

## Catheter ablation of atrial fibrillation: Radiofrequency catheter ablation for redo procedures after cryoablation

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### Abstract

**AIM:** To evaluate the effectiveness of two different strategies using radiofrequency catheter ablation for redo procedures after cryoablation of atrial fibrillation.

**METHODS:** Thirty patients (paroxysmal atrial fibrillation: 22 patients, persistent atrial fibrillation: 8 patients) had to undergo a redo procedure after initially successful circumferential pulmonary vein (PV) isolation with the cryoballoon technique (Arctic Front Balloon, CryoCath Technologies/Medtronic). The redo ablation procedures were performed using a segmental approach or a circumferential ablation strategy (CARTO; Biosense Webster) depending on the intra-procedural findings. A 7-d Holter monitoring was performed at 3, 12 and 24 mo after the ablation procedure. After discharge, patients were scheduled for repeated visits at the arrhythmia clinic.

**RESULTS:** During the redo procedure, a mean number of 2.9 re-conducting pulmonary veins (SD  $\pm$  1.0 PVs) were detected (using a circular mapping catheter). In

20 patients, a segmental approach was sufficient to eliminate the residual pulmonary vein conduction because there were only a few recovered pulmonary vein fibres. In the remaining 10 patients, a circumferential ablation strategy was used because of a complete recovery of the PV-LA conduction. All recovered pulmonary veins could be isolated successfully again. At 2-year follow-up, 73.3% of all patients were free from an arrhythmia recurrence (22/30). There were no major complications.

**CONCLUSION:** In patients with an initial circumferential pulmonary vein isolation using the cryoballoon technique, a repeat ablation procedure can be performed safely and effectively using radiofrequency catheter ablation.

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**Key words:** Atrial fibrillation; Catheter ablation; Cryoablation; Pulmonary veins; Supraventricular arrhythmias

**Core tip:** We have summarized our initial experience with two different strategies for redo procedures using radiofrequency catheter ablation. Thirty patients had to undergo a redo procedure after initially successful circumferential pulmonary vein isolation with the cryoballoon technique. The redo ablation procedures were performed using a segmental approach or a circumferential ablation strategy depending on the intra-procedural findings. All recovered pulmonary veins could be isolated successfully again. At 2-year follow-up, 73.3% of all patients were free from an arrhythmia recurrence.

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## INTRODUCTION

Catheter ablation has become the first line of therapy in patients with symptomatic, recurrent, drug-refractory atrial fibrillation (AF)<sup>[1-7]</sup>. Cryoablation has been shown to be a safe and effective technique for pulmonary vein (PV) isolation<sup>[1]</sup>. Although the acute success rates are high there is a significant arrhythmia recurrence rate after cryoablation during midterm follow-up<sup>[8-14]</sup>. According to a recently published study, catheter ablation with the cryoballoon technique resulted in maintenance of sinus rhythm in 74% of patients with paroxysmal atrial fibrillation and in 42 % of patients with persistent atrial fibrillation [median follow-up: 12 (7-16) mo<sup>[15-21]</sup>. Recovery of pulmonary vein conduction is one major reason for recurrences of atrial fibrillation. This is a crucial issue for cryoablation of AF because the cryoballoon is available with a rigid uniform design only (size: 23 or 28 mm; CryoCath Technologies, Quebec, Canada/Medtronic, Minneapolis, MN). Taking into account the high degree of variability of the pulmonary vein anatomy it becomes clear that the contact between the balloon catheter and the pulmonary vein ostium cannot be equally good in all parts of the PV ostium. Therefore, insufficient tissue contact of the cryoballoon seems to be a key mechanism for recovery of initially successfully isolated pulmonary veins and AF recurrences in these patients during follow-up<sup>[22-26]</sup>.

There are no established strategies for redo procedures after pulmonary vein isolation with the cryoballoon technique. From a theoretical point of view it seems to be reasonable to use the cryoablation technique for the redo procedure again because of its favourable lesion characteristics<sup>[1,22]</sup>. Such procedures can be performed either by using the cryoballoon technique again or by using a standard cryoablation catheter (*e.g.*, Freezor Max; Medtronic). The major concern with the cryoballoon technique for redo procedures is that there might be insufficient tissue contact in the same areas as during the initial procedure again. This might be a risk factor for further arrhythmia recurrences. Alternatively, repeat ablations can be performed with a segmental approach and a standard cryoablation catheter (*e.g.*, Freezor Max; Medtronic). However, a segmental approach using a cryoablation catheter is limited by the long duration of the cryoapplications required for achieving permanent lesions and by the fact that the position of the cryoablation catheter cannot be optimized during energy delivery.

Because of these limitations radiofrequency catheter ablation seems to be a promising approach. Therefore, the aim of our study was to analyse the data on pulmonary vein conduction recovery after pulmonary vein isolation with the cryoballoon technique and to evaluate two different strategies for redo procedures using radiofrequency catheter ablation.

Depending on the extent of pulmonary vein conduction recovery we performed either a segmental pulmonary vein re-isolation or an anatomically-based circum-

ferential pulmonary vein ablation in combination with a potential-guided segmental approach using radiofrequency energy application<sup>[19,20]</sup>.

## MATERIALS AND METHODS

### Patient population

A total of 30 patients (21 men, 9 women; mean age 59.6 ± 10.0 years) with a recurrence of symptomatic atrial fibrillation after pulmonary vein isolation with the cryoballoon technique were enrolled in this study. Table 1 summarizes clinical characteristics of the patients enrolled in our study. A repeat procedure was planned because of recurrent episodes of paroxysmal atrial fibrillation in 23 patients or persistent AF in 7 patients. The redo procedures were performed at a mean interval of 12.5 ± 9.3 mo) after the initial ablation procedure. Prior to the initial ablation procedure paroxysmal AF had been present in 22 patients and persistent AF had been present in 8 patients. The initial ablation procedures had been performed at our University Hospital Center (between November 2007 and July 2009). The initial patient cohort consisted of 103 patients undergoing cryoablation as the primary procedure. Thus, the overall arrhythmia recurrence rate was 29.1% after the initial cryoablation procedure. For the initial procedure a cryoballoon device had been used in all patients who had to undergo a repeat ablation procedure (23 mm: 0 patients, 28 mm: 30 patients; CryoCath Technologies/Medtronic). In addition, a standard cryoablation catheter (Freezor Max 3; Medtronic) had been used in 4 patients. During the initial procedure a mean number of 11.6 ± 4.9 cryoapplications had been made using the cryoballoon device and a mean number of 4.0 ± 2.0 cryoapplications had been made in those patients in whom the standard cryoablation catheter (Freezor Max; Medtronic) had been used. At the end of the initial ablation procedure all pulmonary veins were isolated successfully. There were no major complications during or after the initial ablation procedure.

The repeat ablation procedures were performed at our University Hospital Center between March 2008 and November 2009. Inclusion criteria were (1) documented episodes of recurrent atrial fibrillation (≥ 30 s) after an initial ablation procedure with the cryoballoon technique (taking into account a blanking period of 3 mo after the initial ablation procedure); (2) severe symptoms despite antiarrhythmic drug therapy (including beta-blockers) or prior attempts of electrical cardioversion; (3) ability and willingness to give informed consent; and (4) age between 18 and 85 years. Patients were not accepted for catheter ablation if one of the following conditions was present: severe valvular heart disease or any other concomitant cardiac disease requiring surgery, severely impaired left ventricular function (left ventricular ejection fraction < 20%), left atrial diameter > 65 mm (parasternal long-axis view), left atrial thrombus, hyperthyroidism, severe renal insufficiency (creatinine ≥ 3 mg/dL) or another severe concomitant illness.

Table 1 Clinical data

Clinical data	Group A	Group B	Total	P value
Patients (men/women)	20 (13/7)	10 (8/2)	30 (21/9)	0.67
Age (yr, mean $\pm$ SD)	60.0 $\pm$ 10.7	58.9 $\pm$ 9.2	59.6 $\pm$ 10.0	0.81
Cardiac disease				0.84
None	8	6	14	
CAD	3	1	4	
DCM	2	1	3	
Valvular heart disease <sup>1</sup>	5	1	6	
Other	2	1	3	
Left ventricular ejection fraction (mean $\pm$ SD)	54.70% $\pm$ 12.00%	53.80% $\pm$ 10.30%	54.40% $\pm$ 11.20%	0.86
Previous cardiac surgery	1	1	2	1.00
Current antiarrhythmic drug therapy prior to the initial ablation procedure	3	2	5	0.94
Class I c (e.g., Flecainide, Propafenone)	6	1	7	
Class III (e.g., Amiodarone, Sotalol)	4/2	3/1	7/3	
Beta-Blocker in combination with a class I c or class III antiarrhythmic drug	2	1	3	
Beta-Blocker	1	1	2	
Digitalis	2	1	3	
Current antiarrhythmic drug therapy prior to the repeat ablation procedure	2	1	3	0.57
Class Ic (e.g., Flecainide, Propafenone)	4	1	5	
Class III (e.g., Amiodarone, Sotalol)	4/2	2/1	6/3	
Beta-Blocker in combination with a class I c or class III antiarrhythmic drug	4	1	5	
Beta-Blocker	2	0	2	
Digitalis	2	4	6	

<sup>1</sup>Not requiring surgery. CAD: Coronary artery disease; DCM: Dilated cardiomyopathy (left ventricular rejection fraction < 40%). Group A: Reconnection of all four pulmonary veins, an anatomically-based circumferential; Group B: Pulmonary vein ablation in combination with a potential-guided segmental approach.

### Cardiac imaging

A three-dimensional transesophageal echocardiography (3-D TEE) was performed in all patients prior to the ablation procedure (X7-2t, 7 MHz/IE 33; Philips Healthcare). The images were available throughout the ablation procedure. The 3-D TEE reconstructions provided an excellent overview over the individual left atrial morphology thereby facilitating the ablation procedure.

### Ablation procedure

AF ablation procedures were performed under conscious sedation at our institution. For the electrophysiological study, vascular access was obtained *via* both femoral veins and the left femoral artery. A 2500-U IV bolus of heparin was given shortly thereafter. First, a 6-F decapolar catheter (Bard, Electrophysiology Division, Lowell, MA) was positioned within the coronary sinus (CS). Then, a single (or double) transseptal puncture was performed under fluoroscopic guidance. Immediately before the transseptal puncture, a 5-F catheter was placed in the ascending aorta to mark this area and to enhance the safety of the procedure. In some patients no transseptal puncture was necessary because of a patent foramen ovale or a residual defect of the atrial septum. Then, a pulmonary vein angiography was performed. After that, all four pulmonary veins were reevaluated during sinus rhythm and during CS pacing using a Lasso-catheter (2515, 7F; Biosense Webster, Diamond Bar, CA). If atrial fibrillation was present at the beginning of the ablation procedure an electrical cardioversion was performed. The further strategy was based on the findings documented by the circular mapping catheter: if there were 1-3 pulmonary veins with recovered PV conduction we decided to perform a re-

isolation of the recovered pulmonary veins using a segmental approach (group A). If there was reconnection of all four pulmonary veins, an anatomically-based circumferential pulmonary vein ablation in combination with a potential-guided segmental approach was performed (group B)<sup>[20]</sup>. In addition, we classified the degree of PV reconnection as minor (PV spike visible on  $\leq$  4 bipoles of the Lasso catheter) or major (PV potential visible on  $\geq$  5 bipoles of the Lasso catheter).

Then, a standard irrigated-tip ablation catheter (7F; D-type, 3.5-mm-tip; Biosense Webster, Diamond Bar, CA) or a CARTO-catheter (NAVI-STAR; 7F; D-type; 4-mm-tip; Biosense Webster) was positioned within the left atrium. After that, a second iv bolus of heparin was administered. During the procedure, the activated clotting time (ACT) was determined at regular intervals to ensure an adequate anticoagulation (ACT between 250 and 300 s).

Then, a segmental re-isolation of the pulmonary veins was performed in the patients assigned to group A using the above-mentioned irrigated-tip ablation catheter (43 $^{\circ}$ ; 25-35 W). Pulmonary vein ablation was performed during sinus rhythm and pacing from the coronary sinus. Pacing was performed from the distal CS during isolation of the left pulmonary veins and from the proximal CS during right PV ablation. If atrial fibrillation was present at the beginning of the ablation procedure or recurred during the procedure an electrical cardioversion was performed. Successful pulmonary vein isolation was assumed if one of the following criteria was met: complete disappearance of the pulmonary vein potential or appearance of a dissociated PV potential (circumferential mapping catheter).

In group B, a circumferential pulmonary vein ablation was performed in combination with a potential-guided

segmental approach in order to achieve complete pulmonary vein isolation. Furthermore, a linear lesion was created at the roof of the left atrium in some patients with persistent atrial fibrillation. In addition, catheter ablation of the mitral isthmus was performed in selected cases.

First, a circumferential pulmonary vein ablation was performed targeting the both left-sided pulmonary veins [43°; 30 W (posterior wall) - 35 W (anterior wall)]. In addition, a Lasso-catheter was placed in the left superior or left inferior pulmonary vein. After completing the circumferential ablation line around the left-sided PVs, the left superior pulmonary vein and the left inferior pulmonary vein were reevaluated using the circular mapping catheter. If there was no complete PV isolation additional RF energy applications (43°; 25-30 W) were applied using a segmental approach (during sinus rhythm/CS pacing or recurrent AF). If the isolation of the left-sided PVs was assumed to be complete the right-sided PVs were targeted in the same way. Then, a linear lesion at the LA roof was created in selected patients (43°; 30-35 W). In a few patients an additional mitral isthmus ablation was performed (if there was evidence for left atrial isthmus-dependent flutter (43°; 35-40 W).

If atrial fibrillation was still present thereafter, an electrical cardioversion was performed. Then, all four pulmonary veins were reevaluated during sinus rhythm using the circumferential mapping catheter.

If necessary additional RF applications were performed using a segmental approach to achieve complete isolation of all four pulmonary veins. Then, the linear lesions at the LA roof were reevaluated during sinus rhythm. The ablation catheter was navigated back along the entire lesion to assess the presence of low-amplitude electrograms and the presence of double potentials or fractionated electrograms. If sharp high-amplitude electrograms were noted, additional RF applications were delivered at these sites in order to achieve a complete ablation line.

In addition, the linear lesions to the mitral annulus were reevaluated (anterior mitral isthmus line). The presence of bidirectional mitral isthmus conduction block was assumed if the following criteria were met: (1) presence of an unidirectional conduction block documented by activation mapping during pacing from the distal bipole of the CS catheter (placed far within the coronary sinus) or the left atrial appendage; (2) documentation of a similar conduction time during pacing from the antero-septal mitral annulus (*via* the ablation catheter) *vs* the distal coronary sinus or the left atrial appendage; and (3) a conduction time > 150 ms in both directions.

In all patients (group A/B), a standard stomach tube (Flocare Nutrisoft M; Nutrica Healthcare, Châtel-St.Denis, Switzerland) or a special EP catheter (7 F; Osypka, Rheinfelden-Herten, Germany) had been introduced *via* a nasogastric route immediately before the ablation procedure in order to mark the esophagus. RF energy applications were avoided if there was a close anatomical relationship to the esophagus (or the power output was

reduced as described previously<sup>[19]</sup>).

Finally, the completeness of the pulmonary vein isolation and of all linear lesions was reassessed after a waiting period of at least 20 min. Repeat selective pulmonary vein angiographies were performed of all targeted PVs. In addition, catheter ablation of the right atrial isthmus was performed in patients with inducible or clinically documented episodes of typical atrial flutter. The completeness of the right atrial isthmus lines was confirmed by differential pacing manoeuvres in all cases.

For the ablation procedure, a Bard EP system (Lab-System Pro, EP Recording System; Bard, Electrophysiology Division, Lowell, MA) and a Stockert RF generator (EP-shuttle; Stockert, Freiburg, Germany) were used. High-resolution x-ray imaging was provided by a Philips device (Philips Medical Systems, Best, The Netherlands).

### Follow-up

After hospital discharge, patients were seen regularly on an outpatient basis. One month after the procedure, a physical examination, a resting electrocardiogram (ECG) and a transthoracic echocardiogram were performed. The patients were questioned whether there was any evidence for an arrhythmia recurrence. In addition, a long-term ECG recording (24-h) was performed.

Three months after the ablation procedure, the patients were re-examined in the same way except for the fact that a 7-d Holter monitoring was performed and that each patient underwent a repeat three-dimensional transesophageal echocardiography to rule out a pulmonary vein stenosis. Then, the patients were seen at 3-mo intervals if asymptomatic. If there was an arrhythmia recurrence or other problems occurred, the further follow-up and future strategy (*e.g.*, electrical cardioversion, repeat ablation procedure) were planned on an individual basis.

Twelve months and 24 mo after the ablation procedure another 7-d Holter monitoring was performed. A blanking period of 3 mo was employed after ablation when evaluating the follow-up results. In addition, all patients were given a questionnaire 24 mo after the ablation procedure. The aim of this questionnaire was to evaluate the clinical status of the patients and to reveal whether there was any evidence for arrhythmia recurrences not detected by the long-term ECG recordings<sup>[20]</sup>.

Oral anticoagulation was continued for at least 3 mo after the procedure in all patients. During the first three mo after catheter ablation the patients received the same antiarrhythmic medication as prior to the ablation procedure. If there was no evidence for an arrhythmia recurrence all antiarrhythmic drugs were discontinued thereafter except for beta-blockers. The beta-blocker therapy was continued thereafter in order to reduce the risk of arrhythmia recurrences during long-term follow-up and to achieve an adequate rate control if such arrhythmia recurrences occurred.

### Statistical analysis

All parameters with a normal distribution are given as

mean  $\pm$  SD. All other parameters are presented as median and 25<sup>th</sup>/75<sup>th</sup> percentiles.  $\chi^2$  tests, *t*-tests, and Fischer's exact test were used to compare nominal, continuous, and dichotomous characteristics of the two study groups at baseline as well as during follow-up. Significance was accepted if the *P* value was  $< 0.05$ . The statistical package of JMP (Version 3.2.6, SAS Institute, Cary, NC) was used for data analysis.

## RESULTS

Thirty patients were enrolled in this study between March 2008 and November 2009. All of them had to undergo a repeat ablation procedure because of a recurrence of symptomatic atrial fibrillation after pulmonary vein isolation with the cryoballoon technique. Prior to the redo procedure, 23 patients suffered from recurrent episodes of paroxysmal atrial fibrillation and 7 patients suffered from persistent AF. The repeat ablation procedure could be performed as planned in all patients.

### Procedural results

**Evaluation of the pulmonary veins:** During the repeat procedure, a mean number of  $2.9 \pm 1.0$  PVs with recovered PV conduction were detected (using a circular mapping catheter). In all patients at least one pulmonary vein with recovered PV conduction was observed. In 4 patients, there was only one pulmonary vein with recovered PV conduction. There were 6 patients with two reconnected veins and 10 patients with three reconnected pulmonary veins. In 10 patients, all four pulmonary veins showed recovered PV conduction. Seven out of 10 patients with four reconnected pulmonary veins suffered from persistent AF.

Minor PV reconnection (PV spike visible on  $4 \leq$  bi-poles of the Lasso catheter) was present in 77 out of 86 reconnected veins (89.5%). Major PV reconnection (PV spike visible on  $> 4$  bi-poles of the Lasso catheter) was found in 9 out of 86 reconnected PVs (10.5%).

### Ablation strategy

After evaluating the pulmonary veins the further ablation strategy was planned based on the intraprocedural findings. In 20 patients (with 1-3 reconnected PVs) re-isolation of the recovered pulmonary veins was performed using a segmental approach (group A). In 10 patients, all four pulmonary veins showed recovered PV conduction. In these patients, an anatomically-based circumferential pulmonary vein ablation in combination with a potential-guided segmental approach was performed (group B). In 3 out of 10 patients in group B, an additional linear lesion was created at the LA roof. In 2 patients in group B, catheter ablation of the mitral isthmus was performed. In addition, catheter ablation of the right atrial isthmus was performed in 5 patients in group A and in 2 patients in group B ( $P = 1.0$ ).

The ablation procedure could be performed as planned in all patients. The mean procedure time was

$156 \pm 41$  min; group A:  $147 \pm 32$  min; group B:  $175 \pm 58$  min;  $P = 0.07$ . This included all preparations and a waiting period (20 min) at the end of the procedure for a final reevaluation of the completeness of the pulmonary vein isolation/linear lesions. The mean fluoroscopy dosage was  $2520 \pm 2055$  cGycm<sup>2</sup>; group A:  $2556 \pm 2178$  cGycm<sup>2</sup>; group B:  $2450 \pm 1810$  cGycm<sup>2</sup>;  $P = 0.87$ .

The segmental approach could be performed successfully in all patients in group A. A mean number of  $2.3 \pm 0.8$  PVs were re-isolated per patient. At the end of the procedure the complete isolation of all four pulmonary veins could be documented in all patients using a circumferential mapping catheter.

In group B, an anatomically-based circumferential pulmonary vein ablation in combination with a potential-guided segmental approach was performed successfully in all patients. In this group, all four pulmonary veins could be re-isolated successfully in all patients (documented using a circular mapping catheter).

There were no major complications (*e.g.*, cardiac tamponade, transient ischemic attacks (TIAs) or stroke, significant pulmonary vein stenosis ( $\geq 70\%$ ), periprocedural death) during the procedure in both groups. A transseptal puncture had to be performed in 17 out of 30 patients. In the other patients no transseptal puncture was necessary because of a patent foramen ovale (7 patients) or a residual defect of the atrial septum (6 patients).

### Clinical outcome

The mean follow-up was  $1004 \pm 751$  d in group A and  $821 \pm 435$  d in group B ( $P = 0.53$ ). The mean overall follow-up was  $940 \pm 653$  d. Six months after the redo procedure, 85.0% of the patients in group A (17/20) and 80.0% of the patients in group B (8/10) were free from an arrhythmia recurrence [ $P = 1.0$ ; in total: 25/30 patients (83.3%)]. Twelve month after the repeat ablation procedure, 80.0% of all patients in group A (16/20) were still free from an arrhythmia recurrence compared to 70.0% of patients in group B (7/10;  $P = 0.66$ ). Thus, the overall success rate was 76.7% at 1-year follow-up (no arrhythmia recurrence in 23 out of 30 patients). Two years after the redo procedure, the overall success rate was 73.3% (no arrhythmia recurrence in 22 out of 30 patients). Fifteen out of twenty patients in group A (75.0%) and 7 out of 10 patients in group B (70.0%) were still free from an arrhythmia recurrence ( $P = 1.0$ ).

According to the analysis of the questionnaire, 24/30 patients (80.0%) were completely asymptomatic at 24-mo follow-up. There were no major complications during or after the ablation procedures (including a follow-up duration of 24 mo). Minor complications were observed in 2 patients (pulmonary vein stenosis  $< 70\%$ : 2 patients).

Analysing the clinical course of the patients who experienced an arrhythmia recurrence during follow-up, 7-d Holter monitoring revealed paroxysmal atrial fibrillation in 5 patients and persistent atrial fibrillation in 3 patients. No modification of the antiarrhythmic medication and no repeat ablation procedure was required in 2 patients

with an arrhythmia recurrence because they were almost asymptomatic. In 2 patients with a symptomatic arrhythmia recurrence symptoms could be controlled by modifying the antiarrhythmic drug therapy. Four patients with symptomatic arrhythmia recurrences had to undergo a third ablation procedure.

## DISCUSSION

Catheter ablation has become an important therapeutic option for patients with highly symptomatic and drug-refractory atrial fibrillation. Cryoablation is a safe and effective technique for pulmonary vein isolation<sup>[1,21]</sup>, which is the cornerstone of catheter ablation in patients with paroxysmal or persistent atrial fibrillation. However, there is a significant arrhythmia recurrence rate after cryoablation during midterm follow-up. Catheter ablation with the cryoballoon technique was reported to result in maintenance of sinus rhythm in 74% of patients with paroxysmal AF and in only 42% of patients with persistent AF during a median follow-up of 12 (7-16) mo<sup>[21]</sup>. Therefore, strategies for redo procedures are of major importance. However, there are no established strategies for redo procedures after PV isolation with the cryoballoon technique so far. Currently applied strategies for redo procedures are repeat ablation procedures with the cryoballoon technique and a segmental approach using a standard cryoablation catheter. Repeat ablation procedures with the cryoballoon technique are limited by the fact that the rigid design of the cryoballoon might result in insufficient tissue contact in the same areas during both procedures (thereby triggering further arrhythmia recurrences). Repeat ablation procedures with a standard cryoablation catheter and a segmental approach are mainly limited by the long duration of (repeated) cryoapplications required for creating permanent lesions.

Therefore, we have evaluated two different strategies for redo procedures using radiofrequency catheter ablation. These ablation strategies included either a mere segmental pulmonary vein re-isolation or alternatively an anatomically-based circumferential PV ablation in combination with a potential-guided segmental approach<sup>[19,20]</sup>. The decision about the ablation strategy was based on the extent of pulmonary vein conduction recovery (documented using a circular mapping catheter at the beginning of the redo procedure).

### Main results

During the redo procedures, a mean number of 2.9 re-conducting PVs (SD  $\pm$  1.0 PVs) were detected. In 20 patients, 1-3 re-conducting PVs were detected. There were only 10 patients in whom all four pulmonary veins showed recovered PV conduction. Minor PV reconnection (PV spike visible on 4  $\leq$  bipoles of the Lasso catheter) was present in 77 out of 86 reconnected veins (89.5%). Major PV reconnection (PV spike visible on > 4 bipoles of the Lasso catheter) was found in 9 out of 86 reconnected PVs (10.5%).

In 20 patients (with 1-3 reconnected PVs) re-isolation of the recovered pulmonary veins was performed using a segmental approach (group A). An anatomically-based circumferential pulmonary vein ablation in combination with a potential-guided segmental approach was performed in 10 patients, because recovered PV conduction of all four pulmonary veins was detected in these patients (group B).

Two years after the repeat ablation procedure, 75.0% of all patients in group A (15/20) were still free from an arrhythmia recurrence compared to 70.0% of patients in group B (7/10;  $P = 1.0$ ). The overall success rate was 73.3% at 2-year follow-up. There were no major complications during or after the ablation procedures in both groups.

The results of our study demonstrate that a repeat ablation procedure after initial PV isolation using the cryoballoon technique can be performed safely and effectively using radiofrequency catheter ablation. In most cases only a few re-conducting PV fibres were found and therefore, a segmental re-ablation approach seems to be sufficient in the majority of patients.

There are two major advantages of radiofrequency catheter ablation over cryoablation for redo procedures after pulmonary vein isolation with the cryoballoon technique. First, due to the high degree of variability of the PV anatomy the contact between the cryoballoon catheter and the pulmonary veins cannot be equally good among all parts of the PV ostium. This limitation can be overcome during the redo procedure in most cases because the majority of areas with insufficient tissue contact during the initial procedure with the cryoballoon technique can be easily reached with a standard RF ablation catheter.

Second, the use of radiofrequency energy delivery after prior cryoablation might result in a very stable lesion formation. Although there are no larger studies analysing the histological characteristics in this setting this effect might have contributed to the favourable results of our study. Nevertheless, further studies are necessary to evaluate the histological changes after repeated cryoablation in comparison to lesions created using RF ablation for redo procedures after cryoablation.

### Limitations

This is a single centre study and, therefore, it is of moderate size. However, follow-up was meticulous including repeat three-dimensional transesophageal echocardiography 3 mo after the procedure to rule out a pulmonary vein stenosis. Furthermore, a 7-d Holter monitoring was performed twelve months and twenty-four months after the ablation procedure. The follow-up duration is longer than in many other studies and all patients underwent the final evaluation 2 years after the redo ablation procedure. Therefore, this study provides very reliable information about the long-term outcome of this patient cohort.

Obviously, the extent of pulmonary vein conduction recovery after cryoablation should be evaluated in a larger patient cohort in a future study. A large randomized study

is needed to compare the effectiveness of different strategies for redo procedures after initial pulmonary vein isolation with the cryoballoon technique (*i.e.*, repeat ablation with the cryoballoon technique or a segmental approach using a standard cryoablation catheter, a segmental pulmonary vein re-isolation using a standard irrigated-tip RF ablation catheter and a circumferential ablation strategy using radiofrequency catheter ablation).

In patients with an initial pulmonary vein isolation using the cryoballoon technique, a repeat ablation procedure can be performed safely and effectively using radiofrequency catheter ablation. In most cases only a few re-conducting PV fibres were found and therefore, a segmental re-ablation approach seems to be sufficient in the majority of patients. Alternatively, a circumferential approach can be performed using RF catheter ablation in patients with complete recovery of all four pulmonary veins. Obviously, the results of this study have to be confirmed in a larger randomized trial.

## COMMENTS

### Background

Catheter ablation has become the first line of therapy in patients with symptomatic, recurrent, drug-refractory atrial fibrillation. Cryoablation has been shown to be a safe and effective technique for pulmonary vein isolation.

### Research frontiers

The arrhythmia recurrence rate is high after cryoablation procedures and there are no established strategies for redo procedures in these patients. It is a matter of discussion whether cryoablation should be used for the redo procedures in these patients again or whether radiofrequency catheter ablation might be advantageous.

### Innovations and breakthroughs

The results demonstrate that a repeat ablation procedure after initial circumferential pulmonary vein isolation using the cryoballoon technique can be performed safely and effectively using radiofrequency catheter ablation.

### Applications

The results suggest that radiofrequency catheter ablation is a good therapeutic option for the treatment of recurrences of atrial fibrillation after circumferential pulmonary vein isolation using the cryoballoon technique.

### Terminology

Catheter ablation: interventional technique for the treatment of cardiac arrhythmias. Atrial fibrillation: disorganized atrial arrhythmia which is mostly induced by ectopic beats originating from the pulmonary veins.

### Peer review

Well written, interesting review experience of the authors about the challenges and difficulties of redo-atrial fibrillation ablation.

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