Radiofrequency Catheter Ablation of Atrial Tachycardia Under Navigation Using the EnSite Array

Sumito Narita, MD; Koji Miyamoto, MD; Takeshi Tsuchiya, MD; Yasutsugu Nagamoto, MD; Takanori Yamaguchi, MD

**Background:** Atrial tachycardia (AT) is sometimes difficult to eliminate by radiofrequency ablation (RFA), but the EnSite array (EA) visualizes the beat-to-beat virtual activation of any tachycardia.

**Methods and Results:** The 51 patients with 74 ATs (mean age 57±18 years, 28 males) undergoing EA-guided RFA were included; 14 patients had had previous open heart surgery and 5 had organic heart disease. RFA was performed at the AT focus for focal AT (n=48) with an endpoint of AT termination and subsequent non-inducibility. RFA was performed at a critical conducting pathway for reentrant AT (n=26) with creation of a block line in the critical reentry circuit. EA revealed that 57 ATs originated in the right atrium (77%) and 17 originated in the left atrium (23%); all but 1 were successfully eliminated. Fluoroscopic time was 19±11 min, the number of RFA applications was 8±7, and the radiofrequency energy was 10,711±12,655J. No complications were noted. All but 2 patients were free of any symptoms during a follow-up of 16±9 months.

**Conclusions:** EA-guided RFA is safe and effective for AT, irrespective of its mechanism, sustainability or origin, and regardless of underlying heart disease. *(Circ J 2010; 74: 59–65)*

**Key Words:** Atrial tachycardia; Catheter ablation; EnSite array

Atrial tachycardia (AT) accounts for approximately 5% of all supraventricular tachycardias. It is sometimes refractory to antiarrhythmic agents, and thus radiofrequency catheter ablation (RFCA) is usually chosen as the first-line therapy. AT is usually categorized as focal (FAT) or macroreentrant (MRAT), according to the mechanism responsible, and the strategy for RFCA needs to be adapted accordingly. Conventional fluoroscopy-guided AT ablation in conjunction with a pacing maneuver has had limited efficacy because it can be difficult to specifically identify the AT focus or to elucidate the entire reentrant circuit. An electroanatomical mapping system has been used to overcome the drawbacks of fluoroscopy-guided RFA for AT, but it still has shortcomings because AT is sometimes nonsustained, multifocal, its reentrant circuit easily changed, especially by a pacing maneuver, or hemodynamically unstable.

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The EnSite multielectrode array (EA), which was recently introduced in Japan, visualizes the beat-to-beat virtual activation of any tachycardia, irrespective of a right or left atrial origin. Recently, the EA has been used in the ablation of atrial fibrillation and other tachyarrhythmias. Notably, virtual beat-to-beat elucidation of AT activation accurately identifies the AT focus and elucidates the entire circuit of reentrant AT, even if the AT is multifocal, changes its reentrant circuit or is hemodynamically unstable. In the present study, we show how EA-guided RFCA works to eliminate AT.

**Methods**

**Patients**

Written informed consent was given by all 51 patients before the study. Consecutive patients (mean age 57±18 years, 28 males) undergoing AT ablation between April 2006 and December 2008 were included; 19 patients (37%) had underlying heart disease (UHD), including previous open heart surgery (OHS) in 14 and other organic heart disease in 5. Previous OHS was performed for atrial septal defect or atrioventricular septal defect in 8, valvular heart disease in 3, tetralogy of Fallot in 1, ischemic heart disease in 1, and resection of myxoma in 1. Other organic heart diseases were dilated cardiomyopathy in 2, hypertrophic cardiomyopathy in 1, cardiac sarcoidosis in 1, and tachycardia-induced cardiomyopathy in 1. Patients with common-type atrial flutter (cAFL) alone or those with AT during or after atrial fibrillation ablation were excluded, as were patients with a gigantic atrium because a site more than 4.0 cm from the center of the EA is unsuitable for activation analysis.7,8 All antiarrhythmic medi-
cations were discontinued more than 5 days before the study. No patients were being treated with amiodarone. Table 1 shows the patients' characteristics and their demographic data.

Electrophysiological Study and Ablation Procedure

Electrophysiological studies were performed in the fasting state. RFCA was performed under conscious sedation by intravenous administration of hydroxyzine pamoate (25–50 mg). A quadripolar electrode catheter was placed at the His bundle and 20-pole multi-electrode catheters were placed within the coronary sinus and the atrium of interest. These catheters were used to record the bipolar electrogram and to pace. RFCA was performed under navigation with the EA (version 3.2 in 33 patients; version 6.0J in 18 patients).

Noncontact Mapping

Details of the EA have been described previously. 6–17 In short, the EA (St Jude Medical, Minnetonka, MN, USA) consists of a multi-electrode array catheter and a custom-designed amplifier system connected to a Silicon Graphics workstation running specially designed system software. The system simultaneously reconstructs more than 3,300 virtual unipolar electrograms and displays them as 3D graphical images of the chamber of interest in isochronal or isopotential mode.

Mapping Procedure

Throughout the study, activated clotting time (ACT) was monitored every 30 min to maintain it between 200 and 300 s for the right atrium (RA) and 300–400 s for the left atrium (LA). If the ACT fell below these thresholds, an appropriate amount of heparin was injected. The EA was introduced into the RA or LA from the right femoral vein. In cases of left AT, the EA was always introduced into the LA by a standard Brockenbrough technique described previously.

RF energy (J)

AT elimination

Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>n</th>
<th>51 (28 males)</th>
</tr>
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<tbody>
<tr>
<td>Age</td>
<td>57±18 years</td>
</tr>
<tr>
<td>No. of AT</td>
<td>74 (1.45 per patient)</td>
</tr>
<tr>
<td>Right/Left AT</td>
<td>57/17</td>
</tr>
<tr>
<td>Focal AT/MRAT</td>
<td>48/26</td>
</tr>
<tr>
<td>NS-ATs</td>
<td>12 (16%)</td>
</tr>
<tr>
<td>Concomitant arrhythmia</td>
<td>23 (cAFL 19, AVNRT 3, AF 1)</td>
</tr>
<tr>
<td>UHD</td>
<td>19 patients (post OHS 14, DCM 2, HCM 1, Sar 1, TICM 1)</td>
</tr>
<tr>
<td>AT CL</td>
<td>34±100 ms</td>
</tr>
</tbody>
</table>

Table 2. Analysis of Parameters With Regard to RA/LA Origin, Mechanism and Sustenance of AT

<table>
<thead>
<tr>
<th>n</th>
<th>RA-MRAT</th>
<th>LA-MRAT</th>
<th>RF pulse (n)</th>
<th>RF energy (J)</th>
<th>Fluoroscopy (min)</th>
<th>AT elimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA-AT</td>
<td>57</td>
<td>37/20</td>
<td>36±100*</td>
<td>8±7</td>
<td>11,154±3,662</td>
<td>18±10</td>
</tr>
<tr>
<td>LA-AT</td>
<td>17</td>
<td>11/6</td>
<td>28±71</td>
<td>8±7</td>
<td>9,249±8,723</td>
<td>25±14</td>
</tr>
<tr>
<td>FAT</td>
<td>48</td>
<td>48/0</td>
<td>373±99**</td>
<td>7±5</td>
<td>7,026±7,988</td>
<td>15±8</td>
</tr>
<tr>
<td>MRAT</td>
<td>26</td>
<td>0/26</td>
<td>299±84</td>
<td>10±6</td>
<td>16,873±16,636**</td>
<td>27±13**</td>
</tr>
<tr>
<td>Sus-AT</td>
<td>62</td>
<td>34/28</td>
<td>334±99</td>
<td>9±7</td>
<td>11,569±13,554</td>
<td>20±12</td>
</tr>
<tr>
<td>NS-AT</td>
<td>12</td>
<td>11/1*</td>
<td>395±95*</td>
<td>7±5</td>
<td>6,348±4,614</td>
<td>17±9</td>
</tr>
</tbody>
</table>

RA, right atrium; LA, left atrium; FAT, focal AT; RF, radiofrequency; Sus-AT, sustained AT. Other abbreviations see in Table 1.

*Significantly higher than the counterparts (P<0.05). **Significantly higher than the counterparts (P<0.01).

Results

All FAT foci and MRAT circuits were clearly demonstrated by the EA. The virtual activation map of the EA revealed (LAA). Virtual activation mapping was performed during sinus rhythm and AT, sometimes in conjunction with a contact voltage map during sinus rhythm, which elucidates the AT substrate. If AT did not occur before virtual activation mapping, programmed stimulation and/or isoproterenol (ISP) injection was performed to induce it. Both FAT and MRAT were examined using a virtual activation map, and activation was further confirmed by the morphology of the virtual unipolar electrograms (VUE). In FAT, the focal discharge pattern was recognized as a centrifugal breakout fashion from an AT focus, which the VUE exhibited as a QS pattern. 15 In MRAT, the critical conducting pathway was elucidated using the virtual activation map. The pathway exit was also elucidated by the virtual activation map in which an rS pattern was demonstrated in the VUE. 31 In patients mapped with EnSite version 6.0J (n=18), contact bipolar voltage mapping was performed during sinus rhythm to identify the AT substrate. In some patients with reentrant AT, entrainment pacing was performed to confirm the reentrant circuit, taking care not to transform the AT into another pattern.

Ablation Procedure

In each patient, a 4- or an 8-mm tip steerable catheter (Fantasista, Japan Lifeline; Blazer II, Boston Scientific) was used to record bipolar electrograms, and to pace and ablate. RF energy was delivered in a temperature-controlled fashion with an upper limit of 50°C and 50W. The end point of RFCA for sustained AT was AT termination and subsequent non-inducibility for FAT, and non-inducibility for nonsustained AT. In patients with MRAT, creation of a block line on the critical conducting pathway was confirmed in addition to termination.

Post-Ablation Management and Follow-up

Immediately after AT ablation, all patients were examined for procedure-related complications using ECG and transthoracic echocardiography. Patients were followed up at 1 week, 1 month, and 3 months after the procedure and every 6 months thereafter, and Holter ECG monitoring was performed if the patient complained of any symptoms.

Statistical Analysis

Data are expressed as mean±SD. Data were analyzed by the unpaired t-test if they were normally distributed, otherwise a nonparametric Mann-Whitney test was used. The χ²-test was used to analyze the independence of the 2 classification criteria in the qualitative data. A P value <0.05 was considered statistically significant.

Table 1.

Table 2.

No patients were being treated with amiodarone. Table 1 shows the patients' characteristics and their demographic data.
**Figure 1.** Distribution of atrial tachycardias (ATs) originating from the right atrium (RA).

**Figure 2.** Representative cases of AT examined within the RA. Case 1: Focal AT (FAT) originating from the crista terminalis. Case 2: Macrocotrent atrial tachycardia (MRAT) rotating around the incisional scar. Case 3: FAT originating from the coronary sinus ostium. Case 4: FAT originating from the right atrial appendage (RAA). Case 5: FAT originating from the tricuspid annulus (isochronal map). Case 6: AT originating from the His bundle region. CT, crista terminalis; SVC, superior vena cava; IVC, inferior vena cava; SCAR, incisional scar; CS, coronary sinus; TV, tricuspid valve.
Figure 3. Distribution of ATs originating from the left atrium (LA).

Figure 4. Representative cases of AT examined within the LA. Case 1: FAT originating from the left atrial appendage (LAA). Case 2: FAT originating from left superior pulmonary vein. Case 3: FAT originating from the LA septum. Case 4: MRAT rotating around the anterior LA (isochronal map). Case 5: FAT originating from the posterior LA. RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein; LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; MV, mitral valve.
that 57 ATs originated in the RA (77%), with a focal mechanism in 37 and reentry in 20 ATs, whereas 17 ATs originated in the LA (23%), with a focal mechanism in 11 and reentry in 6. AT was sustained in 62 patients and nonsustained in 12 patients (Table 2). A total of 74 ATs and 23 other concomitant atrial tachyarrhythmias were identified using the EA. Concomitant arrhythmias were cAFL in 19 patients, atrioventricular nodal reentrant tachycardia in 3, and atrial fibrillation in 1.

**ATs Originating in the RA**

The EA revealed 37 FATs and 20 MRATs among 57 ATs from the RA. FAT foci were distributed along the crista terminalis (CT) in 13, the RA free wall in 9, the coronary sinus ostium in 6, the tricuspid annulus in 4, the right atrial appendage in 2, the superior vena cava in 2, and the intraatrial septum in 1 (Figure 1). The 20 reentrant RA-ATs included MRAT associated with an OHS in 13, MRAT associated with a non-operation-related RA scar in 3, MRAT related to the CT gap in 2, and reentrant AT originating from the His region in 2. The mean cycle length (CL) of these RA-ATs was 364±100 ms. All ATs were abolished by RFCA with a mean number of 8±7 RF pulses and RF energy of 11,154±13,662 J. RFCA was performed during AT in 49 and during sinus rhythm in 8 patients. Mean fluoroscopic time was 18±10 min. The success rate was 100% in this group (Table 2). Representative cases are shown in Figure 2.

**ATs Originating in the LA**

The EA revealed 11 FATs and 6 MRATs among 17 ATs from the LA. The 11 focal LA-ATs were distributed as follows: LAA in 4, right superior pulmonary vein (RSPV) in 3, LA septum in 2, mitral annulus in 1, and LA posterior wall in 1. Among the 6 reentrant LA-ATs, the reentrant AT was localized to the anterior AT in 2, peri-mitral reentry in 2, and reentry involving the LA roof in 2 (Figure 3). Some representative virtual activation patterns of ATs originating from the LA are shown in Figure 4. The mean CL was 284±71 ms and ATs were abolished with a mean number of 8±7 RF pulses and RF energy of 9,249±8,723 J. The fluoroscopic time was 25±14 min (Table 2). Figure 5 is a representative case of FAT originating from the left side of the intraatrial septum. The isopotential map of LA is shown. The FAT focus is shown as the center of the colored circle graded by the depth of negative deflection in the virtual unipolar electrograms (VUE). RAO, right anterior oblique view; LAO, left anterior oblique view.

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**Table 3. Comparison of Parameters Between Patients With UHD and Without**

<table>
<thead>
<tr>
<th></th>
<th>Patients with UHD (n=19)</th>
<th>Patients without UHD (n=32)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years old)</td>
<td>60±18</td>
<td>56±18</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>10/9</td>
<td>18/14</td>
<td>NS</td>
</tr>
<tr>
<td>Post OHS</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CL (ms)</td>
<td>339±96</td>
<td>350±100</td>
<td>NS</td>
</tr>
<tr>
<td>No. of AT</td>
<td>31 (1.55/patient)</td>
<td>43 (1.42/patient)</td>
<td>NS</td>
</tr>
<tr>
<td>FAT/MRAT</td>
<td>14/17</td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RF energy (J)</td>
<td>16,459±17,091</td>
<td>6,150±4,495</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>No. of RF</td>
<td>11±5</td>
<td>6±5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fluoroscopy (min)</td>
<td>23±13</td>
<td>17±9</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Abbreviations see in Tables 1,2.

*Significantly higher than the counterparts (P<0.05). **Significantly higher than the counterparts (P<0.01).
Comparison of AT in Different Subgroups

The mean tachycardia CL was longer in the RA-AT group than in the LA-AT group, but other parameters were similar between these 2 groups (Table 2). When comparing FAT and MRAT, the number of RF pulses, delivered RF energy, and fluoroscopic time were greater in the MRAT group, whereas tachycardia CL was longer in the FAT group. When comparing sustained and nonsustained AT, the percentage of FAT was higher in the nonsustained AT group (92% vs 55%).

Parameters were analyzed with regard to the presence or absence of UHD (Table 3). There was no significant difference in age, gender, CL or the number of ATs per patient. Energy and the number of RF applications were greater in patients with UHD, and the fluoroscopic time was longer. cAFL coexisted in 12 of 14 patients with previous OHS.

Success, Recurrence and Complications

EA-guided RFCA resulted in acute success in 50 of 51 cases (99%). The result was independent of whether the AT was sustained (n=62) or nonsustained (n=12), of RA (n=57) or LA origin (n=17), had a focal (n=48) or reentrant mechanism (n=26), or occurred in patients with UHD (n=20) or without UHD (n=31) (Tables 2, 3).

No cardiac tamponade, thromboembolism or valve/chordae injury were noted. All but 2 patients were free of any symptoms during a follow-up of 16±9 months (recurrence rate, 2.7%).

Discussion

Main Findings

EA-guided RFCA for AT was effective and safe, irrespective of UHD or the mechanism, sustainability and origin of the AT, with a success rate of 99% and a recurrence rate of 2.7%. We would like to stress that even in patients with multiple or nonsustained ATs, almost all ATs were eliminated, guided by the beat-to-beat virtual activation analysis.

Analysis of AT Activation and Results of RFCA

We took care to place the EA in an optimal position because placement is crucial for accurate analysis of the AT focus in FAT and for the critical conducting pathway of MRAT. A distance no greater than 4.0cm from the center of the EA to an endocardial site has been reported as the most important factor for reliable virtual activation analysis. Many OHS patients present with MRAT in which the reentrant circuit consists of a broad, low-voltage zone. In the low-voltage zone, the fractionated electrograms are recorded during sinus rhythm or AT. The resolution virtual activation map is limited to some extent in the low-voltage zone. In cases of reentrant circuit including such a low-voltage zone, we usually performed contact bipolar mapping initially to localize the low-voltage zone in an attempt to localize the AT substrate or potential reentrant circuits in the region, and then superimposed the virtual activation map on the contact substrate map to make interpretation of virtual activation analysis easier.

Comparison of ATs in the RA and LA

Kistler et al observed FATs from the RA more frequently than from the LA,18 which is consistent with our finding (37 vs 11, respectively). The AT foci were mainly distributed at preferential sites, such as the CT, coronary sinus ostium, tricuspid annulus in the RA, and near the pulmonary vein and LAA in the LA. The mechanism of FAT was not analyzed in detail in this study, and thus micro-reentry, abnormal automaticity, and triggered activity might have occurred.

Analyzing activation in the LA with the EA seems to be technically more difficult than in the RA, but accurate and clear elucidation of LA activation was achieved by locating the tip of the EA in the LAA in order to place the EA optimally at the center of the LA to cover the entire LA activation. LA-AT was not associated with scar in the present study, although Ouyang et al reported that some patients undergoing mitral valve operation may have an incision-related AT in the LA.19

Comparison of FAT and MRAT

In the present study, FATs comprised two-thirds of all ATs. When compared with MRATs, FATs have a longer CL and require fewer RF pulses and less energy. The reason for the difference in the AT CL is unclear; the difference in RFCA could be explained by the fact that a single application of RF energy to the AT focus may eliminate FAT, whereas creation of a block line was always needed to eliminate MRAT. We previously reported that in patients with previous OHS, the “corridor” of the MRAT circuit between the incisional scar and CT might be a good target for incisional AT.20

AT in Patients With UHD

In patients with UHD, more fluoroscopic time, RF energy, and RF pulses are required to eliminate AT than in idiopathic AT patients. In the present study, elucidation of the entire reentrant circuit of AT was achieved in most cases of MRAT associated with an incisional scar, which may be related to adequate placement of the EA, the combined use of contact voltage and virtual activation maps, and care taken to avoid the ventricular repolarization effect.

Concomitant Arrhythmia

In 19 patients, the targeted arrhythmia coexisted with cAFL, which is known to be induced frequently in patients with OHS (12 of 14 patients). Atrioventricular nodal reentrant tachycardia coexisted in 3 patients: FAT from the RA free wall, MRAT with post-atrial septal defect closure, and LA MRAT with dilated cardiomyopathy.

Strength of EA

The nonsustained form of AT is sometimes difficult to map by conventional fluoroscopy-guided or electroanatomical mapping because those methods need a certain amount of time to construct a satisfactory activation map. In addition, they are based on the assumption that all recording points are on the same activation pattern. Therefore, in nonsustained or polymorphic AT in which the activation pattern changes as the AT is sustained, those mapping methods do not contribute to the elucidation of the AT focus. Hoffmann et al reported that in 12% of patients, electroanatomical maps could not be constructed because of nonsustained or noninducible tachycardia.21

The EA provides a detailed picture of AT activation in a beat-to-beat fashion. In patients with nonsustained tachycardia or those who are hemodynamically fragile, the power of the “1-beat” analysis by the EA is worth emphasizing.

Shortcomings and Limitations of the EA

A unipolar electrogram represents both local and distant electrical activities despite the decreasing contribution to the amplitude of the electrogram with increasing distance, which indicates that the unipolar electrogram may be hampered by the large, remote electrical activity of depolarization or repo-
larization. Intrinsic deflection, however, is still a reliable marker for local activation. In the present study, we took care to avoid the effects of remote electrical activity by placing the EA catheter at a site closest to the FAT focus or possible critical channel of MRAT. In addition, patients with a gigantic atrium were excluded from the study because local activation at an endocardial site more than 4.0 cm from the center of the EA is inaccurate. Because ventricular depolarization/repolarization affects virtual activation mapping, analysis of AT activation was performed during a long R-R interval or after intravenous adenosine triphosphate injection to prolong the R-R interval.

EA has some shortcomings in analyzing the virtual activation of low-voltage zones, as mentioned before. It is also difficult to analyze the activation of tunnel-like structures such as the superior vena cava, coronary sinus, and pulmonary veins. The exit of activation from such structures can be analyzed by virtual activation mapping, and additional contact mapping is recommended for the analysis of the activation of these structures.

### Conclusion

EA-guided RFCA for AT elimination is safe and effective, irrespective of the mechanism, sustainability or origin of the AT, and regardless of the presence of UHD.

### Disclosure

Dr Tsuchiya has been a speaker and served as a consultant for Nihon Kohden and St Jude Medical.

### References

2. Tsai CF, Tai CT, Chen SA. Catheter ablation of atrial tachycardia. In: Cardiac electrophysiology from cell to bedside, 4th edn. Futura; 2004; 1060 – 1068.