Electrogram Patterns Predictive of Successful Catheter Ablation of Accessory Pathways

Value of Unipolar Recording Mode

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Background. Transcatheter electrical ablation has been used in the treatment of arrhythmias, and most experience has been obtained by ablating the normal atrioventricular conduction system. Less information is available on ablation of atrioventricular accessory pathways.

Methods and Results. Catheter ablation of overt accessory pathways was attempted in 135 patients with 142 distinct pathways, including 21 right parietal or anteroseptal, 47 posteroseptal, and 74 left lateral pathways. We sought to identify the type and value of electrophysiological parameters associated with successful ablation outcome. For this purpose, the unipolar recording mode was used in addition to bipolar anterograde and retrograde parameters. With a mean follow-up of 16±6 (mean±SD) months, fulguration was successful in eliminating preexcitation in 129 patients (96%), including all seven with two distinct accessory pathways. The first ablation attempt was successful in 110 patients, and two or more attempts were performed in 25 patients. Bipolar electrograms associated with success of fulguration showed a shorter atrioventricular conduction time (40±13 versus 53±17 msec, p<0.0001) and an earlier main ventricular deflection relative to delta wave onset (−1.7±10 versus ±5±7 msec, p<0.001) than electrograms associated with unsuccessful outcome. The only parameter dealing with retrograde conduction (i.e., ventriculoatrial conduction time during reciprocating tachycardia) was not predictive (86±17 versus 93±17 msec). Neither was the atrial to ventricular electrogram amplitude ratio. Two unipolar parameters were found to be predictive of successful outcome: 1) The three different patterns PQS, P-QS, P-rS of unipolar waves recorded at the annulus were associated with respective success rates of 97%, 78%, and 55% (p<0.001). 2) Intrinsic deflection timing occurred −4±8 and 6±7 msec relative to delta wave onset in successful attempts and in failures, respectively (p<0.001). Logistic regression analysis revealed a single independent factor predictive of success, the unipolar pattern (p=0.03), with an odds ratio of 7:1 (PQS pattern versus P-rS pattern). In the group of 18 patients who underwent a first unsuccessful but second successful attempt, comparison of electrograms revealed no difference in the ventriculoatrial conduction time but a significant improvement in anterograde parameters and unipolar pattern distribution.

Conclusions. Some distinctive electrogram parameters concerning anterograde conduction are associated with success of accessory pathway fulguration. The unfiltered unipolar recording mode (PQS pattern) contributes significantly to optimizing the accuracy of accessory pathway localization. (Circulation 1991;84:188–202)

Transcatheter electrical ablation is a promising procedure for the treatment of different arrhythmias.1–10 Most experience has been obtained by ablating the normal atrioventricular conduction system. Less information is available on fulguration of atrioventricular accessory pathways (APs). Complete ablation of the anomalous pathway has been achieved in an extremely variable percentage of patients,3–10 depending on AP location, technical factors, or mapping accuracy. Logically, the optimal ablation site would be the site of recording of Kent bundle activity, but its identification and validation are very arduous and time-consuming.5,7,8,11,12 The value of other (indirect) criteria has not been systematically studied. In 135 patients, we sought to identify the type.
and value of electrophysiological parameters predictive of successful ablation outcome. For this purpose, the unipolar recording mode was used in cardiac mapping, in addition to conventional bipolar electrograms. This report examines the success of fulguration when a given ablative energy was delivered to sites with different endocardial patterns.

Methods

Patient Characteristics

The study population included 135 patients, 92 men and 43 women, with a mean age of 31±12 years (range, 11–62 years). All patients but three were suffering from spontaneous orthodromic reciprocating tachycardia, paroxysmal atrial fibrillation, or both. Four patients were resuscitated from ventricular fibrillation. Three patients, all sportsmen, were asymptomatic but accepted curative treatment that was proposed because of the presence of two electrophysiological risk factors for potentially malignant arrhythmias: a sustained atrial fibrillation inducible by one atrial extrastimulus and a minimal preexcited ventricular response of 200 msec or less. A structural heart disease was present in eight patients: dilated cardiomyopathy in four, Ebstein’s disease in two, aortic insufficiency in one, and corrected transposition of great vessels in one. The 135 patients had a combined total of 142 APs; seven patients had two distinct APs. The locations were as follows: anteroseptal (11 APs), right parietal (10 APs), right posteroseptal (22 APs), left posteroseptal (25 APs), and left parietal (74 APs). All patients had either permanent or intermittent preexcitation on the electrocardiogram (ECG).

Baseline Electrophysiological Study: Acquisition of Endocardial Data

After providing informed consent, patients underwent electrophysiological study. Antiarrhythmic drugs were discontinued for at least five half-lives, except amiodarone in eight patients. Three or four 6F multipolar electrode catheters (USCI, Billerica, Mass.) were placed simultaneously or subsequently in the His bundle region, the right atrium, and the right ventricle. The coronary sinus was catheterized in all patients with septal or left parietal APs and in patients who previously had not had a diagnostic study. The catheter used for delivering shocks was a 6F bipolar, tripolar, or quadripolar electrode catheter (USCI) with 5-mm interelectrodes in all cases, tested earlier for fulguration. It was introduced through the left subclavian vein for right-sided and posteroseptal APs or via a retrograde transaortic approach for left parietal APs.

Bipolar electrograms were recorded at a paper speed of 100 mm/sec with a polygraph (model VR12, Electronics-For-Medicine, Pleasantville, N.Y.) using filtering at 30–500 Hz. “Unfiltered” unipolar electrograms were obtained on surface ECG channels of the VR12 recorder and analyzed at a paper speed of 100 or 150 mm/sec, with a gain of 10 mm/mV. Unipolar recordings during preexcitation were made at the preablation and adjacent sites. Furthermore, in most patients with left parietal APs, unipolar electrograms were recorded through the catheter left in place in the coronary sinus. Unfiltered atrial electrograms during reciprocating tachycardia were not studied because their precise onset was often not discernible.

Determination of Ablation Site

Determination of a stable endocardial reference. Use of a stable endocardial reference facilitated mapping and gave a more precise and reproducible electrogram than did electrocardiographic leads. Indeed, the ablation catheter was moved around the reference catheter, which provided both the radiographic area of AP location and near-optimal values of electrophysiological parameters of atrial and ventricular AP insertions.

Reference catheter positioning specifically depended on AP location. In anteroseptal APs, the reference was easily obtained from the quadripolar catheter (5-mm interelectrodes) at the His bundle region by the selection of the earliest recorded ventricular deflection. Great care was taken during

Figure 1. Recordings showing discrepancy in anterograde and retrograde activation-time maps in patient with left lateral accessory pathway. A hexapolar 2-mm interelectrode catheter is left in stable position in the coronary sinus (CS). During orthodromic reciprocating tachycardia (ORT), the distal bipolar (12) records earliest atrial deflection (arrow on left panel). During preexcited sinus rhythm (SR), earliest bipolar (BIP) ventricular deflection occurs at the proximal bipolar (56) of the coronary sinus catheter (arrow on right panel). This ventricular activity is nearly synchronous with preexcitation onset (vertical line) and is associated with shortest atrioventricular conduction time.
manipulation of catheters to avoid a traumatic transient block in AP conduction, which would have precluded further mapping. In posteroseptal APs, the reference was the proximal bipole of the quadrupolar catheter left in place in the proximal coronary sinus. In left lateral APs, the reference was provided by a stable hexapolar or octopolar electrode catheter (2-mm interelectrodes) left in place in the coronary sinus: we performed both mapping of retrograde conduction during reciprocating tachycardia or echo beats (shortest ventriculoatrial conduction time [VA time] value) and mapping of anterograde AP conduction by selecting the bipole that recorded the earliest ventricular deflection during preexcitation. In 12 of the 74 patients (16%), we found a discrepancy in the recording site of anterograde and retrograde AP conduction, with the result that the bipole recording the earliest anterograde activation time was one or two interelectrode intervals from the bipole recording the retrograde AP breakthrough (Figure 1).

In right parietal APs, an anatomically stable catheter was very difficult to obtain. We simultaneously used two catheters, each serving as a reference for the other until the presumed optimal ablation site was obtained. We did not use catheterization of the right coronary artery, which allows more rapid and precise mapping of the right annulus.

**Determination of ablation site.** The site of shock delivery was determined essentially using two criteria: 1) the shortest VA time during orthodromic reciprocating tachycardia and 2) the earliest ventricular potential relative to QRS complex onset during manifest preexcitation. These criteria were both appreciated relative to the reference electrogram. In all cases, the site was selected by obtaining a synchronous or earlier activation time than the reference electrogram at a site not surrounded by an earlier activated zone. In right as well as left posteroseptal APs, the criteria above were found on the right side of the septum, outside the coronary sinus.

Furthermore, pace mapping was performed using 14-mA stimuli to reproduce preexcited QRS complexes. Concordant pace maps were sought particularly in posteroseptal and in left parietal APs, where the position of the catheter was frequently on the ventricular border of the annulus. Stimulation of the bordering atrial endocardium was excluded by the absence of delay-spike-QRS and the presence of an adjacent (reference) atrial electrogram within the paced QRS or by pacing performed during atrial
fibrillation. Concordant pace maps were used as additional criteria for determination of the ablation site, but only the underlying endocardial electrograms were analyzed, depending on ablation outcome.

In some patients, particularly those with anteroseptal APs, we recorded a potential consistent with direct AP activity. Although a late atrial potential was easily ruled out, we were unable to strictly exclude an early ventricular potential.

**Endocardial Bipolar and Unipolar Electrograms**

In each site used for shock delivery, the following bipolar mapping data were measured manually: VA time (the VA interval) during orthodromic reciprocating tachycardia was measured from the earliest onset (intracardiac or ECG recording) of narrow QRS complex to the peak of the main atrial potential. Two measurements of ventricular electrogram timing were assessed relative to the delta wave onset in surface ECG leads: the interval from the delta wave onset to the peak of the main (maximal amplitude) ventricular potential (Figure 2) and the interval from the delta wave onset to the peak of the first of any rapid ventricular potential preceding the main potential. The local atrioventricular conduction time was measured between the peaks of the main atrial and ventricular potential during preexcitation. The ratio of the amplitude of the atrial electrogram to that of the ventricular electrogram (A/V ratio) was then determined. Although an A/V ratio close to 1 would probably be optimal, the stable position of the catheter was very dependent on the AP location or the mode of catheter approach, so that it could be on the atrial or ventricular side of the annulus.

At each ablation site, six characteristics of unipolar electrograms were evaluated: waveform configuration, amplitudes of both the atrial and ventricular electrograms, A/V ratio, timing of the ventricular downstroke, and downstroke slope. In all cases, ventricular waveform was predominantly negative with a fast continuous downstroke classically labeled as the intrinsic deflection (Figure 2). The onset of this downstroke was used to measure the local activation timing. In rare cases, this downstroke was discontinuous (i.e., it had two slopes), and timing was determined at the onset of the fastest slope. If the waveform changed as the electrode pressed against the myocardium (resembling a monophasic action potential), the catheter was withdrawn. Since there are no systematic studies of unipolar electrograms in the endocardial annulus region, we did not know the different patterns of the respective atrial and ventricular components. Therefore, waveform configuration was described (see “Results”) in different groups according to morphology. The amplitude of the atrial and ventricular electrograms was measured and expressed in millivolts. The slope of the ventricular downstroke was calculated from voltage and the time interval from the beginning to the nadir of the potential and was expressed as millivolts per 10 msec. When the interpretation of an individual complex was difficult (continuity of atrial and ventricular waves), a review of the adjacent sites of electrograms with more distinctly separated waves often permitted clear differentiation of the two components. Furthermore, rapid atrial stimulation was performed to obtain atrial electrograms not conducted via the AP. Comparison of the isolated atrial electrograms with the composite electrogram observed during preexcitation allowed the differentiation of the two forms of activity (Figure 2). In some

**Table 1. Comparison of Bipolar Electrograms at Site of First Ablation Attempt According to Accessory Pathway Location**

<table>
<thead>
<tr>
<th>AP</th>
<th>VA time (msec)</th>
<th>A/V ratio</th>
<th>AV time (msec)</th>
<th>Timing of main V deflection (msec)</th>
<th>Timing of first V deflection (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right parietal and anterosetal (n=21)</td>
<td>97±21</td>
<td>4±7</td>
<td>46±20</td>
<td>−6±14</td>
<td>−23±13</td>
</tr>
<tr>
<td>Right posteroseptal (n=22)</td>
<td>94±14</td>
<td>1±2</td>
<td>45±16</td>
<td>−3±11</td>
<td>−14±11</td>
</tr>
<tr>
<td>Left posteroseptal (n=25)</td>
<td>96±16</td>
<td>1.2±1</td>
<td>46±10</td>
<td>−2±7</td>
<td>−14±8</td>
</tr>
<tr>
<td>Left lateral (n=74)</td>
<td>80±13</td>
<td>0.7±1</td>
<td>40±14</td>
<td>2±8</td>
<td>−6±8</td>
</tr>
</tbody>
</table>

Values are mean±SD.

AP, accessory pathway; VA time, ventriculoatrial conduction time; A/V ratio, ratio of amplitude of atrial electrogram to that of ventricular electrogram; AV time, local atrioventricular conduction time. The two measures of ventricular electrogram timing were assessed relative to delta wave onset in surface electrocardiographic leads; negative value means that potential occurs before delta wave onset.

**Table 2. Mean Values of Unipolar Atrial/Ventricular Ratio According to Bipolar Ratio**

<table>
<thead>
<tr>
<th>Bipolar A/V ratio</th>
<th>Unipolar A/V ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>8±6%</td>
</tr>
</tbody>
</table>

Values are mean±SD.

A/V ratio, ratio of amplitude of atrial electrogram to that of ventricular electrogram.
cases preexcitation was intermittent, making the atrial and ventricular waves easy to differentiate.

**Catheter Ablation Protocol**

The patients were anesthetized with 4 mg/kg body wt thiopental. A switching device (Ela Medical, Montrouge, France) allowed the catheter to be switched quickly from the recording to the cardioversion mode. The anodal output of the defibrillator (Defigard, Robert et Carriere, Paris) was connected to a 66-cm² paddle positioned on the chest closest to the ablation catheter. Three unipolar distal cathodal shocks of 160 J were delivered successively at each attempt. In seven patients with septal APs, one or two shocks were delivered because of prolonged atrioventricular block. If ablation was unsuccessful, fulguration was repeated during the same session after remapping or within the next few days, when preexcitation had transiently disappeared. Three distal 160-J shocks were also delivered during each new attempt.

After catheterization in all patients, efficient antiocoagulation was obtained with subcutaneous calcium heparinate. Patients with left lateral APs also received intravenous heparin (1 mg/kg body wt) immediately after the ablation session. Twenty-four–hour ECG (Holter) recordings were taken in each patient both before and at days 1 and 5 after the attempted ablation. Blood was sampled for cardiac enzyme levels 6 hours after fulguration. An electrophysiological study was performed on day 5 or 6 to assess anterograde conduction, using a catheter left in place after fulguration. A long-term electrophysiological study was performed in the referring laboratory in 28 patients at 2–7 months after ablation. Patients were discharged at day 10 with 4–5 mg/kg body wt sotalol. This prophylactic drug was prescribed empirically for a 6-week postablation period because of sudden death in one of our previous patients.

**Statistical Analysis**

Results are expressed as group mean ± SD. Noncontinuous variables were analyzed by the \( \chi^2 \) test. Owing to the nongaussian distribution of some data, we used nonparametric analysis of variance to compare values of electrogram patterns according to AP location. Further, the relation between unipolar and bipolar electrograms was evaluated using analysis of variance and the Pearson correlation test. Statistical significance was set at \( p < 0.05 \).
Electrogram patterns were then evaluated depending on subsequent outcome. Successful ablation was defined as both the disappearance of preexcitation on serial ECGs and the absence of spontaneous tachycardia recurrence during follow-up. In one patient, an intermittent preexcitation was resumed late, but this case was considered a success because of the inability to induce reciprocating tachycardia and the deterioration of anterograde AP conduction. Cases were termed “failures” when the result of the first ablation attempt was unsuccessful, even if AP was subsequently ablated during another attempt. Two modes of statistical analysis were used: 1) Electrograms recorded during the first ablation attempt of each distinct AP (n=142) depending on subsequent success or failure were compared by using analysis of variance or the $\chi^2$ test. Significant variables were then entered into a multivariate analysis (logistic regression analysis) to identify the major independent parameter(s) predicting ablation outcome. 2) Electrograms recorded in the same patients during a first unsuccessful attempt and a second successful attempt (n=18) were compared by using the Wilcoxon test on matched series.

Results

Results of Fulguration: Patient Follow-up

One ablation attempt was successful in 110 patients with 115 distinct APs. In each of the 25 other patients, two or more attempts were made to ablate the 27 other APs. The mean value of the postablation creatine kinase–MB fraction was 56±31 IU/l (normal values, 0–16 IU/l); 31±14 IU/l in right lateral and anteroseptal APs, 46±24 and 43±23 IU/l in right and left posteroseptal APs, respectively, and 68±33 IU/l in left lateral APs ($p<0.001$). Each fulguration session lasted 2–2.5 hours in most cases.

Fulguration was successful in eliminating conduction through the AP in 129 patients (96%), including all seven with two distinct APs. No recurrence of tachycardia occurred in these patients over a follow-up period of 16±6 months. No preexcitation resumed in any patient except the one in whom it was intermittent. Follow-up electrophysiological study performed in 27 other patients confirmed the complete elimination of anterograde and retrograde AP conduction. Fulguration was unsuccessful in six patients (4%), three with posteroseptal APs, one with left posterior AP, and the only two patients with “left anterior” preexcitation. Preexcitations referred to as left anterior yielded a typical ECG pattern of left lateral AP in standard leads, but maximal preexcited QRS complexes were predominantly negative in the $V_1$ lead. We have found such preexcitation to be unapproachable by usual (nonsteerable) catheters and with a retrograde aortic approach. In one patient, the optimal electrogram patterns were recorded through an electrode catheter inadvertently
introduced at the midportion of the left anterior descending coronary artery.

The ablative procedure was uncomplicated in 127 patients, except for the occurrence of transient sinus pause or atrioventricular block immediately following shocks. Side effects were observed in eight patients (6%). Complete atrioventricular block occurred in two patients with septal APs, necessitating in one the subsequent implantation of a dual-chamber pacemaker. It is noteworthy that atrioventricular block developed 12 hours after fulguration in one patient with a posteroseptal AP. Three patients presented transient atrial fibrillation at day 5 or 6. One patient presented a well-tolerated pericardial effusion at day 3, and another had a pulmonary embolism after discharge.

One patient experienced on day 5 two nocturnal episodes of ventricular fibrillation 2 hours apart, each necessitating external cardioversion. Serial ECGs recorded frequent ventricular premature beats with a very short (300-msec) coupling interval; their morphologies were close to the preexcitation pattern, indicating an origin around the ablation site. Twelve hours after the second ventricular fibrillation, all arrhythmias had disappeared without drugs, as documented by Holter recordings, and could not be triggered by exercise test or isoproterenol infusion. Myocardial scintigraphy was unable to detect any myocardial defect. No ventricular late potentials were recorded by signal-averaged ECG. No ventricular tachycardia was inducible at electrophysiological study performed on day 10. Preexcitation had returned with anterograde block occurring at 120 beats/min; under isoproterenol infusion, the shortest preexcited RR interval was 360 msec during induced atrial fibrillation. Given the great deterioration of anterograde AP conduction, ventricular fibrillations were attributed to
TABLE 3. Comparison of Unipolar Electrograms at Site of First Ablation Attempt According to Accessory Pathway Location

<table>
<thead>
<tr>
<th>AP</th>
<th>Pattern distribution (%)</th>
<th>Atrial potential amplitude (mV)</th>
<th>Ventricular potential amplitude (mV)</th>
<th>Slope of downstroke (mV/10 msec)</th>
<th>Timing of intrinsic deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POS n %</td>
<td>P-OS n %</td>
<td>P-rS n %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right parietal and anterosetal (N=21)</td>
<td>11 52</td>
<td>7 33</td>
<td>3 15</td>
<td>7 ±7</td>
<td>46 ±26</td>
</tr>
<tr>
<td>Right posteroseptal (N=22)</td>
<td>7 32</td>
<td>8 36</td>
<td>7 32</td>
<td>7 ±8</td>
<td>73 ±31</td>
</tr>
<tr>
<td>Left posteroseptal (N=25)</td>
<td>7 28</td>
<td>9 36</td>
<td>9 36</td>
<td>6 ±4</td>
<td>65 ±16</td>
</tr>
<tr>
<td>Left lateral (N=74)</td>
<td>39 53</td>
<td>21 28</td>
<td>14 19</td>
<td>7 ±4</td>
<td>84 ±31</td>
</tr>
<tr>
<td>p</td>
<td>NS</td>
<td>NS</td>
<td>&lt;0.0001</td>
<td>NS</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Values are mean ± SD.
AP, accessory pathway; A/V ratio, ratio of amplitude of atrial electrogram to that of ventricular electrogram; N, total number APs in region; n, number of APs showing particular pattern distribution in given region; NS, not significant.

an arrhythmogenic effect of fulguration. Follow-up at 15 months in this patient was uneventful.

Bipolar Patterns at the Ablation Site

Characteristics of bipolar electrograms at the site of the first ablation attempt are compared in Table 1 according to AP location. Ablation sites in right parietal and anterosetal APs were associated with a predominant atrial electrogram (A/V ratio, 4 ±7), the longest VA time during reciprocating tachycardia (VA time, 97 ±21 msec), and the earliest local ventricular electrogram timing. Ablation sites in left parietal APs showed a predominant ventricular electrogram (A/V ratio, 0.7 ±1), the shortest VA time (80 ±13 msec), and the least early ventricular potential relative to delta wave onset. Left parietal APs were thus ablated from the ventricular side of the annulus, whereas right-sided APs were ablated from the atrial side. Ablation sites in posteroseptal APs gave intermediary electrogram values.

Unipolar Patterns at the Ablation Site

In most cases unipolar atrial electrograms had a very low amplitude, a positive uniphasic shape, and no rapid component. The amplitude of the atrial electrogram was far lower than that of the ventricular deflection despite a wide range of respective amplitudes measured in the bipolar recording mode (Table 2). It was only when the bipolar A/V ratio had a high value that the atrial waveform showed a diphasic shape with a fast deflection.

Unipolar ventricular electrograms on the annular endocardial surface showed different patterns. In one small area, only wholly negative electrograms were found. Outside the small area of negativity, we did find some initial positivity. When the distance to this area of negativity increased, positive deflection became greater. The temporal relation of the atrial and ventricular components provided three different groups (Figures 3 and 4): 1) In a small localized area, no delay was found between atrial (P) and ventricular waves; as a result, the descending slope of the P wave appeared to be prolonged by the ventricular QS-like downstroke (PQS pattern), thus making the transition nondiscernible (Figures 2, 3 [site E], and 4 [right electrogram]). 2) In the immediate surrounding annulus, the ventricular downstroke was separated from the descending slope of the P wave by a clear notch or a descending or isoelectric line (P-QS pattern); the connection nearly always occurred at or under the baseline level (Figure 3 [sites B, C, and D]). 3) Further away, the ventricular electrogram had an rS pattern (Figures 3 [site A] and 4 [left electrogram]) and was separated from the descending slope of the P wave (P-rS pattern). Therefore, slight movements of the recording catheter led to great changes in unipolar waveform detectable by a mere visual examination of the oscilloscopic screen. These three

TABLE 4. Mean Values of Anterograde Conduction Bipolar Parameters According to Unipolar Waveform

<table>
<thead>
<tr>
<th>Unipolar pattern</th>
<th>A/V ratio</th>
<th>AV time (msec)</th>
<th>Timing of main potential (msec)</th>
<th>Timing of first potential (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PQS</td>
<td>1.2±2</td>
<td>37±13</td>
<td>-2.5±11</td>
<td>-12±10</td>
</tr>
<tr>
<td>P-QS</td>
<td>1±2</td>
<td>43±13</td>
<td>0±9</td>
<td>-10±12</td>
</tr>
<tr>
<td>P-rS</td>
<td>1.8±5</td>
<td>53±13</td>
<td>2.7±8</td>
<td>-7±11</td>
</tr>
<tr>
<td>p</td>
<td>NS</td>
<td>&lt;0.0001</td>
<td>0.018</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean ± SD.
A/V ratio, ratio of amplitude of atrial electrogram to that of ventricular electrogram; AV time, local atrioventricular conduction time; NS, not significant.
patterns could also be distinguished in the coronary sinus (particularly its mid and distal parts) and compared at adjacent sites (Figure 5).

Table 3 shows the distribution of unipolar patterns and other characteristics according to AP location at the ablation site. The ST segment was elevated in all but four sites, and the T wave was positive in all but 12 sites. As in the bipolar recordings, we also found a high amplitude of ventricular electrograms in left parietal sites and the earliest ventricular timings in right-sided sites. The relation between the three groups of unipolar pattern and anterograde conduction bipolar parameters is shown in Table 4. Patterns PQS, P-QS, and P-rS were associated with increasing values of local atrioventricular conduction time and progressively later ventricular activation timing relative to preexcitation onset. This progressively later timing was observed whatever the mode of definition of local activation. In this respect, the unipolar intrinsic deflection usually correlated with the peak ventricular potential ($r=0.68$) but sometimes with the first potential ($r=0.58$). In some cases, an apparent discrepancy could be observed between bipolar and unipolar patterns, either a POS pattern associated with a “late” ventricular potential or a P-rS pattern with an “early” ventricular potential (Figure 6).

**Electrogram Patterns Depending on Ablation Outcome**

A similar distribution of AP location was observed between successes and failures ($p=0.6$) of the first ablation attempt. Comparison of bipolar electrograms is described in Table 5. There was no significant difference either in the A/V ratio or in the only parameter concerning retrograde AP conduction, that is, VA time. Owing to very different A/V ratios depending on AP location, we compared VA time values according to 1) each septal, right or left, free
TABLE 5. Values of Bipolar Electrogram Parameters and Creatine Kinase–MB Level According to Ablation Outcome

<table>
<thead>
<tr>
<th>AP ablations</th>
<th>VA time (msec)</th>
<th>A/V ratio</th>
<th>A-V time (msec)</th>
<th>Timing of main V deflection (msec)</th>
<th>Timing of first V deflection (msec)</th>
<th>CK-MB (IU/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First attempt successful (n=115)</td>
<td>86±17</td>
<td>1.2±3</td>
<td>40±13</td>
<td>−1.7±10</td>
<td>−12±11</td>
<td>56±31</td>
</tr>
<tr>
<td>First attempt unsuccessful (n=27)</td>
<td>93±17</td>
<td>1.6±4</td>
<td>53±17</td>
<td>5±7</td>
<td>−6±11</td>
<td>55±35</td>
</tr>
<tr>
<td>p</td>
<td>NS*</td>
<td>NS</td>
<td>0.0001</td>
<td>&lt;0.001</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Subgroup†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First attempt unsuccessful (n=18)</td>
<td>92±19</td>
<td>1.8±6</td>
<td>51±18</td>
<td>5±8</td>
<td>...</td>
<td>54±38</td>
</tr>
<tr>
<td>Second attempt successful (n=18)</td>
<td>95±18</td>
<td>1.3±2</td>
<td>44±15</td>
<td>−4±11</td>
<td>...</td>
<td>28±11†</td>
</tr>
<tr>
<td>p</td>
<td>NS</td>
<td>NS</td>
<td>0.045</td>
<td>&lt;0.01</td>
<td>...</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Values are mean±SD.
AP, accessory pathway; VA time, ventriculoatrial conduction time; A/V ratio, ratio of atrial electrogram to that of ventricular (V) electrogram; AV time, local atroventricular conduction time; CK-MB, MB isoenzyme of creatine kinase; NS, not significant; . . ., insufficient data.
*VA time remains not predictive even in each accessory pathway (AP) location. In 74 left lateral APs, VA time in successes and failures was respectively 79±13 vs. 84±13 msec; in 47 posteroseptal APs, 97±16 vs. 96±17 msec; in 21 right APs, 96±22 vs. 104±13 msec.
†Values are for 18 of the 27 unsuccessful AP ablations.
‡Value significantly lower than after the first attempt, despite the same delivered energy.

wall AP location and 2) A/V<1 or A/V≥1. The VA time was not significant irrespective of AP location (Table 5 legend) or the A/V ratio (p>0.8). On the other hand, bipolar electrograms associated with success of fulguration showed a shorter atroventricular conduction time (40±13 versus 53±17 msec, p<0.0001) and an earlier timing of the main ventricular potential relative to delta wave onset (−1.7±10 versus 5±7 msec, p<0.001). Owing to a significant overlapping between groups, only the lowest values had a high predictive value (Table 6). The timing of the first ventricular potential was not predictive. Likewise, comparison of unipolar electrograms showed that an earlier timing of intrinsic deflection was associated with subsequent ablation success as well as pattern distribution (Table 7). Success was 97% (Table 6), 78%, and 55% with the PQS, P-QS, and P-rS patterns, respectively.

The four significant variables were entered into a logistic regression analysis with success as the dependent variable. This analysis revealed a single independent factor, unipolar pattern (p=0.03), with an odds ratio of 7:1 (PQS pattern versus P-rS pattern). There was no significant difference between P-QS and P-rS patterns.

In the group of 18 patients who underwent a first unsuccessful but a second successful attempt, comparison of electrograms (Tables 5 and 7) revealed no difference in VA time, and in the successful attempts, a shorter atroventricular conduction time (p=0.045).

TABLE 6. Prevalence of Predictive Electrogram Patterns and Respective Ablation Success Rates

<table>
<thead>
<tr>
<th>Electrogram pattern</th>
<th>Prevalence in 142 APs (%)</th>
<th>Prevalence in 115 successful ablations (%)</th>
<th>Prevalence in 27 failures (%)</th>
<th>Ablation success rate %</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipolar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main V-delta≤−10 msec</td>
<td>17</td>
<td>20</td>
<td>4</td>
<td>96</td>
<td>92–100</td>
</tr>
<tr>
<td>Main V-delta≤0 msec</td>
<td>75</td>
<td>80</td>
<td>54</td>
<td>87</td>
<td>80–94</td>
</tr>
<tr>
<td>AV time≤50 msec</td>
<td>80</td>
<td>84</td>
<td>63</td>
<td>85</td>
<td>82–88</td>
</tr>
<tr>
<td>AV time≤40 msec</td>
<td>52</td>
<td>58</td>
<td>26</td>
<td>91</td>
<td>88–94</td>
</tr>
<tr>
<td>Unipolar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ID-delta≤−10 msec</td>
<td>20</td>
<td>23</td>
<td>4</td>
<td>96</td>
<td>92–100</td>
</tr>
<tr>
<td>ID-delta≤0 msec</td>
<td>83</td>
<td>91</td>
<td>48</td>
<td>89</td>
<td>86–92</td>
</tr>
<tr>
<td>PQS pattern</td>
<td>45*</td>
<td>54*</td>
<td>7</td>
<td>97</td>
<td>95–99</td>
</tr>
</tbody>
</table>

APs, accessory pathways; CI, confidence interval; Main V-delta, interval from delta wave onset to peak of main ventricular potential; AV time, local atroventricular conduction time; ID-delta, interval from delta wave onset to onset of intrinsic deflection (ID).
*To appreciate the low prevalence of the PQS pattern, it is to be noted that this criterion was not intentionally sought per se.
TABLE 7. Values of Unipolar Electrogram Parameters According to Ablation Outcome

<table>
<thead>
<tr>
<th>AP ablations</th>
<th>Pattern distribution (%)</th>
<th>Atrial potential amplitude (mV)</th>
<th>Ventricular potential amplitude (mV)</th>
<th>A/V ratio</th>
<th>Slope of downstroke (mV/10 msec)</th>
<th>Timing of intrinsic deflection (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PQS P-QS PrS n % n % n %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First attempt successful (N=115)</td>
<td>62 54 35 30 18 16</td>
<td>7±5</td>
<td>75±31</td>
<td>0.11±0.1</td>
<td>15±6</td>
<td>-4±8</td>
</tr>
<tr>
<td>First attempt unsuccessful (N=27)</td>
<td>2 7 10 37 15 56</td>
<td>8±7</td>
<td>67±33</td>
<td>0.14±0.2</td>
<td>12±6</td>
<td>6±8</td>
</tr>
<tr>
<td>p</td>
<td>&lt;0.0001</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Subgroup*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First attempt unsuccessful (N=18)</td>
<td>2 11 7 39 9 50</td>
<td>8.5±7</td>
<td>68±37</td>
<td>0.16±0.2</td>
<td>11±6</td>
<td>6±9</td>
</tr>
<tr>
<td>Second attempt successful (N=18)</td>
<td>8 45 9 50 1 5</td>
<td>7±6</td>
<td>72±30</td>
<td>0.09±0.1</td>
<td>13±7</td>
<td>-4±9</td>
</tr>
<tr>
<td>p</td>
<td>0.006</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Values are mean±SD.
AP, accessory pathway; A/V ratio, ratio of atrial electrogram to that of ventricular electrogram; N, number of successful or unsuccessful AP ablations; n, amount of N falling within a given pattern distribution; NS, not significant.
*Values are for 18 of the 27 unsuccessful AP ablations.

and an earlier ventricular activation time (p<0.01). Unipolar pattern distribution (Figure 7) and intrinsic deflection timing were also significantly different.

**Discussion**

These results in a large series show that ablation of APs is likely to be successful irrespective of location, when shocks are delivered at sites demonstrating some distinctive electrogram patterns.

**Bipolar Electrogram Patterns**

Bipolar electrograms at the successful ablation site are marked by an early timing of the main ventricular potential and a short local atioventricular conduction time; these characteristics progressively diminish as one moves from the site. However, a significant overlap of values occurs between successes and failures. The atrial or ventricular position for the catheter (the A/V ratio) does not influence ablation results. Surprisingly, the retrograde conduction time value has no predictive value for ablation outcome (in overt APs) unlike anterograde conduction parameters; this does not exclude its reliability in guiding the ablation of concealed APs. Furthermore, when comparing parameters recorded before an unsuccessful attempt and a subsequent successful attempt,
Values of retrograde VA intervals do not change significantly, whereas those concerning anterograde conduction improve, indicating that the first attempt has failed because of an inaccurate AP localization. These results show the greater reliability of anterograde parameters and support the hypothesis of an atrial arborization of APs. In this hypothesis, more energy (or sessions) would be necessary for achieving ablation using the VA time to guide therapy. Our results suggest, when considering ablation, that much attention must be paid to anterograde rather than retrograde conduction mapping, particularly when anterograde and retrograde AP breakthroughs are found at different (though adjacent) sites. Use of anterograde parameters is sufficiently reliable for making the ideal but fastidious AP potential recording unnecessary. From our experience of left lateral AP ablation, we have become aware that the success rate is not altered whether or not the Kent bundle potential is recorded, despite the theoretical advantages of such recording. The present study reporting a success rate of 96% demonstrates this datum irrespective of AP location and thus allows an important gain in preablation mapping time; furthermore, the expected gain in success rate by using AP potential recording would necessarily be limited (maximum, 4%). Use of anterograde mapping is less common than retrograde mapping except in intraoperative epicardial mapping and we are unaware of any previous study that has rigorously examined the values of anterograde conduction parameters. When referring only to these parameters on the oscilloscope screen, the AP insertion area can be quickly determined during sinus rhythm, without repeated measurements of activation times on recording paper. Although it is easy to discern shorter atrioventricular intervals, the assessment of ventricular timing requires careful attention because of the imprecision of the two factors involved: 1) The point of delta wave onset in surface ECG leads may be unclear when its gradient is low, particularly in left-sided APs. 2) The selection of the potential from the bipolar electrogram pattern representing the true local activation time is not yet universally adopted. In this respect, timing of the unipolar intrinsic deflection is not ambiguous and is particularly useful in the interpretation of bipolar multicomponent electrograms for clearly showing the local acti-
cation time. Intrinsic deflection is always prominent and well defined, even when recorded at the atrial side of the annulus or in the coronary sinus. Its timing is correlated in the present study with the peak of the main bipolar potential, but in some cases its timing is correlated with the peak of the first potential, leading to a conflicting interpretation of bipolar timings. In fact, this discrepancy could be resolved using bipoles with 1–2-mm interelectrode spacing.

Unipolar Electrogram Patterns

Two parameters in the unipolar waveform were found to be predictive of ablation outcome: the configuration of the ventricular waveform (QS- or rS-like) and the temporal relation between atrial and ventricular signals. Although considered in three separate groups, the unipolar annular electrograms formed one continuum. The precise determination of merged waveforms may sometimes be difficult, particularly on the atrial side of the annulus, and often necessitates either a review of neighboring recordings or stimulation techniques to differentiate the two components. Whether or not a long or short P wave duration can influence the whole configuration needs further study. Furthermore, because similar patterns can be observed with a catheter floating within the cardiac cavities, other associated characteristics must be considered to achieve differentiation: the endocardial electrogram has a high amplitude, a rapid downstroke, and a positive repolarization with ST segment elevation. These data were dynamically recorded during an ongoing procedure, thus showing the transition from intracavitary to endocardial electrograms. In our patients, the presence of an initial, even an embryonic, r wave in the ventricular electrogram was associated with a considerably reduced ablation success rate. In such cases, we assume that the center of primary activation is located some distance away. Indeed, several studies\(^\text{17,23–28}\) have previously demonstrated that the pure negative (QS-like) waveform is circumscribed in the area of excitation origin, estimated at 100–200 \(\mu\)m along the fast axis by Spach et al.,\(^\text{27}\) Gallagher et al.\(^\text{13}\) underlined the value of QS morphology of unipolar epicardial data in localizing AP, suggesting that this pattern is linked to an epicardial AP location while an endocardial AP (usually right-sided) shows an rS morphology. In the present study using endocardial mapping, the similar high prevalence of QS morphology (PQS or P-QS) found in 81–85% of right or left parietal AP suggests that the unipolar pattern is not reliable for differentiating endocardial from epicardial pathways.

Multivariate analysis demonstrated that unipolar pattern distribution is the only independent factor predictive of success, with the electrogram group PQS achieving the highest success rate (97%). The PQS pattern was recorded in a small central area; outside this area, a separation of the atrial and ventricular waves appeared, and this increased with the ventricular downstroke beginning later and later, yielding a P-QS and then a P-rS pattern. These patterns correlated with significantly different bipolar electrograms. The PQS pattern corresponded to the shortest local atrioventricular intervals and the earliest ventricular potentials. The P-rS pattern corresponded to the longest atrioventricular intervals and the latest ventricular potentials, whereas the P-QS pattern corresponded to intermediary bipolar parameter values. Therefore, a unipolar electrogram provides a combination of the information provided by both bipolar parameters. Nevertheless, in some cases, a discrepancy appears between unipolar and bipolar patterns with the result that a favorable change in the unipolar waveform can be perceptible between two adjacent recording sites without an apparent improvement in bipolar parameter values. This suggests a different resolution power of the unipolar recording mode that may optimize AP localization and be decisive when two close sites give similar bipolar electrograms. The eventual discrepancy between bipolar and unipolar activation timings is due in part to the too-wide interelectrode distance (5 mm) recording complex electrograms at the confluence of the atrium, accessory pathway, and ventricle. Therefore, this study urges clinicians to use bipoles with a 1–2-mm separation, which gives sharp spike recording and makes local activation timing more precise. In fact, a unipolar electrogram gives direct information on the proximity of the excitation origin (i.e., the AP itself), whereas bipolar electrograms provide indirect data that are relative to a reference (the delta wave onset) for which no critical value exists, indicating how close the AP is (apart from the recording of the Kent bundle potential). These results in humans bear striking resemblances to recent experimental studies\(^\text{25,29,30}\) showing both the accuracy of the site of the “primary minimum” (derived from the potential-distribution mapping) in localizing the origin of electrical fields and its superiority over activation-time mapping (obtained from bipolar electrograms).

Despite unstable tracings in some cases, other theoretical or practical reasons favor unipolar recording. Unipolar mapping shows the recording provided by the distal electrode of the ablation catheter, which then serves to deliver ablative shocks. Bipolar recordings are the combination of data recorded by distal and proximal electrodes. A bipolar recording might show an apparent optimal pattern provided by the contribution of the proximal electrode, but the ablative energy would be delivered through the distal electrode. This possibility is demonstrated in Figure 8 but becomes less significant with the use of close bipoles. Furthermore, the unipolar recording mode gives information on the quality of the contact of the electrode with the myocardium through ST-T wave patterns. Last, PQS pattern recording allows quick and accurate AP localization (including in the coronary sinus) and may thus save time and reduce x-ray exposure.

Side Effects of Fulguration

Since the optimal delivered energy for ablating AP is unknown, the use of three successive 160-J shocks
is quite empirical and is performed to reduce the risk of resurgence of preexcitation and the need for additional ablation sessions. Such cumulative delivered energy has been reported by other authors with relatively good safety. In the present work, pericardial effusion was observed in one patient. No migration of mural thrombi occurred, probably because of systematic anticoagulant treatment. The most fearful side effect is the occurrence of sudden death. We previously observed one such case, and in the present study ventricular fibrillations occurred in one patient (i.e., a total of two of 305 patients who underwent AP ablation); we attribute these phenomena to an arrhythmogenic effect of fulguration, particularly as they occurred early (days 7 and 5 after ablation, respectively). In both patients, shocks were applied at the ventricular side of the mitral annulus (bipolar A/V ratios of 0.14 and 0.1, respectively) with resulting high levels of creatine kinase–MB isoenzyme release (92 and 112 IU/l, respectively). A decrease in delivered energy and lesion size or resulting high levels of creatine kinase–MB isoenzyme release (92 and 112 IU/l, respectively). A decrease in delivered energy and lesion size or atrial positioning of the catheter might reduce this risk reported also with radio frequency ablation. prophylactic sotalol therapy is quite empirical and is an alternative to reducing the risk reported also with radio frequency ablation.

In conclusion, these results confirm the efficiency of catheter ablation of accessory pathways. A high success rate is obtained when shocks are delivered at sites demonstrating some distinctive electrogram patterns. Anterograde conduction parameters show a predictive value for ablation outcome, whereas retrograde conduction parameters do not. The unfiltered unipolar recording mode provides significant complementary data for accurately localizing the AP insertion site.

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Electrogram patterns predictive of successful catheter ablation of accessory pathways.

Value of unipolar recording mode.

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