Monitoring the Local Electrogram at the Ablation Site during Radiofrequency Application for Common Atrial Flutter

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Recent studies have suggested that the attenuation of the local electrogram amplitude recorded from the ablation electrode during radiofrequency (RF) application predicts lesion growth. This study examined the time course of local electrogram amplitude during ongoing RF delivery in patients with common atrial flutter (AFl). In 71 patients with AFI, RF energy was applied to the anatomical isthmus. Termination of AFI was noted during 68 of 625 applications of RF energy. The changes in local atrial electrogram amplitude observed at all successful sites were analyzed. With increasing duration of the RF delivery, the electrogram amplitude decreased exponentially to reach a steady state within a mean duration of 17±3 sec, which was significantly longer than that of the steady-state temperature. The average decrease in the amplitude was 67±13%. In 16 patients in whom an increase in the power of RF energy had resulted in AFl termination, there was a dose-response relationship between the power and the amplitude decrease. The decrease in local electrogram amplitude appears to be a reliable marker for the efficacy of tissue heating and may be useful as an endpoint for individual applications. Local electrogram monitoring may offer an optimal energy strategy in AFI ablation.  

Key Words: Amplitude decrease; Atrial flutter; Catheter ablation; Local electrogram

Catheter ablation using radiofrequency (RF) energy is a well-established method for curing patients with supraventricular tachycardia and is being used for treatment of common atrial flutter (AFI). Previous studies have shown that the mechanism of AFI is a macro-reentrant circuit confined to the right atrium, and that the lower part of the right atrium is crucial for the development of AFI. Delivery of RF current to either the inferior vena cava-tricuspid annulus (IVC-TA) isthmus or to the coronary sinus ostium-tricuspid annulus (CSos-TA) isthmus has resulted in a reasonable ablation success rate. Recent reports have described the mechanism of successful AFI ablation as local bidirectional block at the anatomical isthmus. This probably is the new marker for the electrophysiological endpoint of the procedure and may predict the long-term success. However, during RF application, the identification of remaining viable conducting myocardium in the anatomic target has not been defined.

The temperature of the electrode-tissue interface is presumed to predict RF lesion volume. However, the rate of tissue temperature rise is progressively slower with increasing distance from the ablation electrode which limits the value of interface temperature measurement for monitoring deeper lesion growth. Recent experimental studies have suggested that the attenuation of the local electrical activity recorded from the ablating electrode may predict RF lesion formation. Little has been reported on the use of local electrogram monitoring at the ablation site in patients undergoing catheter ablation. The purpose of the present study, therefore, was to investigate the time course of local electrograms associated with the interruption of AFI during RF energy delivery.

Methods

Patients

The series includes 71 consecutive patients, referred to hospital between January 1993 and April 1996 for RF ablation of common AFI. The 71 patients consisted of 53 men and 18 women aged 15–82 years (mean, 59±16). They had documented episodes of common AFI for a period of 1–10 years and had taken 3 or more antiarrhythmic drugs that failed to control recurrences. In 8 patients, AFI were established for more than 3 months, and 22 patients also had episodes of documented atrial fibrillation. Structural heart disease was present in 17 patients (hypertensive heart disease in 7, coronary artery disease in 5, mitral valve disease in 3, dilated cardiomyopathy in 1 and Ebstein's anomaly in 1) and sick sinus syndrome in 10.

Electrophysiological Study

Electrophysiological evaluations were performed after informed consent had been obtained. Patients were studied in the postabsorptive state under light sedation, and antiarrhythmic drugs were withdrawn for at least 5 half-lives before the study. Four multi-electrode catheters with 2- or 5-mm interelectrode spacing were introduced percutaneously through both the femoral and the left subclavian veins and positioned in the right atrium and coronary sinus. One 6F quadrupolar or duodecapolar Halo catheter (Cordis Webster) was positioned on the lateral right atrium (RA). Other multipolar catheters were positioned to record the His bundle and proximal coronary sinus activity. One 7F deflectable, 4-mm tipped, quadrupolar catheter with 2-mm interelectrode spacing (Cordis Webster) was used for the
mapping and ablation procedures. Bipolar endocardial electrogams were filtered between 40 and 400 Hz and simultaneously recorded with the standard 12-lead electrocardiogram on a computerized 32-channel system (EP Lab, Quinton). For patients in sinus rhythm at the beginning of the procedure, incremental atrial pacing using a programmable stimulator (NEC-Sanei), with a rectangular stimulus pulse of 2-msec in duration at twice the diastolic threshold amplitude, was performed from the high right atrium or proximal coronary sinus to induce AFI.

**Catheter Ablation and Local Electrogram Monitoring**

Unmodulated 520-kHz RF current was delivered through a generator (Nova Flame, Inter Nova), and the energy was applied in either the power mode (20–50 W for 60–120 sec) or the temperature-guided mode in which the power output was titrated to achieve a temperature of 60–70°C at the ablation site. During AFI, ablation was anatomically guided and directed along the line between the TA and the CSos, and in some patients, additionally along the line between the posterior margin of the CSos and the Eustachian ridge. Care was taken to locate a stable catheter position by assessing the stable local electrogram amplitudes. During each energy application, the local electrogram at the ablation site, current, and impedance were continuously monitored.

To clearly record the local electrogram at the ablation site during RF application, a specially designed filtering system was used. This filter was composed of 4 high-cut filters and 1 low-cut filter. The first high-cut filter attenuated the interference caused by the 520 kHz RF noise, and then all the noise with frequencies of 1 kHz or higher entering the recorder was rejected through the other 3 high-cut filters. The low-cut filter, which was located on the RF current delivery side, blocked the influx of current with frequencies of 1 kHz or higher coming from the endocardial electrogams to the generator. A previous study has shown that the local bipolar electrogram at the ablation site during RF application can be clearly recorded using this device. Although the unipolar technique would have the advantage of eliminating the contribution of viable myocardium around the ablation electrode to the local electrogram amplitude at the ablation site, the drawbacks are the inability to record an undisturbed discrete electrogram during RF energy delivery. Therefore, in the present study only the bipolar recordings from the distal electrode pair were used at the ablation site.

While monitoring the local electrogram through the ablation electrode, RF energy was first applied to the anatomical isthmus close to the TA during AFI. In 7 patients, ablation could not be performed during AFI, because of frequently occurring spontaneous terminations of AFI. In these cases, all energy applications were performed during atrial pacing from the proximal coronary sinus. When the local atrial electrogram amplitude decreased by greater than 50%, the application was considered to be effective. The ablation electrode was then moved to the next site toward the CSos after the local atrial electrogram had reached a steady-state amplitude. When the local atrial electrogram amplitude decreased by less than 50% despite a RF energy delivery of 10–20 sec during the steady-state phase of the local electrogram, the power output was gradually increased by 10 W increments up to 50 W and the application was then continued. When increasing the power output did not further decrease the amplitude of the local atrial electrogram, the ablation electrode was moved to another position. Radiofrequency applications were repeated until the AFI was terminated. The endpoint for the procedure was either the inability to reinduce common AFI by pacing or the creation of bidirectional conduction block at the anatomical isthmus. In the first 61 patients, we attempted to re-induce AFI by pacing. The stimulation protocol for AF induction included programmed stimulation (1–3 extrastimuli) or burst pacing (10–20 beats) at progressively shorter cycle lengths up to the lack of 1:1 atrial capture during isoproterenol infusion (0.5–4 μg/min). For the subsequent 10 patients, the pattern of the activation sequence in the right atrium was assessed additionally during pacing from both sides of the ablation site to obtain evidence of bidirectional block at the CSos-TA isthmus after the final RF application.

**Follow-up**

All patients were monitored for 1–2 days after the procedure. They were discharged without antiarrhythmic drug therapy and underwent close follow-up both by us and by their own physicians. In 53 of the 71 patients, a late electrophysiological study was performed 3 months after ablation.

**Statistical Analysis**

Continuous variables were expressed as mean ± SD. Comparisons between electrophysiological parameters were performed using the Student’s t-test, and the percent changes in the local atrial electrogram amplitude with application of RF energy were compared by repeated measures ANOVA. Fisher’s exact test was used to analyze the change in the local atrial electrogram amplitude with increasing power output. A value of p<0.05 was considered significant.

**Results**

The re-entrant circuit of AFI was interrupted and rendered noninducible in 69 patients (97%) by RF energy delivery. Extending the ablation line to the Eustachian ridge was required to eliminate the AFI in 8 patients. The total energy of RF delivery per session was 1800–10,5150 J (mean 19,547±20,053 J). The number of RF applications per session was 2–43 (mean, 8.8±7.0). In 2 patients, AFI could not be interrupted despite 32 and 43 RF energy applications, respectively. They underwent a second session with successful ablation of AFI. There were no complications in any of the cases. Clinical and electrophysiological variables for the 71 patients are shown in Table 1.

**Local Electrogram During Radiofrequency Application**

It was possible to record the local electrogram at the ablation site during RF energy application in all sessions. After the onset of the RF energy application, the local atrial electrogram amplitude at the ablation site decreased exponentially, and with increasing duration of the RF delivery it reached a steady state (Fig 1). Relatively sharp deflections of the target site electrograms appeared to be a characteristic that correlated with a rapid decrease in the amplitude of the electrogram during RF energy application. When the catheter had poor endocardial contact and the local atrial electrogram amplitude at the ablation site was unstable, the decrease in the amplitude was less than 50%. Further, with a relatively short duration of RF energy delivery, the amplitude of local electrogram gradually increased after the...
cessation of the RF energy application (Fig 2). There was no measured changes in impedance for RF energy applications associated with the termination of AFl. Abrupt rises in the impedance, when observed, always occurred during the steady-state phase of the local electrogram with the application of RF energy.

**Local Electrogram and Termination of AFl**

In 64 of the 71 patients, ablation was performed during AFl and termination of AFl was noted during 68 of 625 applications of RF energy. The decrease in the amplitude associated with the termination of AFl was measured for these applications. The mean time to AFl termination was 25±20 sec (range, 3–79 sec). The mean duration of reaching steady-state electrograms was 17±3 sec (Fig 3). The average baseline amplitude of the local atrial electrogram measured at the successful ablation sites was 1.04±0.47 mV (range, 0.4–2.3 mV) and the amplitude just before the termination of AFl was 0.30±0.12 mV (range, 0.10–0.50 mV) (Table 2). The average decrease in the amplitude at successful ablation sites was 67±13% (range, 40–92, %).

Applications that resulted in large decreases in the amplitude of the local atrial electrogram, associated with termination of AFl, tended to take longer, but there was no significant correlation between the percent-decrease in the amplitude of the local atrial electrogram and the duration of RF delivery (R=0.34, p=NS). Moreover, the duration between the onset of the steady-state electrogram and the termination of AFl varied considerably.

There was no significant difference in the decrease in the amplitude between the 20, 30, and 40 W outputs (0.43±0.23 (57±39%), 0.46±0.17 (65±9%), 0.58±0.39 (71±11%) mV, respectively; p=NS), and the power output did not predict the degree of amplitude decrease. However, at each individual site in 16 patients in whom an increase in the power output of RF energy had resulted in the termination of AFl, the amplitude decrease was larger (62±14% vs 60±16%, p=NS), and this difference was significant when compared to the data in Table 2.

### Table 1  Clinical and Electrophysiological Characteristics of 71 Patients

<table>
<thead>
<tr>
<th>Age, yrs</th>
<th>59±16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, M/F</td>
<td>53/18</td>
</tr>
<tr>
<td>Structural heart disease</td>
<td>17</td>
</tr>
<tr>
<td>Hypertensive heart disease</td>
<td>7</td>
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<tr>
<td>Coronary artery disease</td>
<td>5</td>
</tr>
<tr>
<td>Valvular heart disease</td>
<td>3</td>
</tr>
<tr>
<td>Dilated cardiomyopathy</td>
<td>1</td>
</tr>
<tr>
<td>Ebstein's anomaly</td>
<td>1</td>
</tr>
<tr>
<td>Arrhythmia feature</td>
<td>8</td>
</tr>
<tr>
<td>Permanent AFl</td>
<td>8</td>
</tr>
<tr>
<td>Paroxysmal AFl</td>
<td>63</td>
</tr>
<tr>
<td>Paroxysmal atrial fibrillation</td>
<td>22</td>
</tr>
<tr>
<td>AFl cycle length, msec</td>
<td>223±29</td>
</tr>
</tbody>
</table>

Data presented are mean value ± SD or number of patients. AFl = atrial flutter; F = female; M = male.

### Table 2  Ablation Results

| No. of RF applications, n | 8.8±7.0 |
| Total RF energy, J | 19547±20053 |
| Time for AFl termination, sec | 25±20 |
| Atrial electrogram amplitude at final successful site, mV | 1.04±0.47 |
| Atrial electrogram amplitude just before termination of AFl, mV | 0.30±0.12 |
| Average decrease in the amplitude at successful ablation site, % | 67±13 |

Data presented are mean value ± SD. RF = radiofrequency.
there was a positive dose-response relationship between the applied power and the decrease in amplitude (Figs 4, 5).

A total of 50 RF energy applications were delivered with a thermistor catheter in 4 patients. The time of when the steady-state electrogram was reached was significantly later compared with that of the maximum temperature (18.4±5.0 vs 6.9±2.4 sec; p<0.01) (Fig 6).

Follow-up
During a mean follow-up period of 26.6±11.1 months (range, 9–48 months), recurrence of AFl was observed in 8 patients (11.3%). Five patients had episodes of AFl. The time to AFl recurrence was 2 weeks in 1 patient, 1 month in 2 patients, and within 3 months in 2 patients (mean, 1.6±1.1 months). The other 3 patients, although they were free from symptoms, had inducible AFl (Table 3). When AFl recurred, it had the same configuration in all. Among the 10 patients who underwent assessment of the atrial activation sequence as an electrophysiological endpoint for the procedure, there was only 1 recurrence. All these patients underwent a second session without further recurrence. Thirteen patients (18.3%) had episodes of atrial fibrillation not previously documented (Table 3).

Discussion
Main Findings
This study demonstrates that the ablation of the atrial tissue at the anatomical isthmus for AFl is associated with a decrease in the amplitude of the local electrogram at the ablation site during application of RF energy. Local electrogram monitoring at the ablation site during RF energy delivery to the CSos-TA isthmus revealed the following: (1) the local electrogram amplitude at the ablation site decreases exponentially to reach a steady state and the steady-state time was 17±3 sec at final successful sites; (2) the average decrease in the amplitude of the local atrial electrogram at all successful ablation sites was 67±13%, and the amplitude of the attenuated steady-state electrogram was 0.5 mV; (3) power output does not predict the magnitude of the amplitude decrease; (4) at each individual site, however, there is a dose-response relationship between the power and amplitude decrease; (5) the local electrogram amplitude continued to decrease after the temperature reached a steady state; and (6) a short duration of RF application or an unstable local electrogram permits a gradual increase in amplitude after the cessation of the pulse. These findings suggest that changes in the local atrial electrogram amplitude at the ablation site during RF ablation may be some sort of marker for the efficacy of
tissue heating, and may be, at least in part, caused by lesion formation.

Comparison With Previous Studies

Few previous studies have investigated the myocardial electrophysiological effects of hyperthermia. Nath et al reported a heat-induced reversible decrease in the action potential amplitude that was linearly proportional to the increase in temperature between 37.0 and 49.9°C when guinea pig right ventricular papillary muscles were exposed to hyperthermic effects. They suggested that changes in myocardial cellular electrophysiological properties caused by hyperthermia, including membrane depolarization and reversible and irreversible loss of cellular excitability, resulted in changes in the action potential amplitude.

Recent experimental studies have found that the local electrogram at the ablation site decreases in amplitude with increasing duration of RF energy delivery. The precise mechanism responsible for the change in the local electrogram amplitude remains speculative. However, the data in the present study demonstrated that premature interruption of the RF application permitted a gradual increase in the local electrogram amplitude after the cessation of the pulse. This phenomenon appears to reflect, in part, the temperature-dependent effects of heating on myocardial electrophysiological properties by RF energy delivery. In other words, the reversible changes in the local electrogram amplitude by RF delivery may be a result of a thermally mediated change in the myocardial electrophysiological properties. In addition, it was observed that the local electrogram amplitude continued to decrease after the temperature had reached a steady state, and the timing at which the steady-state electrogram was reached was significantly later compared with that of the maximum temperature.

Studies using canine thigh muscle preparations have shown that there is an intramural large temperature gradient near the ablation electrode during and after RF delivery. This tissue temperature profile mimics the observation seen with the changes in the local electrogram at the ablation site in the present study, which may be explained by the slower conductive heating characteristic of tissue at greater distances.

It has recently been demonstrated that the decrease in the local electrogram amplitude during atrial tissue ablation recorded from the ablating electrodes was highly specific and sensitive for the creation of atrial lesions. One clinical study reported that the mean atrial electrogram amplitude at the successful ablation site associated with termination of AFl was attenuated by RF application (from 0.87±0.56 mV to 0.45±0.48 mV). However, monitoring of the local electrogram during the RF application was not performed in that study, and concerns remain as to whether that decrease in the local electrogram amplitude associated with AFl interruption has any clinical implication.

Clinical Implications

The results of this study suggest that the time course of the lesion growth by RF energy delivery can be predicted. This may have potential implications for local electrogram monitoring during RF ablation. The decrease in local electrogram amplitude appears to represent a reliable marker of the efficiency of RF ablation and may be a useful endpoint for individual applications. This may explain why the recurrence rate was relatively low in the present study compared with the previous studies in which the local bidirectional conduction block was not used consistently as an endpoint for the procedure. Thus, local electrogram monitoring offers an optimal energy strategy in common AFl ablation and will assist the operator in adjusting the power output and RF delivery time. On the basis of the present study, it may be predicted that the attenuation of the local electrogram amplitude should be more than 60%, or the steady-state electrogram amplitude should be less than 0.5 mV, in order to achieve an efficacious ablative effect for AFl ablation.

 Conversely, local electrogram monitoring at the ablation site was also helpful in predicting the adequacy of elec-
trod-electrode coupling during the RF application. In this study, unstable catheter positioning or improper electrode-tissue coupling did not produce an adequate attenuation of the amplitude despite moderate power outputs, and the inadequate attenuation was reversible. If, at maximal power levels, adequate attenuation of the amplitude cannot be attained, the ablation catheter may need to be manipulated to obtain better electrode-tissue coupling. Criteria for an optimal energy strategy using local electrogram monitoring for common AFl ablation should be developed.

References