Catheter Ablation of Typical Atrial Flutter
A Randomized Comparison of 2 Methods for Determining Complete Bidirectional Isthmus Block

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Background—Complete bidirectional isthmus conduction block (CBIB) was initially assessed by sequential detailed activation mapping at both sides of the ablation line during proximal coronary sinus and anteroinferior right atrium pacing. Mapping only the ablation line ("on-site" atrial potential analysis) was recently reported as a means of CBIB identification. The study was designed to compare these 2 techniques prospectively regarding the diagnosis of CBIB.

Methods and Results—In 76 consecutive patients (mean age, 63.4±10.5 years), typical atrial flutter ablation was performed using either the activation mapping technique (group I) or on-site atrial potential analysis (group II). Criteria for CBIB using on-site atrial potential analysis was the recording of parallel, widely spaced double atrial potentials along the ablation line. The CBIB criterion was retrospectively searched using the alternative technique at the end of the procedure. In successful patients, the mean radiofrequency delivery duration was longer in group II (845±776 versus 534±363 s; P=0.03). On-site, clear-cut, widely spaced double atrial potentials and activation mapping suggesting CBIB were concomitantly observed in only 47 patients (54%), and ambiguous/atypical double potentials were recorded in 31 patients (39%).

Conclusions—Although feasible, the on-site atrial potential analysis seemed to be inferior to the classic activation mapping technique, mainly because of the ambiguity of electrogram interpretation along the ablation line. However, when combined with the activation mapping technique, it provided additional information regarding isthmus conduction properties in some cases. Therefore, optimally, both methods should be used concomitantly. (Circulation. 2001;103: 1434-1439.)

Key Words: atrial flutter • catheter ablation • conduction

Over the past few decades, continuous improvement of intra-cardiac mapping techniques contributed to a better understanding of the typical atrial flutter (AF) circuit.1–4 Arrhythmia recurrences are now prevented by creating a radiofrequency (RF) linear lesion at the inferior vena cava–tricuspid annulus (IVC-TA) isthmus.5,6 Conduction properties of this critical isthmus were initially studied using sequential detailed activation mapping at both sides of the ablation line during pacing at the proximal coronary sinus (pCS) and anteroinferior right atrium (AIRA).7 This method (here called the activation mapping technique) allows fair differentiation between complete and incomplete isthmus conduction block,8 which is critical to ensure a good clinical outcome, because residual delayed isthmus conduction is associated with a high AF recurrence rate.6,8 It was recently reported that mapping only the ablation site (here called on-site atrial potential analysis) could also identify complete bidirectional isthmus conduction block (CBIB) if parallel, widely spaced, double atrial potentials (WSDP) were recorded all along the line during both AIRA and pCS pacing.9 The present study was thus designed to compare both methods of identifying CBIB prospectively.

Methods

Population
From September 1998 to March 2000, 76 consecutive patients (mean age, 63.4±10.5 years) suffering from recurrent (67%) and/or highly symptomatic (54%) AF with the IVC-TA isthmus being part of the tachycardia circuit, as demonstrated by entrainment maneuvers, were included in the study. All patients provided written, informed consent. The study protocol was approved by the hospital ethics committee. AF was present for a mean of 2.5±2.5 years, despite the use of 1.4±0.9 antiarrhythmic medications, including amiodarone, in 30 patients.

Ablation Procedure
Patients were studied in a postabsorptive state and after all antiarrhythmic drugs except amiodarone had been stopped for $\approx$5 half-lives. A multipolar Halo catheter (Irvine Biomedical Inc), with a distal dipole located close to the anterior lip of the ablation line, was used to record the right atrial activation sequence around the TA. (Figure 1). A multipolar catheter was inserted within the CS, with a proximal bipole located at its ostium. The ablation catheter with

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either a 4-mm (n=23) or 8-mm tip (n=53) was placed close to the ventricle within the isthmus. Stepwise withdrawal of the ablation catheter was performed during RF delivery.

The RF generator (Irvine Biomedical Inc) was preset to deliver 50 or 100 Watts while using a 4- or 8-mm tip ablation catheter, respectively, with a common target temperature of 70°C. During RF pulses, appropriate filters allowed on-site atrial potential analysis and movement of the ablation catheter according to atrial potential morphology. Initially or after AF termination and after each RF pulse, pacing was elicited from pCS and AIRA at a cycle length of 600 ms. Electrograms from all catheters were filtered between 30 and 250 Hz, recorded, and stored on a computerized, multichannel system (Prucka Engineering). The end point of the procedure was achievement of an atrial activation sequence suggesting CBIB, as assessed by the activation mapping technique. Procedural success was based on this criteria, which we considered for the purpose of end point definition as the reference method.

Randomization into 2 Groups
In group I, ablation was conducted using only the activation mapping technique to determine CBIB, as previously reported. Complete anteroposterior mapping of the ablation line using the ablation catheter was performed only at the end of the procedure.

In group II, ablation was conducted during AIRA pacing, and only atrial potentials were recorded along the ablation line and pCS electrograms and surface leads II and V1 were displayed. When WSDP were recorded along the full ablation line from TA to IVC, CBIB was said to be present, and electrograms from the Halo catheter were then visualized. Ablation was pursued if the atrial activation sequence suggested residual isthmus conduction.

A retrospective analysis of all pulses was performed by 2 experienced physicians (N.S. and F.A.) in a blinded fashion. Particular attention was paid to the presence or absence of concordance between local on-site recording of WSDP and atrial activation sequence at IVC-TA isthmus.

Definitions
The complete clockwise isthmus block pattern was defined as a purely craniocaudal atrial activation sequence along the Halo catheter during pCS pacing. The distal bipole of the Halo catheter should be depolarized later than more proximal bipoles. An incomplete clockwise isthmus block pattern was indicated by partial craniocaudal AIRA activation with atrial depolarization at the distal bipole of the Halo catheter recorded simultaneously or earlier than those recorded at one of the more proximal bipoles during pCS pacing.

A complete counterclockwise isthmus block pattern was defined as depolarization of the pCS area recorded later than that at the His bundle region during AIRA pacing. CBIB was indicated by an association of clockwise and counterclockwise isthmus block patterns.

WSDPs were defined as 2 distinct atrial potentials, separated by a clear isoelectric line. Positional pacing was indicated by pacing that was successively delivered at the pCS, posterior lip of the ablation line, and posteroinferior right atrial wall at the same cycle length (600 ms; Figure 1).

Statistical Analysis
Unpaired t tests, x^2 tests, and Fisher’s exact test were used to compare the 2 groups. For all tests, a 2-sided P < 0.05 was considered statistically significant. Results are expressed as mean±SD.

Results
Each group included 38 patients. No differences were found in relevant clinical data before ablation in the 2 groups (Table 1). CBIB was obtained in all group I patients. In 3 of the 38 group II patients, the ablation procedure failed, with absence of CBIB in 2 patients and achievement of only incomplete isthmus block in 1 patient. The use of both techniques for CBIB assessment did not lead to an increase in fluoroscopy time compared with a previous series using 1 technique only. In successful patients, procedure duration, x-ray exposure, and number of RF pulses were similar in the 2 groups. However, the mean total duration of RF delivery was longer when the recording of WSDP was used to guide the procedure (Table 2).

| TABLE 1. Patient Data Before Ablation |
|-------------------------------|-----------------|-----------------|-----|
|                               | Group I         | Group II        | P   |
| n                             | 38              | 38              | NS  |
| Age, y                        | 64±9            | 63±12           | NS  |
| Sex, male/female              | 32/6            | 33/5            | NS  |
| Heart disease, n              | 19              | 17              | NS  |
| No. of antiarrhythmic drugs   | 1.4±0.9         | 1.5±1.0         | NS  |
| Amiodarone, n                 | 18              | 11              | NS  |
| Associated atrial fibrillation,n | 14             | 10              | NS  |
| Ablation catheter tip (4/8 mm),n | 11/27          | 12/26           | NS  |
Group I

On-Line Analysis

In 4 patients, stabilizing the inferior portion of the Halo catheter close to the ablation line was difficult and required frequent repositioning during the procedure. In one of these patients, because of an inability to correctly position this catheter, ablation was performed using on-site recording (crossover of 1 patient). Perfect concordance between clockwise and counterclockwise isthmus block was observed in all patients.

In 7 patients, incomplete clockwise isthmus block pattern was observed. In 4 of these 7 patients, posterior lip pacing led to a greater spike-to-distal Halo atrial potential interval, therefore excluding residual isthmus conduction. In those particular patients, the spike-to-distal Halo atrial potential interval dramatically shortened during posteroinferior right atrial wall pacing (Figure 2). These observations were thought to be due to transverse conduction crossing the crista terminalis, and ablation was stopped. Conversely, in 3 patients, posterior lip pacing led to a shorter spike-to-distal Halo atrial potential interval, identifying the presence of residual isthmus conduction, and ablation was continued (Figure 3).

Retrospective Analysis

Concomitant with an activation mapping sequence suggesting CBIB, clear-cut WSDP were present in 24 patients (63%) (Figure 4). In the remaining patients (n=14; 37%), local atrial potentials were considered atypical (Figure 5 and Table 3).

In 2 patients, an incomplete isthmus block pattern was identified using activation mapping, although clear-cut WSDP were recorded by the ablation catheter. After subsequent RF pulses, CBIB was recorded, and the interval duration between the 2 atrial components of the WSDP further lengthened (Figure 1).

Group II

On-Line Analysis

Control of isthmus conduction properties using activation mapping was achieved after recording clear-cut WSDP in 20 patients. CBIB was confirmed in 17 of these patients (85%). In the remaining patients, ablation was pursued based on an analysis of activation mapping. In 17 patients, WSDP were considered atypical (Table 3), although they possibly corre-
lated with CBIB. This was confirmed using activation mapping and positional pacing in all patients except one. In another patient, atrial potentials recorded along the ablation line were so ambiguous that isthmus conduction properties could not be determined using this criteria, and ablation was continued after crossover. Overall, crossover to the activation mapping technique was required in 5 patients.

Retrospective Analysis
In 4 patients, 3.25±1.7 (range, 1 to 5) RF pulses (403±270 s) were delivered after the atrial activation sequence had shown CBIB. At that moment, on-site atrial electrogram analysis did not show WSDP. It was only later that WSDP were thought atypical but suggestive enough to correlate with CBIB. In another patient, although the atrial activation sequence recorded in the Halo catheter was that of complete clockwise block, a multicomponent potential was recorded close to the IVC. Subsequent RF delivery was followed by splitting this potential into 2 separate atrial components, without modification of the sequence of atrial activation in the Halo catheter during pCS pacing (Figure II).

Overall Population
Concordance between CBIB pattern using activation mapping and typical WSDP was observed in 41 patients (54%). In patients with clear-cut WSDP along the ablation line, the mean intervals between the 2 atrial components measured close to the TA were 138±39 ms (range, 80 to 239 ms) and 115±22 ms (range, 78 to 179 ms) during AIRA and pCS pacing, respectively. An interval <90 ms was recorded in only 2 patients with CBIB.

Positional Pacing and Transcrystal Conduction Capabilities
In the last 11 patients, positional pacing was systematically performed. Evidence for transverse conduction across the crista terminalis was found in 10 (91%). An incomplete clockwise isthmus block pattern was recorded in 4 of these 10 patients (40%), although posterior lip pacing excluded residual isthmus conduction (Figure 2).

Follow-Up
Over a mean follow-up of 9±6 months (range, 1 to 20 months), one successful group I patient had a recurrence of AF 3 months after the initial procedure. A subsequent reablation was successfully performed.

Discussion
This is the first study that prospectively compares, in a randomized fashion, 2 methods of analyzing the flutter isthmus conduction properties during AF ablation. Our results show that although recording WSDP along the ablation line can predict the achievement of CBIB, the analysis of on-site atrial potentials is often difficult. Concomitant observation of clear-cut WSDP and activation mapping suggesting CBIB was present in only 54% of the patients.

Comparison Between the 2 Techniques
Activation Mapping Technique
Because identifying CBIB using the activation mapping technique correlates with long-term success,8,11 this technique was chosen as the reference method. Correct positioning of the Halo catheter is a critical prerequisite to identify residual isthmus conduction. Difficulties in accurately positioning this catheter were encountered in 10% of the cases. Theoretically, very slow yet persistent conduction can be limited to the ablation line and, therefore, be misdiagnosed, despite optimal Halo placement. In only one group II patient, fractionated potentials were recorded posteriorly on the ablation line when the AIRA activation sequence during pCS pacing showed complete isthmus block. After the delivery of an additional RF pulse, WSDP were recorded without AIRA activation sequence modification. This can suggest local residual conduction confined to the ablation line10 or, more likely, ablation of a local dead-end pathway, because the spike-to-second component of the WSDP interval did not change after RF delivery (Figure II). Finally, the most difficult issue was the interpretation of incomplete clockwise isthmus conduction block patterns, which will be discussed later.

On-Site Atrial Potential Analysis
Double potentials separated with an isoelectric interval have been considered the result of local conduction block.12 This concept was first applied in patients in whom AF recurred after an initial successful ablation.9 Then, recording WSDP along the ablation line was proposed as a direct criterion for CBIB.10 In this study, several limitations appeared when

**TABLE 3. Distribution and Characterization of Atypical Double Potentials**

<table>
<thead>
<tr>
<th>Characterization</th>
<th>Group I</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-parallel DP (shorter close to IVC)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Multiple atrial components during AIRA pacing only</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Short interval duration between 2 atrial components</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Wide electrically silent area</td>
<td>...</td>
<td>5</td>
</tr>
</tbody>
</table>

Data are expressed as number of cases. DP indicates double potential.

*Several types of atypical DP could be observed in the same patient.
using this criteria. Although clear-cut WSDP were recorded in 58% of the cases, activation mapping suggested persistent isthmus conduction in 11% of them. One could hypothesize that the site of residual conduction was missed during ablation line mapping. However, it is a classic observation that 2 Hisian potentials separated by a flat isoelectric line are recorded, despite persistent atrioventricular conduction, in patients with advanced intra-Hisian conduction disturbances. By analogy, very slow conduction across the ablation line cannot totally be excluded, even in the presence of WSDP. Lack of correlation between the mere observance of WSDP and isthmus block was suggested in our earlier study of isthmus block description.

Recording clean-cut WSDP was often not possible, and double potentials were considered atypical in 31 patients. In extreme cases, this led to unnecessary RF delivery (4 cases). Misdiagnosis of CBIB is possible in the presence of a wide electrically silent area, unless the catheter is sequentially moved on the anterior side of the line, which is the equivalent of activation mapping. This phenomenon should be differentiated from residual small and fragmented atrial potentials by a high-quality recording system with a high-gain setting. Recording multiple atrial potentials during AIRA pacing and WSDP during pCS pacing suggests unidirectional residual conduction or the presence of a dead-end pathway connected to the anterior lip of the ablation line (Figure 5). Because of great interindividual variability, no minimal value of an interatrial potential interval duration above which one could consider the presence of CBIB highly likely has been reported in the literature. The lack of this cut-off value was one of the factors which made on-site atrial potential analysis difficult. Our results suggest that an interpotential interval <90 ms may indicate residual isthmus conduction.

### Isthmus Conduction Block and Transverse Conduction Across the Crista Terminalis

In early studies, the AIRA activation sequence was shown to result from 2 wavefronts during pCS pacing: one traveling clockwise through the IVC-TA isthmus and the other traveling counterclockwise around the TA. After isthmus block, the latter becomes predominant, giving rise to a purely counterclockwise AIRA activation sequence. This is valid only if a permanent line of conduction block is present posteriorly between the vena cava ostia. The crista terminalis was initially identified as the anatomical structure supporting posterior transverse conduction block during AF. Recent studies have shown that transverse conduction block at the crista terminalis was mainly functional and that the line of block may be at the posteromedial right atrium (sinus venosa region). In lower loop reentry, a recently described variant of AF, the circuit encircles the IVC and crosses the crista terminalis. Both transcristal conduction and/or residual isthmus conduction can therefore lead to the incomplete isthmus conduction pattern.

In our study, positional pacing allowed differentiation between both mechanisms without the need for concomitant crista terminalis mapping. Along with Arenal et al., we noticed that transcristal conduction was frequently observed at a pCS pacing cycle length of 600 ms. However, the incomplete clockwise isthmus block pattern related to it was seen in only 4 of 10 patients. The remote location of the CS ostium with regard to the ablation line and crista terminalis, as well as the conduction properties across the latter, certainly conditioned these observations. A pattern of incomplete clockwise isthmus block was observed in 16 patients, but residual isthmus conduction was identified in only half of them. This could explain the known lack of recurrence in some patients, despite apparent incomplete isthmus block at the end of the procedure.

### Limitations

For historical reasons, we have used the activation mapping technique for many years. Because on-site atrial potential analysis is rather new, a learning curve may be required. However, we performed the ablation procedure with the new technique in a pilot series of patients before starting the randomized study. Because on-site potential analysis required a precise analysis of limited areas along the ablation line, one could hypothesize that a 4-mm electrode would be more appropriate than an 8-mm electrode for atrial potential definition. However, we did not find any significant difference between either type of catheter in the ability to appropriately identify WSDP. Although the distal ablation dipole was displayed during the ablation procedure in group I, we did not use it to look for WSDP until the end of the procedure. The predictive value of CBIB achievement in the presence of WSDP was not calculated because the activation mapping technique could (although only rarely) misdiagnose residual isthmus conduction. Newly developed techniques for high-density mapping were not used to validate transverse conduction across the posterior wall of the right atrium. According to the methodology used in group II, Halo depolarization was visualized before ruling out fast transcristal conduction, which could theoretically artificially increase the number of pulses in this group. However, in patients who received unnecessary RF pulses, the atrial activation sequence was that of complete clockwise isthmus block, which does not suggest fast transcristal conduction.

### Clinical Implications

As was already reported, on-site atrial potential analysis is a feasible way to determine the presence of CBIB after RF ablation. However, it seemed to be more difficult to perform than the classic activation mapping technique, mainly because of its frequent difficulty in electrogram analysis. However, on-site atrial potential analysis brought additional information in some cases. We think that concomitant use of both techniques should improve specificity in the determination of CBIB. Even with the use of both techniques, a wrong diagnosis of incomplete isthmus block can still be made in the presence of fast transverse conduction across the crista terminalis. In this situation, positional pacing allowed differentiation between true incomplete clockwise isthmus block and CBIB with fast transcristal conduction.

### References


