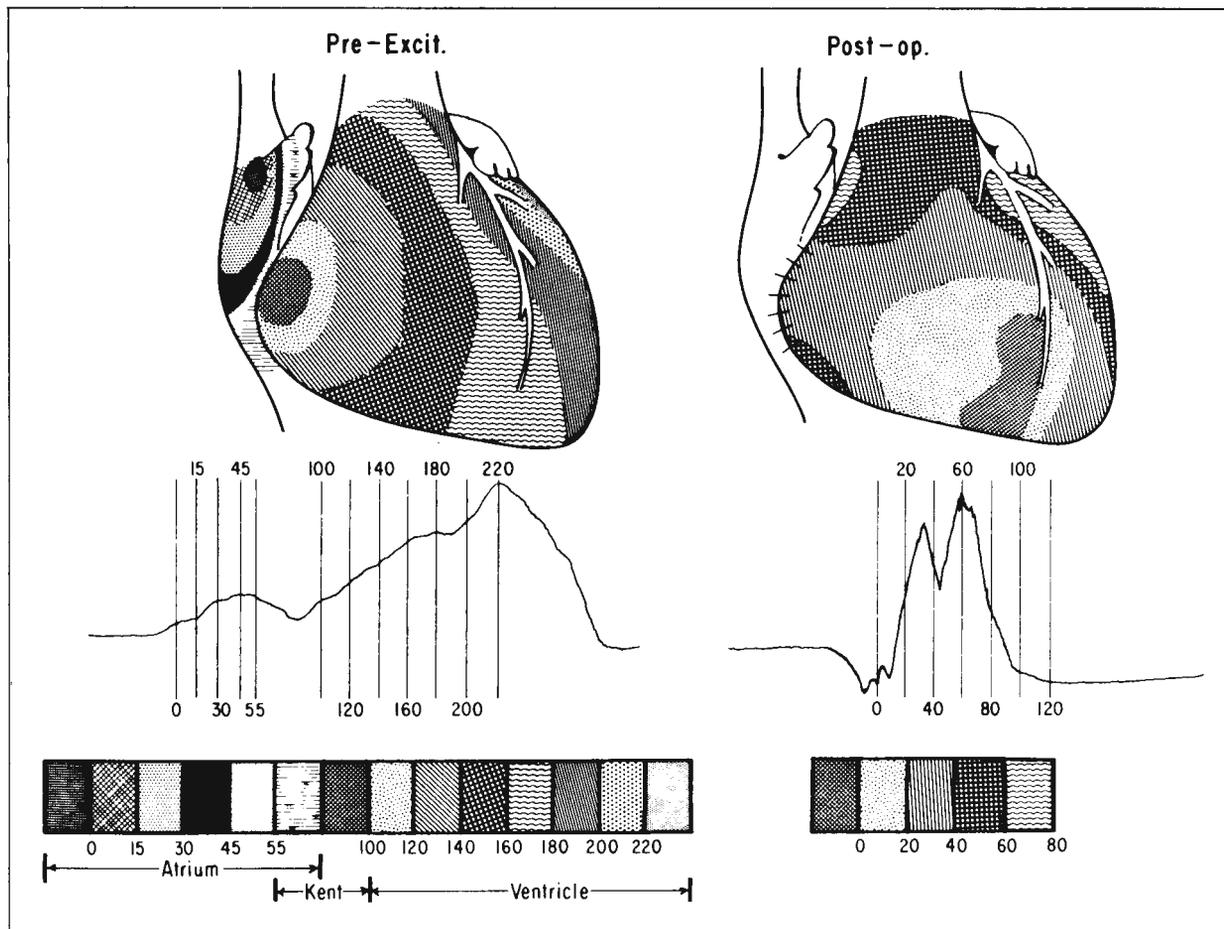


Fig. 2—Ventricular epicardial activation sequence map in a patient with type B WPW syndrome. On the left is the activation map and lead II ECG recording during pre-excitation, and on the right is the map of epicardial excitation and the ECG following surgical interruption of the A-V region where pre-excitation was recorded. The sequence key below each map indicates the relative activation times. During pre-excitation (left map) a focal region at the lateral right A-V sulcus is activated first and closely follows atrial activation of the adjacent atrial muscle. Following surgical interruption earliest activation occurs at the region of the ventricular septum. (Modified from J. P. Boineau and E. N. Moore, "Evidence for Propagation of Activation Across an Accessory Atrioventricular Connection in Types A and B Pre-excitation," *Circulation* 41:382, 1970. Reproduced by permission of The American Heart Association, Inc.)

accessory bypass tract (bundle of Kent) can produce an electrocardiogram exhibiting the Wolff-Parkinson-White syndrome (1).

Bundle of His Electrograms in Pre-excitation.

The other development in cardiac electrophysiology that has contributed recently to our better understanding of the pre-excitation syndrome is His bundle electrocardiography. The electrogram recorded from the bundle of His contains three complexes recorded from the lower right atrial septum (A), the His bundle (H), and the ventricular septum (V). The atrial-to-His bundle activation time (A-H interval) is roughly equal to A-V nodal conduction time and the His-to-ventricular septal activation time (or to

the earliest ventricular depolarization represented on an electrocardiogram) reflects conduction time within the ventricular specialized conduction system (H-V interval). Sufficient numbers of studies in normal patients and in dogs have provided us with normal A-H (50-120 msec in man) and H-V (25-55 msec in man) values.

Figure 3 presents electrograms recorded simultaneously from the right atrium (RA), bundle of His (BH), left Purkinje fiber and left ventricular muscle (LPF) together with a lead II electrocardiogram (3). The tracing labeled S is a recording denoting the time that an electronically simulated lateral accessory A-V bypass pathway pre-excited the

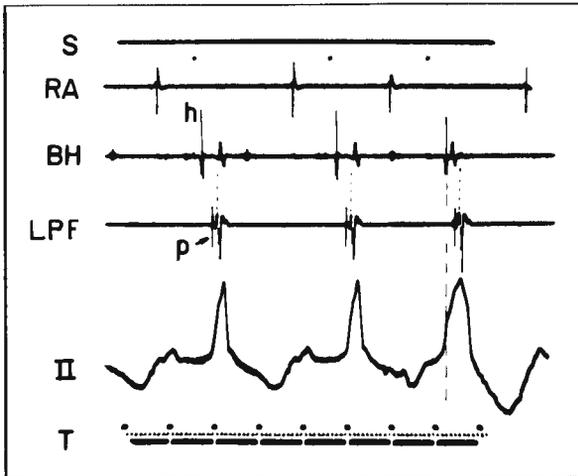


Fig. 3—Electrograms and electrocardiograms recorded during pre-excitation using electronic circuitry to simulate an accessory atrioventricular bypass tract. Right atrial (RA), bundle of His (BH), and left Purkinje ventricular muscle (LPF) electrograms were recorded simultaneously with the lead II ECG. The upper tracing, S, indicates the time when the lateral wall of the right ventricular base was pre-excited by the "electronic A-V bypass" circuitry. Pre-excitation occurred 80 msec after the atrial electrogram in all three beats. The third beat is a premature atrial beat and the A-V nodal conduction time increased due to the prematurity. Since the conduction time remained constant over the "electronic accessory bypass" tract, obvious pre-excitation occurred in the third beat as indicated by the inscription of the QRS complex (ventricular depolarization) before the depolarization of the bundle of His and Purkinje system. (Modified from E. N. Moore and J. F. Spear, "Electrophysiological Studies on Pre-excitation in the Dog Using an Electronically Simulated Atrioventricular Bypass Pathway," *Circulation Res.* 31:174, 1972. Reproduced by permission of The American Heart Association, Inc.)

base of the right ventricle at the middle of the right A-V sulcus. It can be noted that the electronically simulated accessory bundle excited the right ventricular base at a constant interval following the RA electrogram in all three beats. The atrial-to-His bundle interval is normal in the first two beats reflecting normal conduction time through the A-V node. The His bundle-to-ventricular septal interval is short, but within normal limits. Both His bundle and Purkinje excitation precede the initiation of the QRS complex in the ECG tracing. Therefore, the presence of pre-excitation is not suspected, that is, the P-R interval is normal and a delta wave is not present. However, there is no question about pre-excitation being present since we have electrically pre-excited the right ventricular base. The amount of ventricular fusion caused by pre-excitation in the

first two beats is too small to be observed without additional procedures.

The major criteria for diagnosing WPW is the presence of a short P-R interval, and a prolonged QRS duration associated with a delta wave. Both of these reflect the presence of ventricular fusion caused by activity being conducted simultaneously over the accessory A-V pathway and normal A-V conduction system. The degree of fusion is influenced by the relative conduction times over the two A-V pathways; as the conduction times over these two pathways become more out of phase, for example, short accessory conduction and long A-V nodal conduction, the delta wave and QRS duration prolong. One can alter the phase relationships of conduction in the accessory and normal A-V pathways in a number of ways including administration of drugs, vagal stimulation, rapid atrial pacing, and introduction of premature beats.

Figure 3 is an example, as mentioned previously, where we know that pre-excitation has occurred in the first two beats since we electrically pre-excited the right ventricular base; yet even with a His bundle electrogram we cannot diagnose this as an example of WPW. The third beat is a premature atrial beat as denoted by the interval between the third and second RA electrograms having a shorter cycle length than that between the first two RA electrograms. Premature atrial beats are normally conducted with an increased conduction time through the A-V node. If the conduction time over the accessory pathway does not increase, or increases less than that through the A-V nodal conduction system, we can anticipate a greater degree of ventricular fusion. The third beat in figure 3 shows marked fusion in the ECG. The fact that an accessory bundle should be strongly suspected is also shown by the BH and LPF electrograms. Both the His bundle (R) and Purkinje (P) depolarization complexes occur following the inscription of ventricular depolarization in the lead II ECG. This fact is emphasized by the dotted line which indicates when the bundle of His was excited during the third QRS fusion complex. Also, the H-V interval in the BH electrogram is too short for normal conduction to have occurred over the ventricular specialized conduction system. An abbreviation of the H-V interval and prolongation of the QRS following a premature atrial beat or rapid atrial pacing suggests that pre-excitation is present.

His bundle electrocardiography and atrial pacing have also demonstrated that the effective refrac-

tory period of the accessory A-V pathway often is longer than for the normal A-V pathway, that is, premature conduction over the accessory pathway fails before conduction fails through the normal A-V node. Therefore, an even earlier premature atrial beat than in figure 3 may result in complete normalization of the QRS complex if conduction over the accessory pathway fails, since, in this case the ventricles are normally activated only through the normal A-V conduction system and ventricular fusion is absent.

It is indeed fortunate that the accessory pathway usually has a longer effective refractory period than the normal A-V transmission system. If this were not the case, then atrial fibrillation in the presence of an accessory A-V bypass tract would be expected to cause ventricular fibrillation in many patients with pre-excitation due to rapid activation of the ventricles over the accessory A-V tract. The fact that atrial fibrillation in a patient with pre-excitation may cause ventricular fibrillation has been documented in both man and the dog. Therefore, it is important in patients with recurrent supraventricular tachycardias in which an atrial pacemaker is being considered as a treatment to terminate the dysrhythmia, that atrial pacing studies be undertaken to rule out the possibility of the presence of an accessory A-V bypass tract.

Summary. In this brief presentation, I have attempted to point out some of the new electrophysiological techniques used in studying the pre-excitation syndrome as well as some of the interesting findings which these techniques have provided. For more detailed particulars on the newer findings on the WPW syndrome, the reviews of Durrer *et al.* and Wallace *et al.* can be recommended (2, 4).

The technique for mapping the sequence of ventricular epicardial activation has provided a mechanism of defining the anatomical site of pre-excitation. Surgical interruption of the atrium and ventricle at the region where pre-excitation was

found has permitted normalization of the ECG of patients having the WPW syndrome. The incapacitating episodes of tachycardia associated with WPW have likewise been eliminated by sectioning of an accessory A-V bypass tract. This technique, however, must still be considered experimental and should be suggested only in WPW patients in whom other methods of controlling the tachyarrhythmias are unsuccessful. Prior to surgery it should be considered essential that other studies such as His bundle electrograms be recorded and suitable electrical pacing studies undertaken to assure the likelihood that the patient is a suitable candidate for surgery. The indications for His bundle electrocardiography in patients with supraventricular tachycardias in which an implanted cardiac atrial pacemaker is being considered should also be emphasized, that is, if pre-excitation were present and the atria were rapidly paced, then ventricular fibrillation might develop due to rapid conduction over an accessory A-V pathway.

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