Mapping of Focal Atrial Tachycardia With an Uninterpretable Activation Map After Extensive Atrial Ablation: Tricks and Tips
Weizhu Ju, Bing Yang, Hongwu Chen, Fengxiang Zhang, Kai Gu, Jinbo Yu, Mingfang Li, Gang Yang, Kejiang Cao and Minglong Chen

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For more than a decade, focal atrial tachycardias (ATs) have been effectively treated by catheter ablation. Generally speaking, focal ATs tend to occur in structurally normal hearts and to manifest a typical centrifugal activation pattern, with the total atrial activation time accounting for <50% of the tachycardia cycle length (TCL). However, in patients who have undergone previous ablation for atrial fibrillation (AF) or those with structural heart disease, focal ATs may have a heterogeneous anatomic distribution and coexisting scar substrate, which can add to difficulties in mapping. Previous extensive ablation and pre-existing substrate may significantly prolong the conduction time in the chamber, which in turn would alter the typical pattern of focal ATs seen with 3-dimensional (3D) mapping and make the diagnosis more difficult. In the present study, we aim to characterize the electrophysiological features of ATs in this unique setting and to delineate an effective mapping strategy further.

Methods

Study Population

From January 2009 to August 2013, there were 80 patients who underwent a second ablation procedure after AF ablation or ablation for ATs in the setting of structural heart disease (postatriotomy and valvular heart disease). In the 80 patients, a total of 146 ATs were mapped, in which 55 ATs were macroreentrant, the other 91 cases of ATs proved to be focal ATs (including microreentry and true focus). Among the 91 focal ATs, 78 cases of AT exhibited an unambiguous centrifugal activation map in the 3D mapping and were successfully ablated at the original site, whereas the other 13 cases of AT (in 13 patients) demonstrated an undistinguishable map not ready to be interpreted. Thus, the 13 patients were included (8 men; average age, 59±7 years) in the study. Among them, 9 cases were encountered in the context of ablation for recurrent AF and the other 4 were cases for recurrent AT originating from the right atrium. The IACT was determined after resetting the annotation. All ATs were successfully eliminated at the originating site.

Conclusions

We delineated a series of focal ATs in the setting of a significantly prolonged IACT encountered in patients after previous extensive ablation. Two activation patterns were identified, which may help facilitate the mapping of focal ATs in this setting. (Circ Arrhythm Electrophysiol. 2014;7:598-604.)

Key Words: atrial ectopic tachycardia ■ focus ■ mapping ■ reentry

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From the Department of Cardiology, The First Affiliated Hospital of Nanjing, Medical University, Nanjing, China.

*Drs Ju and Yang contributed equally to this work.

Correspondence to Minglong Chen, MD, The First Affiliated Hospital of Nanjing Medical University, Guangzhou Rd, Nanjing 210029, China. E-mail chenminglong@njmu.edu.cn

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advanced into the high right atrium and coronary sinus via the left femoral and left subclavian veins, respectively. Data were recorded with a Prucka system (Prucka Cardiolab EP; GE Healthcare, Milwaukee, WI) or BARD system (BARD), and filtered at 30 to 400 Hz, and 0.05 to 500 Hz for intracardiac electrograms and surface electrogram recordings, respectively.

**Three-Dimensional Activation Mapping**

Three-dimensional activation mapping was performed to identify the origin of ATs and to delineate the activation pattern of the tachycardia using the CARTO (Biosense-Webster Inc., Diamond Bar, CA) or EnSite NavX/Velocity (Endocardial Solutions, Inc, Minneapolis, MN) systems. Typically, a coronary sinus atrial electrogram was used as the reference signal. For each AT, the beginning of the mapping window of interest (WOI) was set to be 50 to 70 ms earlier than the onset of P wave, allowing the local activation time of the assumed origin or mid-diastolic isthmus to be allocated within the beginning of the WOI. In cases where the onset of the P wave could not be clearly distinguished, the WOI was set to make the reference signal located at the middle of the interval. The duration of the WOI was set to be 10 to 20 ms less than the TCL. In general, 100 to 200 points (in CARTO system) or 200 to 300 points (in EnSite system) were collected to reconstruct the geometry of the atrial chamber and to delineate the AT mechanism. Sites with the voltage of ≥0.05 mV were defined as electric silence and displayed in gray color. For each point sampled by the system, an automated algorithm was used to annotate the potential. In general, the maximum dv/dt part of the signal was annotated in EnSite NavX/Velocity system, whereas the down slope algorithm was applied to annotate the electrogram when CARTO was used. The manual adjusting was necessary in the case that the catheter-induced premature beat or far field ventricular potential was sampled.

**Analysis, Validation of ATs, and Reseting of the Activation Map**

In general, for cases of macroreentrant AT, the total activation time would span the entire WOI, and the phenomenon of early meets late would be observed on the map. Meanwhile, a focal AT would reveal itself as a centrifugal source spreading radially, and consequently no early meets late area will be observed. In all subjects, a multisite mapping was performed to identify the origin of ATs and to delineate the activation pattern of the tachycardia.

**Catheter Ablation of the Focal ATs**

Radiofrequency energy was applied at the earliest activation site based on mapping using an irrigated ablation catheter (Navistar catheter; Biosense-Webster, Diamond Bar, CA, or IBI; St. Jude Medical, St Paul, MN) with a power of 30 W, temperature limit of 43°C and irrigation rate of 17 mL/min. The endpoint of the procedure was defined as termination of AT and noninducibility of sustained AT by programmed stimuli with or without isoproterenol infusion.

**Statistical Analysis**

Continuous variables were expressed as mean±SD or median (range).

**Results**

**Patient Characteristics**

Patient characteristics are provided in the Table. The mean age of the patients was 59±7 years. The mean left atrial size was 43±3 mm and mean left ventricular ejection fraction was 61±2%. Four patients had documented hypertension, including 1 subject with previous inferior wall myocardial infarction. Two patients had undergone previous surgical atriotomy.

**Table. Clinical Characteristics of Patients With Focal Atrial Tachycardias and Prolonged Intra-atrial Conduction Time**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age, y</th>
<th>LAD, mm</th>
<th>Context</th>
<th>Index Ablation</th>
<th>TCL, ms</th>
<th>WOI, ms</th>
<th>IACT, ms</th>
<th>% IACT/ WOI</th>
<th>Location of l</th>
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<tbody>
<tr>
<td>1</td>
<td>F 58</td>
<td>41</td>
<td>CAF</td>
<td>CPVI, R, A</td>
<td>266</td>
<td>256</td>
<td>260</td>
<td>1.02</td>
<td>Anterior wall of LA</td>
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<tr>
<td>2</td>
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<td>38</td>
<td>CAF</td>
<td>CPVI, R, P</td>
<td>253</td>
<td>243</td>
<td>313</td>
<td>1.29</td>
<td>Septum of LA</td>
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<tr>
<td>3</td>
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<td>40</td>
<td>aAFL</td>
<td>CTI, F</td>
<td>274</td>
<td>264</td>
<td>284</td>
<td>1.08</td>
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<tr>
<td>4</td>
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<td>46</td>
<td>CAF</td>
<td>CPVI, R, A, P, S, CFAE</td>
<td>450</td>
<td>440</td>
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<td>0.88</td>
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<tr>
<td>5</td>
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<td>CPVI, R, A, P, S, CFAE</td>
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<td>344</td>
<td>1.19</td>
<td>Posterior wall of LA</td>
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<tr>
<td>6</td>
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<td>CAF</td>
<td>CPVI, R, M, CFAE</td>
<td>260</td>
<td>250</td>
<td>245</td>
<td>0.98</td>
<td>Ridge between LAA and LPV</td>
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<tr>
<td>7</td>
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<td>CAF</td>
<td>CPVI, A, S, CFAE</td>
<td>320</td>
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<tr>
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<td>CTI, F</td>
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<td>420</td>
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<tr>
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<td>CTI, F</td>
<td>290</td>
<td>275</td>
<td>285</td>
<td>1.04</td>
<td>Septum of RA</td>
</tr>
<tr>
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<td>CPVI, A</td>
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<td>190</td>
<td>235</td>
<td>1.24</td>
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<td>280</td>
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<tr>
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<tr>
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<td>CTI</td>
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<td>220</td>
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<tr>
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<td>CPVI, A</td>
<td>215</td>
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<td>215</td>
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</tr>
<tr>
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<td>47</td>
<td>aAFL</td>
<td>CTI</td>
<td>232</td>
<td>215</td>
<td>232</td>
<td>1.06</td>
<td>Posterior wall of LA</td>
</tr>
</tbody>
</table>

A indicates anterior wall; aAFL, atypical atrial flutter; CAF, continuous atrial fibrillation; CFAE, complex fractionated atrial electrogram; LAD, left atrial diameter; MI, mitral isthmus line; P, posterior wall; R, roof; RA, right atrial; S, left atrial septum; TCL, tachycardia cycle length; and WOI, window of interest.
one for mitral valve repair and another for atrial septal defect. The median duration of AF or AT symptoms was 18 months (range, 9–60 months). All patients had undergone ≥1 previous ablation procedure for AF or AT. The time from the previous index ablation procedure to the current procedure was 1 to 30 months.

Electrophysiological Characteristics

A total of 13 sustained ATs were mapped. The mean TCL was 296±70 ms (range, 209–450 ms). In the initial 3D activation map before reset, 2 types of activation pattern were identified, which were referred to as pseudo-macroreentry (4 cases) and chaotic activation (9 cases).

Figure 1. Shown is a 3-dimensional activation map of an atrial tachycardias focus located at the ridge between the left atrial appendage and the left pulmonary vein (case 7). Because of the previous mitral isthmus ablation and block, the map shows macroreentry rotating around the mitral annulus. However, the results of entrainment mapping demonstrated a centrifugal post pacing interval (PPI) response. An attempt of radiofrequency ablation terminated the tachycardia. A, Activation map and (B) voltage map (see Figure 3 for schematic diagram). MV indicates mitral valve; and TCL, tachycardia cycle length.

Figure 2. Three-dimensional activation map of a focal atrial tachycardia (AT; tachycardia cycle length [TCL], 305 ms; window of interest [WOI], 290 ms) located at the left atrial upper posterior wall with intra-atrial conduction time exceeding the WOI duration (case 5). A, Before resetting, the map shows a chaotic activation pattern not readily differentiated (left, modified posterior-anterior view; right, anterior-posterior view). Entrainment mapping at 3 different sites located at distinct segments of the atrium showed a centrifugal post pacing interval (PPI) response at the posterior wall. B, Based on entrainment mapping, the AT was assumed to have a focal origination from the posterior wall. The latest activation was reset as the earliest activation in the WOI. Focal AT was revealed and was terminated by single radiofrequency energy delivery at the site of origin. Note the low-voltage areas on the roof, septum, and lateral wall, which may account for the significantly prolonged intra-atrial conduction time (344 ms; see Figure 4A for schematic diagram). MV indicates mitral valve; and TCL, tachycardia cycle length.
As the name suggests, a pseudo-macroreentry pattern demonstrated a focus mimicking as a macroreentry in the 3D map attributed to its early meets late activation pattern, which was found in 4 cases. An example of pseudo-macroreentry is shown in Figure 1. The map demonstrates a focus located at the ridge between the left pulmonary vein and the left atrial appendage. The patient had previously had circumferential pulmonary vein ablation plus mitral isthmus line lesions for persistent AF. Because of the block at the mitral isthmus line, the focus depolarizes the atrium in a unidirectional fashion rather than a centrifugal pattern, consequently mimicking macroreentry around the mitral annulus. Multisite entrainment along the mitral annulus also ruled out the possibility of macroreentry. Tachycardia was terminated by focal ablation at the site of origin, and the block of mitral isthmus line was subsequently demonstrated. In this pattern, the IACT/WOI ranges from 0.93 to 0.98.

A chaotic activation pattern was seen in 9 cases. In these cases, the map before resetting demonstrated a disorderly color arrangement, not readily differentiated as focal or macroreentrant. As shown Figure 2A, neither a centrifugal site of origin nor macroreentry was obvious before resetting the map. Entrainment mapping revealed a centrifugal PPI response at the posterior wall. Therefore, the tachycardia was assumed to be a focus originating from posterior wall. The latest activation part in the window of interest was reset as the earliest part, thus a focus originating from posterior wall was revealed, as depicted in Figure 2B. The IACT was determined after annotation reset, with IACT/WOI range from 1.02 to 1.29.

Ablation
All ATs were successfully eliminated by radiofrequency ablation at the site of origin.

Follow-Up
No complication in any of patients undergoing AT ablation was observed. After a median follow-up of 40 months (range, 5–51 months), all patients were free of tachycardia.

Discussion
The present study investigated the electrophysiological characteristics of focal ATs encountered in patients that have had previous extensive atrial ablation. In this situation, focal ATs may not be readily distinguished from other mechanisms based on 3D mapping because of significantly prolonged IACT. On the basis of the relationship between the duration of WOI and IACT, 2 types of activation patterns were identified, and the mapping strategy was further delineated.

In terms of left atrium, the IACT during sinus rhythm usually takes ≈75 to 82 ms in control normal hearts and 105 to 108 ms in persistent AF atria, based on our previously published data and other published reports. Meanwhile, the shortest TCL for ATs should be ≈200 ms. Taking these 2 factors into account, it may be safely concluded that during ATs, electric activity may only be recorded in only one half of the TCL. This may serve as one of the key points by which to differentiating the focal ATs and macroreentry. However, the rule would become invalid in an atrium with significantly prolonged conduction time, whether in the case of diseased atria delineated in a previous report or atria postextensive ablation as demonstrated in the present series.

The 2 types of activation patterns were identified in accordance with the relationship between IACT and duration of WOI. In the pseudo-macroreentry pattern, the IACT
approaches but does not exceed the WOI, with the focal AT always originating from the vicinity of an area of anatomic or functional block. This milieu allows for the residual part of atrium to be activated in a unidirectional pattern, with the contralateral part of the blocked region being the latest depolarized site. If the total activation time is >85% of the WOI duration, the 3D map may display the illusion of macroreentry (Figure 3). In the chaotic activation pattern, the IACT exceeds the WOI, making the annotation of the signal when compared with the reference difficult, which is critical for locating ATs. There may be 3 possible scenarios in this setting as demonstrated in Figure 4. The major difference among the types depends on the relationship between the WOI and true activation route of the focal AT. Figure 5 demonstrates a case of chaotic activation, which is in line with the B type of Figure 4.

When faced with this setting of focal ATs, we provide some useful tricks and tips to identify the site of origin in a straightforward way, which has proven to be efficient in our experience. First, standard entrainment mapping and substrate analysis may help to differentiate between macroreentry and focal or localized reentry in the localization of ATs. However, entrainment mapping may not be feasible because of either inability to capture the atrium or degeneration into another AT or AF. More importantly, neither entrainment mapping nor substrate analysis can localize focal ATs accurately. A resetting of the signal annotation based on the 2 patterns would make it possible as shown in Figure 4. We provided a solution in face of the mapping of ATs postextensive ablation in Figure 6.

**Clinical Implications**

The evolution of 3D electroanatomic mapping system has dramatically reduced the difficulty of mapping for complex tachycardia, as well as expanded the scope of clinically curable arrhythmias by catheter ablation. By projecting the activation time when compared with a selected electric signal reference on the 3D geometry of the mapped cardiac chamber point by point, the system allows intuitive review of the activation mode of the whole chamber through the various isochrones in a 3D fashion. However, the 3D system per se does not always accurately represent the mechanism of the tachycardia. The rigid interpretation of the map could

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**Figure 5.** Three-dimensional activation maps of a focal atrial tachycardia (AT; tachycardia cycle length [TCL], 267 ms; window of interest [WOI], 250 ms; case 12) located at the septal side of a previously ablated cavotricuspid isthmus. **A,** Before resetting, the map shows a chaotic activation pattern not readily differentiated. However, entrainment mapping raises the possibility of a focus located at the septum. **B,** On the basis of this assumption, we reset the annotation as shown in the figure from inside the window of interest (WOI) to outside the WOI (yellow arrow). A focal AT that activated the atrium with a counterclockwise rotation was revealed. At the end of procedure, the conduction time from coronary sinus ostium to low lateral right atrium was shown to be 328 ms. See Figure 4C for schematic diagram. PPI indicates post pacing interval.
lead to a false diagnosis, which may in turn result in a pro-
tracted and unsuccessful procedure. Generally speaking,
macroreentry always presents with continuous propagation
around a central obstacle, whereas a focal AT exhibits itself
as a focus spreading centrifugally. Nevertheless, settings,
such as those as delineated in the present series, would sub-
vert the rule. The present study raises the necessity to be
alert to this situation. Successful interpretation of the colors
in the map has important therapeutic implications.14,15

In clinical practice, the IACT exceeding 85% of TCL in
focal ATs is extremely rare in the setting of no previous atrial
ablation or surgery,10 but not uncommon in atria postexten-
sive ablation, especially when linear lesions were performed.
In this sense, linear lesions and defragmentation within the
atrium not only lead to iatrogenic arrhythmias but also result in
complex substrate complicating the mapping of ATs. To avoid
this situation, it is proposed that defragmentation in the atrial
body should be cautiously performed, and that the location
and course of linear lesions should be carefully designed.14,16

**Limitations**

The study cohort was relatively small and from a single center.
Furthermore, the patients were highly selected, and the actual
prevalence could not been determined. We also speculate that this
may be related to the degree of previous atrial ablation, and the
prevalence may consequently vary based on an individual center.

The true mechanism of the focal ATs remains to be
determined. Nevertheless, based on the stable entrainment
response, localized reentry may be the most likely mechanism
accounting for ATs in the present series, which is commonly
encountered in the context of previous AF ablation.15

At the end of procedure, the IACT during sinus rhythm was
not routinely investigated. It could not be determined whether
the prolonged conduction time was resulted from delayed
conduction during high-rate activation or preexisting slow
conduction or both.

**Conclusions**

We report 1 series of focal ATs in the unique milieu resulting
from extensive ablation in atrium body. The markedly pro-
longed IACT makes the mapping of focal ATs challenging.
Two activation patterns were identified and the correspond-
ning straightforward approaches were delineated to assist in
characterization of these ATs. Additional studies are needed to
explore the relationship between previous ablation strategies,
the degree of conduction time prolongation, and prevalence of
ATs in this particular setting.

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the article and have had full access to all the data in the study, and we
take full responsibility for the integrity of the data and the accuracy
of the data analysis.

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**Disclosures**

None.

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**Figure 6.** The flow chart for the mapping of atrial tachycardias encountered in the setting of previ-
ous extensive ablation. In the annotation resetting
of chaotic pattern, the principle is to set the acti-
vation of the region that demonstrates good post
pacing interval at the earliest part of the window
of interest.

### CLINICAL PERSPECTIVE

The evolution of radiofrequency catheter ablation has made most of the atrial tachycardias (AT) a kind of clinically curable disease. In the process, mapping the tachycardia to make the complete understanding of its mechanism feasible is of essential importance for the successful elimination of the arrhythmias. However, for ATs or other complex arrhythmias, placing more catheters is often insufficient to interpret the electrophysiological mechanisms accurately. Hence, the 3-dimensional (3D) mapping system developed. By combining the anatomic information with electric signals, the 3D map depicts the arrhythmic core of the tachycardia iteration: electroanatomic characterization and treatment. J Am Coll Cardiol. 2004;44:1071–1079.

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