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Characteristics of Local Electrogram Predicting Successful Transcatheter Radiofrequency Ablation of Left-Sided Accessory Pathways

XU CHEN, MD, MARTIN BORGGREFE, MD, MOHAMMAD SHENASA, MD, FACC,
WILHELM HAVERKAMP, MD, GERHARD HINDRICKS, MD,
GÜNTER BREITHARDT, MD, FESC, FACC

Münster, Germany

Objectives. The purpose of this study was to analyze and compare the local electrograms recorded at successful and unsuccessful sites of ablation to identify the criteria that may predict successful sites and minimize unnecessary radiofrequency delivery.

Background. Transcatheter ablation of accessory pathways using radiofrequency energy requires extremely precise localization of an accessory pathway.

Methods. Local electrograms from 50 consecutive patients with left-sided accessory pathways who underwent transcatheter radiofrequency ablation were analyzed. During catheter ablation, localization of accessory pathways was performed in 39 pathways during pre-excited sinus rhythm and in 14 pathways during orthodromic tachycardia. A total of 429 local electrograms at target sites obtained before delivery of radiofrequency current was analyzed. A prospective study was performed in another 20 patients using the criteria derived from the retrospective study.

Results. Accessory pathway conduction block was achieved in 36 (92%) of 39 pathways in which mapping was performed during pre-excited sinus rhythm and in 9 (64%) of 14 pathways in which mapping was performed during orthodromic tachycardia ($p < 0.05$). When mapping was performed during pre-excited sinus rhythm, a combination of four variables (that is, an accessory pathway potential, stability of local electrograms, atrial activation >1 mV and ventricular activation preceding the onset of the delta wave) showed a 62% probability of success. In contrast, excluding these variables resulted in a 95% probability of failure (noneffective or transiently effective). The prospective study shows that the use of these criteria can significantly reduce the number of current applications. When mapping was performed during orthodromic tachycardia, recording the earliest atrial activation was the most powerful predictor of success. A stable local electrogram with a small notch on the ventricular potential, presumed to be an accessory pathway potential, may add predictive value.

Conclusions. Transcatheter radiofrequency ablation is highly effective in the treatment of patients with left-sided accessory pathways. Specific characteristics of local electrograms can be important predictors of success or failure. Mapping during pre-excited rhythm renders ablation more effective than does mapping during orthodromic tachycardia.

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Transcatheter ablation of accessory pathways using radiofrequency current has recently been reported (1–4) to have a success rate of 90%. Because radiofrequency energy can induce only a small superficial lesion (5), ablation using this energy requires extremely precise localization of the accessory pathway. Recording of accessory pathway potential has recently been shown (6–10) to be feasible and useful in ablation of an accessory pathway. However, delivery of radiofrequency energy to the site where a presumed accessory pathway potential is recorded often has no effect or induces only a transient block of accessory pathway conduction. The purpose of the present study was to analyze and compare the local electrograms recorded at successful and unsuccessful sites of ablation to define criteria for selection of appropriate target sites.

Methods

Study patients. From January 1990 to July 1991, 50 consecutive patients with 53 left-sided accessory pathways underwent transcatheter radiofrequency ablation in our laboratory using a protocol that was approved by the Hospital of the University of Münster Ethics Committee. There were 17 female and 33 male patients with a mean age of 36 ± 14 years (range 15 to 68). The indications for catheter ablation were ineffective drug therapy of symptomatic spontaneous tachyarrhythmia related to the accessory pathway, intolerable side effects of antiarrhythmic drugs during long-term

From the Department of Cardiology/Angiology, Hospital of the Westfälische Wilhelms-University of Münster and Institute for Research in Arteriosclerosis, Münster, Germany.

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Address for correspondence: Martin Borggrefe, MD, Westfälische Wilhelms-Universität, Medizinische Klinik und Poliklinik, Innere Medizin C, Albert-Schweitzer-Strasse 33, D-4400 Münster, Germany.

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therapy and potential sudden cardiac death in the setting of fast ventricular response during atrial fibrillation or flutter. Forty-three accessory pathways were located in the left free wall; 10 were in the left posteroseptal region. Forty-one patients had manifest pre-excitation (manifest accessory pathways) on the surface electrocardiogram (ECG) and nine had concealed accessory pathways.

Electrophysiologic study. After written informed consent was obtained, electrophysiologic studies were performed with the patient in the postabsorptive nonsedated state, by using conventional techniques of intracardiac recording and stimulation previously reported from our laboratory (11). Briefly, multipolar electrode catheters were introduced percutaneously from peripheral veins and positioned into the high right atrium, coronary sinus, His position and right ventricular apex. The stimulation protocol included the introduction of single (and rarely double) premature stimuli in the high right atrium at cycle lengths of 600 and 375 ms and right ventricular apex at cycle lengths of 500, 430, 370 and 330 ms. Anterograde conduction properties of the accessory pathway were assessed by incremental atrial pacing, beginning at a rate just exceeding the sinus rate until accessory pathway conduction block occurred; retrograde conduction of the accessory pathway was assessed by incremental ventricular pacing. A concealed pathway was diagnosed when there was no pre-excitation during sinus rhythm or during pacing in the right atrium and coronary sinus.

Mapping technique. A 7F Polaris catheter (quadripolar catheter with 5-mm interelectrode spacing and a 4-mm long, large tip electrode, Mansfield Scientific, Inc.) was used in most patients. A HAT-260 bipolar catheter (temperature-controlled bipolar catheter with a 4-mm long, large tip electrode and 5-mm interelectrode spacing [Dr. Osypka GmbH] was used in three patients. Both catheters were used for mapping as well as ablation. With the Seldinger technique, electrodes were inserted percutaneously into the right femoral artery. Under biplane fluoroscopic guidance, electrodes were then advanced and positioned against the mitral valve anulus, directly opposite the electrode of the coronary sinus catheter, which was placed at the site of the accessory pathway determined by recording the earliest retrograde atrial activation during orthodromic tachycardia. An eight-channel thermorecorder (Schwartze, Uniscript UD 210, Picker International GmbH) was used for simultaneous recording of four surface ECG leads (I, II, V_1 and V_6) and endocardial electrograms at a paper speed of 100 or 200 mm/s. Bipolar endocardial electrograms obtained by means of the ablation catheter were recorded with an amplification of 10 or 20 mm/mV and a filter bandwidth of 20 to 500 Hz.

Pathways were localized in 37 patients with 39 manifest accessory pathways during sinus rhythm or during atrial pacing if there was no prominent pre-excitation on the surface ECG. In nine patients with concealed accessory pathways and in the first four patients with manifest accessory pathways, mapping was performed only during orthodromic tachycardia.

Radiofrequency current application. The radiofrequency generators Dr. Osypka GmbH HAT-100 (in the first 28 patients) and HAT-200 S (in the last 22 patients) were used to deliver energy through the ablation catheter. Both radiofrequency generators deliver a continuous sinusoidal unmodulated waveform with alternating frequencies of approximately 500 kHz and maximal output power of 50 W. Energy was delivered in a unipolar mode between the tip of the ablation electrode and a $10 \times 16\text{-cm}^2$ external backplate electrode. The preset power output was 15 to 30 W and preset time ranged from 20 to 30 s. If there was no effect after several current applications or poor contact between the catheter electrode and the endocardium was suspected, or both, or after a current application that induced only transient accessory pathway block, the preset power output and pulse duration were increased to 50 W and 30 to 60 s, respectively. When there was significant pain during current application or current breakdown due to an increase in impedance, power output was reduced. When a temperature-controlled catheter was used, the temperature was set between 70° and 90°C.

All patients underwent predischarge electrophysiologic studies 4 to 7 days after the ablation session. The ablation procedure was considered successful only when both anterograde and retrograde accessory pathway conduction were no longer present as determined by atrial and ventricular programmed stimulation at the end of the ablation procedure and at the predischarge electrophysiologic study. A transient effect was defined as return of pathway conduction after an effective energy application during the ablation procedure. Ineffective current application was defined as no change in accessory pathway conduction after radiofrequency current application.

Measurement of local endocardial electrograms. Endocardial electrograms of the 5 beats immediately preceding delivery of radiofrequency current were analyzed. Electrograms were categorized into three groups according to the effects of energy application: electrograms from successful sites, sites with transient effects and noneffective sites. If two or more energy applications were performed at one site, it was considered as one site.

Definition. Accessory pathway potentials were considered to be present during pre-excited sinus beats or during atrial pacing if 1) there was a discrete potential between local atrial and ventricular activation during sinus rhythm or after an atrial extrastimulus with pre-excitation (Fig. 1A); 2) the potential preceded the onset of delta wave; 3) the accessory pathway potential disappeared after effective energy application (Fig. 1B) or 4) during atrial extrastimulation when conduction block occurred over the accessory pathway (Fig. 2); and 5) the accessory pathway potential from noneffective sites had the characteristics of 1), 2) and 4) and a configuration and timing similar to those recorded from effective sites.

Local electrograms of the 5 beats before energy delivery

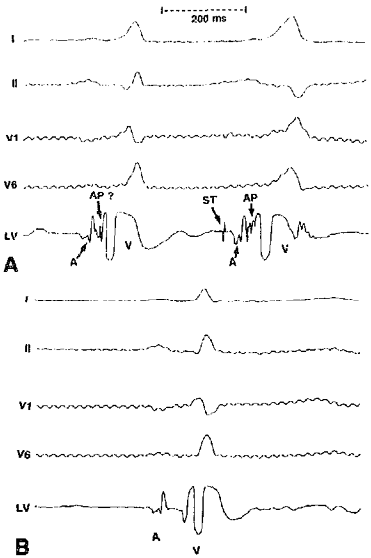

Figure 1. A, Recording of an accessory pathway potential in a patient with left lateral and posterior free wall pathways. During sinus rhythm, the electrogram was recorded from the posterior free wall region. After local atrial activation, a monophasic slurred potential appeared that presumed to be an accessory pathway potential but was not separate from the local atrial potential. After an atrial extrastimulus, three small slurred deflections were recorded that were clearly separate from local atrial and ventricular activation. B, Endocardial electrograms from the same patient at the same site after radiofrequency current application (power 30 W, pulse duration 20 s) successfully interrupted the accessory pathway. The local atrial potential maintained its timing and configuration and the assumed accessory pathway potential disappeared after energy application. This finding confirmed that the origin of the potential was the accessory pathway. The second accessory pathway 2-cm from the ablated pathway was also interrupted after an additional radiofrequency application. A = local atrial activation; AP = accessory pathway potential; LV = left ventricle; ST = stimulus; V = local ventricular activation.

were analyzed for determination of their stability. Electrograms were considered unstable if the amplitude of the atrial or accessory pathway potential changed by >10%, a deflection of local electrograms disappeared or a new deflection appeared.

The following variables were measured in cases of man-

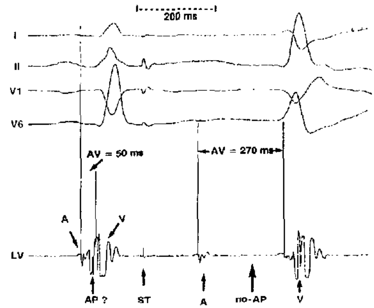

Figure 2. Surface electrocardiogram and endocardial electrogram from a patient with a posteroseptal accessory pathway. A large potential after the local atrial potential was recorded and was presumed to be an accessory pathway potential. It appeared before the delta wave but could not be separated from the local atrial and ventricular potentials. The presumed accessory pathway potential disappeared with the delta wave after a premature stimulus in the right atrium blocked conduction of the accessory pathway. The interval from onset of the atrial potential to onset of the ventricular potential (AV) prolonged from 50 to 270 ms. Abbreviations as in Figure 1.

ifest accessory pathways recorded during sinus rhythm or atrial pacing (Fig. 3): amplitude of local atrial activity and of the accessory pathway potential; duration of the accessory

Figure 3. Measurement of endocardial electrograms at ablation site (see text for definitions). A-AP = interval from onset of the atrial potential to onset of the accessory pathway potential; AP-V = interval from onset of the accessory pathway potential to onset of the ventricular potential; other abbreviations as in Figures 1 and 2.

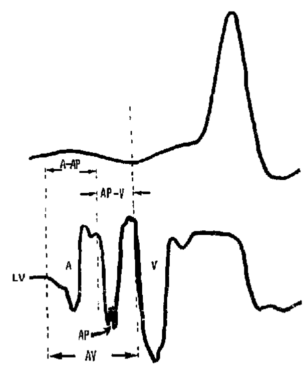

Table 1. Comparison of Local Electrograms in Successful, Transiently Effective and Noneffective Sites by Mapping During Pre-excited Rhythm

	Successful Sites (n = 36)	Transiently Effective Sites (n = 48)	Noneffective Sites (n = 229)	p_1	p_2	p_3
AP potential	29 (81%)	30 (63%)	96 (42%)	0.09	0.0004	0.05
Stability	34 (94%)	30 (63%)	140 (61%)	0.006	0.0002	0.52
aA ≥ 1 mV	29 (81%)	28 (58%)	108 (47%)	0.036	0.0002	0.21
V delta ≥ 0 ms	31 (84%)	26 (54%)	142 (62%)	0.002	0.003	0.30

aA = amplitudes of local atrial electrograms; AP = accessory pathway; p_1 = p value between successful and transiently effective sites; p_2 = p value between successful and noneffective sites; p_3 = p value between transiently effective and noneffective sites; V delta ≥ 0 ms = onset of local ventricular activation earlier than or simultaneously with the onset of the delta wave on the surface electrocardiogram.

pathway potential; interval from the onset of the atrial potential to the onset of the accessory pathway potential; interval from the onset of the accessory pathway potential to the onset of ventricular activation; interval from the onset of the local atrial potential to that of the ventricular potential and interval from the onset of local ventricular activation to that of pre-excitation on the surface ECG. The onset of a potential was defined as the first deflection from baseline with the slope >45° at a paper speed of 100 mm/s (12). The ratio of the amplitude of the accessory pathway potential to that of the local atrial potential and the ratio of the amplitude of the local atrial potential to that of the local ventricular potential were also calculated. In the unstable electrograms, a mean value was calculated for the last 5 beats.

For electrograms recorded during orthodromic tachycardia, only an isolated potential between ventricular and atrial potentials was considered as a possible accessory pathway potential as no validation was performed with premature stimulation because of potential displacement of the catheter. The intervals from the beginning of the QRS complex on the surface ECG to the possible accessory pathway potential and to the earliest atrial activation were measured. The criteria for stability of electrograms were the same as for manifest pathways.

Statistical analysis. Basic comparative statistics were calculated by using the chi-square test with the Fisher exact test or a two-tailed *t* test for independent mean values. Continuous data are presented as mean value ± 1 SD.

To determine which variables were independently predictive of success or failure, the correlation between the individual variables and the results of current application were analyzed. Variables that were predictive of success or failure at $p < 0.10$ on the basis of univariate analysis were used for stepwise logistic regression analysis by using the Statistical Package for the Social Science (SPSS) programs. The "failure" group included the transiently effective and noneffective groups. The variable that was significant, had an independent predictive value and was best able to improve the value of the discrimination criteria was selected. Sensitivity, specificity, positive and negative predictive values and accuracy of univariate and multivariate predictors were calculated.

For validation, the multivariate predictor function was applied prospectively in the last 20 consecutive patients with left-sided manifest accessory pathways who underwent radiofrequency ablation in our laboratory.

Results

In 42 and 8 patients, respectively, one or two ablation procedures were performed. Forty-five (85%) of 53 accessory pathways were successfully interrupted by radiofrequency catheter ablation. Accessory pathway block was achieved in 36 (92%) of 39 manifest accessory pathways in which mapping was performed during pre-excited sinus rhythm and in 9 (7 with concealed and 2 with manifest pathways) (64%) of 14 accessory pathways in which mapping was performed during orthodromic tachycardia ($p < 0.05$). Data were obtained for all 42 successful and 16 unsuccessful ablation procedures.

A total of 429 local electrograms performed before delivery of radiofrequency current were recorded and analyzed, including 45 from successful sites, 62 from transiently effective sites and 322 in noneffective sites (mean 8.8 ± 7.4 electrograms per ablation). Electrograms were further classified into those with manifest or concealed accessory pathways.

Comparison of the electrograms from successful, transiently effective and noneffective sites during pre-excited rhythm. A total of 313 electrograms was recorded during ablation of manifest accessory pathways with mapping during pre-excited sinus rhythm. Characteristics of the local electrograms from different ablation sites are summarized in Tables 1 and 2.

Accessory pathway potential (Table 1). The accessory pathway potential recorded by means of the ablation catheter was a monophasic or multiphasic discrete deflection that appeared before the delta wave on the surface ECG, with a duration between 10 and 20 ms and an amplitude between 0.3 and 2 mV (Fig. 1A). It disappeared after effective energy

Table 2. Comparison of Measurements of Local Electrograms at Successful, Transiently Effective and Noneffective Sites

	Successful Sites	Transiently Effective Sites	Noneffective Sites	p_1	p_2	p_3
aA (mV)	1.4 ± 44	1.17 ± 0.63	0.97 ± 0.68	0.10	0.0001	0.13
aAP (mV)	1.1 ± 0.84	0.86 ± 0.43	0.75 ± 0.41	0.12	0.004	0.38
aAP/aA	0.93 ± 0.41	0.85 ± 0.47	0.96 ± 0.68	0.46	0.83	0.43
aA/aV	0.15 ± 0.18	0.14 ± 0.18	0.12 ± 0.21	0.78	0.48	0.68
A–AP (ms)	34 ± 15	37 ± 15	39 ± 9	0.42	0.15	0.78
A–V (ms)	53 ± 14	57 ± 19	59 ± 13	0.39	0.13	0.62
AP–V (ms)	20 ± 5	23 ± 8	21 ± 8	0.12	0.31	0.37
V delta (ms)	−2 ± 4	−4 ± 8	−5 ± 7	0.34	0.11	0.17

aAP = amplitude of accessory pathway potential; A–AP = interval from onset of the atrial potential to onset of the accessory pathway potential; aAP/aA = ratio between amplitude of the accessory pathway potential and the atrial potential; aA/aV = ratio between amplitude of the atrial potential and amplitude of the ventricular potential; A-V = interval from onset of the atrial potential to onset of the ventricular potential; AP–V = interval between onset of the accessory pathway potential to onset of ventricular activation; other abbreviations as in Table 1.

application (Fig. 1B) or a premature stimulus (Fig. 2). Recognition of an accessory pathway potential is relatively easy if the patient has an intermittently anterograde conducting accessory pathway (Fig. 4). Pacing the right atrium or coronary sinus is very useful for identifying accessory pathway potential in some patients without pre-excitation during sinus rhythm (Fig. 5). Recording at a paper speed of 200 mm/s and activating the amplitude limit of the amplifiers often made it easier to recognize and distinguish the accessory pathway potential from local atrial or local ventricular activation.

Accessory pathway potentials were recognized and validated in 32 (73%) of 44 ablation procedures by mapping during pre-excited sinus rhythm. Success was achieved in 29 (91%) of 32 attempts in which accessory pathway potentials were recorded and in 7 (58%) of 12 attempts in which no accessory pathway potential could be detected ($p < 0.05$). Accessory pathway potentials were recognized at 29 (81%) of 36 successful sites in comparison with 30 (63%) of 48 at transiently effective sites ($p = 0.09$) and 96 (42%) of 229 at noneffective sites ($p = 0.0004$).

Electrogram stability (Table 1). Only 2 (6%) of 36 successful sites showed an unstable electrogram, including one recorded during atrial flutter, which itself may be responsible for an unstable electrogram. In contrast, 18 transiently effective sites (37%) and 89 noneffective sites (39%) demonstrated an unstable local electrogram ($p = 0.006$ and 0.0002, respectively).

Figure 4. Endocardial electrograms from a 24-year old patient with a history of recurrent paroxysmal supraventricular tachycardia related to a left-sided accessory pathway. The accessory pathway conducted intermittently during sinus rhythm and complete block occurred during atrial pacing at 120 beats/min. During incremental ventricular pacing, the accessory pathway conducted retrogradely up to 230 beats/min. In the posteroseptal region, a large monophasic potential with an amplitude of 2 mV and a duration of 20 ms between local atrial activation and local ventricular activation was recorded during pre-excited beats, which disappeared with a nonpre-excited beat. Radiofrequency current delivered at this site at a power output of 20 W and a preset time of 20 s resulted in permanent block of the accessory pathway. Abbreviations as in Figure 1.

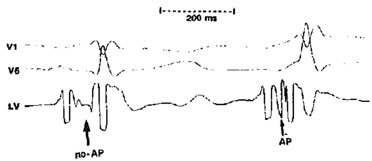

Figure 5. Surface electrocardiogram and endocardial electrogram from a patient with a left lateral free wall pathway. In this patient, there was no pre-excitation during sinus rhythm and no accessory pathway potential (AP) was recorded (first heartbeat), even during right atrial pacing. Premature stimulus (ST) in the coronary sinus induced predominant pre-excitation (second heartbeat). A multiphasic potential was recorded at this site, which started before the delta wave and was presumed to be an accessory pathway potential. Radiofrequency energy application at 30 W for 30 s at this site achieved complete block of the accessory pathway. Other abbreviation as in Figure 1.

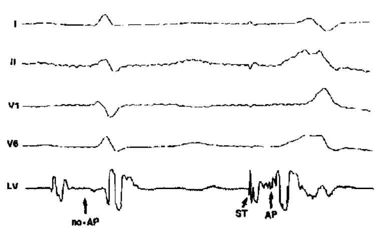

Table 3. Univariate Predictor of Outcome in Ablation of Left-Sided Accessory Pathways

	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Accuracy (%)
AP potential	82	51	27	92	56
Stability	96	35	25	97	62
aA ≥ 1 mV	84	49	25	92	44
V delta ≥ 0 ms	75	43	23	88	45

Abbreviations as in Table 1.

Electrogram amplitudes (Tables 1 and 2). The amplitude of the local atrial potential was significantly higher at successful ablation sites. An atrial potential amplitude >1 mV was measured at 29 (81%) of 36 successful sites compared with 28 (58%) of 48 at transiently effective sites ($p = 0.036$) and 108 (47%) at noneffective sites ($p = 0.0002$). The amplitude of the accessory pathway potential was also significantly higher at successful sites than at transiently effective and noneffective sites (mean 1.1 ± 0.8 vs. 0.86 ± 0.43 and 0.75 ± 0.41 mV, $p = 0.12$ and 0.004, respectively). There were no significant differences in the ratio between the amplitude of the accessory pathway and that of the atrial potential and the ratio between the amplitude of the atrial potential and that of the ventricular potential among the three groups.

Electrogram intervals (Table 2). There were no significant differences in the interval from the onset of atrial activation to the accessory pathway potential and to the onset of ventricular activation among the three groups. The interval between the onset of the accessory pathway potential and the onset of the ventricular potential was also similar among the three groups. The onset of ventricular activation before the delta wave on the surface ECG was found at the majority (84%) of successful sites compared with 54% of transiently effective sites ($p = 0.002$) and 62% at noneffective sites ($p = 0.003$).

Univariate analysis. Four variables correlated with the success of current application: an accessory pathway potential, stability of local electrograms, atrial activation >1 mV and onset of ventricular activation before the delta wave. Table 3 lists the predictors of success at the $p < 0.05$ level and shows the sensitivity, specificity and the positive and negative predictive value of univariate function. No single variable was predictive of successful ablation with an acceptable accuracy. The best single variable was the presence of an accessory pathway potential, with 82% sensitivity, 51% specificity, 27% positive predictive value, 92% negative predictive value and an overall accuracy of 56%.

Multivariate analysis. To improve the predictive value of individual predictors, stepwise discriminant analysis was applied to construct a multivariate predictor function. A combination of atrial potential amplitude >1 mV, stability of local electrograms, existence of accessory pathway potential and onset of ventricular activation before the delta wave has 80% sensitivity, 79% specificity, 62% positive predictive value and 95% negative predictive value. The overall accuracy was 78%.

Prospective study. In our last 20 patients with manifest left-sided accessory pathways, radiofrequency current was applied only at the sites where the local electrogram fulfilled at least three of the four criteria. Success was achieved in 19 (95%) of 20 cases. A mean of 4 ± 5 current applications (median 2) was needed to achieve accessory pathway block.

Temperature-monitored ablation. In three patients, temperature-controlled ablation catheters were used during the procedure. Thirty-one electrograms obtained before delivery of current were analyzed from these patients. The temperature increased to a preset temperature at 16 (76%) of 21 sites where a stable electrogram was recorded but at only 1 site where an unstable electrogram was recorded. At 6 of 10 unstable sites, the mean temperature was <50°C. The temperature at the unstable sites increased slowly to a maximal temperature (Fig. 6) in 15 ± 8 s compared with 6 ± 5 s at stable sites ($p < 0.01$).

Characteristics of electrograms recorded during orthodromic tachycardia. In the first four patients with manifest accessory pathways and in nine patients with 10 concealed accessory pathways, the mapping procedures were performed during orthodromic tachycardias. A total of 116 electrograms were analyzed (9 from successful sites, 14 from transiently effective sites and 93 from noneffective sites. Stable electrograms were recorded at all successful sites, 9 (64%) of 14 transiently effective sites and 60 (65%) of 93 noneffective sites ($p < 0.001$). A possible accessory pathway potential was seen at 30 sites (6 [67%] of 9 successful sites, 7 [50%] of 14 transiently effective sites and 17 [18%] of 93 noneffective sites), which was often only a small notch on the end of the local ventricular activation curve (Fig. 7). No attempt was made to validate these signals by premature stimulation because this often induces displacement of the catheter. A possible accessory pathway potential was not recorded during any of the failed ablation attempts. The mean interval from the onset of ventricular activation to the onset of the possible accessory pathway potential at these 30 sites was 58 ± 14 ms. The interval between the onset of ventricular activation and the earliest atrial activation was significantly shorter at successful sites compared with noneffective sites (68 ± 17 vs. 83 ± 17 ms, $p < 0.01$), but no significant differences were observed between successful sites and transiently effective sites (68 ± 17 vs. 72 ± 15 ms).

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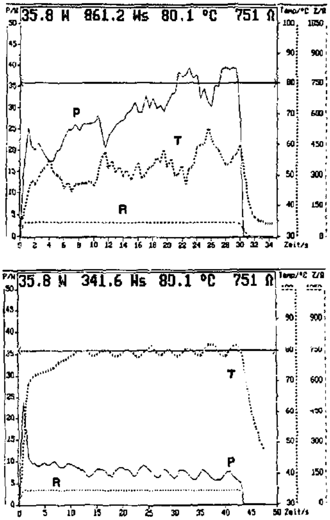

Figure 6. Simultaneous recordings of power (P), impedance (R) and catheter tip temperature (T) during two current applications in a patient with a left posteroseptal accessory pathway. For both applications, the temperature was preset at 80°C. **Panel A** was recorded at a site with unstable local electrograms. The temperature curve was also very unstable. Although the power output was very high (mean 28.7 W, 861 J), the temperature increased slowly and the mean temperature was only 52°C. No effect was noted after this current application. **Panel B** was recorded at the same site but with stable local electrograms recorded. The temperature reached the preset temperature of 80°C in 8 s and persisted until the end of current application with a relative lower output (mean 7.9 W, 238 J). Complete accessory pathway conduction block was achieved after this current application.

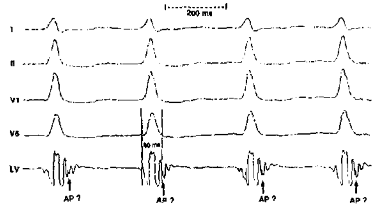

Figure 7. Local electrogram from a patient with a left lateral free wall concealed pathway. During orthodromic tachycardia, a small notch on the local ventricular potential was recorded. It was presumed to be an accessory pathway potential. Delivery of a radiofrequency pulse at this site terminated the tachycardia and achieved complete block of the accessory pathway. Abbreviations as in Figure 1.

The amplitude of local atrial activation and of possible accessory pathway potentials was not measured because most of these potentials were obscured within the ventricular electrogram. Stepwise logistic statistical analysis was not performed because the number of patients in this group was too small.

Repeat energy applications at transiently effective sites. Forty-one repeat energy applications with higher output or longer pulse duration, or both, were made after a transiently effective pulse without a change in catheter position. Permanent block of the accessory pathway was achieved after 1 repeat pulse, no effect was observed after another 5 repeat pulses and transient block of pathway was again induced at the remaining 35 sites.

Follow-up. After an average of 11 ± 13 months, accessory pathway conduction resumed in four patients (9%). All pathways were successfully ablated during repeat ablation procedure.

Discussion

Precise localization of an accessory pathway is an essential prerequisite for successful transcatheter ablation. Previously, the site of an accessory pathway was inferred from the localization of the earliest atrial activation during reentrant tachycardia. Direct recordings of accessory pathway potentials can be obtained from a catheter position in close proximity to an accessory pathway and may be more reliable for localizing the pathway. Isolated case reports (13–17) of direct recording of accessory pathway potentials were limited to right-sided pathways. In 1988, Jackman et al. (7,8) reported the successful recording of accessory pathway potentials in 45 of 49 left-sided pathways by using a specially designed catheter in the coronary sinus. However, this catheter is not feasible for catheter ablation because of its very small electrodes; in addition, delivery of current in the coronary sinus may induce severe damage. Recently (1–4), radiofrequency ablation of left-sided pathways from the ventricular insertion was achieved with a high success rate. Direct recording of accessory pathway potentials by ablation catheters in the left ventricle has been shown to be feasible. However, delivery of energy to those regions where accessory pathway potentials are presumed often is not effective or only transiently interrupts accessory pathway conduction. Therefore, the purpose of our study was to identify the characteristics of local electrograms that would identify successful sites and establish criteria that are predictive of outcome and minimize unnecessary current delivery. To the best of our knowledge, only limited data have been reported (10) on the characteristics of local electrograms during radiofrequency ablation of accessory pathways.

Successful ablation of accessory pathways using radiofrequency energy depends on 1) precise localization of pathways, and 2) adequate delivery of radiofrequency current to the pathways. The latter is influenced by the size of the distal electrode of the ablation catheter, the contact between the catheter and the endocardium, the heart chamber used for delivery of current, the actual delivered energy and the radiofrequency generators used. Analysis of local electrograms not only identifies the criteria for localization of accessory pathways, but also may yield criteria that may reflect the contact between the catheter tip and the endocardial surface.

Predictive values of local electrogram. Our study shows that the local electrograms obtained at successfully ablated sites are clearly different from those obtained at unsuccessful sites. Several individual variables correlated with successful ablation, but the best individual variable (that is, recording of the accessory pathway potential) had only a 27% positive predictive value. However, when multivariate analysis was used, a higher predictive value for success was achieved. Delivery of radiofrequency energy to a site where a stable electrogram with an accessory pathway potential was recorded with the amplitude of atrial activation >1 mV and where ventricular activation had occurred before the onset of the delta wave had a 62% probability of success. In contrast, without these features, a probability of 95% failure (noneffective or transiently effective) can be expected. Our prospective study has confirmed that using these criteria can significantly reduce the number of current applications.

Characteristics of the accessory pathway potential during pre-excited sinus rhythm. In most cases, the accessory pathway potential that was recorded by the ablation catheter at successful sites during pre-excited rhythm had a relatively sharp deflection in contrast to an atrial potential, which normally has a smooth curve. In some cases, the accessory pathway potential was not dissociated from local atrial or ventricular activation, resulting in so-called continuous activation. A critically timed premature stimulus may separate it from other components of the local electrogram (Fig. 1A). Disappearance of the presumed accessory pathway potential after an effective energy application (Fig. 1B) or after a premature stimulus (Fig. 2) confirms the origin of this potential. Recognition of an accessory pathway potential is relatively easy if the patient has an intermittently anterograde conducting accessory pathway (Fig. 4). Pacing the right atrium or coronary sinus is very useful in identifying an accessory pathway potential in some patients without preexcitation during sinus rhythm (Fig. 5).

Stability of electrograms. An unstable electrogram often suggests poor contact between the catheter and endocardial surface. It may either induce an increase in impedance, which inhibits the further delivery of energy, or prevent the development of sufficient temperature at the ablation site. The temperature necessary for coagulation of biologic tissue varies between 60° and 100°C (18–20). In our experience using temperature-monitored catheter ablation with radiofrequency energy at the sites where unstable electrograms were recorded, the temperature at the tip of the catheter increased slowly and the average temperature often did not exceed 50°C. The temperature curve also appeared unstable (Fig. 6), which may explain why an unstable local electrogram often predicts failure of energy application.

Amplitude of atrial potentials. The results of this study show that the amplitude of atrial potentials is an important predictor of success in ablation of left-sided accessory pathways at the ventricular site of insertion. A large atrial potential recorded in the ventricle suggests that the catheter is close to or against the atrioventricular (AV) ring which is just the route of the accessory pathway. Experimental studies have shown (21) that displacement of the ablation catheter by as little as 3 to 5 mm from the mitral anulus results in a very small amplitude of the atrial potential and renders it unsuitable for ablation. Thus, the ablation catheter should be inserted as close as possible to the mitral anulus to record the largest atrial potential.

Comparison with other studies. Recently, Haissaguerre et al. (22) reported the electrographic patterns in ablation of accessory pathways by using bipolar and unipolar recordings. However, their results are not comparable with those in the present study because they used direct current energy, which can induce much larger lesions than those induced by radiofrequency energy (5). In contrast to ablation with radiofrequency energy, extremely precise localization of the pathway may not be essential for direct current ablation. Second, direct current energy is delivered within several milliseconds. Therefore, stability of the catheter and good contact between the catheter and endocardium are less critical for direct current ablation than for ablation using radiofrequency energy. Furthermore, the most predictive variables in our study were not included in their study with bipolar recordings (22). Thus, prospectively controlled studies using bipolar and unipolar recordings should be performed to refine the criteria for ablation using radiofrequency energy.

Electrographic intervals. In contrast to the findings of Haissaguerre et al. (22), there were no significant differences in the interval from the onset of atrial activation to the onset of ventricular activation between the successful and failed sites. A possible reason for this is that Haissaguerre et al. (22) did not attempt to validate the accessory pathway potential. Thus, in some patients, the measured interval between the atrial and the ventricular potential may not represent a real interval between these potentials but could signify an interval between the atrial potential and the accessory pathway potential, which may result in a shorter measured interval between the atrial and the ventricular potential. Our results showed that the accessory pathway potential presented more frequently at successful sites, which may result in a shorter interval between atrial potential and ventricular potential.

Mapping during orthodromic tachycardia. In our study, ablation was performed during orthodromic tachycardia in the first four patients with manifest accessory pathways and in nine patients with 10 concealed accessory pathways. The success rate was significantly lower than that with mapping during pre-excited sinus rhythm. Recording of the earliest atrial activation was still the most important criterion in ablation of concealed accessory pathways. A presumed accessory pathway potential that was often only a small notch on the ventricular potential (Fig. 7) was recorded in 6 (43%) of 14 cases during orthodromic tachycardia. In contrast, an accessory pathway potential validated by premature stimulation was recorded in 32 (73%) of 44 cases by mapping during pre-excited sinus rhythm. All presumed accessory pathway potentials recorded during orthodromic tachycardia were found during successful procedures; none were seen during unsuccessful procedures. These results suggest that it is relatively difficult to record, recognize and validate accessory pathway potentials during orthodromic tachycardia. Localization of an accessory pathway mainly on the basis of recording the earliest atrial activation is not as precise as mapping with direct recording of accessory pathway potentials during pre-excited sinus rhythm. Stability of the electrogram also plays an important role in ablation of an accessory pathway when mapping during orthodromic tachycardia.

Transient effects. The transient effects of energy application have been observed (23–26) during ablation of the AV junction and accessory pathways using direct current or radiofrequency energy. In our study, the results of measurements at transiently effective sites ranged between those obtained at successful sites and at noneffective sites. This finding suggests that these sites might not be far from the pathways. Thus, repeating current application using a higher output and longer pulse duration at transiently effective sites may produce permanent block of an accessory pathway. In contrast to this expectation, only 1 of 41 of repeated pulses with higher energy achieved permanent success. In the single successful case, displacement of the catheter could not be excluded because a slight change in local electrograms before delivery of the repeat pulse was noted. Thus, applying a repeat current pulse with higher energy after a transiently effective pulse without performing new mapping of the accessory pathway location does not seem to be useful.

Limitations. Not all accessory pathway potentials were validated by interventions such as premature stimulation, especially at some noneffective sites and in patients with concealed accessory pathways. However, our study has also shown that detection of accessory pathway potentials based on the configuration of and time relation to other potentials (atrial, ventricular) could also be an important predictor, even in ablation of concealed accessory pathways. Thus, it may not be essential to validate these accessory pathway potentials using stimulation maneuvers that may markedly prolong the procedure and cause displacement of the catheter.

Cumulative effects of radiofrequency pulses on the accessory pathways could not be excluded in some cases with relatively broad pathways. Because radiofrequency current can induce only a small lesion, more than one current application might be needed to achieve complete block of accessory pathways in cases with a "thick accessory pathway." Thus, some local electrograms recorded from effective sites might be classified as having come from noneffective sites, which might obscure the difference between successful and unsuccessful sites. However, our results suggest that this may not have a major influence on the results because there were still significant differences between electrographic measurements from noneffective and effective sites. Furthermore, our prospective investigation confirmed that the criteria derived from this study are useful and reliable.

The findings in this study were obtained only from left-sided accessory pathways that were ablated at the ventricular site of insertion. Therefore, the results cannot be extended to right-sided accessory pathways, which are ablated at the atrial side in most institutions. A prospective investigation to determine electrographic criteria that predict successful ablation of right-sided accessory pathways is warranted.

Conclusions. The results of this study suggest that 1) transcatheter radiofrequency ablation is highly effective in the treatment of patients with left-sided accessory pathways; 2) certain characteristics of local electrograms have an important role in predicting the success or failure of catheter ablation; 3) mapping during pre-excited rhythm renders ablation more effective than does mapping during reciprocating supraventricular tachycardia in patients with manifest pre-excitation; and 4) applying a repeat current pulse with higher energy after a transiently effective pulse without performing new mapping of the accessory pathway location does not seem to be useful.

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