Electromagnetic Versus Fluoroscopic Mapping of the Inferior Isthmus for Ablation of Typical Atrial Flutter
A Prospective Randomized Study

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Background—Radiofrequency catheter ablation within the tricuspid annulus–inferior caval vein isthmus can cure typical atrial flutter. The target for ablation, nonetheless, is relatively wide, and standard ablation procedures may require significant exposure to radiation.

Methods and Results—A total of 50 patients (mean age, 58±11 years) with typical atrial flutter were prospectively randomized to receive isthmus ablation using conventional fluoroscopy for catheter navigation (group I, n=24) or electromagnetic mapping (group II, n=26). Complete bidirectional isthmus block was verified with double potential mapping. If complete isthmus block could not be achieved after 20 radiofrequency pulses or 25 minutes of fluoroscopy, the patients were switched to the other group. Eight patients from group I (33%) but only 1 patient from group II (4%) were switched. Overall, complete isthmus block was achieved in 47 of 50 patients (94%). The overall fluoroscopy time, including the placement of the diagnostic catheters, was 22.0±6.3 minutes in group I and 3.9±1.5 minutes in group II (P<0.0001). The fluoroscopy time needed for isthmus mapping was 17.7±6.5 minutes in group I and 0.2±0.3 minutes in group II (P<0.0001).

Conclusions—Electromagnetic mapping during the induction of linear lesions for the ablation of atrial flutter permitted a highly significant reduction in exposure to fluoroscopy while maintaining high efficacy, and it allowed the time required for fluoroscopy to be reduced to levels anticipated for diagnostic electrophysiological studies. (Circulation. 2000;102:2082-2086.)

Key Words: catheter ablation ■ arrhythmia ■ atrial flutter ■ electrophysiology ■ mapping

Radiofrequency (RF) catheter ablation has been established as the treatment of first choice for symptomatic patients with accessory pathways and atroventricular node reentrant tachycardia with a favorable efficacy risk profile.1–4 Within the last few years, the indications for catheter ablation were extended to include atrial flutter. Catheter mapping studies have demonstrated that a common myocardial isthmus between the tricuspid annulus (TA) and the inferior caval vein (ICV) is an integral part of the circuit.5–8 Linear lesions induced with RF catheter ablation have cured the arrhythmia by producing an electrically insulated barrier within this “inferior isthmus.”7,9–14 The target for ablation, nonetheless, is relatively wide and variable. Because of this, standard ablation procedures may be time-consuming and may require significant exposure to the radiation that is used for the orientation and manipulation of the catheters within the target area. Concerns regarding the risks to patients from radiation associated with conventional RF catheter ablation for supraventricular tachycardia have been stressed.15

Recently, a novel method for electromagnetic catheter-based nonfluoroscopic mapping of the heart was introduced.16 Experimental and first clinical studies indicated that the results obtained using this system were accurate and reproducible.17–19 This electromagnetic system might be especially useful for mapping an anatomically defined target area (ie, the inferior isthmus). In the present clinical study, the impact of electromagnetic isthmus mapping on total fluoroscopy exposure was compared with conventional fluoroscopic mapping in patients with typical atrial flutter in a prospective, randomized fashion.

Methods

Study Patients
A total of 50 consecutive patients (40 men and 10 women; mean age 58±11 years; Table) with isthmus-dependent counterclockwise or clockwise atrial flutter were prospectively studied. In patients with clockwise flutter, concealed entrainment with post–pacing-interval measurements was performed to prove the isthmus-dependent nature of the arrhythmia. Indications for isthmus ablation were recurrent symptomatic tachycardias or hemodynamic concerns during atrial flutter.
Clinical Characteristics of the Study Patients

<table>
<thead>
<tr>
<th></th>
<th>Group I (n=24)</th>
<th>Group II (n=26)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>58.3±10.7</td>
<td>56.8±11.7</td>
<td>NS</td>
</tr>
<tr>
<td>Sex, male/female</td>
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<td>21/5</td>
<td>NS</td>
</tr>
<tr>
<td>Structural heart disease, n (%)</td>
<td>16 (66.7)</td>
<td>18 (69.2)</td>
<td>NS</td>
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<tr>
<td>Atrial flutter CL, ms</td>
<td>235±45</td>
<td>225±50</td>
<td>NS</td>
</tr>
<tr>
<td>Atrial enlargement on echocardiography, n (%)</td>
<td>11 (45.8)</td>
<td>13 (50)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Data are expressed as mean±SD or No. of patients. CL indicates cycle length.

RF Catheter Ablation

The electrophysiological study and ablation were performed with the patients in a fasting, nonsedated state, after having obtained written, informed consent. In all patients, multipolar electrode catheters were placed in the right ventricular apex and proximal coronary sinus under fluoroscopic guidance. Mapping the myocardial isthmus between the inferior aspect of the TA and the ICV was performed during pacing in the proximal coronary sinus with cycle lengths of 500 to 600 ms. In patients with sustained atrial flutter at the beginning of the mapping procedure, terminating the arrhythmia was done using multiple extrastimuli or high-rate overdrive pacing to restore sinus rhythm.

All patients were randomly assigned to undergo isthmus ablation with conventional fluoroscopic isthmus mapping (group I, n = 24) or electromagnetic (Carto, BiosenseWebster) isthmus mapping (group II, n = 26). In both groups, RF energy was delivered sequentially with the 4-mm tip electrode of a deflectable 7-French catheter (Navistar, BiosenseWebster). The preselected temperature at the tip of the catheter was 60°C to 70°C, and the pulse duration was 60 to 90 seconds. The ablation catheter was not withdrawn during the individual applications of energy. Complete bidirectional isthmus conduction block was verified with double-potential mapping during pacing from both sides of the lesion line.14 If complete isthmus block could not be achieved after 20 RF pulses or 25 minutes of fluoroscopy, the patients were switched to the other group.

Electromagnetic System

The electromagnetic mapping system consists of an external, ul- tralow emitter of a magnetic field, a set of 2 catheters with miniature magnetic field sensors, and a processing computer unit (Carto, BiosenseWebster).16-17

Electromagnetic Mapping

The ablation catheter was advanced into the right atrium under fluoroscopic guidance, and one specific point was acquired at the most inferior point of the TA. At that site, a small atrial potential and a larger ventricular potential were recorded. After having acquired this point, the mapping procedure was continued using the electromagnetic mapping system without fluoroscopy. The catheter was then slightly rotated to 2 additional points at the TA, 1.5 to 2 cm septally and laterally, respectively (Figures 1 and 2). Three points were then acquired at the mouth of the ICV; one was directly opposite to the inferior point of the TA, and the other 2 points were slightly lateral and medial (Figure 2). The 3 points at the TA were tagged with green dots, and the 3 points at the ICV with pink dots. In this way, the individual myocardial isthmus extension was clearly defined and could be depicted in the 3D space (“6-point reconstruction”). The sites of all RF pulses were annotated on the electroanatomical isthmus map (Figure 2). The “bottom” view (strictly caudal projection) was mainly used to manipulate the ablation catheter because lateral or septal displacement can be judged, as can the distance from the TA and ICV (Figures 1 and 2). Additional projections, like the right anterior oblique view, were used if necessary.

After inducing the first line of lesions, the isthmus was remapped to control for double potentials and conduction times. In cases of incomplete lesion lines, the ablation catheter was repositioned for precise localization of gaps, and RF energy was then specifically applied to the identified gaps.

Fluoroscopic Mapping

In the conventional fluoroscopic group, biplane fluoroscopy with right anterior oblique and left anterior oblique projections was used for orientation and manipulation of the ablation catheter during the mapping procedure. The fluoroscopy was continuous. During the individual energy applications, fluoroscopy was used continuously only when it was difficult to stabilize the ablation catheter. In cases of energy application with stable catheter positions, fluoroscopy was only used periodically to control catheter position.

After inducing the first line of lesions, the isthmus was remapped to control for double potentials and conduction times. In cases of incomplete lesion lines, gaps were identified and RF energy was then specifically applied to the identified gaps.

Figure 1. Methodological presentation of an electroanatomical map of complete right atrium during ongoing, typical, clockwise atrial flutter, with different projections, including the bottom (caudal) view, which was used for isthmus mapping in this study (note the head-and-eye icon for orientation). Points at TA were tagged green, and points at ICV were tagged pink. In caudal projections, inferior isthmus is indicated by white rectangle. White arrow in C indicates intended ablation line within the isthmus between most inferior aspect of the TA and the corresponding site at the mouth of the ICV. In the present study, only the inferior isthmus, and not entire right atrium, was mapped for ablation (see Figure 2). The colors in this example represent activation times (red indicates early; purple, late). SCV indicates superior caval vein; AP, anteroposterior.
Follow-Up
After hospital discharge, follow-up assessment was performed during periodic visits to the supervising cardiologist; assessments included 12-lead ECG and 24-hour Holter monitoring. In the event of atrial flutter recurrence, a repeat electrophysiological study and ablation were advised.

Statistical Analysis
Quantitative data were expressed as mean±SD. Statistical comparisons were performed using the Student’s t test, Mann Whitney U test, or $\chi^2$ analysis as appropriate. $P<0.05$ was considered statistically significant.

Results
General Ablation Results
In 8 patients from group I (33%), a switch to electromagnetic mapping was performed after 20 RF pulses ($n=1$) or after 25 minutes of fluoroscopy ($n=7$) without achievement of isthmus conduction block, whereas in only 1 patient from group II (4%) was a switch to conventional fluoroscopic mapping performed. Thus, the success rate for complete isthmus conduction block within the study limits of 20 RF pulses or 25 minutes of fluoroscopy were 67% in the fluoroscopic group and 96% in the electromagnetic group ($P<0.05$). In 6 of the 8 patients (75%) who switched from group I to group II, a complete isthmus conduction block could be achieved using the electromagnetic system for mapping. In the only patient who switched from group II to group I, a complete isthmus conduction block could not be achieved with conventional fluoroscopic mapping. Overall, complete bidirectional conduction block was achieved in 47 of the 50 study patients (94%). No procedure-related complications were observed in this study.

Fluoroscopy Times
The overall fluoroscopy time, including the placement of the diagnostic catheters, was $22.0±6.3$ minutes in group I and $3.9±1.5$ minutes in group II ($P<0.0001$). The fluoroscopy times needed for the placement of the diagnostic catheters were not significantly different between groups I and II ($4.3±1.6$ versus $3.7±1.4$ minutes; $P=NS$). The fluoroscopy time needed for isthmus mapping was $17.7±6.5$ minutes in group I and $0.2±0.3$ minutes in group II ($P<0.0001$). In 16 patients from group II (62%), the entire isthmus-mapping part of the ablation for typical atrial flutter was performed nonfluoroscopically. Overall, total fluoroscopy times and isthmus mapping fluoroscopy times were reduced in the electromagnetic mapping group by 82.3% and 99%, respec-
Fluoroscopy for Atrial Flutter Ablation

When using conventional RF ablation to cure typical atrial flutter, fluoroscopy in 1 or 2 planes is used to orient and navigate the catheter. In addition, fluoroscopy is often also used during the delivery of individual bursts of energy, especially when it is necessary to judge unstable or displaced positions of the catheter. This may lead to substantial exposure to fluoroscopy during isthmus ablation, even in experienced centers, with fluoroscopy times lasting from 31±10 minutes to 114±45 minutes, even in recent studies.\textsuperscript{10,13,20–24}

It might be anticipated that fluoroscopy exposure is even higher in low-volume centers.

In the present study, the overall fluoroscopy time, including the placement of the diagnostic catheters, was 22.0±6.3 minutes in group I (conventional fluoroscopic mapping) and 3.9±1.5 minutes in group II (electromagnetic mapping). However, 33% of the patients in group I switched to group II after 20 RF pulses or 25 minutes of fluoroscopy, and the ablation procedure was performed using the electromagnetic system. The highly significant difference in overall fluoroscopy exposure between the 2 groups in our study might thus be underestimated. In 62% of the patients in the electromagnetic mapping group, the entire isthmus-mapping part of the ablation for typical atrial flutter was performed nonfluoroscopically.

The positive significance of isthmus ablation in patients with atrial flutter on quality of life has recently been described.\textsuperscript{25} In addition, catheter ablation is curative in many patients, may obviate the need for long-term antiarrhythmic drug medication, and may be more cost effective in the long term than antiarrhythmic drug therapy. However, substantial fluoroscopy exposure, which is necessary for conventional isthmus ablation, carries the well-known inherent risks of radiation during long-term follow-up.\textsuperscript{15} Kovoor et al\textsuperscript{15} even concluded that the small risks of radiation-induced malignancy should be explained to patients undergoing procedures requiring prolonged fluoroscopy to ensure that they are fully informed of all potential risks. The significant reduction in radiation exposure that can be achieved with electromagnetic mapping for isthmus ablation in patients with atrial flutter may, therefore, have an impact on the long-term safety of this invasive treatment strategy.

New Developments in Isthmus Ablation

Jaïs et al\textsuperscript{26} described successful irrigated-tip catheter ablation of atrial flutter that is resistant to conventional RF catheter ablation. Although the exact reason for resistance to conventional RF energy application is unclear, it may be due to an unusually thick isthmus myocardium; saline irrigation of the ablation electrode produces larger and deeper lesions.\textsuperscript{27} Jaïs et al\textsuperscript{28} recently described a randomized comparison of irrigated-tip versus conventional-tip catheters for the ablation of common flutter and reported a significant reduction in fluoroscopy time with the irrigated-tip catheter (9±6 versus 18±14 minutes). Alternatively, a larger, 8-mm tip electrode can achieve larger lesion volumes compared with 4-mm tip electrodes; this may facilitate isthmus ablation in patients with atrial flutter.\textsuperscript{29}

Recently, Nakagawa and Jackman\textsuperscript{30} described their initial experience with using the electromagnetic mapping system to examine the global right atrial activation pattern in patients during atrial flutter. In their article, they concentrated on the methodological aspects of the electromagnetic system with respect to atrial flutter ablation.\textsuperscript{30} Shah et al\textsuperscript{31} performed high-density electromagnetic mapping of activation through an incomplete isthmus ablation line in 8 patients, with
recurrence of atrial flutter after previous catheter ablation. In the present study, only the area between the inferior aspect of the TA and the corresponding border toward the ICV (target-area mapping) was performed, in contrast to mapping an entire cardiac chamber (eg, the right atrium). This allows a clinically oriented approach toward direct isthmus ablation in patients with typical atrial flutter.

Conclusions
In this prospective, randomized study, total fluoroscopy times and isthmus mapping fluoroscopy times were reduced in the electromagnetic mapping group by 82.3% and 99%, respectively, compared with conventional fluoroscopic mapping in patients with typical atrial flutter undergoing isthmus ablation. In addition, overall procedure time was significantly shorter in the electromagnetic mapping group. A substantial reduction in exposure to radiation by using electromagnetic mapping may have an impact on the long-term safety of this invasive procedure that has widespread clinical application.

References
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