Effect of Isthmus Anatomy and Ablation Catheter on Radiofrequency Catheter Ablation of the Cavotricuspid Isthmus

Antoine Da Costa, MD; Emmanuel Faure, MD; Jérôme Thévenin, MD; Marc Messier, PhD; Samuel Bernard, RN; Kihel Abdel, RN; Christophe Robin, MD; Cécile Romeyer, MD; Karl Isaaz, MD, FESC

Background—Cavotricuspid isthmus (CTI) characteristics are rarely documented when comparing catheters in radiofrequency ablation (RFA) of atrial flutter (AFL). Our objectives were (1) to evaluate the impact of CTI morphology and length on ablation procedures and (2) to compare the efficacy of an 8-mm-tip catheter with an irrigated cooled-tip RFA in the subgroup presumed to be more difficult to treat (with a long CTI, >35 mm).

Methods and Results—Over a period of 17 months, 185 patients accepted the protocol and underwent an isthmogram in preparation for RFA. Groups were classified according to CTI length and CTI morphology. RFA was performed with an 8-mm-tip catheter for patients with a short CTI, ≤35 mm (n = 123), whereas randomization between an 8-mm-tip and a cooled-tip catheter applied to patients with a longer CTI, >35 mm (n = 62). For long CTI, 32 patients were assigned to an 8-mm catheter and 30 patients to the cooled-tip RFA ablation group. In this subset, RF application (18.2 ± 17 versus 19 ± 13 minutes) and x-ray exposure (20.8 ± 18 versus 18 ± 13 minutes) did not differ between the 8-mm-tip and the cooled-tip procedures. Number of applications (9.9 ± 11 versus 18.6 ± 15 minutes; P < 0.0001) and x-ray exposure (11.7 ± 11 versus 19.5 ± 16 minutes, P = 0.0001) differed significantly between patients with short and long CTIs. Patients with short and straight CTIs required 3 times fewer RFA applications and shorter x-ray exposure compared with other CTI morphologies (pouch-like recesses and concave characteristics).

Conclusions—The number of RF applications required for a complete isthmus block in long CTIs is not influenced by the choice between an 8-mm or cooled-tip catheter. Procedure parameters, however, are significantly influenced by CTI length and morphology. Pouch-like recesses and concave characteristics account for much longer ablation times at all CTI lengths. (Circulation. 2004;110:1030-1035.)

Key Words: atrial flutter • catheter ablation • angiography • structure

Radiofrequency catheter ablation (RFA) of the cavotricuspid isthmus—dependent atrial flutter1,2 (CTI-AFL) is the treatment of choice when its high efficacy is considered.3–6 Despite a high success rate, ablation of the CTI can be extremely difficult in some patients.7,8 The vast span seen in ablations (1 to 30 or more RF applications) must thus reflect phenomena as yet unqualified. Recent right atrial angiographic studies have demonstrated a highly variable isthmus anatomy with various configurations and topologies.9,10 These anatomic aspects seem to lead to more difficult ablation sessions10; one study correlated 100 isthmus anatomicies with number of applications and reached significance (P = 0.05 exactly), correlating median RF applications to concave isthmus. A smaller study with 40 patients reported a linear relationship between isthmus length and number of applications.11 Although irrigated and 8-mm-tip catheters were found to be more effective and as safe as conventional 4-mm-tip catheters for AFL-RFA,12,13 the studies comparing these were unfortunately not randomized or showed debatable results.14,15 There was thus a need for a prospective randomized comparison of the efficacy and safety of cooled-tip and 8-mm-tip catheters while considering the influence of CTI anatomy and length on ablation success.10,11 The aim of this prospective study was 2-fold, as follows: (1) to evaluate the impact of CTI morphology and length on AFL-RFA procedures and (2) to randomly compare the efficacy and safety of an 8-mm-tip catheter with those of an irrigated cooled-tip catheter for RFA in a subgroup of patients with presumably more difficult, >35-mm-long CTIs.
Methods

Study Population
The study was approved by the Institutional Research Board of the Saint-Etienne Hospital and by its Ethics Committee in October 2001. From November 2001 to April 2003, there were 219 consecutive symptomatic patients with counterclockwise, typical AFL referred for RFA who agreed to sign an informed consent. AFL was diagnosed when (1) the surface ECG showed flutter waves that were predominantly negative in leads II, III, and aVF and positive in lead V1, with a regular atrial rate between 240 and 340 bpm; (2) the intracardiac electrogram displayed the following activation sequence: high right atrium then low right atrium, a counterclockwise inferior vena cava (IVC)-tricuspid isthmus activation sequence followed by left atrial activation established with a dodecapolar lead; and (3) an isthmus participation in the arrhythmic circuit as demonstrated by entrainment maneuvers (concealed entrainment in the isthmus). Exclusion criteria were as follows: (1) absence of informed patient consent; (2) iodine contraindication (allergy, kidney failure with creatinine $\geq$150 $\mu$mol/L, or lithium treatment); (3) age $<$18 years; (4) inability to catheterize (vena caval clip); (5) AFL recurrence after a previous ablation session; and (6) pregnancy.

Over the 17-month inclusion period, 219 consecutive patients with AFL were considered eligible. Thirty-four patients were excluded, and the remaining 185 (32 women; 67 years old; range, 20 to 88 years) signed an informed consent and underwent an isthmogram in preparation for RFA.

Electrophysiological Testing, IVC–Tricuspid Isthmus Mapping, and AFL Ablation

Electrophysiological Study
Patients were taken off antiarrhythmic drugs for at least 5 half-lives (with the exception of amiodarone), then fasted to undergo an electrophysiological study. Two catheters were introduced through the right femoral vein into the right atrium. A 6F quadrupolar catheter with an interelectrode distance of 5 mm (Bard Electrophysiology) was advanced to the His-bundle position, then a dodecapolar catheter with a 5-mm bipolar separation (Bard) was positioned in the coronary sinus. The distal tip was placed in the coronary sinus ostium as electrodes 1,2 (H1). Electrodes 3,4 (H2), 5,6 (H3), and 7,8 (H4) were located close to the IVC–tricuspid isthmus, whereas electrodes 9,10 (H5) and 11,12 (H6) recorded the low and high right atrial activation, respectively. Surface ECGs (leads I, II, III, and V1) with a regular atrial rate between 240 and 340 bpm; (2) the intracardiac electrogram displayed the following activation sequence: high right atrium then low right atrium, a counterclockwise inferior vena cava (IVC)-tricuspid isthmus activation sequence followed by left atrial activation established with a dodecapolar lead; and (3) an isthmus participation in the arrhythmic circuit as demonstrated by entrainment maneuvers (concealed entrainment in the isthmus). Exclusion criteria were as follows: (1) absence of informed patient consent; (2) iodine contraindication (allergy, kidney failure with creatinine $\geq$150 $\mu$mol/L, or lithium treatment); (3) age $<$18 years; (4) inability to catheterize (vena caval clip); (5) AFL recurrence after a previous ablation session; and (6) pregnancy.

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Right Atrial Angiography
Biplane angiography was performed after mapping and shortly before RF energy delivery. An isthmogram was performed by positioning a SF pigtail catheter in the IVC just at the level of the splenic and hepatic veins.\textsuperscript{9,10} Contrast solution was injected during 3 to 5 seconds for a total of 50 cm$^3$ in each patient. The angiograms were digitally acquired, thus allowing replay and storage of right anterior oblique (RAO) frames as reference during the subsequent ablation. Measurements were calibrated by interelectrode spaces projecting perpendicular to the given cine view. The length of the CTI was obtained at 25° in the RAO projection between the IVC and the lower hinge point of the tricuspid valve (points A and B in Figure 1). CTI length measurements and morphology analysis were made on the latest atrial diastolic frame (confirmed by the opening of the tricuspid valve in the next frame). The perpendicular distance between the line connecting A and B and the deepest point of the isthmus was quantified. If a single injection did not allow a clear delineation of the CTI, the angiogram was repeated. Considering previous works,\textsuperscript{9,10} patient groups were classified by CTI length (short, $\leq$35 mm, or long, $>35$ mm) and further subdivided by CTI morphology as straight, concave, or presence of a pouch-like recess (Figures 1 and 2). The straight aspect was defined as a maximal distance between A and B, with an isthmus depth $\leq$2 mm. An independent operator performed all measurements and analyses (S.B.).

Catheter Ablation
Catheter randomization was performed (for long CTIs) after right atrial angiography. An RF current application (unmodulated, sine wave) was delivered in the unipolar mode between the distal ablation catheter tip and a cutaneous patch electrode placed over the left scapula with a maximal target temperature of 60°C for 60 seconds for conventional ablation (8-mm-tip catheter). RF delivery by the same operator (A.D.C.) was applied point-by-point and was started at the ventricular aspect of the tricuspid annulus when a stable
electrogram with a small atrial and large ventricular amplitude was observed. The catheter was withdrawn after each application, under fluoroscopic guidance, to produce a linear and continuous lesion until the IVC was reached. RF delivery was applied until a bidirectional isthmus block could be obtained. For all measurements, the filter was set at from 30 to 500 Hz.

An 8F quadripolar deflectable catheter with an 8-mm-tip electrode (Boston EP Technologies) was used for RFA in the group with short CTIs (≤35 mm), whereas patients with long CTIs, >35 mm, were randomly assigned to an 8-mm-tip thermocouple catheter with a power limit of 70 W and a target temperature of 60°C (Saint-Jude EP Technologies Livewire 8-mm-large curve-XLS, Daig Corp) or to ablation with an irrigated 5-mm-tip thermocouple catheter (Cordis-Biosense-Webster Thermocool-F-curve, Diamond Bar) with a temperature-controlled RFA delivery at a power limit of 40 W and a target temperature of 50°C applied for 60 seconds at each point. Saline (0.9%) was infused through the irrigated catheter with a Geini Imed pump (battery-powered to avoid 50-Hz line noise) at a rate of 17 mL/min during RFA delivery. Between applications, a flow rate of 3 mL/min was used to maintain patency.

When more than 30 RFA applications (cumulatively 1800 seconds) were unsuccessful, short CTIs switched to cooled-tip ablation, and long CTIs crossed over to the alternative catheter. The procedure end point was defined as a complete bidirectional isthmus block described elsewhere. Reversal of the right atrial depolarization sequence was established by a complete cavitricuspid map using a multipolar mapping catheter straddling the line of block and by recording widely separated local double potentials along the ablation line during atrial pacing. When signs of conduction block were observed during RF application with proximal coronary sinus pacing, 1 extra RF application lasting 1 minute was performed at that site. Pacing was performed at a cycle length of 600 ms from the proximal coronary sinus and the low lateral right atrium. The status of the bidirectional block was assessed continuously over the 30-minute period after bidirectional block occurrence. Thirty minutes after the bidirectional block was validated, all patients underwent a postablation control by burst pacing at cycle lengths as short as 180 ms. On occasion, conduction resumed after ablation, which reinitiated a complete RFA sequence until the bidirectional block could be observed again, resetting the 30-minute waiting period. A cumulative time of RF delivery was recorded, and fluoroscopy time was calculated as total fluoroscopy time used for catheter positioning and RFA, including time to proof of bidirectional block. Venous thromboses were systematically prevented by subcutaneous low-molecular-weight heparin for 7 days.

Follow-Up

After catheter ablation, all patients underwent continuous ECG monitoring for at least 24 hours before hospital discharge. Cumulative risk of atrial fibrillation was determined by outpatient follow-up and on recurring symptoms or palpitations. The outpatient follow-up was performed by the referring cardiologist and by the medical practitioner. ECGs were programmed at each consultation, at the end of follow-up, and on recurring symptoms.

Statistical Analysis

Summary values are given ±SD. The differences among groups were analyzed by ANOVA. A probability value of \( P<0.05 \) was accepted as statistically significant. The number of applications, procedure duration, and x-ray exposure were analyzed on an intention-to-treat basis. The mean follow-up for the entire population was evaluated by use of the Kaplan-Meier method and by the log-rank test.

Study Population

Patient characteristics are summarized in Table 1. Seventy-six patients (41%) had structural heart disease. Structural heart disease included 26 cases of ischemic cardiomyopathy (previous bypass surgery in 6), 25 of dilated cardiomyopathy, 2 of hypertrophic cardiomyopathy, 4 of right ventricular dysfunction caused by pulmonary hypertension, 2 of interatrial communication (1 with previous surgery), and 17 of valvular heart diseases: mitral regurgitation in 10 patients, aortic regurgitation in 3 patients, mild mitral stenosis with regurgitation in 2 patients, and aortic prostheses in 2 patients. Before ablation, 148 patients were on antiarrhythmic drugs (Vaughan Williams classification): class Ic (n=36), class III (n=100), class II (n=8), and class IV (n=7). At the beginning of the procedure, 133 patients were in AFL, 43 in sinus rhythm, and 9 in atrial fibrillation. Patients in sinus rhythm underwent burst pacing (coronary sinus or low right lateral
TABLE 1. Population Characteristics

<table>
<thead>
<tr>
<th>Study Population</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>67±11</td>
</tr>
<tr>
<td>Sex (% women)</td>
<td>32/185 (17.3%)</td>
</tr>
<tr>
<td>Structural heart disease</td>
<td>76/185 (41%)</td>
</tr>
<tr>
<td>History of previous atrial fibrillation</td>
<td>86/185 (46.5%)</td>
</tr>
<tr>
<td>Antiarrhythmic agent, previous AFL RF</td>
<td>148/185 (80%)</td>
</tr>
<tr>
<td>Oral anticoagulant agent, previous AFL RF</td>
<td>112/185 (60.5%)</td>
</tr>
<tr>
<td>Left atrial systolic diameter, mm</td>
<td>42.6±7</td>
</tr>
<tr>
<td>Left ventricular ejection fraction, %</td>
<td>58±12</td>
</tr>
<tr>
<td>Systolic pulmonary pressure, mm Hg</td>
<td>38±13</td>
</tr>
<tr>
<td>Inferior vena cava isthmus length, mm</td>
<td>32±6.6</td>
</tr>
<tr>
<td>No. of applications for validated RFA (&gt;30 min)*</td>
<td>12.8±13</td>
</tr>
<tr>
<td>X-ray exposure, min</td>
<td>14.3±13</td>
</tr>
<tr>
<td>Procedure duration, min</td>
<td>72±26</td>
</tr>
<tr>
<td>Antiarrhythmic drug after discharge</td>
<td>75/185 (40.5%)</td>
</tr>
<tr>
<td>Anticoagulant agent after discharge</td>
<td>92/185 (49.7%)</td>
</tr>
<tr>
<td>Oral anticoagulant agent</td>
<td>93/185 (50.3%)</td>
</tr>
</tbody>
</table>

*Successful RF ablation of atrial flutter is validated only when the bidirectional block is still present after a 30-minute waiting period.

TABLE 2. Angiographic Results and Ablation Measurements

<table>
<thead>
<tr>
<th>CTI Dimension</th>
<th>No. of Patients</th>
<th>RF Applications, min</th>
<th>X-Ray Exposure, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population, 32±6.6 mm, mean±SD</td>
<td>185</td>
<td>13±13</td>
<td>14±13</td>
</tr>
<tr>
<td>Type of CTI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short (&lt;35 mm)</td>
<td>123</td>
<td>10±11</td>
<td>12±11</td>
</tr>
<tr>
<td>Short, straight</td>
<td>83</td>
<td>6±5</td>
<td>8±6</td>
</tr>
<tr>
<td>Short, concave</td>
<td>24</td>
<td>17±14</td>
<td>17±13</td>
</tr>
<tr>
<td>Short, pouch-like recess</td>
<td>16</td>
<td>20±18</td>
<td>23±16</td>
</tr>
<tr>
<td>Long (&gt;35 mm)</td>
<td>62</td>
<td>19±15</td>
<td>20±16</td>
</tr>
<tr>
<td>Long, straight</td>
<td>25</td>
<td>17±15</td>
<td>19±20</td>
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<td>20</td>
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<td>20±14</td>
</tr>
<tr>
<td>Long, pouch-like recess</td>
<td>17</td>
<td>21±14</td>
<td>20±13</td>
</tr>
</tbody>
</table>

Atrial flutter at cycle lengths as short as 180 ms to obtain a flutter. The sinus rhythm was restored by electric cardioversion (internal or external) for patients in atrial fibrillation (n=9), and the decision to ablate was based on a documented ECG of typical AFL.

Angiographic and AFL Ablation Results
Angiographic analyses are summarized in Tables 2 and 3. Anatomic morphology was assessed: 108 patients had a straight CTI, 44 patients had a concave CTI with a mean depth of 5±2.9 mm (range, 2.6 to 11.7 mm), and 33 patients presented a pouch-like recess with a mean depth of 6.9±2.6 (range, 2.1 to 12.4 mm).

RFA results are summarized in Table 4. Bidirectional block was obtained in 99% of patients, with a mean RF application time of 12.8±13 minutes and mean fluoroscopic time of 14±13 minutes. There were 2 local significant procedure-related complications (2 false arterial femoral eurysms requiring surgical treatment). In patients with long CTI (n=62), 32 patients were randomly assigned to the 8-mm group and 30 patients to the cooled-tip RFA group.

Overall, the duration of applications (9.9±11 versus 18.6±15 minutes; P<0.0001) and x-ray exposure (11.7±11 versus 19.5±16 minutes; P=0.0001) differed significantly between patients with short and long CTI. Patients with short, straight CTI had significantly (P<0.05*) lower RFA applications and x-ray exposure compared with all other CTI morphologies: short, straight* (5.7±4.6 RF applications and 7.8±6 minutes x-ray; n=83); short, concave (17±14 and 17.5±13; n=24); short, pouch-like recess (20±18 and 23±16; n=16); long, straight (17±15 and 9±20; n=25); long-concave (19±16 and 19.5±14; n=20); and long, pouch-like recess (21±14 and 20±13; n=17).

Follow-Up
After a mean follow-up of 9.5±5 months, AFL recurred in 4 of 185 patients (2.2%), and a second successful ablation procedure was performed, obtaining a bidirectional isthmus conduction block (Table 4). One patient required a third RFA.

Discussion
Major Findings
This randomized study evidenced that cooled-tip and large-tip catheters are equally efficient and safe for ablation of AFL in patients presenting with long CTIs. Both techniques yield the same results in terms of procedure parameters and primary success rates as well as similar low arrhythmia recurrence rates. Both ablation techniques appear to be equally safe.

Both CTI length and isthmus characteristics such as conduction block (Table 4). One patient required a third RFA.
demonstrated that cooled-tip catheters seemed more effective and as safe as 8-mm-tip catheters.12–15 Thus, ablation of typical AFL with an irrigated-tip catheter was recently recommended as first-line therapy.22 Only 2 randomized studies demonstrated that both catheter techniques were equivalent, although several limitations were underlined.14,23

We hypothesized here that RFA lesions were expected to be deeper with a cooled-tip RFA catheter, and the large surface area of the 8-mm-tip catheter may provide a cooling effect that simulates what happens with a cooled-tip catheter. These 2 catheter techniques were thus applied to presumably difficult ablations, patients with long CTI (>35 mm). Results demonstrated equivalence in this subset of patients. An open-loop showerhead catheter was chosen here, whereas in 2 published studies, the catheter used was a closed-loop cooled-tip catheter; both studies arrived at similar results compared with 8-mm-tip catheters.14,23

Impact of Right Atrial Length and Anatomy for AFL RFA

Previous anatomic and angiographic reports studying human hearts have pointed to the anatomic variability of the isthmus, reporting an average width of 27±3.3 to 37±8 mm and different morphologies.9,10,24 In a landmark study, the authors revealed a highly variable isthmus anatomy and its impact to adjust the ablation tactic.10 The presence of a eustachian valve or concave isthmus was associated with statistically more RF applications, and the same trend was seen for patients with deep pouches.10

Our angiographic study, the largest on this subject, demonstrates that CTI morphology and CTI length affect RF procedures. Fewer RF applications and less x-ray exposure could be correlated with patients with short, straight CTIs.

Study Limitations

Right atrial angiography provides a guide to CTI anatomy but no detailed information regarding the thickness of the isth-
mus. Phased-array intracardiac echocardiography, a more recent technique, could better define the cavotricuspid isthmus anatomy and thickness. The randomization between 8-mm and irrigated catheters could have been applied to the entire patient population.

Conclusions

Irrigated and 8-mm-tip catheters are equally efficient in the ablation of long CTIs. Angiographic correlation of isthmus-dependent AFL with ablation reveals a significant correlation between number of RF applications and CTI morphology. Catheter assessments and comparisons should not be performed without precisely qualifying the target tissue morphology.

Disclosure

Dr Messier is an employee of the Medtronic Bakken Research Center BV, 5 Endepolsdomein, 6229 GW Maastricht, the Netherlands.

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