Phase Analysis in the Wolff-Parkinson-White Syndrome with Surgically Proven Accessory Conduction Pathways: Concise Communication

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Twenty-one patients with the Wolff-Parkinson-White (WPW) syndrome who underwent surgical division of the accessory conduction pathway (ACP) were studied by gated blood-pool scintigraphy. In each case, a functional image of the phase was generated, based on the fundamental frequency of the Fourier transform. The location of the ACP was confirmed by electrophysiologic study, epicardial mapping, and surgery. Phase analysis identified the side of preexcitation correctly in 16 out of 20 patients with WPW syndrome with a delta wave. All patients with right-cardiac type (N = 9) had initial contraction in the right ventricle (RV). In patients with left-cardiac type (N = 10), six had initial movement in the left ventricle (LV); but in the other four the ACPs in the anterior or lateral wall of the left ventricle (LV) could not be detected. In patients with multiple ACPs (N = 2), one right-cardiac type had initial contraction in the RV, while in the other (with an intermittent WPW syndrome) the ACP was not detected. These observations indicate that abnormal wall motion is associated with the conduction anomalies of the WPW syndrome. We conclude that phase analysis can correctly identify the side of initial contraction in the WPW syndrome before and after surgery. However, as a method of preoperative study, it seems difficult to determine the precise site of the ACP by phase analysis alone.

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The Wolff-Parkinson-White (WPW) syndrome is a disorder of cardiac conduction that was described in 1930 as "bundle branch block with short P-R interval in healthy young people prone to paroxysmal tachycardia" (*1*). Activation of the ventricular myocardium proceeds through a fusion of the ectopic impulse, conducted through an accessory conduction pathway (ACP), and the normal propagation passing through the atrioventricular (AV) node. Traditionally, patients with the WPW syndrome have been classified into two types, A and B (*2*). Type A is supposed to have an ACP between the left atrium and ventricle, while in Type B it involves the right side. There are some exceptions, however. Ueda et al. added a Type C, comprising those patients in which the right precordial leads showed a QS or Qr pattern (*3*). The classification of WPW types is clinically useful because the surgical therapy varies with the site of the ACP, which is indicated by the type. Surgical transection of an ACP is indicated when a patient with WPW syndrome has frequent and prolonged attacks of tachycardia, becoming completely incapacitated or suffering cardiac failure. In these cases, the site of an ACP should be established precisely by electrophysiological study or epicardial mapping before surgery, but precise location of the ACP is difficult by electrocardiography (ECG) alone.

An assessment of cardiac function by functional images has become popular in cardiovascular nuclear medicine (*4–13*). Clinical usefulness of the phase and amplitude images using the fundamental frequency of the Fourier transform has been described in ischemic heart disease, bundle branch block, and other conduction anomalies (*4–10*). Phase analysis has been applied to the

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WPW syndrome (*11-13*), but exact correlation between the site of an ACP and the abnormality on the phase image remains uncertain.

The purpose of this study is to determine whether phase analysis can detect the side of preexcitation correctly, whether the contraction patterns change after surgery, and furthermore, whether we can determine the precise position of the ACP preoperatively by this method. In this study, the usefulness and limitations of phase analysis for detection of the ACP side and its precise site were evaluated in patients who had ACPs confirmed by epicardial mapping and surgery.

MATERIALS AND METHODS

Patients. The study series consisted of 21 consecutive patients with the WPW syndrome, aged 11 to 62 yr, who underwent both an equilibrium gated blood-pool study and surgical division of the ACP. All patients had the radionuclide study before surgery, and eight had repeat studies after surgery. A twelve-lead ECG was recorded from each patient before and after surgery. Patients were classified into three groups: Types A and B, based on whether the maximum QRS voltages in precordial leads were mainly anterior or posterior (*2*), and Type C as described above (*3*). One patient also had ECG abnormalities associated with Ebstein's anomaly, two had right bundle branch block (RBBB), and one had Graves' disease with RBBB. The remaining 17 patients had no other complications.

Surgical estimation of ACP. An intracavitary ECG was obtained before surgery using electrodes inserted intravenously. After the introduction of catheters, the electrophysiologic study was performed and the sequence of antegrade ventricular activation and retrograde atrial activation was recorded. Epicardial excitations were measured in all patients during surgery to locate the ACP accurately. The ACP detected by these studies was then transected surgically in the portion between atrium and ventricle (*14,15*), after which the delta wave was absent in all patients, indicating that the ACP was no longer present.

Radionuclide study. Red blood cells were labeled in vivo with 20 mCi (740 MBq) of Tc-99m after the intravenous injection of stannous pyrophosphate (20-30 μg/kg of $SnCl_2$). Equilibrium gated blood-pool studies were performed about 30 min after injection of Tc-99m using a scintillation camera interfaced to a nuclear medicine computer system. The camera's detector was positioned in a modified 35-40° left anterior oblique (LAO) view. A low-energy, all-purpose, slant-hole collimator was generally used. In patients after surgery (N = 1) or during a tachycardial attack (N = 1), a high-sensitivity collimator was used to minimize the data acquisition time. Using acquisition software supplied by the computer manufacturer, 16 frames of data per cardiac cycle were collected in 64 × 64 matrix. Approximately 300-500 Kcounts were acquired in each frame. Either hardware (2×) or software (2×) zoom was used to enhance the spatial resolution. In two patients, the gated blood-pool data were also obtained during tachycardia (Cases 13 and 16 in Table 1) to analyze the relations of the contraction sequence and search for a possible reentry pathway.

Phase analysis. The program to perform phase analysis was originally developed using BASIC and subroutine programs supplied by the computer manufacturer. The algorithm applied was based on principles already described by others (*4,5*). A discrete Fourier transform was applied to 16 points of a time-activity curve for each pixel and the phase and amplitude of the fundamental frequency were mapped. The phase values in radians (Pr) were converted to those in msec (Pt) by assuming that 2π radians correspond to the RR interval (msec), that is:

$$\text{Pt} = \text{RR interval} \times \frac{\text{Pr}}{2\pi}.$$

The phase image was displayed using 16 frames of cine format. Each frame represents 20 msec and pixels having the same phase are blackened. The difference in timing between the initial contractions in the two ventricles was considered significant when it was more than 40 msec. The end-diastolic frame of the blood-pool images was superimposed on each frame of the phase display for identification of cardiac chambers. In selecting regions of interest (ROI) on the right ventricle (RV) and left ventricle (LV), images of end-diastole (ED), end-systole (ES), and a stroke-volume functional image were used for reference. In order to shorten the processing time and to eliminate the noise caused by background radioactivity, data processing was performed within these ROIs.

Comparison of phase analysis and the result of surgery. The side of initial contraction identified by the phase image was compared with the surgically proven location of the ACP. To evaluate the possibility of detecting more precisely the site of an ACP by phase analysis, we divided each ventricle into three regions in LAO view: septal, middle, and lateral. The region of initial phase was determined visually using the cinematic display described above and was compared with the surgically confirmed site of the ACP.

RESULTS

Of 21 patients who underwent surgical correction of the WPW syndrome, 11 were type A, eight were Type B, and two were Type C. Two patients had an intermittent WPW syndrome, and one of the two (Case 5) did not show an ECG delta wave during her radionuclide study (Table 1). According to the location of the ACP

TABLE 1. PATIENTS WITH THE WPW SYNDROME WHOSE ACPs WERE CONFIRMED BY SURGERY

No.	Age	Sex	ECG type	Localization of ACP			Comments
				Surgery	Phase	Agreement	
1	53	M	B	R	RM	no	
2	11	M	B	R	RS	no	RBBB
3	24	F	B	R	R–	no	
4	20	F	B	R	RS	yes	Graves' disease, RBBB
5	46	F	A	R(con)L(int)	N	no	intermittent†
6	49	M	A	L	LL	no	
7	61	F	A	L(int)	LL	yes	intermittent
8	47	M	A	L	N	no	
9	40	M	C	R,R(con)	R–	no	Ebstein's anomaly
10	25	F	B	R	R–	no	
11	52	F	B	R	RL	yes	RBBB
12	58	M	A	L	N	no	
13	24	M	B	R	RM	yes	HR = 204/min
14	52	M	C	R	RS	yes	
15	53	M	A	L	N	no	
16	22	F	B	R	RL	yes	HR = 150/min
17	62	F	A	L	LL	yes	
18	47	M	A	L	N	no	
19	55	F	A	L	LL	yes	
20	47	M	A	L	LL	yes	
21	28	M	A	L	LM	yes	

* Abbreviations are: ECG = electrocardiography, ACP = accessory conduction pathway, R = right side, L = left side, RS = right septal, RM = right middle, RL = right lateral, LS = left septal, LM = left middle, LL = left lateral, R– = ACP is on the right side, but precise site not determined, N = not detected, RBBB = right bundle branch block, int = intermittent, con = concealed, HR = heart rate, † = No delta waves during radionuclide study.

confirmed by surgery, we classified the WPW syndrome into two groups, right-cardiac type (R type) and left-cardiac type (L type); therefore, the subjects consisted of nine R type and ten L type. Multiple ACPs were detected in two patients; one had ACPs on both sides and the other had two ACPs on the right side. The surgically confirmed locations of the ACPs are schematically represented in Fig. 1. In all R-type patients and in six out of ten L-type patients, the side of initial contraction was determined correctly by Fourier analysis of the gated blood-pool study. However, the other four with L type, who had ACPs at the left anterior or lateral wall, could not be detected by phase image. Of the two patients with multiple ACPs, the one with right-cardiac type had an

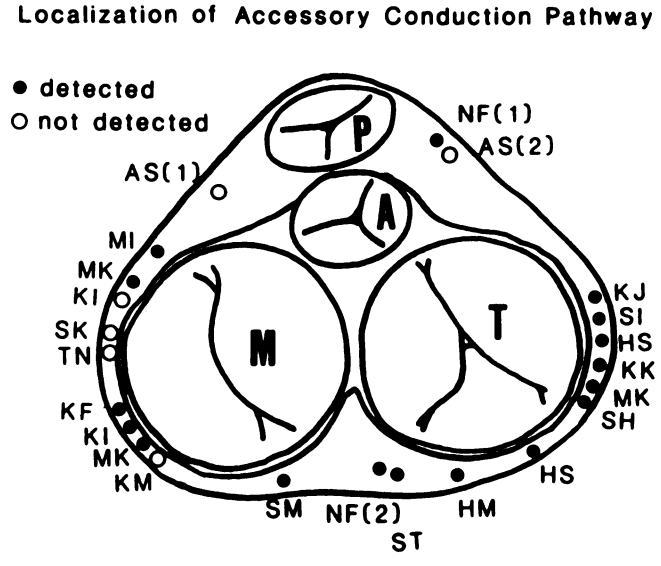

FIG. 1. Schematic cross-section of heart at level of atrioventricular valves, showing sites of surgically proven ACPs. Side of ACP detected (●) and not detected (○) by phase analysis. Valve labeling: A = aortic, P = pulmonary, M = mitral, T = tricuspid.

TABLE 2. SUCCESS OF PHASE ANALYSIS IN LOCATING SITE OF ACP

Location of ACP	No. of patients	Correct *re* side	Correct *re* region
Right	9	9	5
Left	10	6	5
Multiple	1	1	0
Total	20	16	10

abnormal initial phase in the RV, but in the other it was not detected because she had an intermittent WPW syndrome and did not show a delta wave during the radionuclide study. Of eight patients who also had a postoperative gated blood-pool study (Cases 2, 4, 5, 6, 8, 10, 12, and 13), the initial contraction in each ventricle occurred simultaneously. Compared with the preoperative study, the patterns of ventricular contraction were apparently changed in five cases, but were unchanged in three cases whose right and left ventricles contracted almost simultaneously by phase analysis before surgery. For 20 patients with the delta waves, comparison of the phase analysis and the site of ACP is summarized in Table 2. The sensitivity of phase analysis for detecting the side of ACP was 80% (16/20): 100% (9/9) for R type, 60% (6/10) for L type and the patient with two right ACPs. As to the precise site of the ACP, we correctly diagnosed 50% (10/20) of the patients with delta waves: 56% (5/9) of the R type and 50% (5/10) L type. In six patients, the side of preexcitation detected by phase image agreed with surgically proven side of the ACP, although the location of initial phase was not strictly in agreement with the surgically determined site. In three R-type patients, the initial phase could not be localized to one region.

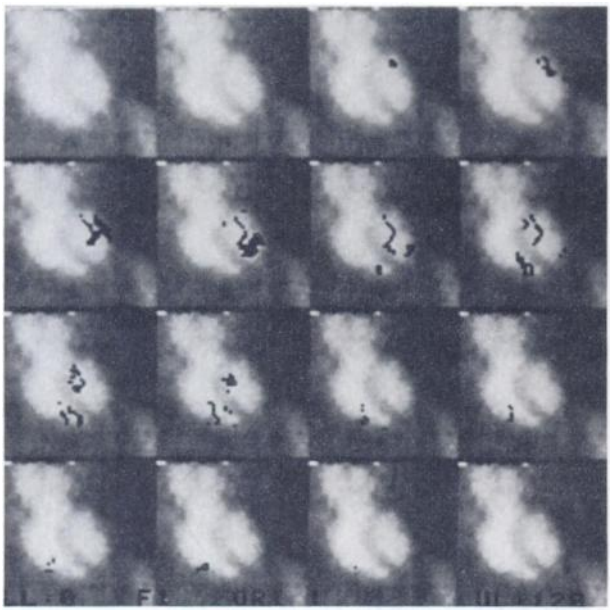

FIG. 2. Case 7. Type A WPW syndrome. ACP was at lateral wall of LV. Contraction is indicated by black pixels; each frame represents 20 msec, progressing from upper left to lower right. Initial movement appeared in Frame 3 by phase analysis, indicating lateral region of LV (LAO projection).

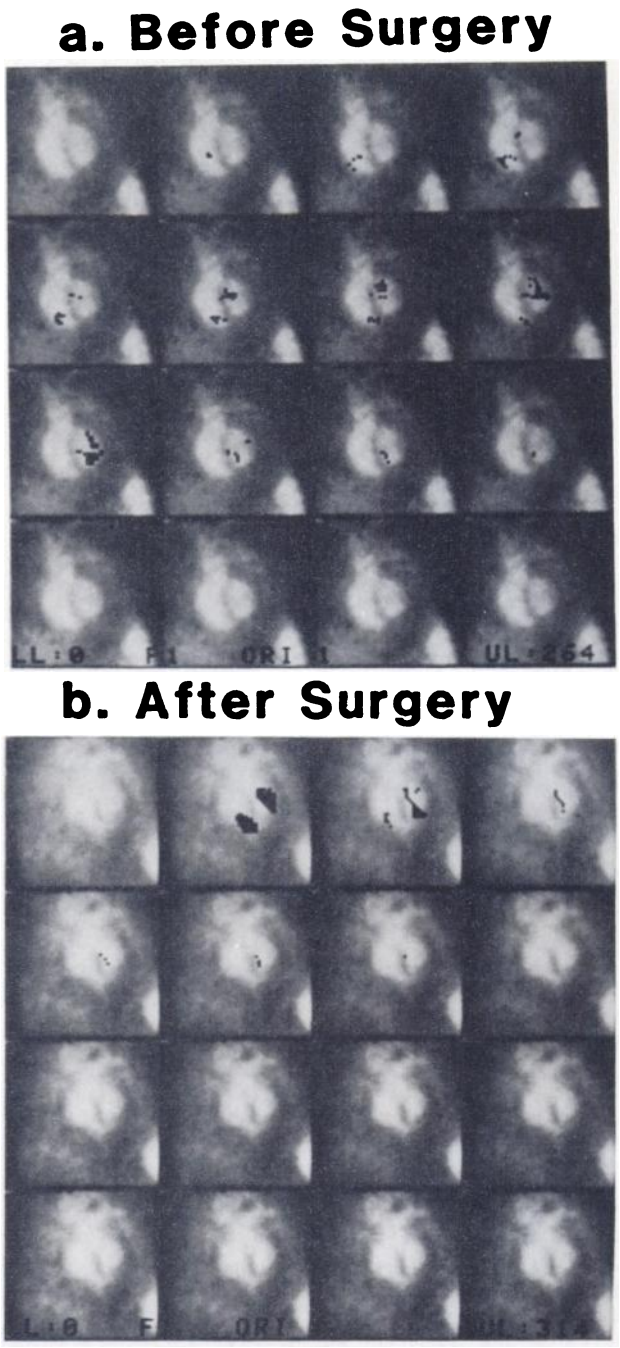

FIG. 3. Case 10. Type B WPW syndrome. ACP was at right posterior wall of right side before surgery (a), but precise pinpointing of ACP is difficult by phase image (Frames 2 and 3). After surgery, contractions are seen simultaneously in both ventricles (b).

Typical or interesting results of phase analysis follow. A man with Type A WPW syndrome, 61 yr old, gave the findings shown in Fig. 2. An ACP of the left-ventricular lateral wall was confirmed by surgery. Phase analysis showed initial movement in the lateral part of LV and

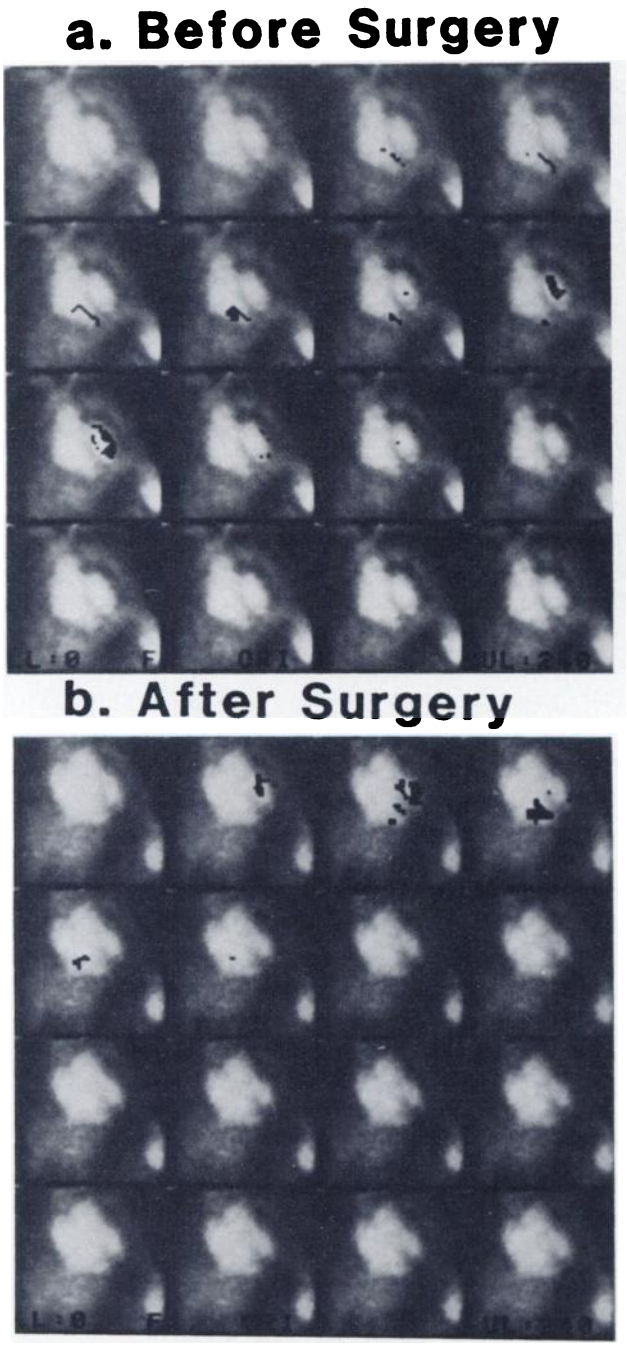

FIG. 4. Case 2. Type B WPW syndrome with RBBB. Initial movement was in right side before surgery (a) and in left side after surgery, due to RBBB (b). An ACP was at right lateral portion of RV. However, initial contraction indicated by black pixels was near septum, as shown in Frame 3.

the spread to RV. A patient with Type B WPW syndrome (F, age 25) produced Fig. 3. Studies before and during surgery indicated that the ACP was at the right posterior wall. By phase analysis, contraction begins in the RV. However, as shown in Frames 2 and 3 of Fig. 3a, the exact location is difficult to make out. Postoperative phase analysis showed the contraction beginning almost at the same time in the two ventricles (Fig. 3b). Figure 4 is a phase image from an 11-yr-old male with Type B

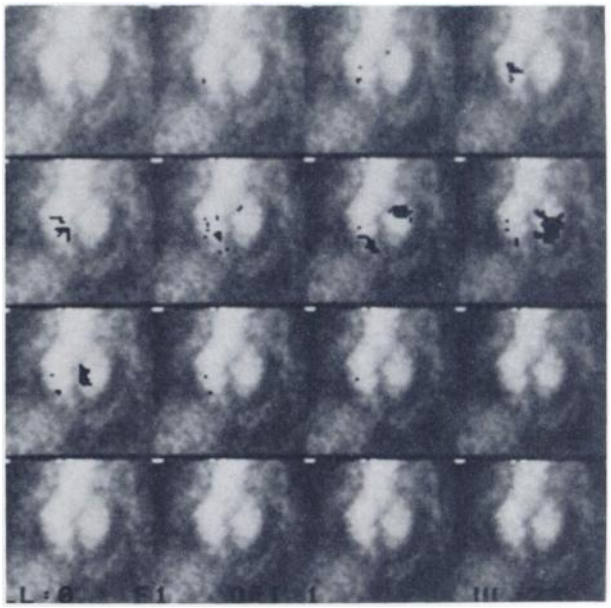

FIG. 5. Case 13. Type B WPW syndrome during attack of tachycardia (heart rate = 204/min.). Contraction begins at mid portion of RV (Frame 2) and spreads to LV (Frame 7).

WPW syndrome associated with RBBB. Initial movement was observed at the right side preoperatively due to preexcitation of the RV (Fig. 4a). After surgical correction of the WPW syndrome, the initial movement was at the left side due to RBBB (Fig. 4b). Although the location of ACP was at the right lateral portion of the RV, the initial movement shown by the phase image was near the septum in the RV. Phase analysis during a tachycardial attack is presented in Fig. 5. This patient had Type B WPW syndrome and an ACP was confirmed at the site of the posterior RV wall. Data were obtained during the tachycardia (heart rate = 204/min) for 5 min using the high-sensitivity collimator. By phase analysis, the contraction begins at the mid portion of the RV and spreads to the entire RV, then to the LV. The tachycardia is presumed to be due to re-entry, but it is uncertain whether or not the movement pattern reflects reentry. Figure 6 is a phase image from a 40-yr-old male with a Type C WPW syndrome. This patient also had an Ebstein's anomaly. Gated blood-pool study showed such a large RA that it and the RV were not well separated. The LV was relatively small. This case had two ACPs, electrophysiologically confirmed, at the anterior and posterior walls of the RV. The phase image, displayed in 40-msecs frames in this case, suffers from excessive random noise due to low amplitude in the atrialized portion of the RV. However, the RV contraction seemed to precede that of the LV, as shown in Fig. 6. The precise location of the initial phase in the RV was difficult to identify.

DISCUSSION

The WPW syndrome is characterized by ECG findings that show a short PR interval and a broad QRS

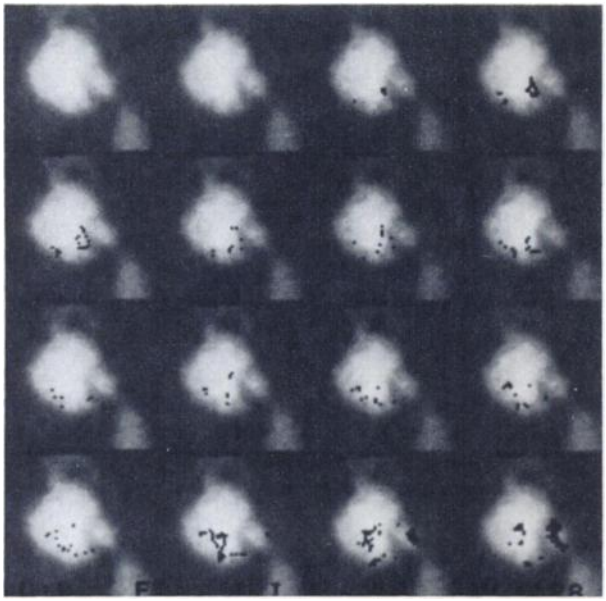

FIG. 6. Type C WPW syndrome with Ebstein's anomaly. Two ACPs in right side were confirmed surgically. Phase images (here 40 msec per frame) had prominent random noise due to poor contractility of atrialized ventricle. However, initial movement was shown in right ventricle.

complex associated with an initial slurring portion, called the "delta wave." Rosenbaum et al. classified the WPW syndrome into Types A and B, based on whether the maximum QRS voltages in the precordial leads were mainly anterior or posterior (*2*). Generally, Type A has an ACP in the left heart and Type B in the right, but there are some exceptions. Furthermore, a patient may have had multiple ACPs (*16*). The classifications by ECG are used because they are convenient clinically, but they are considered too simplified to pinpoint the location of an ACP.

Surgical correction of a WPW syndrome is considered when a patient suffers from frequent and prolonged attacks of tachycardia and becomes completely incapacitated or suffers from cardiac failure (*14,15*). Because the recent development of electrophysiologic study techniques using intravenous catheters, epicardial mapping, and surgery can provide precise information on the site of the bypass tract, we compared the results of phase analysis with this surgically proven location of ACP.

All of Type B and six out of ten Type A patients were correctly diagnosed regarding the side of preexcitation by radionuclide study. A patient with intermittent WPW syndrome was not detected because at the time of her radionuclide study, she did not show the specific ECG pattern. Four Type A patients whose side could not be ascertained had ACP in the left anterior or lateral wall of LV, although they showed delta waves during their radionuclide study. More quantitative assessment is required to detect the precise site of ACP. We determined the initial phase visually. However, in some patients, it is difficult to locate the exact site of the initial phase in the phase image or cinematic display. Strict agreement between the initial phase and the site of ACP was obtained in half of the patients. This result is considered to be unsatisfactory when phase analysis is used as a preoperative study. Technical improvement such as reduction of random noise, type of display, multiple projections, and more quantitative processing to detect the site of initial phase may enhance the detectability. Application of gated blood-pool tomography is also expected. Further study is required for more precise location of ACPs.

It is interesting to analyze the phase abnormality during a tachycardial attack, since it may be that the abnormality of wall motion associated with the reentry mechanism can be mapped on the functional image. There are several factors affecting the result of phase analysis—for example, overlap of the blood pools of chambers, arrhythmia during tachycardia, and the site of the ACP. Although we could perform phase analysis during tachycardia in two patients, we could not confirm that these cases had a reentry pathway, and contraction patterns were essentially the same compared with those in the WPW syndrome without tachycardia. Further studies in such patients are indicated.

There are some limitations to the detection of ACPs by Fourier functional images. Several views are desirable to detect the precise site of initial activation. Although the functional image contains three-dimensional information, the abnormal movement of a given segment is detected best when the segment is viewed tangentially. The overlap of blood pools of different chambers may cause indication of an abnormal value of phase even in a region of normal contraction. We obtained RAO, LAO, and occasionally LPO or left lateral views to analyze wall motion, but overlap of blood pools cannot be completely avoided in RAO, LPO, and left lateral views. Even in the modified LAO view, separation of RA and RV is not sufficient in some cases. Using least-squares phase analysis, Turner et al. have reported that the sequence of onset of inward movement during ventricular tachycardia was similar to the sequence of depolarization (*17*). However, the sequence of contraction detected by phase analysis is also influenced by asynergy of the ventricles or low amplitude of wall motion due to other cardiac diseases, such as coronary artery disease or cardiomyopathy.

The correlation of abnormality between excitation and wall motion is an interesting problem. Although we could not obtain sufficient echocardiographic data in all patients, abnormal motion of interventricular septum (IVS) and left-ventricular posterior wall (LVPW) has been reported by echocardiography. Hishida et al. studied 52 patients with WPW syndrome by echocardiography and report that the abnormal LVPW motion was observed in all Type A and ten of 32 Type B patients,

and that abnormal IVS motion was observed in ten Type B patients (*18*). On the other hand, Francis et al. reported that the motions of the IVS and LVPW were normal in all of 14 Type A patients (*19*). There are also other echocardiographic reports of abnormal wall motion in the WPW syndrome, but the results were not in agreement (*18–20*). Our results using phase analysis showed a high incidence of phase-image abnormality compared with that of previous reports using echocardiography. These observations indicate that abnormal wall motion is associated with preexcitation.

Our approach failed in four patients of the L type whose ACP was either on the left anterior or lateral wall. This may be because the first harmonic is only a gross approximation of a time-activity curve. But the superiority of multiharmonic analysis has not been established yet, and detailed study will be needed. For the diagnosis of the presence of the WPW syndrome, the ECG is sufficient. The role of phase analysis in patients with this syndrome depends on whether it can detect more precisely the site of the ACP. Although intraoperative epicardial mapping is indispensable and most accurate for surgery (*15*), a noninvasive and reliable method will be very useful before surgery. At present it seems difficult to pinpoint the site of an ACP preoperatively by phase analysis alone. Nevertheless, the gated blood-pool study and phase analysis will be useful for the assessment of patients before and after surgery or medication, to detect changes of contraction pattern and to evaluate ventricular contractility. Phase analysis will also be useful if ECG findings are indeterminate in patients with suspected WPW syndrome, since the side of preexcitation is determined easily. Improved technique and algorithms to detect the onset of contraction are expected to elucidate abnormal wall motion in the WPW syndrome using radionuclide studies.

In conclusion, phase analysis indicated the side of preexcitation correctly in 16 of 20 patients (80%) with delta waves. These observations indicate that the abnormal wall motion is associated with the conduction anomalies of the WPW syndrome. Further clinical experience with the WPW syndrome and technical improvements are necessary to determine the precise site of an ACP. Phase analysis has provided interesting information before and after surgery.

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