Specific Linear Left Atrial Lesions in Atrial Fibrillation
Intraoperative Radiofrequency Ablation Using Minimally Invasive Surgical Techniques

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OBJECTIVES
A specific left atrial (LA) linear lesion concept for treatment of paroxysmal and permanent atrial fibrillation (AF) was tested using intraoperative ablation with minimally invasive surgical techniques.

BACKGROUND
Curative treatment for patients with chronic AF is among the main challenges of interventional electrophysiology.

METHODS
Seventy patients (mean age 53 ± 10 years) with drug-refractory persistent (n = 28) or paroxysmal (n = 42) AF underwent intraoperative radiofrequency (RF) ablation using video-assisted minimally invasive techniques via a right anterolateral minithoracotomy. Contiguous lesion lines involving the mitral annulus and the orifices of the pulmonary veins were placed with RF energy application under direct vision to prevent anatomically defined LA re-entrant circuits.

RESULTS
Mean follow-up was 18 ± 7 months in patients with permanent AF and 18 ± 5 months in patients with paroxysmal AF. Antiarrhythmic drug treatment was instituted in patients with postoperative atrial arrhythmias to allow "reverse electrical remodeling" and was discontinued after three months. Six months following ablation, 93% of the patients were in sinus rhythm in both groups, and after 12 months, 95% and 97%, respectively. As major complications, one esophagus perforation and one circumflex coronary artery stenosis were observed.

CONCLUSIONS
A pure linear lesion line concept confined to the left atrium targeting specifically at elimination of anatomically defined LA "anchor" re-entrant circuits eliminated AF in 90% of the patients treated with intraoperative ablation using minimally invasive surgical techniques over a mean follow-up of 1.5 years. (J Am Coll Cardiol 2002;40:475–80)

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Curative treatment of chronic atrial fibrillation (AF) remains one of the main challenges of interventional electrophysiology. Given the complex electrophysiologic nature of AF, interventional treatment strategies target pathophysiologic cornerstones of AF (i.e., the initiating or the maintaining factors). Clinical electrophysiologic studies from Haïssaguerre et al. (1) clearly identified the critical role of initiating foci-triggering episodes of paroxysmal AF.

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Cox et al. (2–4), in contrast, developed a complex surgical technique for treatment of AF with multiple biventricular incisions, pulmonary vein (PV) isolation and a critical mass reduction with amputation of both atrial appendages. The hypothesis of their concept was that elimination of all hypothetical biventricular functional re-entrant circuits should prevent the perpetuation of AF. Widespread application of the surgical maze procedure may have been precluded by the relatively time-consuming nature of this extensive operation, including median sternotomy, despite very high success rates. Recently, modifications of the maze procedure have been introduced with less extensive incisions and partial replacement of surgical incisions with cryoablation or radiofrequency (RF) energy application in addition to mitral valve surgery (5–12).

In the present study, we describe a new concept of intraoperative RF ablation using minimally invasive surgical techniques without the need for median sternotomy as a primary indication for curative treatment of paroxysmal and persistent AF. The specific hypothesis underlying this restricted pure linear lesion concept is that the elimination of anatomically defined left atrial (LA) re-entrant circuits involving the mitral annulus and the PV orifices should prevent the perpetuation of paroxysmal and persistent AF.

METHODS

Study patients. Seventy patients with either persistent AF (n = 28) or paroxysmal (n = 42) AF for more than two years were included in this study (Table 1). In the group of patients with paroxysmal AF, all patients had two or more episodes per week lasting >12 h. As an inclusion criterion, all patients were highly symptomatic despite multiple antiarrhythmic drug-treatment regimen, including class I and...
class III antiarrhythmic drugs (Table 1). Left heart catheterization with coronary angiography, transthoracic and transesophageal echocardiography as well as two 24-h electrocardiograms (ECGs) were performed in all patients before operation. All patients gave written informed consent on the investigational nature of the procedure, which was approved by the institutional review committee.

**Surgical approach.** All patients were operated on using a video-assisted minimally invasive surgical approach via a right anterolateral minithoracotomy. After femoro-femoral cardiopulmonary bypass was established, direct aortic clamping was performed using a transthoracic clamp (Chitwood clamp, Scanlan, St. Paul, Minnesota). Either antegrade cold crystalloid cardioplegia or cold blood cardioplegia (grade cold crystalloid cardioplegia or cold blood cardioplegia (Scanlan et al., 2000)). Either antegrade cold crystalloid cardioplegia or cold blood cardioplegia was applied for myocardial protection. The left atrium was incised parallel to the interatrial groove anterior to the right PVs, allowing access to the mitral annulus as well as exposure of the orifices of the PVs.

**RF ablation.** The RF alternating current (500 kHz, modified HAT 200S; Osypka GmbH, Grenzach-Wyhlen, Germany) was delivered in a unipolar mode between the 10-mm T-shaped tip electrode of a specially designed ablation probe (Osypka GmbH) and a 10 × 16 cm external backplate electrode. Temperature-guided energy applications were performed with a preselected catheter tip temperature (Osypka GmbH) and a 10 × 16 cm external backplate electrode. Temperature-guided energy applications were performed with a preselected catheter tip temperature of 60°C. Based on catheter stability, induction of a well-visualized lesion line, and achievement of the preselected catheter tip temperature, the ablation probe was stepwise withdrawn after 20 to 40 s.

The first part of the RF application protocol consisted of placing a contiguous lesion line extending from the inferior aspect of the mitral annulus (P3 segment of the posterior leaflet) to the left PVs (Fig. 1). The second line connected the left lower and upper PV orifices. From there, a third line coupled the left and right PVs. Then, the right upper pulmonary vein (RUPV) and right lower pulmonary vein (RLPV) orifices were connected. Care was taken to advance the tip of the ablation probe only a few millimeters inside the proximal funnel-shaped parts of the PVs. Finally, the line at the LA roof was connected to the surgical incision to prevent “incisional reentry.” This specific linear lesion line concept tested the hypothesis of targeting the perpetuation of chronic AF by elimination of anatomically defined “anchor” re-entrant circuits within the left atrium in contrast to functionally determined re-entrant circuits and in contrast to treating the initiating triggers of AF. The dotted line indicates the LA incision.

**Postoperative management and follow-up.** All patients were monitored with continuous ECG recordings for the first three postoperative days. Daily 12-lead ECGs and two 24-h ECGs were performed within the first 10 postoperative days. In addition, both transthoracic and transesophageal echocardiography were performed between postoperative days 5 and 10. In cases of recurrence of AF or atypical LA flutter, electrical cardioversion followed by antiarrhythmic drug treatment (class Ic or amiodarone) was instituted. According to the study protocol, antiarrhythmic drug treatment was withdrawn three months after operation.

All patients were seen in the outpatient clinic at 6 weeks, 3 months, 6 months and 12 months after operation. Twelve-lead ECG, 24-h ECG, and echocardiography were performed in all patients during each follow-up visit. All patients and referring physicians were instructed to docu-
ment on the ECG if recurrences of an arrhythmia were suspected. Oral anticoagulant therapy was prescribed for at least three months.

**Statistical analysis.** Quantitative data were expressed as mean ± SD. Statistical comparisons were performed after analysis of variance (ANOVA) for repeated measurements. Statistical analysis was performed using ANOVA for repeated measures, the Student t test for single comparisons and chi-square analysis. Differences were considered significant at p values < 0.05.

**RESULTS**

**Operative course.** The overall operation time in patients with persistent AF (group I) measured 134 ± 38 min, and in patients with paroxysmal AF it was 137 ± 35 min, respectively (NS), and the aortic cross-clamp times were 44 ± 20 min and 43 ± 15 min, respectively (NS). The antiarrhythmic treatment time for induction of the lesion lines measured 18 ± 5 min and 16 ± 4 min, respectively (NS).

**Rhythmologic course during in-hospital period.** In 18/28 patients (64%) with persistent AF (group I), AF or atypical atrial flutter occurred between the 2nd and 10th postoperative days compared to 16/42 patients (38%) with paroxysmal AF (group II) (p < 0.05). All patients with atrial tachyarrhythmias were electrically cardioverted and/or treated with antiarrhythmic drugs (class Ic or amiodarone).

At the day of hospital discharge, 24/28 patients (86%) in group I and 40/42 patients in group II (95%) were in sinus rhythm, respectively (NS). The patients of groups I and II were discharged 12 ± 6 days and 10 ± 3 days after operation, respectively (NS).

**Rhythmologic course and antiarrhythmic treatment during follow-up.** Mean follow-up in patients with persistent AF (group I) was 18 ± 7 months (range 10 to 31 months), and in patients with paroxysmal AF (group II) 17 ± 5 months (range 11 to 31 months) (NS) (Fig. 2). All patients had a follow-up period of at least six months. After six weeks, 25/28 patients (89%) of group I and 38/42 patients (90%) of group II were in sinus rhythm, respectively (NS), and after three months, 25/28 (89%) of group I and 39/42 patients (93%) of group II, respectively (NS) (Fig. 2). After 6 and 12 months, 26/28 patients (93%) and 18/19 patients (95%) in group I and 39/42 patients (93%) and 34/35 patients (97%) in group II were in stable sinus rhythm, respectively (NS).

In group I, 18/28 patients (64%) were discharged on antiarrhythmic drugs compared to 16/42 patients (38%) in group II (p < 0.05) (Fig. 2). The percentage of patients of group I (persistent AF) on antiarrhythmic drugs declined over time and measured 68% after 6 weeks, 61% after 3 months, 26% after 6 months and 38% after 12 months. The percentage of patients of group II (paroxysmal AF) on antiarrhythmic drugs was 45% after 6 weeks (p < 0.05 compared to group I), 43% after 3 months (p < 0.05 compared to group I), 23% after 6 months (NS compared to group I) and 14% after 12 months (NS compared to group I).

One patient of group I underwent RF catheter ablation of the inferior isthmus for treatment of typical atrial flutter, and two patients had catheter ablation for gap-related LA flutter during follow-up. One patient of group II underwent RF catheter ablation of ectopic atrial tachycardia, and one patient had catheter ablation of gap-related LA flutter during follow-up.

**Complications.** One patient developed neurologic and septicemic symptoms. In this patient, a fistula was found between the esophagus and the left atrium, requiring reoperation on the 10th postoperative day. An additional reoperation was necessary owing to a fistula involving the left bronchus system with subsequent left-sided pneumectomy.

One patient complained of angina pectoris six weeks after operation. Coronary arteriography revealed a significant stenosis of the circumflex coronary artery requiring percutaneous transluminal coronary angioplasty (PTCA) and stent implantation.
Minor bleeding complications were observed in an additional two patients. No mortality was observed during the complete follow-up period, and no patient was lost to follow-up.

Echocardiographic data. Preoperative LA diameter on echocardiography was slightly larger in patients with persistent AF (group I) compared with patients with paroxysmal AF (group II) (4.6 ± 0.6 mm vs. 4.2 ± 0.4 mm, NS). Data on mitral valve E/A ratio and LA appendage velocity are given in Figure 3.

**DISCUSSION**

**Main findings.** A restrictive pure linear lesion approach confined to the left atrium targeting at elimination of anatomically defined LA re-entrant circuits eliminated AF in more than 90% of the patients treated over a mean follow-up period of 1.5 years. Placement of strategic contiguous linear lesions under direct vision allowed validation of a treatment strategy targeting at modification of the arrhythmia substrate irrespective of trigger elimination or critical mass reduction.

**Curative treatment concepts for AF.** Clinical electrophysiologic studies from Haïssaguerre et al. (1) clearly identified the critical role of initiating foci—triggering episodes of paroxysmal AF. These triggers have been found in the majority of cases in the area of the PV orifices, but they may also be located in several other areas of both atria. Radiofrequency catheter ablation directly targeting the active foci or ostial disconnection of the PV muscle strands may result in curative treatment of a substantial portion of patients with paroxysmal AF, although high recurrence rates have been recently reported (1,13,14).

In contrast to the initiating triggers, a modification of the maintaining substrate may be necessary for treatment of persistent AF and for patients with prolonged episodes of paroxysmal AF. The hypothesis of the surgical maze procedure was the elimination of all hypothetical biatrial functional re-entrant circuits to prevent the perpetuation of AF (2–4). This could be realized with multiple biatrial incisions, PV isolation and a critical mass reduction using amputation of both atrial appendages. The extensive maze procedure proved to be effective in patients with persistent AF. Subsequently, the linear lesion line concept for modification of the substrate maintaining the arrhythmia was adopted by interventional electrophysiologists for treatment of chronic AF (15,16).

Significant problems have been faced with long procedure times and substantial risks, including systemic thromboembolism. Recently, Haïssaguerre et al. (17) summarized their experience with septal and LA linear ablation for treatment of AF in 44 patients. A mean of 2.7 procedures per patient were necessary to treat 25 patients (57%) successfully without antiarrhythmic drugs. However, the mean cumulative duration of procedures measured about 10 h and fluoroscopy times close to 3 h, respectively, in their study (17).

The role of electroanatomic mapping has been investigated for induction of linear lesions in patients with AF, with divergent results (18,19). The geometries of the lesions that have been applied percutaneously so far seem to be empirical, and validation of lesion geometry concepts with percutaneous means is difficult. Consequently, clinical failure of percutaneously placed lesion lines may be the result of insufficient lesion extension and/or geometry, or ablation failure may be due to the insufficient realization of the proposed lesion lines—that is, the induction of noncontiguous lesions without achievement of linear conduction block. Therefore, in contrast to trigger elimination, no specific pure linear lesion line concepts targeting the perpetuation of AF could be validated percutaneously in a substantial patient series with persistent AF.

In the present study, the operation theater on one side and RF energy application on the other side were combined to test a new concept of intraoperative RF ablation of chronic AF aiming at a modification of the maintaining substrate. A purely LA approach of intraoperative RF energy application was applied that was restricted to eliminate LA anatomically determined macrore-entrant "anchor" circuits involving the PVs and the mitral annulus. The hypothesis behind this approach was that anatomically defined reentrant circuit are especially "helpful" to maintain AF because they may be more stable in contrast to purely functionally determined but more unstable circuits.

Patients with chronic persistent AF revealed significantly more AF relapses in the early postoperative period and more often needed antiarrhythmic drug treatment, which might be explained by the further developed arrhythmia substrate. In patients with early relapses of AF, antiarrhythmic medication with previously ineffective drugs was instituted and then finally withdrawn after three months in most patients. The rationale for this concept was to stabilize the atria during the phase of “reverse electrical remodeling.” Interestingly, the long-term success rate was equally high in patients with previously persistent and paroxysmal AF.

Therefore, the concept of strategically placed linear lesion lines targeting at the perpetuation of AF by elimination of anatomically defined LA re-entry proved to be highly effective in this patient cohort, with success rates exceeding 90%. In addition, normalized LA mechanical transport function could be documented in all patients with postoperative sinus rhythm.

Intraoperative RF ablation as a primary indication for curative treatment of persistent and paroxysmal AF using minimally invasive surgical techniques without the need for median sternotomy was shown to be feasible, with a mean operation time of 2 h. The judgment on the efficacy-risk profile of this highly invasive therapy needs to consider the inherent risks of RF-induced linear lesions within the left atrium. A high degree of surgical expertise, with minimally invasive surgical techniques together with close cooperation
Figure 3. Echocardiographic data on left atrial (LA) diameter, E/A ratio at mitral valve and flow velocity within the left atrial appendage (LAA) following intraoperative ablation of atrial fibrillation. Open bars = permanent atrial fibrillation; Solid bars = paroxysmal atrial fibrillation.
with interventional electrophysiologists, is a prerequisite for this interdisciplinary treatment modality.

**Study limitations, complications and future perspectives.**

In the present study, 70 consecutive patients with highly symptomatic, drug-resistant persistent or paroxysmal AF underwent intraoperative ablation. Two significant complications were observed. The patient with a circumflex coronary artery stenosis underwent PTCA and stent implantation and had an uneventful follow-up. The other patient developed a fistula between the esophagus and the left atrium, as well as a fistula to the left bronchus system that required two reoperations. The complications in both patients are most likely directly related to RF energy application within the left atrium. The complication regarding the esophagus resulted in a slight but specific modification of the surgical procedure—that is, compresses are now inserted in the pericardial space separating the LA wall from the esophagus, thereby preventing RF energy penetration toward the esophagus.

Currently, no widespread application of a curative treatment of persistent AF exists. The extensive maze operation and its modifications have good results, but they require long operation times and median sternotomy, thus precluding widespread application as a primary indication for AF operation (5–12). Percutaneous catheter ablation, in contrast, seems to be feasible for patients with paroxysmal AF, but no substantial data are available for patients with persistent AF as the linear lesion line concept is not yet practicable when applied percutaneously. In addition, no pure linear lesion concept targeting at modification of the substrate irrespective of triggers has been validated percutaneously thus far. The present study is not a modification of the maze operation but follows a completely different pathophysiologic concept, namely the prevention of anatomic LA re-entrant circuits without mass reduction and without treatment of potential triggers. Applying this concept with minimally invasive surgical means without median sternotomy showed success rates exceeding 90% during a mean follow-up of 1.5 years. In addition, LA mechanical transport function normalized in all patients, with postoperative sinus rhythm allowing discontinuation of oral anticoagulant therapy. In the future, this intraoperatively validated strategic linear lesion line concept might be transferred to catheter ablation, provided that new navigation and catheter technologies will allow the transfer to percutaneous ablation techniques.

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**REFERENCES**