Electrogram Criteria for Identification of Appropriate Target Sites for Radiofrequency Catheter Ablation of Accessory Atrioventricular Connections

Hugh Calkins, MD; Yoon-Nyun Kim, MD; Steve Schmultz, PhD; Joao Sousa, MD; Rafel El-Atassi, MD; Angel Leon, MD; Alan Kadish, MD; Jonathan J. Langberg, MD; and Fred Morady, MD

Background. Catheter ablation of accessory atrioventricular (AV) connections using radiofrequency current has been demonstrated to be effective in the majority of patients with the Wolff-Parkinson-White syndrome or paroxysmal supraventricular tachycardia involving a concealed accessory AV connection. However, electrogram criteria have not been established to guide attempts at radiofrequency catheter ablation.

Methods and Results. The characteristics of local electrograms recorded at successful and unsuccessful sites of radiofrequency catheter ablation were determined in 132 patients. Electrograms recorded at a total of 438 sites were analyzed: 338 recorded during ablation of 90 manifest accessory AV connections and 100 recorded during ablation of 44 concealed accessory AV connections. During ablation of manifest accessory AV connections, the independent predictors of outcome were electrogram stability ($p<0.001$), the interval between activation of the ventricular electrogram and onset of the QRS complex ($p<0.001$), and the presence of an accessory AV connection potential ($p<0.001$). Radiofrequency energy delivery at sites demonstrating stable electrograms, a probable or possible accessory AV connection potential, and activation of the local ventricular electrogram before the onset of the QRS complex had a 57% probability of success compared with a 3% probability of success at sites without these features. During ablation of concealed accessory AV connections, the independent predictors of outcome were electrogram stability ($p=0.02$), the presence of an accessory AV connection potential ($p=0.05$), and the presence of retrograde continuous electrical activity ($p=0.04$). Sites demonstrating a stable local electrogram, an accessory AV connection potential, and retrograde continuous electrical activity had an 82% probability of success compared with only a 5% probability of success at sites demonstrating none of these features.

Conclusions. The local electrogram parameters of greatest importance in predicting the success or failure of radiofrequency catheter ablation of accessory AV connections are electrogram stability, the presence of an accessory AV connection potential, and the timing of ventricular activation relative to the QRS complex (for manifest accessory AV connections) or retrograde continuous electrical activity (for concealed accessory AV connections). Awareness of these variables during attempts at radiofrequency catheter ablation of accessory AV connections may minimize the number of unnecessary applications of radiofrequency energy. (Circulation 1992;85:565–573)
in detail the results of mapping during attempts at radiofrequency catheter ablation. Therefore, electrogram criteria to guide attempts at radiofrequency catheter ablation have not been established. Electrogram characteristics that may be of importance include the presence of electrogram stability, an accessory AV connection potential (K potential), continuous electrical activity, the absolute and relative amplitudes of the atrial and ventricular components of the local electrogram, the interval between the atrial and ventricular components of the local electrogram, and the timing of the atrial and/or ventricular components of the local electrogram relative to the QRS complex.

The objective of this study was to analyze and compare the local electrograms recorded at successful and unsuccessful sites of radiofrequency catheter ablation to identify the electrogram characteristics that best identify target sites that have a high likelihood of success or failure.

Methods

Patient Characteristics

The electrograms evaluated in this study were obtained from 132 patients who underwent successful radiofrequency catheter ablation of an accessory AV connection at the University of Michigan Medical Center. One hundred thirty patients had a single accessory AV connection and two patients had two accessory AV connections. Each patient had no inducible supraventricular tachycardia and no evidence of an accessory AV connection at the termination of the ablation procedure and during a minimum of 3 months of follow-up. Seventy-four patients were men and 58 were women. One hundred twenty-eight patients had no evidence of structural heart disease, two had Ebstein’s anomaly, one had dilated cardiomyopathy, and one had coronary artery disease. Mean patient age was 35±12 years; mean duration of symptoms before catheter ablation was 8±10 years.

Characteristics of Accessory AV Connections

Ninety accessory AV connections were manifest and 44 were concealed. Ninety-three accessory AV connections were located in the free wall of the left ventricle, 22 were posteroseptal, 14 were located in the free wall of the right ventricle, and five were midseptal. Mean anterograde effective refractory period of manifest accessory AV connections was 282±74 msec. Mean AV block cycle length of manifest accessory AV connections was 307±93 msec, and mean ventriculoatrial (VA) block cycle length of all accessory AV connections was 284±60 msec.

Electrophysiology Testing

Each patient underwent a diagnostic electrophysiology test in conjunction with catheter ablation. The electrophysiology test was performed in the fasting state. Informed consent was obtained under an investigational protocol approved by the human research committee at the University of Michigan. All antiarrhythmic agents were discontinued at least five half-lives before the procedure. Three 6F quadripolar electrode catheters with 1-cm interelectrode spacing were inserted into a femoral vein and positioned at the high right atrium, His bundle position, and apex of the right ventricle. A 7F quadripolar catheter with a central lumen (USCI) or a 6F orthogonal electrode catheter (Mansfield/Webster, Mansfield, Mass.) was positioned in the coronary sinus via the right internal jugular vein in the majority of patients. Leads VI, I, and III and the intracardiac electrograms were recorded on a Siemens-Elma Mino-graph 7 recorder at paper speeds of 100 or 200 mm/second. The objective of the diagnostic portion of the electrophysiology test was to define the conduction properties of the accessory AV connection and to localize the accessory AV connection to a general region of the heart.

Ablation Protocol

After preliminary localization of the accessory AV connection, precise mapping was performed with a 7F catheter with a 4-mm distal electrode, 5-mm interelectrode spacing, and a deflectable tip (Mansfield/Webster). This catheter was also used for ablation of the accessory AV connections. Accessory AV connections located on the left side of the AV ring were approached from the ventricular aspect of the mitral annulus. The catheter was inserted into a femoral artery and passed retrogradely across the aortic valve into the left ventricle. The catheter was then positioned against the mitral annulus, and precise mapping was performed.

Right-sided, posteroseptal, and midseptal accessory AV connections were approached from the atrial side of the tricuspid annulus. The catheter was inserted into a femoral vein, passed up the inferior vena cava, and positioned against the tricuspid annulus. Accessory AV connections capable of antegrade conduction were mapped primarily during sinus rhythm, and concealed accessory AV connections were mapped during ventricular pacing or orthodromic AV reciprocating tachycardia. Target sites for ablation of manifest accessory AV connections were identified by the presence of discrete atrial and ventricular electrograms, early ventricular activation relative to onset of the delta wave, and/or a discrete potential suggestive of a K potential preceding the QRS complex. Target sites for ablation of concealed accessory AV connections were identified by the presence of discrete atrial and ventricular electrograms, the presence of a presumed K potential, and early atrial activation.

Catheter ablation was performed using radiofrequency energy delivered as a continuous unmodulated sine wave at 350 kHz (Radionics RF-3, Burlington, Mass.) between the distal electrode of the ablation catheter and a large skin electrode positioned on the chest. Twenty-five to 36 W was delivered for 10–20
seconds or until there was a sudden rise in impedance indicative of coagulum formation.

Recording and Analysis of Electrograms

The characteristics of local electrograms recorded at successful and unsuccessful sites of radiofrequency catheter ablation were determined in each patient. Electrograms recorded at a total of 438 sites were analyzed: 338 recorded during ablation of manifest accessory AV connections and 100 recorded during ablation of concealed accessory AV connections. Sites at which accessory AV conduction was transiently interrupted were excluded from analysis. A maximum of 10 and a mean of 3.4±3.1 electrograms were analyzed for each accessory AV connection. If more than 10 applications of radiofrequency current were required, the first nine unsuccessful sites and the successful site were used for analysis purposes.

The local electrograms were recorded using the distal pair of electrodes of the ablation catheter, which had a 5-mm interelectrode distance. The electrograms were filtered at 50–500 Hz, amplified at a gain of 20 mm/mV, and recorded at paper speeds of 100 or 200 mm/second using a Siemens-Elma Mingo-graph 7 recorder. Electrograms of manifest accessory AV connections were recorded during sinus rhythm. Electrograms of concealed accessory AV connections were recorded during sinus rhythm and during ventricular pacing (16 patients) or orthodromic AV reciprocating tachycardia (28 patients). Each electrogram was analyzed independently in blinded fashion by two of the authors. If their analyses differed significantly, the electrogram was analyzed by a third author, and a consensus was reached.

The amplitude, morphology, and timing of the atrial, accessory AV connection, and ventricular components of each local electrogram were determined. Morphological features that were evaluated included the stability of the local electrogram, the presence of continuous electrical activity, and the presence of a K potential. Stability of the local electrogram was determined based on analysis of three to five local electrograms recorded immediately before delivery of radiofrequency energy. Electrograms were classified as unstable if there was more than a 10% change in the AV ratio or appearance or disappearance of a major deflection in the local electrogram. An electrogram was classified as continuous if less than a 5-msec isoelectric segment was present between the atrial and ventricular components of the local electrogram (Figure 1). Determination of the presence of a K potential was based strictly on morphological features of the local electrogram. Deflections suggestive of a K potential were not verified with pacing maneuvers.5,6 Local electrograms were classified as demonstrating a probable K potential, a possible K potential, or no K potential (Figure 2). A probable K potential was defined as a deflection in the local electrogram that preceded the onset of the QRS complex and was distinct from the atrial and ventricular components of the local electrogram. A possible K potential was defined as a deflection that preceded the onset of the QRS complex and merged with the atrial or ventricular components of the local electrogram.

The onset and activation time of the K potential and atrial and ventricular components of each local electrogram were determined (Figure 3). The electrogram onset was defined as the first deflection from baseline with a slope greater than 45° at a paper speed of 100 mm/second.7 The activation time was defined as the point of maximal amplitude of the local electrogram.7,8 For manifest accessory AV connections, the following intervals were measured: onset of the atrial electrogram to onset of the ventricular electrogram (AoVo interval), onset of a probable K potential to onset of the ventricular electrogram (KoVo interval), and onset of the ventricular electrogram to onset of the QRS complex (VoQRS interval). These intervals were also determined based on activation times (AaVa, KaVa, and

---

**Figure 1.** Recording obtained during ventricular pacing at a successful ablation site of a concealed left lateral accessory atrioventricular (AV) connection. Shown are surface lead V1 and the intracardiac electrograms recorded in the coronary sinus (CS) at the His bundle position (HBE) and at the ablation site (Lat Mitral Annulus) during ventricular pacing at a cycle length of 350 msec. Intermittent retrograde VA conduction through the accessory AV connection is observed during ventricular pacing. The first electrogram recorded demonstrates retrograde conduction through the accessory AV connection with the earliest retrograde atrial activation observed at the lateral mitral annulus (shown by arrow). The second electrogram demonstrates retrograde conduction through the AV node. Earliest retrograde atrial activation is now observed at the His bundle position (shown by asterisk). Continuous electrical activity is observed between the ventricular (V) and atrial (A) components of the local electrogram recorded at the lateral mitral annulus only when retrograde conduction occurs via the accessory AV connection. S, ventricular pacing stimulus.
FIGURE 2. Recordings show examples of a probable, possible, and absent accessory atrioventricular (AV) connection potential (K). Shown are surface leads V, and the local electrograms recorded at successful ablation sites in three different patients. Left panel demonstrates a probable K potential recorded at the lateral mitral annulus (Lat. M.A.). A discrete deflection preceding the onset of the QRS complex is present between the atrial and ventricular components of the local electrogram. Center panel demonstrates a possible K potential recorded at the posterior tricuspid annulus (Post. T.A.). A small deflection can be seen fusing with the atrial electrogram and occurring before the onset of the QRS complex. Right panel shows a successful ablation site recorded at the lateral mitral annulus (Lat. M.A.) with no evidence of a K potential.

VaQRS interval). For concealed accessory AV connections, the intervals that were measured included onset of the local ventricular electrogram to onset of the local atrial electrogram (VoAo interval), onset of the local ventricular electrogram to onset of a probable K potential (VoKo interval), and onset of the QRS complex to onset of the atrial component of the local electrogram (QRS-Ao interval). These intervals were also determined based on activation times (VaAa, VaKa, and QRS-Aa interval).

**Statistical Analysis**

All data are expressed as mean±1 SD. Comparisons between successful and unsuccessful sites were made using Student’s t test or by χ² analysis. Univariate logistic regression was performed to determine the significance of individual predictive variables. Multivariate stepwise logistic regression was performed to select the group of variables that best predicted outcome. A probability value less than 0.05 was considered significant.

**Results**

Comparison of Successful and Unsuccessful Sites During Ablation of Manifest Accessory AV Connections

The characteristics of local electrograms recorded at successful and unsuccessful ablation sites for manifest accessory AV connections are summarized in Table 1. A greater proportion of electrograms recorded at successful ablation sites demonstrated electrogram stability and/or a K potential compared with unsuccessful sites (p<0.001 and p<0.05, respectively). The intervals between activation of the atrial and ventricular components of the local electrograms (AaVa), ventricular activation and QRS onset (Va-

<table>
<thead>
<tr>
<th>Variable</th>
<th>Successful sites (n=90)</th>
<th>Failed sites (n=248)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>85 (94%)</td>
<td>191 (77%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>K potential</td>
<td>69 (77%)</td>
<td>129 (52%)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Probable</td>
<td>30 (33%)</td>
<td>52 (21%)</td>
<td>0.07</td>
</tr>
<tr>
<td>Possible</td>
<td>39 (43%)</td>
<td>77 (31%)</td>
<td>0.15</td>
</tr>
<tr>
<td>CEA</td>
<td>46 (51%)</td>
<td>99 (40%)</td>
<td>0.07</td>
</tr>
<tr>
<td>AoVo (msec)</td>
<td>50.2±19.2</td>
<td>51.3±18.8</td>
<td>0.64</td>
</tr>
<tr>
<td>AaVa (msec)</td>
<td>50.6±17.9</td>
<td>60.0±22.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>VoQRS (msec)</td>
<td>13.5±10.8</td>
<td>10.5±12.9</td>
<td>0.05</td>
</tr>
<tr>
<td>VaQRS (msec)</td>
<td>-7.44±13.4</td>
<td>-18.1±18.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KoVo (msec)</td>
<td>11.9±12.8</td>
<td>28.5±12.4</td>
<td>0.001</td>
</tr>
<tr>
<td>KaVa (msec)</td>
<td>31.7±11.4</td>
<td>45.7±19.6</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Stability, no major change in morphology or amplitude of local electrogram immediately before delivery of radiofrequency energy; K potential, accessory atrioventricular connection potential; CEA, continuous electrical activity; AoVo, interval from onset of atrial electrogram to onset of ventricular electrogram; AaVa, interval from activation of atrial electrogram to activation of ventricular electrogram; VoQRS, interval from onset of ventricular electrogram to onset of the QRS complex; VaQRS, interval from activation of ventricular electrogram to onset of QRS complex; KoVo, interval from onset of K potential to onset of ventricular electrogram; KaVa, interval from activation of K potential to activation of ventricular electrogram.
Table 2. Electrogram Amplitudes at Successful and Unsuccessful Sites During Ablation of Manifest Accessory Atrioventricular Connections

<table>
<thead>
<tr>
<th>Location</th>
<th>Successful sites</th>
<th>Unsuccessful sites</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A ampl (mV)</td>
<td>K ampl (mV)</td>
<td></td>
</tr>
<tr>
<td>Left-sided</td>
<td>0.69±0.76</td>
<td>0.32±0.31</td>
<td>0.78</td>
</tr>
<tr>
<td>V ampl (mV)</td>
<td>2.65±2.53</td>
<td>2.02±1.52</td>
<td>0.04</td>
</tr>
<tr>
<td>A/V ratio</td>
<td>0.89±1.86</td>
<td>1.03±3.04</td>
<td>0.76</td>
</tr>
<tr>
<td>Right-sided</td>
<td>0.98±1.26</td>
<td>0.86±1.00</td>
<td>0.64</td>
</tr>
<tr>
<td>V ampl (mV)</td>
<td>0.95±0.96</td>
<td>1.06±1.14</td>
<td>0.70</td>
</tr>
<tr>
<td>A/V ratio</td>
<td>1.99±3.53</td>
<td>1.64±2.94</td>
<td>0.65</td>
</tr>
<tr>
<td>Posteroseptal</td>
<td>1.06±0.95</td>
<td>1.40±1.11</td>
<td>0.26</td>
</tr>
<tr>
<td>V ampl (mV)</td>
<td>0.26±0.12</td>
<td>0.42±0.40</td>
<td>0.35</td>
</tr>
<tr>
<td>A/V ratio</td>
<td>1.89±2.11</td>
<td>2.50±2.16</td>
<td>0.33</td>
</tr>
</tbody>
</table>

A ampl, amplitude of atrial component of local electrogram; K ampl, amplitude of accessory atrioventricular connection component of local electrogram; V ampl, amplitude of ventricular component of local electrogram; A/V ratio, ratio of amplitude of atrial to amplitude of ventricular component of local electrogram.

QRS), and between K potentials and the ventricular component of the local electrogram (KaVa and KoVo) were significantly shorter at successful sites than at unsuccessful sites (p<0.01). The AaVa interval was similar at successful ablation sites in patients with marked preexcitation (HV interval <20 msec) and at successful ablation sites in patients with only mild preexcitation (HV interval >20 msec, p=0.56).

Shown in Table 2 are the electrogram amplitudes that were recorded at successful and unsuccessful sites during radiofrequency catheter ablation of manifest accessory AV connections. The amplitude of the atrial component of local electrograms and K potentials were similar at successful and unsuccessful sites of radiofrequency energy delivery during ablation of left, posteroseptal, and right-sided accessory AV connections. The amplitude of the ventricular component of local electrograms was greater at successful sites than at unsuccessful ablation sites during ablation of left-sided accessory AV connections but was similar at successful and unsuccessful sites during ablation of right and posteroseptal accessory AV connections.

Predictors of Success During Ablation of Manifest Accessory AV Connections

Electrogram characteristics that were predictive of outcome during ablation of manifest accessory AV connections based on univariate analysis were electrogram stability (p<0.001), the presence of a probable or possible K potential (p<0.001), the AaVa interval (p<0.001), the VaQRS interval (p<0.001), the KoVo interval (p=0.03), and the KaVa interval (p<0.001). Radiofrequency energy delivery was successful at five of 62 unstable sites (8.1%) versus 85 of 226 stable sites (38.8%, p<0.001). Accessory AV connections were successfully ablated at 69 of 198 ablation sites (34.8%) demonstrating a probable or possible K potential versus 21 of 140 sites (15%) without a K potential (p<0.001, Figure 4). The relation between the probability of success and the AaVa interval is shown in Figure 5. Sites with an AaVa time greater than 100 msec had only a 10% predicted probability of success, whereas the predicted probability of success was 42% at sites demonstrating an AaVa time less than 30 msec.

Figure 4. Recordings show examples of unsuccessful and successful ablation sites of a right lateral accessory atrioventricular (AV) connection. At the successful site, a deflection is seen between the atrial (A) and ventricular (V) components of the local electrogram that is consistent with activation of an accessory AV connection (Pos K). The interval between the atrial and ventricular components of the local electrogram is shorter and the ventricular component of the local electrogram occurs earlier relative to the QRS onset (dashed line) at the successful compared with the unsuccessful site. Lat TA, lateral tricuspid annulus.

Figure 5. Graph shows interval between activation of the atrial and ventricular components of local electrograms (AaVa interval) as a predictor of outcome during radiofrequency catheter ablation of manifest accessory atrioventricular connections. Probability of success is plotted on the vertical axis and AaVa interval (msec) is plotted on the horizontal axis. As the AaVa interval shortens, probability of successful ablation increases. Individual points represent observed probabilities of success; curve represents predicted probability of success.
The relation between the probability of success and the VaQRS interval is shown in Figure 6. Radiofrequency energy delivery at sites at which ventricular activation occurred more than 40 msec after the onset of the QRS complex had only a 10% predicted probability of success, whereas the predicted probability of success was 50% at sites at which ventricular activation occurred 10 msec before the onset of the QRS complex. Using multivariate logistic regression, the independent predictors of outcome during ablation of manifest accessory AV connections among the variables evaluated were electrogram stability ($p<0.001$), the VaQRS interval ($p<0.001$), and the presence of either a probable or possible K potential ($p<0.001$). The predictive importances of a probable or possible K potential were similar; therefore, they were grouped together. Table 3 shows the predicted probabilities of success based on the presence or absence of these three electrogram characteristics. Radiofrequency energy delivery at sites demonstrating stable electrograms, a probable or possible K potential, and a VaQRS interval $>0$ msec had a 57% predicted probability of success compared with a 2% predicted probability of success at sites demonstrating electrogram instability, no K potential, and a VaQRS $<-15$ msec.

**Figure 6.** Graph shows interval between activation of the local ventricular electrogram and onset of the QRS complex (VaQRS interval) as a predictor of outcome during radiofrequency catheter ablation of manifest accessory atrioventricular connections. Probability of success is plotted on the vertical axis and VaQRS interval (msec) is plotted on the horizontal axis. The earlier the local ventricular activation relative to the onset of the QRS complex, the greater the probability of successful ablation. Individual points represent observed probabilities of success; curve represents predicted probability of success.

<table>
<thead>
<tr>
<th>Stability</th>
<th>K potential</th>
<th>Va QRS ≥0 msec</th>
<th>Probability of success (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>57±6</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>−</td>
<td>36±4</td>
</tr>
<tr>
<td>+</td>
<td>−</td>
<td>+</td>
<td>28±6</td>
</tr>
<tr>
<td>−</td>
<td>+</td>
<td>+</td>
<td>18±8</td>
</tr>
<tr>
<td>+</td>
<td>−</td>
<td>−</td>
<td>14±3</td>
</tr>
<tr>
<td>−</td>
<td>+</td>
<td>−</td>
<td>9±4</td>
</tr>
<tr>
<td>−</td>
<td>−</td>
<td>+</td>
<td>6±3</td>
</tr>
<tr>
<td>−</td>
<td>−</td>
<td>−</td>
<td>3±1</td>
</tr>
</tbody>
</table>

Stability, no major change in morphology or amplitude of local electrogram immediately before delivery of radiofrequency energy; K potential, presence of probable or possible accessory atrioventricular connection potential; Va QRS ≥0 msec, activation of ventricular component of local electrogram begins before QRS onset; Va QRS ≤−15 msec, activation of ventricular component of local electrogram occurs more than 15 msec after onset of QRS complex.

TABLE 3. Predicted Probability of Success During Ablation of Manifest Accessory Atrioventricular Connections

Comparison of Successful and Unsuccessful Sites During Ablation of Concealed Accessory AV Connections

The characteristics of local electrograms recorded at successful and unsuccessful ablation sites for concealed accessory AV connections are summarized in Table 4. Electrogram stability was observed more frequently at successful than at unsuccessful ablation sites ($p<0.01$). All timing parameters and the proportion of sites demonstrating retrograde continuous electrical activity and a probable or possible K potential were similar at successful and unsuccessful ablation sites. At successful ablation sites, the interval between the onset of the QRS complex and activation of the atrial component of the local electrogram and the VaAa interval were similar at sites that were mapped during ventricular pacing and at sites that were mapped during orthodromic reciprocating tachycardia ($p>0.2$).

The amplitudes of the atrial (0.45±0.12 versus 0.34±0.41 mV), K (0.32±0.32 versus 0.35±0.31 mV), and ventricular (2.66±1.85 versus 2.64±1.63 mV) components of local electrograms were similar at successful and unsuccessful ablation sites of concealed left-sided accessory AV connections ($p>0.2$). Only three concealed accessory AV connections in this series were right-sided or posteroseptal; therefore, a similar analysis could not be performed for these sites.

**Predictors of Success During Ablation of Concealed Accessory AV Connections**

Electrogram characteristics predictive of outcome during radiofrequency catheter ablation of concealed accessory AV connections based on univariate analy-
Table 4. Comparison of Successful and Unsuccessful Sites During Ablation of Concealed Accessory Atrioventricular Connections

<table>
<thead>
<tr>
<th>Variable</th>
<th>Successful sites (n=44)</th>
<th>Failed sites (n=56)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>39 (89%)</td>
<td>36 (64%)</td>
<td>0.005</td>
</tr>
<tr>
<td>K potential</td>
<td>35 (80%)</td>
<td>38 (68%)</td>
<td>0.6</td>
</tr>
<tr>
<td>Probable</td>
<td>23 (52%)</td>
<td>23 (41%)</td>
<td>0.5</td>
</tr>
<tr>
<td>Possible</td>
<td>12 (27%)</td>
<td>15 (27%)</td>
<td>0.9</td>
</tr>
<tr>
<td>CEA</td>
<td>23 (52%)</td>
<td>19 (34%)</td>
<td>0.06</td>
</tr>
<tr>
<td>VaAa (msec)</td>
<td>51.5±30.0</td>
<td>59.8±21.8</td>
<td>0.08</td>
</tr>
<tr>
<td>VoAo (msec)</td>
<td>82.4±29.9</td>
<td>89.0±27.7</td>
<td>0.25</td>
</tr>
<tr>
<td>VoKo (msec)</td>
<td>70.5±27.7</td>
<td>79.3±27.3</td>
<td>0.28</td>
</tr>
<tr>
<td>VaKa (msec)</td>
<td>39.9±22.1</td>
<td>46.3±13.8</td>
<td>0.25</td>
</tr>
<tr>
<td>QRS-Aa (msec)</td>
<td>129±45.2</td>
<td>137±39.8</td>
<td>0.31</td>
</tr>
<tr>
<td>QRS-Ao (msec)</td>
<td>132±37.0</td>
<td>140.2±42.0</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Stability, no major change in morphology or amplitude of local electrogram immediately before delivery of radiofrequency energy; K potential, accessory atrioventricular connection potential; CEA, continuous electrical activity; VaAa, interval from activation of ventricular electrogram to activation of atrial electrogram; VoAo, interval from onset of ventricular electrogram to onset of atrial electrogram; VoKo, interval from onset of ventricular electrogram to onset of accessory atrioventricular connection potential; VaKa, interval from activation of ventricular electrogram to activation of atrial electrogram; QRS-Aa, interval from onset of QRS complex to activation of the atrial component of local electrogram; QRS-Ao, interval from onset of QRS complex to activation of atrial component of local electrogram.

The results of this study identify the characteristics of local electrograms recorded at sites of radiofrequency energy delivery that are predictive of outcome during catheter ablation of accessory AV connections. Electrogram characteristics that proved to be independent predictors of outcome during ablation of manifest accessory AV connections included electrogram stability, the presence of a K potential, and the interval between activation of the local ventricular electrogram and onset of the QRS complex. Stable sites that demonstrated a K potential and at which ventricular activation occurred before the QRS complex had a 57% probability of success compared with less than a 5% probability of success at sites without these features. Independent predictors of outcome during ablation of concealed accessory AV connections included electrogram stability, the presence of a possible or probable K potential, and the presence of continuous electrical activity. Sites demonstrating a stable local electrogram, retrograde continuous electrical activity, and a K potential had an 82% probability of success compared with only a 5% probability of success if none of these features were present.

Main Findings

Electrogram Intervals

Both the AaVa interval and the VaQRS interval were predictive of outcome during ablation of manifest accessory AV connections. However, only the VaQRS interval was an independent predictor of outcome. The earlier the ventricular activation occurred relative to the QRS complex, the greater the probability of success. Sites at which local ventricular activation occurred more than 40 msec after the QRS complex had less than a 10% probability of success. In contrast, sites at which local ventricular activation occurred more than 10 msec before the QRS complex had a 50% probability of success. Earlier ventricular activation did not further increase the probability of success. This may reflect the importance of other factors to the success of radiofrequency catheter ablation. These factors may include contact pressure between the catheter and the myocardium, catheter stability, and myocardial wall thickness at the ablation site.

Activation timing in this study was based on the tallest peak of the bipolar electrogram. This criterion was used because it can be recognized quickly and reproducibly, and because recent studies have demonstrated that activation timing of bipolar electrograms determined using this criterion best correlates with activation timing determined using the maximal negative slope of unipolar electrogram recordings.
Electrogram timing based on electrogram onset was not predictive of outcome. This may be due to the effect of far-field electrical activity on electrogram onset.\textsuperscript{5,6,8} As the interelectrode distance increases, the bipolar local electrogram may record electrical activity occurring at greater distances from the bipolar.\textsuperscript{5,8} In this study, local electrograms were recorded using ablation catheters with 5-mm interelectrode spacing. It is possible that electrograms recorded using a smaller interelectrode distance would have detected less far-field electrical activity and that the predictive accuracy of electrogram timing based on the onset of electrograms would have improved.\textsuperscript{5}

Ventricular activation at successful ablation sites occurred a mean of 7 msec after the onset of the QRS complex. Local ventricular activation at the ablation site may have occurred after the QRS onset because of a subepicardial location of some accessory AV connections. The electrical wavefront would have to travel from the subepicardial aspect of the ventricle to the endocardial position of the ablation catheter before local ventricular activation could be recorded.

No electrogram timing variable was an independent predictor of outcome during ablation of concealed accessory AV connections. However, retrograde continuous electrical activity was a predictor of successful ablation. The relatively greater importance of continuous electrical activity compared with local electrogram timing during ablation of concealed compared with manifest accessory AV connections may be due to the smaller number of electrograms that were evaluated.

**Accessory AV Connection K Potentials**

The presence of a probable or possible K potential was an independent predictor of outcome during ablation of both concealed and manifest accessory AV connections. However, the presence of a K potential at a site of radiofrequency energy delivery neither guaranteed success nor was a requirement for success. During ablation of manifest accessory AV connections, the success rate was significantly greater at sites demonstrating a probable or possible K potential (35\%) than at sites without a K potential (15\%). A similar relation was observed during ablation of concealed accessory AV connections. Although no previous study has evaluated the importance of recording a K potential during radiofrequency catheter ablation, Warin et al.\textsuperscript{10,11} reported that K potentials are an important electrogram marker during ablation of accessory pathways using direct current energy. The 75\% prevalence of K potentials at sites of successful catheter ablation in this study is somewhat greater than the 50\% prevalence reported by Warin et al.\textsuperscript{11} but is similar to the 92\% prevalence reported by Jackman et al.\textsuperscript{5,6} during diagnostic electrophysiology studies using an orthogonal electrode array or multipolar electrode catheters with 2-mm interelectrode spacing. The inability to record a K potential at every successful ablation site may reflect the location of the ablation catheter relative to the accessory AV connection. If, as demonstrated previously by Jackman et al.\textsuperscript{5,6} the catheter is located very close to either the ventricular or atrial insertion of the accessory AV connection, the accessory pathway potential may fuse with the local atrial or ventricular electrogram, and therefore accessory pathway activation may not be apparent.

**Electrogram Stability**

Electrogram stability was an independent predictor of outcome during ablation of both concealed and manifest accessory AV connections. During ablation of manifest and concealed accessory AV connections, the probability of success was significantly greater at sites with a stable local electrogram compared with unstable sites (39\% versus 8\%). This finding is consistent with earlier studies that have recognized the importance of tissue contact during radiofrequency catheter ablation.\textsuperscript{12} For successful ablation to be accomplished, tissue heating must occur at the catheter tip.\textsuperscript{13} Unstable electrogram recordings most likely result from poor electrode contact with the endocardium and hence may reflect inadequate tissue heating and thermal injury.

**Study Limitations**

A limitation of this study is that K potentials were not validated with pacing maneuvers.\textsuperscript{5,6} Thus, we cannot be certain that a deflection that was morphologically consistent with a K potential actually represented activation of an accessory AV connection. Validation was not performed both because of the time-consuming nature of the validation procedure as well as the possibility of catheter dislodgment during pacing maneuvers. However, the absence of validation procedures may add to the clinical importance of our findings. We have demonstrated that K potentials identified only on a morphological basis are important predictors of success during ablation. This suggests that morphological identification of accessory pathway activation is sufficient and that there may not be a need to perform validation procedures during attempts at catheter ablation.

A second limitation of this study is that we did not routinely record electrograms at unsuccessful sites of radiofrequency energy delivery immediately after energy delivery to be certain that catheter dislodgment had not occurred during energy delivery. Therefore, catheter dislodgment during the application of radiofrequency energy may have confounded the accurate determination of the predictive value of electrogram characteristics.

A third limitation is that all of the patients in this study had typical accessory AV connections and that the results of this study therefore do not apply to patients with atypical accessory AV connections that conduct relatively slowly.

Last, it should be noted that the value of electrogram characteristics in predicting the outcome of ablation will be influenced by the interelectrode spacing and the size of the distal electrode of the
ablation catheter, the amount of radiofrequency energy delivered, the chamber used for mapping and ablation, and the criteria used to select target sites. Therefore, our results are applicable only in patients who undergo catheter ablation with the same techniques used in this study.

Conclusions

Accurate localization is a critical requirement for successful catheter ablation of accessory AV connections with the use of radiofrequency energy. Generally recognized guidelines for mapping have included identification of a K potential, early local ventricular activation relative to the onset of the delta wave, and early retrograde atrial activation during orthodromic AV reciprocating tachycardia or ventricular pacing. It is noteworthy that in the patients in this study, radiofrequency energy was delivered only at sites that were believed to fulfill these general criteria. Nevertheless, a mean of 7.2±6.7 applications of radiofrequency energy were required for successful ablation, indicating that many sites that superficially may appear to be appropriate target sites are actually inappropriate.

Important findings of this study that may not have been generally recognized by clinical electrophysiologists are 1) timing intervals measured using the onset of conventional bipolar electrograms do not predict the outcome of ablation attempts as accurately as measurements that are based on the tallest peak of the electrogram (i.e., activation time), 2) the presence of a presumed K potential at a particular site does not guarantee successful ablation of an accessory AV connection, nor does the absence of a K potential rule out the possibility of successful ablation, 3) no single mapping criterion can predict successful ablation as accurately as analysis of a constellation of mapping criteria, and 4) no constellation of mapping criteria can predict successful ablation with 100% accuracy, possibly because of important variables that cannot be accurately assessed, such as microdislodgment of the ablation catheter or inadequate electrode–tissue contact pressure.

The results of this study can be used as a practical guide for the clinical electrophysiologist during catheter ablation of accessory AV connections. Based on analysis of variables such as electrogram stability, the presence of a K potential, the timing of local ventricular activation relative to the delta wave in patients with manifest preexcitation, and the presence of retrograde continuous electrical activity in patients with concealed accessory AV connections, the probability of successful ablation at any particular site can be estimated. This type of probability analysis should prove helpful in minimizing the number of ineffective applications of radiofrequency energy in patients undergoing catheter ablation of an accessory AV connection.

References


KEY WORDS • radiofrequency energy • Wolff-Parkinson-White syndrome • catheter ablation
Electrogram criteria for identification of appropriate target sites for radiofrequency catheter ablation of accessory atrioventricular connections.
H Calkins, Y N Kim, S Schmaltz, J Sousa, R el-Atassi, A Leon, A Kadish, J J Langberg and F Morady

Circulation. 1992;85:565-573
doi: 10.1161/01.CIR.85.2.565

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1992 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/85/2/565