Catheter-Induced Linear Lesions in the Left Atrium in Patients With Atrial Fibrillation

An Electroanatomic Study

Sabine Ernst, MD, Feifan Ouyang, MD, Felix Löber, Matthias Antz, MD, Karl-Heinz Kuck, MD

Hamburg, Germany

OBJECTIVES

In this study using radiofrequency current and the electroanatomic mapping system CARTO, four line designs were tested in 84 patients suffering from drug-refractory atrial fibrillation (AFib).

BACKGROUND

Prevention of AFib by trigger elimination within the pulmonary veins (PVs) has been recently reported, but the success may be lesser in patients with chronic AFib or large atria requiring linear lesion deployment.

METHODS

Type A encircled the ostia of all four PVs with a connection to the mitral annulus (MA). In type B, three lines connected anatomic barriers. Type C encircled both septal and lateral PVs with connections between PVs and to the MA. Type D encircled PVs only. In the initial 12 patients (type D/1), line validation was performed without, and in 23 patients (type D/2) with, an additional catheter inside the encircled PVs.

RESULTS

The ability to achieve completeness of all intended lines was 5% in type A, 21% in type B, 29% in C, 66% in type D/1, and 61% in type D/2. This resulted in stable sinus rhythm in 19% (4/21 patients) in type A, 32% (6/19 patients) in type B, 50% (7/14 patients) in type C, 58% (7/12 patients) in type D/1, and 65% (15/23 patients) in type D/2, respectively, over a mean follow-up of 620 ± 376 days. Besides thromboembolic events (one stroke and one transient ischemic attack), total occlusion of a PV was a major complication in one patient, and acute tamponade in two patients.

CONCLUSIONS

Complete lesions in the left atrium were difficult to achieve using conventional radiofrequency current technology, but were associated with sinus rhythm in 74% of patients during long-term follow-up, whereas incomplete lesions led mostly to recurrences of AFib or gap-related atrial tachycardia. (J Am Coll Cardiol 2003;42:1271–82) © 2003 by the American College of Cardiology Foundation

Catheter ablation of atrial fibrillation (AFib) has been attempted by either elimination of the initiating trigger or by modifying the substrate for maintenance of the arrhythmia. Prevention of AFib by trigger elimination within the pulmonary veins (PVs) can be successful in up to 71% of patients (1–3). The success rate may be lower in patients with chronic AFib or large atria mostly due to extra-PV triggers that cannot be ablated during electrophysiological study. Therefore, substrate modification may be mandatory either as primary or as additional treatment after successful isolation of the PVs. We have recently shown that multiple linear lesions may be successfully deployed within the right atrium (RA), but do not prevent AFib episodes in the vast majority of patients (4).

Compartmentalization of the left atrium (LA) by surgically deployed linear lesions has prevented AFib episodes (5,6). Application of linear lesions within the LA by catheter techniques has been reported with variable success (7,8). In those reports, completeness of lines was not validated in detail. Thus, it was unclear whether AFib recurrences were due to incomplete lines or an inadequate line design. Furthermore, incomplete linear lesions predispose to gap-related tachycardia (AT) (9).

This paper presents four different line designs within the LA aiming at modification of the myocardial substrate for AFib and/or isolation of PVs in humans.

METHODS

Patient population. Between June 1997 and August 2000, a total of 84 patients (66 male; mean age, 58.3 ± 8.7 years) underwent primary catheter ablation for AFib in the LA. All patients suffered from either intermittent or chronic symptomatic (n = 15) AFib for a mean duration of 10 ± 8 years and were refractory to a median number of four antiarrhythmic agents (including amiodarone in 64 patients). A total of 46 patients had undergone previous ablation procedures that failed to change their arrhythmia: 34 patients an RA linear lesion ablation for AFib, three patients a PV isolation attempt using ultrasound energy, nine patients a bidirectional isthmus blockade for atrial flutter. All patients suffered from symptomatic AFib presenting with symptoms such as palpitations, dizziness, or presyncope despite antiarrhythmic treatment. The ethical committee in Freiburg, Germany, had approved the study.
protocol, and all patients gave their written consent. After exclusion of intracardiac thrombi by transesophageal echocardiography, patients were studied in a fasting state under continuous sedation.

Electrophysiologic study. Two standard catheters were positioned: a His bundle recording catheter (Parahis, Biosense Webster, Waterloo, Belgium) advanced via femoral vein access, as well as a multipolar catheter (A 20, Biosense Webster) advanced in the distal coronary sinus (CS) via the left subclavian vein. Subsequently, trans-septal access using a modified Brockenbrough technique was performed and either a single standard 8F sheath (SL1, DAIG, St. Jude Medical, Minnetonka, Minnesota) or a custom-made 11F double sheath system (Cordis Roden, Roden, the Netherlands) was advanced. Using this double-sheath technique (in nine patients of group A and B), the inner preformed sheath guides the catheter tip so that it is in parallel and not tangential orientation to the atrial wall and can be gently dragged along the intended line (10). In type D/2 ablation procedures, a double trans-septal puncture with two 8F sheaths was performed. After trans-septal puncture, activated clotting time was adjusted to 250 to 300 s by repeat intravenous Heparin bolus throughout the procedure. In addition, a continuous infusion with heparinized saline was connected to the trans-septal sheaths (flow rate 15 ml/h) to avoid thrombus formation or air embolism.

Three-dimensional mapping. The electroanatomic mapping system (CARTO) was used to reconstruct the LA, which has been previously described in detail (11). In brief, a 4-mm tip mapping and ablation catheter (NAVI-Star, Biosense Webster) was advanced to the LA via the trans-septal sheath. Mapping was performed during stable pacing conditions from the CS or from the RA septum. In case of AFib, sinus rhythm (SR) was restored by external cardioversion. If DC shock failed, intravenous flecainide (up to 1.5 mg/kg body weight, n = 12 patients) was administered and cardioversion repeated. After completion of the mapping, all endocardial potentials were manually annotated.

Ablation design. Type A consisted of two lines: a circular lesion, which incorporated all PV ostia and a connection from the encircling line (close to the inferior lateral PV) to the mitral annulus (MA) (Fig. 1A). This concept copies the “core” line of the surgical Maze procedure and interrupts by the lateral connection to the MA the potential macroreentry around the annulus.

Type B consisted of three lines: the first connecting the superior septal to the superior lateral PV (roof line), the second connecting the middle of the roof line to the anterior MA, and the third connecting the roof line towards the posterior MA leaving an intentional gap of 2 to 3 cm to allow activation of the LA appendage (Fig. 1B). This design investigates a pure substrate modification attempt without any trigger elimination by PV isolation.

Type C consisted of two encircling lines around the septal superior and inferior PV ostia as well as the lateral superior and inferior PV ostia, respectively. In addition, linear connections along the posterior wall between the two encircling lines and towards the lateral MA were deployed (Fig. 1C). This design combines both the PV isolation with the substrate modification attempt to interrupt potential reentry circuits between the PV segments and around the MA.

Type D, as type C without the connections between the PV encircling lines (Fig. 1D). After the experience of incomplete lesion deployment in type C, the connections were omitted to avoid iatrogenic gap-related tachycardia.

Ablation. The linear lesions were applied by moving the ablation catheter along the previously designed lines in temperature-controlled mode (maximum temperature 55°C, maximum duration of 180 s, maximum 50 W).

End point for radiofrequency current (RFC) delivery was either the total elimination of the local potential or a maximum of 180 s. In case of an impedance drop by >10 Ω, RFC energy was immediately stopped to prevent carbonization at the catheter tip.

Line validation. Validation was performed by conventional mapping criteria followed by a repeat three-dimensional reconstruction while pacing either from CS or RA septum.

In type A, complete lines lead to an isolation of the encircled area, as previously described (10). The electroanatomic activation map showed a sudden change from early to late activation along the ablation line and/or no potentials at all within the isolated area. Conduction gaps were identified by sites with single potentials and by local early activation (Fig. 2A).

In type B, completion of the anterior line was characterized by an abrupt change of the activation sequence recorded from the multipolar catheter placed distally in the CS while pacing from the RA septum (Fig. 2B). Furthermore, double potentials could be found along the lines when pacing from sites opposite to the ablation line: from RA septum for the anterior and posterior line and from the CS for the LA roof line. Accordingly, the electroanatomic map showed a sudden change of the local activation times.

In type C, isolation of the PV segments was defined by a decrease of local voltage amplitude of >70% within the isolated areas using the amplitude voltage feature of the

### Abbreviations and Acronyms

- AFib: atrial fibrillation
- AT: atrial tachycardia
- CS: coronary sinus
- LA: left atrium/atrial appendage
- LAA: left atrial appendage
- MA: mitral annulus
- PV: pulmonary vein
- RA: right atrium/atrial appendage
- RFC: radiofrequency current
- SR: sinus rhythm

Abbreviations and Acronyms

- AFib = atrial fibrillation
- AT = atrial tachycardia
- CS = coronary sinus
- LA = left atrium/atrial appendage
- LAA = left atrial appendage
- MA = mitral annulus
- PV = pulmonary vein
- RA = right atrium/atrial appendage
- RFC = radiofrequency current
- SR = sinus rhythm
CARTO system and a cut-off limit of 0.1 mV (12). Completion of the connecting lesions in type C was determined by pacing maneuvers from the proximal and distal CS while recording double potentials along the ablation lines (Fig. 2C).

In type D, two different approaches were used: in the initial 12 patients (type D/1), successful encircling of the PV segments was defined as in type C (Fig 2D). In the remaining 23 patients (type D/2), an additional catheter (ParaHis, Biosense Webster, Diamond Bar, California) was placed inside the respective PV before lesion deployment to demonstrate a PV spike potential on one or more bipolar

Figure 1. Intended line designs: anterior posterior projections of a mesh graph of the electroanatomic mapping system CARTO of an LA with the pulmonary veins (PV) and the trans-septal sheath depicted as colored tubes. Ablation lines are depicted by multiple red dots. (A) A long encircling line around all four PV ostia (roof line) and a connection to the lateral mitral annulus (MA). (B) Roof line between the right and left superior PV ostium. The anterior line connects the middle of the roof line to the superior MA; the posterior line aims at the inferior MA with an intentional gap of approximately 3 cm. (C) Two encircling lines around the ostia of the superior and inferior PVs on both the septal and lateral sides. Additional connections between the PV segments (posterior line), the lateral PV segment, and the MA. (D) Encircling lines around the PVs on both sides without additional connection lines.
Figure 2. Line validation (A) pulmonary artery (PA) projection of an activation map of the electroanatomic mapping system in the patient with a single persisting gap in the lateral aspect of the posterior line as depicted by the gradual change of colors at the site of the conduction gap. Complete lesions demonstrate double potential while constantly pacing from the coronary sinus (CS). Continued on next page.
Figure 2 Continued. (B) Comparison of the pre- and post-ablation activation map in a left anterior oblique projection for type B. The right-hand panel demonstrates the activation sequence along a multipolar catheter advanced in the distal CS while constantly pacing from the RA septal site. Please note the prolongation of the activation time after complete anterior line deployment in the distal CS electrodes. Continued on next page.
electrograms. Validation of the completeness of the encircling PV isolation line was demonstrated by loss or dissociation of the PV spikes (Fig. 2E).

**Definitions.** Lines were classified as being either complete, having a single or multiple conduction gaps.

Upon completion of the post-ablation maps, a manual contrast injection in the ostia of all PVs was performed after type C and D line deployment to exclude acute PV stenosis. **Follow-up.** All patients were initially followed on their previous antiarrhythmic medication that was continued throughout the ablation procedure. Anticoagulation was advised with warfarin (international normalized ratio 2 to 3), or with aspirin (300 mg per day) if the patient refused to take warfarin. One day after the procedure, a 12-lead electrocardiogram (ECG), transthoracic echocardiography, and a 24-h Holter recording were performed. These were repeated after one, three, and six months by the referring physicians or by the ablation center (where all data was collected and reviewed). In case of stable SR after three months, antiarrhythmic medication was discontinued. Pa-
Figure 2 Continued. (D) Comparison of voltage in the pre- and post-ablation maps in a posterior-anterior projection of the LA. The voltage is depicted according to the color spectrum shown in the right upper corner, ranging from low (<0.1 mV, red) to high-voltage (>1.5 mV, purple). Continued on next page.
Results

Procedural data. The 84 patients underwent a total of 107 procedures. The average procedure time was 8.4 ± 1.7 h from sheath insertion to sheath extraction. A mean duration of 33.3 ± 30.5 min of fluoroscopy was used, ranging from up to 145 min (Patient 8) in the first 10 procedures to as low as 7.1 min with increasing experience of the investigators. A mean number of 43.2 ± 15.3 radiofrequency applications were deployed (Table 1).

Validation of line completeness and results of follow-up. In type A, a mean number of 49.2 ± 15.7 RFC applications were delivered over a mean total line length of 202 ± 32 mm (185 ± 28 mm for the PV isolation segment) (Table 2, Fig. 3). Complete lines were achieved in a single patient (during the second ablation session). This resulted in the creation of a silent area in the posterior part of the LA (10). In a second patient, a single gap persisted despite multiple radiofrequency applications at the inferior lateral part of the LA (Fig. 2A). In the remaining patients, multiple conduction gaps persisted in the roof (12 patients) and septal (10 patients) lines.

During a mean follow-up of 974 ± 408 days, the patient with complete lines remained in SR without antiarrhythmic medication. The patient with the single gap was in SR with frequent atrial extrasystoles on antiarrhythmic medication. Of the 18 patients with incomplete lines, only two were in

Table 1. Overview of Patient Demographics and Procedural Data for Each Line Design

<table>
<thead>
<tr>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D/1</th>
<th>Type D/2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td># of patients treated</td>
<td>21</td>
<td>20 (19 ablated)</td>
<td>14</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td># of procedures</td>
<td>27</td>
<td>20</td>
<td>16</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>Mean age (yrs)</td>
<td>60 ± 6</td>
<td>56 ± 10</td>
<td>62.1 ± 6.4</td>
<td>54.2 ± 9.6</td>
<td>62.1 ± 6.4</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>19/2</td>
<td>15/4</td>
<td>10/4</td>
<td>7/5</td>
<td>20/3</td>
</tr>
<tr>
<td>AFib duration</td>
<td>11.3 ± 9</td>
<td>8.2 ± 5.9</td>
<td>11.7 ± 10</td>
<td>9.8 ± 6.4</td>
<td>8.7 ± 7.5</td>
</tr>
<tr>
<td># of chronic AFib</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td># of intermittent AFib</td>
<td>18</td>
<td>16</td>
<td>10</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Mean number of episodes/months</td>
<td>12 ± 8</td>
<td>16 ± 11</td>
<td>16 ± 11</td>
<td>17 ± 14</td>
<td>16 ± 11</td>
</tr>
<tr>
<td>Mean duration of episodes (h)</td>
<td>21 ± 23</td>
<td>20 ± 19</td>
<td>21 ± 20</td>
<td>20 ± 16</td>
<td>26 ± 23</td>
</tr>
<tr>
<td>Procedure duration (h)</td>
<td>8.7 ± 5.6</td>
<td>8.8 ± 2</td>
<td>9.4 ± 0.8</td>
<td>7.3 ± 1.5</td>
<td>7.7 ± 1.8</td>
</tr>
<tr>
<td>Fluoroscopy (min)</td>
<td>63 ± 44</td>
<td>29 ± 11.8</td>
<td>19.3 ± 8.4</td>
<td>15.7 ± 6.2</td>
<td>23.2 ± 9.9</td>
</tr>
<tr>
<td># of RFC application</td>
<td>49.2 ± 15.7</td>
<td>46.7 ± 15.7</td>
<td>46.4 ± 14.7</td>
<td>33.9 ± 9.0</td>
<td>34.1 ± 16.1</td>
</tr>
<tr>
<td>Total length of ablation line (mm)</td>
<td>202 ± 32</td>
<td>177 ± 23</td>
<td>309 ± 96</td>
<td>188 ± 36</td>
<td>–</td>
</tr>
<tr>
<td>Length of PV isolation line(s) (mm)</td>
<td>185 ± 28</td>
<td>–</td>
<td>septal: 109 ± 28</td>
<td>septal: 101 ± 16</td>
<td>septal: 114 ± 16</td>
</tr>
</tbody>
</table>

Numbers are given as mean ± SD.
AFib = Atrial fibrillation; PV = pulmonary vein; RFC = radiofrequency current.
Two patients with incomplete connections towards the MA were in SR, whereas six patients had recurrences of AFib. During a follow-up of 511 days, conduction gaps persisted despite repeat RFC applications. In the remaining 10 patients, multiple gaps were evident during the ablation session, one patient (type D/2) suffered a stroke, leading to vision disturbances within 48 h after the procedure, and one patient (type D/2) suffered from incessant LA macroreentrant tachycardia due to persisting gaps in either the roof or anterior line and underwent subsequent catheter ablation.

In type D/1 (Fig. 3D), a mean number of 33.7 ± 9.0 RFC applications were delivered over a mean total line length of 188 ± 36 mm (101 ± 16 mm and 96 ± 20 mm for the septal and lateral PV isolation segment, respectively). Complete encircling was achieved around the septal PVs in all patients, around the lateral PVs in 7/12 patients. After two repeat procedures, this segment was completed in one more patient. During a follow-up of 400 ± 126 days, four of the eight patients with complete linear lesions were in stable SR without antiarrhythmic medication, whereas four patients had persistent AFib episodes despite continued antiarrhythmic medication. Three of the four patients with an incomplete lateral PV segment remained in SR.

In type D/2 (Fig. 3E), a mean number of 34.1 ± 16.1 RFC applications were given over a mean total line length of 215 ± 39 mm (114 ± 16 mm and 110 ± 24 mm for the septal and lateral PV segment, respectively). Complete PV encircling was achieved in all but one patient for the septal segment, but remained incomplete in 10/23 patients for the lateral segment after the initial ablation procedure. In repeat procedures this linear lesion was completed in four additional patients. During a mean follow-up of 324 ± 140 days, 12/14 patients with complete lines remained in stable SR, whereas only 3/9 patients with incomplete lines remained arrhythmia-free.

**Complications.** In two patients (type A and B) transseptal puncture resulted in acute tamponade, requiring immediate pericardiocentesis. One patient (type A) underwent the same procedure four weeks later; the other shifted to type C six months later. Although no impedance rise had been evident during the ablation session, one patient (type A) suffered a stroke, leading to vision disturbances within 48 h after the procedure, and one patient (type D/2) suffered a transient ischemic attack (without morphologic changes in sequential computed tomography scans). The symptoms resolved gradually during follow-up. In one patient of group

---

**Table 2.** Follow-Up of Treated Patients With Regard to the Respective Ablation Type: Patients Are Categorized With Respect to Results of Line Validation After the Final Ablation Session

<table>
<thead>
<tr>
<th>Type</th>
<th># of patients treated</th>
<th># of procedures</th>
<th>Mean follow-up duration</th>
<th>Complete lines (n) with rhythm outcome</th>
<th>Incomplete lines (n) with rhythm outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21</td>
<td>27</td>
<td>974 ± 408</td>
<td>1 pt SR</td>
<td>19/20</td>
</tr>
<tr>
<td>B</td>
<td>20 (19 ablated)</td>
<td>20</td>
<td>827 ± 330</td>
<td>3 pts SR + AES</td>
<td>3 pts SR</td>
</tr>
<tr>
<td>C</td>
<td>14</td>
<td>16</td>
<td>511 ± 142</td>
<td>1 pt i.AFib</td>
<td>15/19</td>
</tr>
<tr>
<td>D/1</td>
<td>12</td>
<td>14</td>
<td>400 ± 126</td>
<td>4 pts AFib</td>
<td>10/14</td>
</tr>
<tr>
<td>D/2</td>
<td>23</td>
<td>30</td>
<td>324 ± 140</td>
<td>12 pts AFib</td>
<td>4/12</td>
</tr>
</tbody>
</table>

AA-TX = antiarrhythmic medication; AES = atrial extrasystoles; AFib = atrial fibrillation; AT = atrial tachycardia; i.AFib = intermittent atrial fibrillation; pt = patient; SR = sinus rhythm.
D/2, a 40% stenosis of the right upper PV was demonstrated at the end of the ablation session but remained asymptomatic during follow-up. One patient of group D/1 developed shortness of breath (initially only on exertion) after an uneventful follow-up period of six months. Because of increasing hemoptysis, the patient underwent repeat bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilated. However, despite bronchoscopies and finally an explorative mediastinoscopy for suspicion of bronchial neoplasm. After transfer to the ablation center, transesophageal echocardiography did not demonstrate any flow in the right upper PV. Direct angiography depicted a totally occluded right upper PV, which was subsequently recanalized and dilate.
antiplatelet and anticoagulation therapy, re-stenosis occurred, necessitating repeat balloon dilation and, finally, stent implantation.

**DISCUSSION**

We have recently shown that linear lesions within the RA can be successfully deployed and validated using the electroanatomic mapping system (4).

In contrast with previously reported data (8,13), RA linear lesions did not prevent AFib recurrences, even when these lesions were complete. Therefore, this study focused on the efficacy of linear lesions within the LA. As in the RA study, the electroanatomic mapping system was used for lesion deployment. Special care was taken on line validation by conventional electrophysiologic criteria and the use of the electroanatomic mapping system, which might explain the difference in procedure time and RFC delivery in other studies (8,12).

The first line design (type A) was intended to compartmentalize a large part of the LA including all four PVs, and, thereby, copy the “core” line of the maze operation. This long single ablation line could only be completed in one of 18 patients, who stayed in SR. All other patients were left with incomplete lines. All except two had recurrences of AFib or AT. The second line design (type B) was aiming solely at the interruption of possible macro-re-entries around anatomic barriers such as PV ostia or the MA. However, the only line that could be completed in 15/19 patients (79%) was the anterior line. In contrast, the roof line turned out to be very difficult, which was mostly due to catheter instability. Catheter stability was enhanced by the use of the double sheath technique allowing a parallel rather than tangential catheter tip orientation at the roof line. As before, complete lines were associated with freedom from AFib recurrences. In type C, encircling of PV segments may also eliminate triggers from within the PVs. Each ablation segment had a shorter lesion length (approximately 11 cm) and, thereby, was easier to achieve. Inability to encircle the lateral PVs can be explained by the anatomic location of the intended line between the ostium of the lateral PVs and the base of the LAA (14). The connections were intended to prevent possible macro-re-entry around the newly pre-formed barriers and the MA. These connections were extremely difficult to achieve and remained incomplete in a large proportion of patients (50%), causing iatrogenic gap-related tachycardia during follow-up.

Therefore, in type D, the additional connections between the PVs were omitted. During follow-up in type D/1, the validation criterion of the reduced signal amplitude (>70% reduction as compared with the pre-ablation map and a cut-off value of 0.1 mV) proved not to be discriminative because only 4/8 patients with complete PV lesions remained in SR, whereas 3/4 patients with incomplete lesions were also in SR. In type D/2, loss of the PV spike potential as the ablation end point demonstrated an improved discriminatory power: 12/14 patients with complete linear lesions stayed in SR, compared with only 3/9 patients with incomplete lesions. In contrast, when the end point was only amplitude reduction, no correlation was found between completeness of lines and maintenance of SR. These findings are not in agreement with previously published data (12). Although there might be a small difference in the ablation design (separate isolation of each PV as compared with an encircling line around both upper and lower PVs), RFC delivery is extremely short (15 to 30 s) and might not even result in a transmural lesion or have an effect on epicardially located autonomic nervous endings.

The high incidence of incomplete ablation lines using a solid 4-mm tip electrode demands further technological improvement. The use of custom-made sheaths improved the catheter-tissue contact, especially at the roof line. Other techniques, such as irrigated tip catheters, were not available at the time of study, but may improve lesion deployment significantly and lower the risk of thromboembolic complications, which was 2.4% in this study.

Although the ablation lines were designed to be at the atrial side, PV occlusion occurred in one patient. Even using the enhanced mapping and navigation tools of the electroanatomic mapping system, assessment of the complex three-dimensional anatomy of the PV-LA junction is difficult, and intrapulmonary ablation cannot be ruled out because distinctive markers for the PV ostia are missing. Even more disturbing, PV occlusion developed slowly. The symptoms such as hemoptysis and shortness of breath were, in our patient, not related to the ablation procedure by the initially involved physicians and led to numerous procedures before the diagnosis of PV occlusion was made.

**Study limitations.** The evidence of complete linear lesions at the end of the ablation session may only be a transient phenomenon, and re-conduction may occur during follow-up, which may account for recurrences, although complete lines were acutely demonstrated. On the other hand, RFC-induced lesions may mature after the ablation session, accounting for the effective treatment of patients defined as “incomplete.” Finally, the growing experience of the investigators in deploying linear lesions in the LA using sequential RFC applications have to be taken into account when judging the effectiveness of the line designs.

**Conclusions.** Complete lesions in the LA were difficult to achieve using conventional RFC technology, but were associated with SR in 74% of patients during long-term follow-up, whereas incomplete lesions led mostly to recurrences of AFib or gap-related AT. Further technological improvement (catheter design, ablation energy, specifically designed trans-septal sheaths) is necessary to improve line completeness and to facilitate line deployment.

Reprint requests and correspondence: Dr. Karl-Heinz Kuck, AK St. Georg, 2. Med. Abteilung (Kardiologie), Lohnühlenstr. 5, 20099 Hamburg Germany. E-mail: sernst1708@aol.com.
REFERENCES


