PACE MAPPING USING BODY SURFACE POTENTIAL MAPS TO GUIDE CATHETER ABLATION OF ACCESSORY PATHWAYS IN PATIENTS WITH WOLFF-PARKINSON-WHITE SYNDROME

Marc Dubuc, MD; Réginald Nadeau, MD; Gaétan Tremblay, MScA; Teresa Kus, MD, PhD; Franck Molin, MD; and Pierre Savard, PhD

Background. A pace mapping technique using body surface potential maps (BSPMs) was developed to guide the positioning of an ablation catheter at the ventricular insertion point of accessory pathways (AP) in patients with the Wolff-Parkinson-White syndrome (WPW).

Methods and Results. The study was performed on 30 WPW patients. BSPMs were recorded with 63 leads distributed over the entire torso surface. The catheter used for radiofrequency ablation was first placed in the vicinity of the ventricular preexcitation site predicted by BSPMs recorded during the Δ wave. BSPMs were then recorded during pacing with this catheter, the comparison between the preexcited and paced BSPMs indicated whether the pacing site was too anterior or posterior with respect to the preexcitation site, and the catheter was moved accordingly. This process was repeated until the preexcited and paced BSPMs were highly correlated (r ≥ 0.8), and ablation then was attempted. It was possible to successfully ablate the AP in 28 patients after an investigation that lasted 54 ± 44 minutes between the recording of the first paced BSPM and that of the BSPM paced at the successful ablation site. Patients with left free wall pathways needed less investigation time compared with patients with pathways of other locations (46 ± 9 versus 100 ± 25 minutes, p = 0.031). The sensitivity of BSPM pace mapping was assessed using pacing with a multipolar catheter, and significant changes were observed on the BSPMs for beats with pacing sites that were only 5 mm apart.

Conclusions. BSPM pace mapping allowed us to achieve a 93% success rate with short investigation durations, provides significant information that cannot be obtained with the standard 12-lead ECG, is a self-correcting procedure that reduces the importance of BSPM alterations due to individual differences in the shape of the torso or heart, and is applicable only to patients with AP showing antegrade conduction. *(Circulation 1993;87:135–143)*

KEY WORDS • mapping • Wolff-Parkinson-White syndrome • catheterization • accessory pathways

Catheter ablation of accessory atrioventricular pathways using radiofrequency current has become the preferred nonpharmacological treatment for patients with the Wolff-Parkinson-White syndrome (WPW). 1–3 Despite its high success rate, catheter ablation of accessory pathways is time consuming because of the intracavitary mapping technique that is used to localize the accessory pathways and requires sequential recordings of numerous local electrograms in the atrioventricular area. To facilitate and shorten the localization procedure, we explored the possibility of combining pace mapping with body surface potential mapping to determine the accessory pathway location and optimize the catheter position before energy delivery.

Yamada et al 4 were the first to identify specific types of body surface potential maps (BSPMs) recorded during the Δ wave in WPW patients. Benson et al 5 correlated the patterns of BSPMs recorded during the Δ wave and the ST segment with the preexcitation sites determined by electrophysiological studies or surgical ablations, and they concluded that at least seven preexcitation sites could be predicted by analysis of the BSPM patterns. Computer simulations reproduced the BSPM patterns associated with these sites, 6 and similar patterns were reported by Nadeau et al, 7 Liebman et al, 8 and Giorgi et al, 9 in patients who underwent arrhythmia surgery and/or an electrophysiological study. Nadeau et al 10 underlined the progressive changes in the morphology of the BSPMs recorded during the Δ wave in patients with adjacent preexcita-
tion sites, reflecting the continuous distribution of the preexcitation sites around the atroventricular ring. This is illustrated in Figure 1, where the position of the minimum and negative potentials on the BSPMs identify the pathway location: prominent negativity on the right side of the anterior torso corresponds to preexcitation sites located in the right ventricle, a minimum on the back corresponds to sites in the left ventricle, and negativity over the entire lower torso corresponds to posteroseptal sites. Otherwise, positivity over the entire lower torso corresponds to anterior sites. For all sites, the maximum always occurs in the left precordial area as the preexcitation vectors point toward the apex.

The ease of interpretation of these BSPM patterns and the progressive changes observed for adjacent preexcitation sites constitute the basis of the BSPM pace mapping method. The first step of this method is to position the catheter in the vicinity of the preexcitation location predicted by the BSPMs recorded during the Δ wave of a normal sinus beat. Then, the ventricles are paced with this catheter, and the BSPMs recorded during the paced QRS are compared with the preexcited BSPMs; this comparison indicates if the pacing site is too anterior or posterior with respect to the preexcitation site, and the catheter is moved accordingly. This process is repeated until the preexcited and paced BSPM patterns are identical; then, radiofrequency ablation is attempted.

Methods

Patient Population

The study group consisted of 19 men and 11 women aged 18–66 years (Table 1). All patients had no other associated heart disease. A Δ wave was present on the ECG of all these patients; it was permanent in 25 and intermittent in five. Twenty-six patients had recurrent palpitations due to orthodromic supraventricular tachycardia despite pharmacological treatment, and four presented with atrial fibrillation and a fast ventricular response. In these four patients, two had a syncpse, and two had a profound hemodynamic compromise documented in-hospital that had to be electrically cardioverted. Written informed consent was obtained from all patients, and all antiarrhythmic medications were stopped at least 24 hours before the ablation procedure.

Intracavitary Recordings and Stimulation

Three 6F quadripolar catheters were inserted into the right femoral vein and positioned in the right atrium,

![Figure 1. Body surface potential maps recorded during the Δ wave in 12 patients with the Wolff-Parkinson-White syndrome who underwent arrhythmia surgery or electrophysiological study. Maps on the left correspond to patients with single preexcitation sites located in the right ventricle, maps on the right correspond to sites in the left ventricle, the upper maps correspond to anterior sites, the middle maps correspond to lateral sites, and the lower maps correspond to posteroseptal sites. The left part of each map corresponds to the anterior torso, the right part corresponds to the posterior torso, isopotential lines join points with the same potential value, and the plus and minus signs identify the sites of the potential maximum and minimum, respectively. Reprinted with permission from Kluwer Academic Publ.](image)

<table>
<thead>
<tr>
<th>TABLE 1. Characteristics of Patient Population</th>
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<tbody>
<tr>
<td>No. of patients</td>
</tr>
<tr>
<td>Male/female</td>
</tr>
<tr>
<td>Location of accessory pathway</td>
</tr>
<tr>
<td>Left free wall</td>
</tr>
<tr>
<td>Right free wall</td>
</tr>
<tr>
<td>Posteroseptal</td>
</tr>
<tr>
<td>Anteroseptal</td>
</tr>
<tr>
<td>Multiple pathways</td>
</tr>
<tr>
<td>Success rate</td>
</tr>
<tr>
<td>No. of radiofrequency applications</td>
</tr>
<tr>
<td>No. of paced body surface potential maps</td>
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<tr>
<td>Time for successful localization (minutes)</td>
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</table>

Data are expressed as mean±SD.
across the tricuspid valve to record His bundle activity, and in the right ventricle. A fourth catheter was introduced into a jugular or subclavian vein and positioned in the coronary sinus. Four surface leads (I, II, III, and V1) were recorded simultaneously with intracardiac electrograms (filtered at 30–500 Hz) on a multichannel oscilloscope (Electronics for Medicine VR-16, Honeywell Inc., Pleasantville, N.Y.) and recorded on a thermal printer (MT-9600, Astro-Med Inc., West Warwick, R.I.) at a paper speed of 100–200 mm/sec and on a Kyowa videocassette recorder. Pacing was performed with a programmable stimulator (Bloom Associates, Reading, Pa.) with stimuli lasting 2 msec and a current strength twice the late diastolic threshold.

The goal of the electrophysiological evaluation before ablation was to demonstrate the participation of the accessory pathway in the 26 patients with orthodromic supraventricular tachycardia. In the four patients with atrial fibrillation, preexcitation during sinus rhythm and atrial fibrillation was the same, and no attempt was made to voluntarily induce arrhythmias.

**Body Surface Potential Mapping**

The body surface potentials were measured with 63 unipolar leads referenced to the Wilson central terminal. These leads were radiotranslucent to prevent interference on the fluoroscopic images during the electrophysiological study and the ablation procedure. The electrodes, which consisted of plastic disks containing Ag-AgCl particles, were mounted on 12 vertical adhesive strips with an interelectrode distance of 6 cm, with 43 electrodes on the front and sides of the torso and 20 electrodes on the back. The first strip was applied over the sternum with the top electrode over the suprasternal notch. The first electrode of each of the 11 other strips was applied at the same level. The set-up time for the BSPM leads was approximately 5–10 minutes. The 63 ECGs were amplified, filtered with a bandwidth of 0.05–200 Hz, multiplexed, sampled at 500 Hz, digitized with a 10-bit analog-digital converter, and stored in a circular memory buffer. During data acquisition, a reference signal from one of the 63 leads was constantly displayed on a terminal to allow the selection of any particular beat for the BSPM analysis, which was carried out on a microVAX II computer (Digital Equipment Corp.).

The first step of the BSPM analysis consisted of displaying all the 63 ECGs of the selected beat so as to visually identify faulty leads. Any faulty signal was then replaced by interpolating the signals from neighboring leads. Baseline shift was corrected by subtracting from each ECG a straight line joining two isoelectric points that were manually selected during the TP intervals that preceded and followed the beat. Band-reject 60-Hz filtering or signal averaging could be used to improve the signal-to-noise ratio, but they were not applied in this study because the quality of the ECG signals did not require further treatment. This preprocessing phase could be performed in <1–2 minutes. To characterize the spatial distribution of the body surface potentials at any specific instant, color isopotential maps were drawn on a terminal. On these maps, the torso surface is represented in a rectangular format. The left side of the map corresponds to the anterior torso, and the right side corresponds to the posterior torso. The isopotential lines that join points with the same potential value are obtained by cubic spline interpolation. The zero potential line is identified by a heavier line, and the plus and minus signs identify the locations of the maximum and minimum.

**BSPM Pace Mapping**

The initial approach to the pathway was guided by BSPMs recorded in sinus rhythm while the patient was spontaneously preexcited or during right atrial pacing if no ventricular preexcitation was apparent in sinus rhythm (the “preexcited” BSPMs). A 7F quadrupolar catheter with a distal electrode with a 4-mm tip, an interelectrode spacing of 5 mm, and a deflectable curve (Mansfield-Webster, Watertown, Mass.) was introduced in a femoral artery and advanced to the left ventricle in a retrograde fashion through the aortic valve if the preexcited BSPMs showed a left-sided preexcitation. If the preexcited BSPMs showed a right-sided preexcitation, the deflectable catheter was introduced in the femoral vein or the subclavian vein depending on whether the pattern of preexcitation was right posterior or right anterior, respectively. The catheter was then advanced in the right ventricle.

Once the ablation catheter was in the ventricle, it was positioned at the atrioventricular ring, under the atrioventricular valve on the ventricular side, near the preexcitation area identified by the preexcited BSPMs. A correct position at the atrioventricular ring was confirmed by the presence of ventricular and atrial deflections on the electrogram recorded between the distal pair of electrodes on the ablation catheter. Pacing of the ventricles using this distal pair was then performed while recording the body surface potentials. To compare these paced BSPMs with the preexcited BSPMs, the paced beat and the preexcited beat were first aligned in the following fashion. The root-mean-square (RMS) signals computed from all the 63 leads of the preexcited beat were visually aligned on the RMS signals of the paced beat so that the Δ wave of the preexcited beat coincided with the upslope of the paced beat (Figure 2A). A correct alignment of the two beats is critical for the rest of the analysis. A common QRS onset was determined on these superimposed RMS signals. To quantitatively assess the similarity between preexcited and paced BSPMs, the correlation coefficient between the preexcited and paced body surface potential distributions was plotted for all sampling instants during the first 40 msec after QRS onset (Figure 2B). Isopotential maps for the paced and preexcited beats were then drawn side by side on the color terminal for the time instant with the highest correlation (Figure 2C). Similar pairs of maps could be rapidly displayed for all successive time instants as in an animated movie.

The qualitative comparison between the paced BSPMs and the preexcited BSPMs allowed us to estimate the relative position of the catheter with respect to the preexcited area (Figure 1). The catheter was moved toward the preexcited area when the patterns of both maps were clearly different. When the patterns of the paced and preexcited BSPMs were similar with a correlation coefficient ≥0.8, application of radiofrequency energy was attempted at this site. In case of failure at this first site, the ablation catheter was moved in the area to obtain a greater correlation coefficient. These
steps were repeated until successful ablation was achieved. The recording of accessory pathway potentials was not considered a prerequisite for ablation.

Ablation

Radiofrequency current was delivered between the 4-mm tip electrode of the ablation catheter and a back plate. Energy was delivered using a 500-KHz radiofrequency generator (HAT 200, Dr. Osypka GmbH, Grenzach-Wyhlen, Germany). Ablation was thought to be successful if both anterograde and retrograde accessory pathway conductions were abolished. After a successful ablation, radiofrequency energy was again applied to avoid the possibility of recurrence and to increase our safety margin. After 30 minutes of observation, absence of anterograde and retrograde accessory pathway conductions in the accessory pathway was reassessed using standard techniques of pacing and programmed stimulation. If the absence of conduction was confirmed, isoproterenol was administered intravenously (≤2 μg/min) to increase the sinus rhythm rate by at least 20%, and the same stimulation protocol was done again so as to assess the absence of atrioventricular conduction in accessory pathway. If the absence of conduction in the accessory pathway was again confirmed, the patient was considered as being successfully ablated, and all catheters were removed.

Statistical Analysis

Data are presented in mean±SD values. Statistical analysis was performed with t tests for unpaired data, and p<0.05 was accepted as the limit of significance.

Results

BSPMs and Accessory Pathway Location

Twenty-nine patients were spontaneously preexcited during sinus rhythm when the reference BSPMs were recorded. The presence of preexcitation was determined by the presence of a Δ wave associated with BSPM patterns (Figure 1) that are quite different from the pattern observed at the beginning of the QRS during normal sinus rhythm (which is characterized by positive potentials over the upper right chest with a potential maximum over the sternal region and a minimum over the lower left thoracic wall). One patient (patient 24) showed intermittent preexcitation, and we had to wait >30 minutes to record the preexcited BSPMs; right atrial pacing, even after administration of 12 mg adenosine i.v., was not effective in making preexcitation apparent in this patient. Another patient (patient 21) required right atrial pacing for antegrade preexcitation to be observed. For the entire patient population, an accessory pathway showing an antegrade conduction on the surface ECG was located in the left free wall in 18 patients and in the right free wall in three and was anteroseptal in five and posteroseptal in four. Whether the preexcitation was left or right sided according to the preexcited BSPMs was confirmed by intracardiac recordings in all patients.

It was possible to successfully ablate the accessory pathways in 28 patients after a localization procedure that lasted 54±44 minutes. The duration of the mapping procedure was measured between the recording of the computer file of the first paced BSPM and that of the BSPM obtained during pacing at the successful ablation site. Patients with left free wall pathways necessitated significantly less localization time compared with other locations (46±9 versus 100±25 minutes, p=0.031).

An example of the application of the BSPM pace mapping procedure for a patient with a right-sided accessory pathway is presented in Figure 3. The on-line analysis of the Δ wave maps recorded during normal sinus rhythm at the beginning of the investigation revealed a right anterior ventricular preexcitation site. The ablation catheter was then positioned approximately at that site, and the ventricles were paced. BSPMs recorded during the paced QRS complex were similar to the preexcited BSPMs; ablation was thus attempted but failed. On the paced BSPMs, the location of the minimum was lower than on the preexcited BSPMs, and negativity extended to the lower torso, whereas the lower torso was positive on the preexcited BSPM. According to Figure 1, this first pacing site was estimated to not be sufficiently anterior, and the ablation catheter was moved to a more anterior site. For the BSPMs recorded during ventricular pacing at this second site, the locations of the BSPM extrema and the BSPM morphology were visually identical to the preexcited BSPM and the correlation coefficient was higher than for the first pacing site. The ablation was successful for this second site.

Another example for a patient with left-sided preexcitation is presented in Figure 4. The Δ wave BSPMs recorded during normal sinus rhythm revealed a left lateral accessory pathway. The ablation catheter was positioned approximately at that site and on the BSPMs recorded during subsequent pacing, the location of the
Ablation

An accessory pathway with antegrade conduction was successfully ablated in 28 patients (93%). Paced BSPMs with a correlation coefficient $\geq 0.80$ were obtained in all patients who were successfully ablated. Furthermore, the successful ablation site was always located where the pacing catheter produced the paced BSPMs with the highest correlation coefficient. Paced BSPMs with a high correlation coefficient ($\geq 0.8$) could not be found in the two patients in whom the ablation failed. Transient pericarditis occurred in one patient, and the echocardiogram performed the next day showed evidence of a small pericardial effusion. No other complication occurred.

Evidence of a second pathway was found in six patients after successful ablation of the first pathway. In two patients, these second pathways were located in the left posterior free wall, in the right anterior free wall in two, and in the left posteroseptal area in one. All these second pathways showed retrograde conduction only and were successfully ablated during the same session. The sixth patient (patient 18) showed two different BSPM morphologies of preexcited beats during spontaneous atrial fibrillation, which suggested the presence of two pathways. After the successful ablation of the anteroseptal pathway, evidence of antegrade preexcitation compatible with a posteroseptal pathway was found. Unfortunately, it was not possible to record good paced BSPMs, and the pathway was not ablated with the catheter technique. This patient was referred for surgery and surgical identification, and division of an atypical Mahaim connection associated with supranormal conduction of the atrioventricular node that mimicked posteroseptal atrioventricular preexcitation was carried out.

Local Electrograms

Characteristics of electrograms recorded at successful sites of radiofrequency ablation are summarized in Table 2. Two probable and two possible accessory pathway potentials were recorded, and no special attempts were made to validate these potentials by pacing maneuvers. Amplitudes measured in millivolts are not available in all patients because of the absence of reliable calibration with our initial recorder. The
TABLE 2. Characteristics of Electrograms Recorded at Successful Sites of Radiofrequency Ablation and Where Best Body Surface Potential Maps Were Obtained

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean±SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A amplitude (mV)*</td>
<td>1.74±1.20</td>
<td>0.5</td>
<td>3.8</td>
</tr>
<tr>
<td>V amplitude (mV)*</td>
<td>3.07±2.74</td>
<td>0.3</td>
<td>8.5</td>
</tr>
<tr>
<td>A/V ratio</td>
<td>0.77±0.90</td>
<td>0.07</td>
<td>5.0</td>
</tr>
<tr>
<td>AV interval (msec)</td>
<td>42.6±16.1</td>
<td>15</td>
<td>70</td>
</tr>
<tr>
<td>V-QRS interval (msec)</td>
<td>18.4±11.5</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>VA interval (msec)</td>
<td>65±10.7</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td>V_A interval (msec)</td>
<td>129±25.2</td>
<td>160</td>
<td>75</td>
</tr>
</tbody>
</table>

A, auriculogram; V, ventriculogram; S, spike of paced ventriculogram.

*Available in seven patients.

n=28.

BSPM Sensitivity

Finally, to assess the sensitivity of the BSPM technique for the detection of small changes in the location of the pacing site, BSPMs were recorded after pacing at ventricular sites separated by known distances in two patients. A multipolar catheter was inserted in the left ventricle with its extremity parallel to the base of the left ventricle (Figure 5). A coronary sinus catheter was used as a reference. The distance between each of the four electrodes was 5 mm. The ECGs for different pacing sites were aligned using the stimulation artifacts and BSPMs were analyzed at the time instant, showing maximum correlation with the reference pacing site (the distal electrode pair). Discernible changes were observed on the BSPMs recorded after a pacing pulse was applied between the electrode pairs 1-2, 2-3, and 3-4. For the more distal electrode pair (1-2), positive potentials covered the lower back; for the central electrode pair (2-3), negative potentials extended to the lower back; and for the proximal pair (3-4), negative potentials covered the entire lower torso and the correlation coefficient was lower than for the central electrode pair. The ECG changes between the beats paced at the distal and central electrode pair are hardly detectable on the standard 12-lead ECG (Figures 6A and 6B), where the polarities of the Q wave, R wave, and S wave on all 12 leads as well as the QRS axis (<−80° and >81°) remained the same for the two beats. Indeed, changes in Q wave polarity for these two beats can be detected on the BSPMs (Figures 5B and 5C) only in the middle of the lower back where none of the standard leads are located. The changes on the 12-lead ECG between the beats paced at the central and proximal electrode pair are more easily detectable with a new Q wave in aVL and a new R wave in leads aVF, II, III, and V6 for the proximal pacing site (Figure 6C) and a QRS axis that changed from −81° to +52°. These changes can be correlated with changes in the polarity of the lower left torso (left leg lead) and the left midaxillary line (V6) on the BSPMs (Figures 5C and 5D).

FIGURE 4. Example of the body surface potential pace mapping procedure for a patient with a left lateral accessory pathway. Panel A: Δ Wave body surface potential map (20 msec after QRS onset) recorded during normal sinus rhythm. Panel B: ECGs (leads II, III, and V1) bipolar electrogram from the catheter tip (VE), correlation coefficient, and body surface potential map recorded during ventricular pacing with the catheter tip located at a first site near the base of the left ventricle. The map was obtained at the time instant having the highest correlation coefficient (0.79) with preexcited maps (20 msec). The arrow under the VE electrogram indicates a probable accessory pathway potential. An ablation attempt at this site was unsuccessful. Panel C: ECGs, electrogram, correlation coefficient, and body surface potential map recorded during ventricular pacing with the catheter located at a second site, which was more posterior with respect to the first one. The map was obtained at the time instant having the highest correlation coefficient (0.9) with preexcited maps (20 msec). An ablation attempt at this site was successful.

V-QRS interval corresponds to the interval between the onset of local ventriculogram recorded by the distal electrodes of the ablation catheter and the onset of the Δ wave on surface leads. VA intervals were measured during right ventricular pacing or orthodromic tachycardia. The V_A interval measures the time between the spike of the paced right ventriculogram, which is easier to identify than the onset of a ventriculogram, and the onset of the retrograde atrial electrogram.
FIGURE 5. Examples of body surface potential maps recorded after pacing at three known sites. Panel A: Left sagittal view of the heart showing the approximate position of the multipolar pacing catheter with its extremity parallel to the base of the left lateral wall. The distance between each of the four electrodes is 5 mm. Panel B: Body surface potential map recorded at 58 msec after a pacing pulse was applied between electrodes 1 and 2. Panel C: Time course of the correlation coefficient between body surface potential maps recorded after pacing between electrodes 1 and 2 and between electrodes 2 and 3. Body surface potential map recorded after pacing between electrodes 2 and 3 at the time instant having the highest correlation coefficient (0.94) with maps recorded after pacing between electrodes 1 and 2 (58 msec after pulse). Panel D: Time course of the correlation coefficient between body surface potential maps recorded after pacing between electrodes 1 and 2 and between electrodes 3 and 4. Body surface potential map recorded after pacing between electrodes 3 and 4 at the time instant having the highest correlation coefficient (0.81) with maps recorded after pacing between electrodes 1 and 2 (62 msec after pulse).

Discussion

The definitive management of patients with WPW has considerably advanced with the introduction of radiofrequency catheter ablation by Jackman et al. in the United States and Kuck et al. in Germany. This therapeutic modality presents considerable advantages over the surgical approach in terms of risk, inconvenience, and cost. Reported results are very impressive with success rate reaching >90%. Success rate usually improves with operator experience. Leather et al. reported a success rate of 52% (23 patients), 60% (23 patients), and 90% (38 patients) during the first, second, and third 3-month intervals of their experience, respectively. Despite this being our initial experience with an ablation technique and limited to a small number of patients, we reached a success rate of 93% immediately, which we believe to be attributable to the use of BSPM pace mapping.

The precise localization of the accessory pathway is of prime importance, more so with radiofrequency catheter ablation than with surgery. This is because the lesions produced by the application of radiofrequency current are small and well defined, estimated to be <6 mm in diameter and <3 mm in depth. The correct positioning of the ablation catheter is difficult to achieve, and repeated discharges may be necessary. This may increase tissue damage, the extent of which is difficult to assess. The procedure of intracavitary ablation is also associated with a significant radiation exposure to both patient and physician. The duration of an ablative procedure is considerably longer than that of a diagnostic electrophysiological study, and reduction of radiation exposure is therefore highly desirable. Schlüter et al. reported that ablation sessions lasted 4.3±1.9 hours with a mean radiation exposure of 54±33.7 minutes. The investigative component (includ-
ing radiation exposure and mapping) of our ablation sessions lasted 54±44 minutes compared with 58±52 minutes for Calkins et al., who reported their combined experience of ablation with atrioventricular node reentry and accessory pathways using standard techniques of intracardiac mapping. BSPM pace mapping was particularly helpful in localizing posteroseptal and left parietal pathways, exceptionally so in anteroseptal ones. In agreement with other authors, we report a greater ease in mapping and ablating left free wall pathways than pathways located elsewhere (46±9 versus 100±25 minutes, p<0.031).

Current criteria for accessory pathway localization during ablative procedures are based on distinctive intracavitary electromogram configurations, shortest atrioventricular conduction parameters, and recording of accessory pathway potentials. The values recorded at the successful sites in our series are very similar to those already described, except considering the number of accessory pathway potentials identified, which is generally greater in other series. We recorded accessory pathway potentials in only four patients at the site where paced BSPM had a coefficient of r=0.80 and the ablation was successful; this could be related to 1) our catheter position, which is located at the ventricular insertion point of the pathway so that we do not record the depolarization of the accessory pathway itself; 2) that there is no clear consensus on the determination of the presence of an accessory pathway potential without pacing maneuvers, which are time consuming; and 3) that the presence of a possible accessory pathway potential was not a prerequisite finding before radiofrequency delivery in our study. However, as illustrated in Figure 4, reliance on the characteristic accessory pathway potential can be misleading. Our experience is that BSPM pace mapping optimizes the accuracy of the identification of the ablation site at the ventricular insertion point of the accessory pathway.

Our results demonstrate a high correlation between endocardial ventricular stimulation and preexcitation, which suggests that the onset of preexcitation is also close to the endocardium. Schlüter et al have commented that the ease with which the endocardial application of radiofrequency current destroys the accessory pathways and the ability to record sharp accessory pathway potentials from endocardial electrodes and are in favor of an endocardial insertion of the accessory fibers.

Characteristic BSPM patterns have been shown to be correlated with sites of ventricular preexcitation as determined during open-heart surgery. Our study confirms that BSPM is highly predictive and demonstrates that it is remarkably accurate when combined with pace mapping, which provides additional information about the location of the catheter with respect to the preexcitation site. Also, BSPMs provide much more information about the spatial distribution of the body surface potentials than the 12-lead ECG, and significant ECG differences in the Δ wave between adjacent preexcitation sites are more easily perceived by comparing maps than 12-lead ECG tracings. In particular, small but meaningful differences in the location of the zero potential line on the back (Figure 5) as the pacing site is displaced by only 5 mm cannot be detected with the standard ECG, which does not include any lead on the back. It must be emphasized that BSPM pace mapping is a self-correcting procedure that reduces the importance of BSPM differences that are not specific to the accessory pathway location, such as those due to individual differences in the size and shape of the torso or heart. For example, one patient with a preexcited BSPM suggestive of a right lateral pathway who was paced at that site showed a right anterior pattern on the paced BSPMs; the pacing catheter was thus moved inferiorly, and the preexcitation site was finally localized in the posteroseptal region. The duration of preexcitation can be short, inasmuch as a distinctive preexcitation pattern can be recorded after QRS onset.

The specific features that characterize the concordance between the paced and preexcited BSPMs are the distribution of negative potentials over the torso surface and the location of the zero potential line and the position of the potential minimum on the body surface. The position of the minimum has been related to the site of earliest depolarization by De Ambroggi et al. Also, Spach et al, using endocardial stimulation in the chimpanzee, noted that the position of the maximum during the Δ wave was relatively stationary on the anterior chest, whereas the position of the minimum changed with the pacing site. Benson et al noted the variability of the minimum at the onset of the Δ wave and suggested that maps recorded before 40 msec could be unreliable. Early variations in the location of the minimum can be attributed in large part to the superposition of atrial potentials; in a preceding study, we have shown that the typical thoracic distribution of positive and negative potentials becomes stable within the first 30 msec of the QRS complex and remains stable for the first half of the QRS complex. There is no point in arbitrarily choosing one time instant over another, and concordance between the paced and preexcited BSPMs can be best established by using the correlation coefficient technique. A high correlation coefficient that remains stable during the Δ wave is a good indicator of concordance.

This technique is applicable only to patients with accessory pathways showing antegrade conduction and not to patients with only retrograde conduction because BSPM pace mapping procedure is restricted to the ventricular side of the pathway and does not allow us to localize the atrial insertion point. Another limitation of BSPM pace mapping could be for patients with ventricular preexcitation starting simultaneously at two distant sites and thus generating misleading body surface potential distributions.

In conclusion, this study demonstrates that BSPM pace mapping can provide useful information about the direction toward which the catheter should be moved to get it closer to the ventricular insertion point of the accessory pathway. This information is complementary to that given by standard localization techniques based on atrioventricular intervals or accessory pathway potentials that basically measure the closeness of the catheter to the accessory pathway.

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