Intra-operative cooled-tip radiofrequency linear atrial ablation to treat permanent atrial fibrillation

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- Permanent atrial fibrillation
- Anti-atrial fibrillation surgery

Aims To demonstrate the safety and efficacy of saline irrigated cooled-tip atrial linear endocardial radiofrequency ablation (SICTRA) concomitant to open-heart surgical procedures in the treatment of permanent atrial fibrillation (AF).

Methods and Results Two hundred and twenty-two patients presenting with permanent AF and the need for cardiac surgery were included. In addition to the cardio-surgical procedure [mitral valve (MV) surgery (n = 94), aortic valve replacement (n = 29), bypass surgery (n = 76 including 24 patients with additional MV surgery), and combined procedures (n = 23)] concomitant SICTRA was performed. In 116 patients, the ablation pattern was restricted to the left atrium alone.

During the mean follow-up of 29 months, 174 patients (78%) converted to sinus rhythm (SR). In patients with SICTRA restricted to the left atrium conversion rates were not different compared to a biatrial approach (83 vs. 74%, P = 0.47). Thirty-days mortality was found to be 4% (9/222). Post-mortem evaluation revealed 23% of all lesions to be histologically non-transmural. In the overall group, only 4% of patients developed sustained secondary regular atrial arrhythmia.

Conclusions SICTRA safely and effectively restores stable SR in 78% of patients with permanent AF undergoing open-heart surgery. Rhythm outcome is not influenced by treatment of the right atrium. Sustained regular atrial arrhythmia with the need for invasive treatment strategies occurs in 4% although intra-operative ablation lesions are often non-transmural.

Introduction

Atrial fibrillation (AF)—due to increasing patient numbers and its prognostic relevance—is recognized as a major health-care problem. Specifically, in patients undergoing cardiac surgery AF predicts worse outcome. Depending upon cardiac pathology, up to 58% of patients (3.5% of all patients) prior to cardiac surgery have documented AF.1–4

Integrating these facts into clinical practise, AF surgery has become more engaged in every-day practise of cardio-surgical centres. The cut-and-sew technique to perform the maze procedure still remains the gold standard for anti-arrhythmic surgery documenting superior efficacy. In order to facilitate and shorten anti-AF procedures, different techniques [radiofrequency- (RF), microwave-, cryo-ablation] to induce linear atrial conduction blocking lesions have been studied. RF ablation is extensively used in invasive electrophysiology and has been established as standard energy source to perform endocardial ablation.3–10

The efficacy of anti-AF procedures still remains under debate because patient-selection, type of AF (permanent vs. paroxysmal), energy-source to induce atrial lesions and lesion pattern influence rhythm outcome. In addition post-operative treatment strategies may determine the success-rates of antiarrhythmic procedures.7–13

We evaluated the efficacy and safety of a concomitant intra-operative cooled-tip RF endocardial atrial ablation approach to treat chronic permanent AF in patients undergoing open-heart surgery.

Methods

Between April 1997 and March 2005, a total of 248 patients (3.6%) out of 6958 presenting for open-heart surgery with a history of AF were identified. Two hundred and twenty-two patients were included in the study having documented chronic permanent AF (lasting longer than 1 year, history of ≥1 failed cardioversion) (Table 1). Twenty-six patients were not included due to paroxysmal character of AF in 21 and persistence of AF less than 1 year in 5 patients. All patients gave informed consent prior to the procedure.

Antiarrhythmic procedure

As a concomitant procedure during open-heart surgery, endocardial atrial saline irrigated cooled-tip radiofrequency ablation (SICTRA) was performed using a standardized lesion set as previously...
In the left atrium (opened via Waterstone’s groove), ostial circular isolation of all pulmonary veins and interconnecting lines was installed. The left atrial appendage was excised (96.8%; n = 215) or suture-closed (3.2%; n = 7) if the appendage could not be mobilized. A connecting lesion to the left superior pulmonary vein and a left atrial isthmus lesion (from the left inferior pulmonary vein isolation line to the mid-portion of the posterior mitral annulus) were added. In the right atrium, a modified Cox-maze-III lesion pattern including ablation lines within the right atrial isthmus and intercaval line was applied (Figure 1).

Endocardial ablation was performed using saline open cooling (up to 320 mL/min) of a 4 mm-tip ablation probe (maximum of 32 W). For continuous endocardial ablation oscillating movements of the probe along the endocardial surface were performed. The ablated atrial tissue was always lifted up during ablation to avoid damage to the mediastinum. Formation of whitish discolouring of the endocardial surface as a subjective criterion for local formation of a sufficient lesion indicated the sign to advance the catheter (Figure 2).

Decision on extent of ablation (biatrial vs. left atrial) was made in the initial phase based on a randomized pattern (total of 120 patients). Later on biatrial ablation was only performed in patients undergoing tricuspid valve surgery (n = 13) and in 33 patients undergoing mitral valve (MV) surgery based on a single surgeon’s preference.

Follow-up

Data were collected until January 2007. The post-operative protocol included medication with metoprolol and oral anticoagulation with coumadin for at least 6 months only stopped if stable sinusrhythm (SR) and biatrial contraction in the absence of prosthetic heart valves were documented. In the initial phase of this study, sotalol (80 mg up to 320 mg/d) or DC-Shock cardioversion were tested in 36 and 35 patients, respectively, but both regimens were terminated because they failed to establish stable SR.

### Table 1 Patient (n = 222) baseline and procedural characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (STD)</th>
<th>Range</th>
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<tbody>
<tr>
<td>Age (year)</td>
<td>68 (9)</td>
<td>37–82</td>
</tr>
<tr>
<td>EF (%)</td>
<td>57 (13)</td>
<td>15–85</td>
</tr>
<tr>
<td>LA dimension (mm)</td>
<td>50 (9)</td>
<td>32–85</td>
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<tr>
<td>Duration of AF (year)</td>
<td>8 (7)</td>
<td>1–40</td>
</tr>
<tr>
<td>EuroSCORE</td>
<td>6.4 (2.1)</td>
<td>2–14</td>
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<tr>
<td>Bypass (min)</td>
<td>167 (36)</td>
<td>75–298</td>
</tr>
<tr>
<td>Aortic clamp (min)</td>
<td>101 (21)</td>
<td>53–164</td>
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</tbody>
</table>

![Figure 1](https://example.com/f1.png) **Figure 1** Schematic view of the right (A) and left (B) atrial incision (Arabic numbers) and ablation (small letters) pattern. (A) Lateral view into the right atrium with excision of the right atrial appendage (1), a perpendicular 3–4 cm incision (2) and a curved incision from the atrioventricular groove to the sulcus terminalis (3), not shown in detail. Ablation lines include cavo-tricuspid isthmus ablation (a), intercaval, (c) and a connecting line transversing the posterior area of the foramen ovale (b). In addition connection ablation lines between medial cut edge of 1 to the tricuspid valve (TV) annulus (d) and between 3 to the TV annulus (e) (CS, coronary sinus ostium; VCI, inferior caval vein; VCS, superior caval vein). (B) View into the left atrium via access in the interatrial groove indicating excision of the left atrial appendage (4) and ablation lines encircling each pulmonary vein ostium (f), interconnecting lines (g), and a connecting line within the left atrial isthmus between the encircling of the left inferior pulmonary vein ostium (LIPV) and the mid-portion of the posterior mitral valve annulus (MV) and between the encircling of the left superior pulmonary vein ostium (LSPV) and 4 (h) (RSPV, right superior pulmonary vein ostium; RIPV, right inferior pulmonary vein ostium).

![Figure 2](https://example.com/f2.png) **Figure 2** Left atrial SICTRA-lesion. (A) Intra-operative view of a left atrial ablation lesion (l) with whitish discolouring of the surface. (B) Pathomorphological cross-section through a left atrial isthmus lesion (arrows indicate hemorrhagic border zone) with undamaged myocardium in the depth (asterisk). (C) Histological specimen of a left atrial isthmus lesion (arrows indicate border zone) with viable myocardium along an intramural vessel (asterisk).
Follow-up constituted of clinical evaluation (every 12 months), 12-lead ECG (12 days post-operatively, after 3, 6, 12 and every 12 months until SR was documented), holter-ECG (at 6 months), and trans-thoracic Doppler-echocardiography (at 6 months). Primary endpoint was occurrence of SR on ECG during routine follow-up. In holter-ECG analysis, recurrent AF was defined as atrial tachycardia without detectable P-waves and irregular R-R intervals lasting longer than 30 s.

Attrial contraction pattern—indicated by demonstration of biphasic flow profile—was determined during trans-mitral (left atrial) and trans-tricuspidal (right atrial) Doppler echocardiography at 6 months.

Sustained secondary arrhythmia was defined as regular atrial tachycardia lasting at least 3 months or recurring after successful cardioversion. These patients underwent invasive electrophysiology to determine the genesis of the arrhythmia and attempt transvenous catheter ablation.

Patients, who died during the initial hospitalization phase, were autopsied and histological evaluation on intra-operatively ablated atrial regions was performed. Transmurality was assessed as depth of detectable thermal damage in relation to wall thickness (complete transmurality correlates to thermal damage detected in the epicardial region).14

Statistical analysis
All variables are given as mean ± standard deviation. Mortality and rhythm-conversion rates were calculated by Kaplan–Meier method and inter-group differences were compared using Log-rank test. Patients who died prior to converting to SR were accounted for as remaining in AF. A two-sided P-value of <0.05 was considered statistically significant difference.

Results
Concomitant SICTRA to treat permanent AF (mean duration 8 ± 7 years) was added to MV reconstruction (n = 45), MV replacement (n = 49), aortic valve replacement (n = 29), CABG (n = 76 including 24 with additional MV surgery), and combined procedures in 23 patients (10 MV plus aortic valve replacement, 11 MV surgery plus tricuspid valve reconstruction, and 2 CABG plus MV replacement plus tricuspid valve reconstruction). SICTRA was successfully performed in all 222 patients either in the right and left atrium (bilateral SICTRA in 106) or restricted to the left atrium in 116 patients (Table 2). The aortic clamp time was 101 ± 21 vs. 99 ± 22 min (P = 0.59). Additional clamp time for the anti-arrhythmic procedure itself was 15 to 19 min.

Rhythm outcome
During follow-up (median 21 months, 1 through 108), overall 174 (78.4%) patients converted to SR. After conversion to atrial paced rhythm (n = 222) at the end of surgery, 157 (70%) patients converted back to AF within the first 12 days after surgery (65 out of 215 available patients in SR). With ongoing follow-up patients converted spontaneously to SR (98% spontaneous, only three patients after DC-shock cardioversion remained in long-term SR) ranking up to a cumulative 12 months SR-percentage of 81.5% (Figure 3).

At 6 months holter-ECG analysis, 76% (142/188) of patients had stable SR without atrial arrhythmia longer than 30 s, 9 patients (4.8%) (including 1 with SR at follow-up ECG) had SR with episodes of atrial arrhythmia (>30 s) classified as AF.

Grouped by the performed extent of the antiarrhythmic procedure (bilateral vs. left atrial alone SICTRA) cumulative 12 months SR rates were 78.2% (overall 78 out of 106 in SR) and 83.9% (overall 96 out of 116 in SR) without statistically significant differences (P = 0.16).

Overall cumulative 12 months SR-rates grouped by performed cardio-surgical procedures were: MV replacement 78.8% (overall 35/49 in SR), MV reconstruction 71.8% (34/45), CABG overall 80.4% (60/76) [CABG plus MV surgery 81.0% (19/24)], aortic valve replacement 82.4% (25/29), and combined procedures 73.7% (15/23) (Table 2). A tendency towards lower rhythm outcome was found in the group of patients with combined procedures compared to CABG-procedures (P = 0.05).

Echocardiography
At 6 months follow-up, 88% of patients in SR were available for trans-thoracic Doppler-echocardiography studies (126/143). In 82% (103/126), a biatrial contraction could be documented, whereas only right atrial contraction was seen in

![Figure 3](https://academic.oup.com/eurheartj/article-abstract/28/23/2909/520378/figure3)

**Figure 3** Kaplan–Meier curve of occurrence of SR during follow-up and 95% confidence interval plot (light grey lines) ranking up to a 12 months cumulative percentage of SR of 81.5% (95% confidence interval, 76.2–86.8%) (patients in SR and patients at follow-up indicated in total numbers).
11% (14/126) and no atrial contraction was found although SR was documented on ECG in 7% (9/126).

**Mortality, autopsy evaluation, and adverse events**

Nine patients died within 30 days post surgery (30 day mortality 4.1%) due to cardiac pump failure (n = 7), cerebral stroke (n = 1), and sepsis (n = 1). An additional 21 patients died in between 6 weeks and 33 months (12 months cumulative survival 89.4%) including 8 patients with Coumadin associated bleeding, mediastinitis in 5, sudden cardiac death in 2, endocarditis in 2, and unknown cause in 4 patients.

No procedure-related deaths were documented during autopsy of the 9 patients who died during their initial hospital stay (2 to 24 days postoperatively). Histologically complete transmurality was documented in 77% (48/62) of all studied intra-operatively applied lesions (11% (1/9) in the left atrial isthmus; 94% (34/36) in the pulmonary vein ostial lesions; 100% (9/9) of lesions across the posterior left atrium; 50% (4/8) right atrial lesions (Figure 2). No thrombotic deposits were detected upon the endocardial surface of ablation lesions.

Symptomatic bradycardia implementing the need for permanent pacemakers was documented in 10 patients (4.5%) after a mean of 5 ± 2 (1–12) months (sinus node dysfunction in 5 and atrioventricular-conduction disturbance in 5). Eight percent of pacemaker patients (8/10) were in SR at their last follow-up visit.

Nine patients (4.1%) presented with sustained secondary arrhythmia after a mean of 12 ± 7 months. Invasive evaluation demonstrated typical right atrial flutter in four (successful transvenous catheter ablation in all four; all patients after left atrial alone SICTRA), right atrial ectopic tachycardia in one (successful catheter ablation), incisional right atrial macroreentry in one (successful catheter ablation), and left atrial tachycardia in three patients (successful catheter ablation in one, patient with atrioventricular nodal ablation, one patient in SR under additional amiodarone medication). Incisional tachycardia was documented to be the electrophysiological mechanism in three patients.

**Discussion**

This is the first report on anti-AF surgery performed using endocardial cooled-tip radiofrequency ablation (SICTRA) in a large patient collective heterogeneous in regard to the underlying cardiac pathology but homogenous in regard to the treated cardiac arrhythmia (permanent AF) and postoperative antiarrhythmic treatment regimen. In 78% of all patients, stable SR was re-established after long-lasting permanent AF producing a biatrial contraction pattern in 82% of patients studied in SR.

**Rhythm success**

The documented rhythm-success rate of 78% stable SR is comparable to data published by different groups using intra-operative RF ablation documenting SR in between 73% up to 90%.6,9,15 Rhythm success is related to the type of AF (paroxysmal vs. permanent) and whether the anti-AF surgery was performed on a concomitant procedure.16 To this regard, the patients studied at our institution present the group with the lowest rhythm success rates (permanent AF, concomitant SICTRA).

Whereas Cox et al. reported superior efficacy applying the cut-and-sew Cox-maze-III-procedure (97–99% conversion rate), others have reported rhythm-success rates to be as low as 72% specifically in patients undergoing MV surgery.17 Comparing the efficacy of the classical cut-and-sew maze technique to RF ablation modified anti-AF procedures, no significant difference when adjusted for type of AF and concomitant surgery (78.3 vs. 84.9% SR rates) was revealed.16 Compared to the cut-and-sew maze, antiarrhythmic procedures modified by intra-operative RF ablation are less time-consuming and appear easier to apply. Long-term rhythm success needs to be established with ongoing follow-up experience.

Differing to rhythm success that directly occurs after cut-and-sew maze techniques, SR is re-established with delay after SICTRA procedures. Usually, within the first six post-operative months SR spontaneously occurs. This spontaneous late rhythm success (30% in SR at discharge, 62% at 3 months, and 76% at 6 months follow-up) determines the postoperative antiarrhythmic treatment regimen. At our institution, studies have documented the uselessness of DC-shock cardioversions within this time-period. Only three patients remained in stable SR after successful cardioversion and 32 converted back into AF within 1 month afterwards. In addition, specific antiarrhythmic medication-like sotalol exhibits no superior conversion properties compared to simple β-blocking agents.13 The concept at our institution is to wait under β-blocking therapy for SR within a 6 months ‘blanking’ period. Afterwards cardioversion, attempts and specific antiarrhythmic medication may be appropriate in patients still in AF.10–13

While the process of spontaneous late conversion is also documented in transcatheter pulmonary vein isolation procedures for AF, the mechanism still remains debatable.12,18 Whereas complete formation of the ablation lesions producing late complete transmurality may be one factor histological analysis documented non-transmural lesions in 23% of all applied ablation lines even though SR was documented in all studied patients who died early. Still the question remains on how much transmurality is needed to achieve rhythm success. Late neuronal remodelling after endocardial ablation may lead to altered autonomic innervation influencing rhythm conversion. Ablation in the ostial region of the pulmonary vein orifice induces thermal damage of nerves.14 Ongoing studies determine the impact of neural remodelling on rhythm success in the surgical treatment of AF.

**Atrial contraction**

Whereas re-establishing SR may lead to better rate control, the need for anticoagulation treatment and haemodynamics mostly depend upon atrial contraction. In our patient, collective 82% of patients with documented stable SR display a biatrial contraction pattern documented on transthoracic echocardiography. These results are in accordance with published data indicating biatrial contraction in 65% up to 100% of patients in SR after biatrial antiarrhythmic surgery.5,19 Only patients with stable SR, left atrial contraction, and no prosthetic heart valve implanted may be taken off anticoagulation therapy. So far 61 patients (all with excised
left auricle) were taken off anticoagulation without any signs of thrombo-embolic complications. Further studies need to evaluate the safety of pausing anticoagulative therapy in patients after successful anti-AF procedure. As a consequence of restored SR, left atrial dimensions decrease indicating positive effects on atrial remodelling.

### Influence of lesion pattern and surgical procedure

In our patient, collective SICTRA was restricted to the left atrium in about half of the patients. No difference in regard to rhythm outcome was documented obviating the need for additional right atrial ablation in the therapy of AF. This concept has been adapted by others in surgical AF-therapy and catheter ablation techniques to treat AF confirming these results. In our experience, typical right atrial flutter is the most common secondary regular arrhythmia in patients after left atrial only SICTRA (3.4% of all patients after left-atrial SICTRA) easily treated by catheter ablation. To avoid this complication though a right atrial isthmus ablation line may be acceptable.

In addition, the fact that only 50% of right atrial lesions displayed transmural damage might have influenced the rhythm outcome results. If ablation in the right atrium consistently produced transmural lesions, the effect of additional right atrial ablation lines may increase rhythm conversion.

Rhythm success was comparable when patients were grouped by the performed cardio-surgical procedures ranking in between 65 up to 83%. Whereas the lowest conversion rates were observed in combined procedures and MV surgery patients (65–76%) rhythm success was higher in CABG and aortic valve replacement patients (79 up to 83%). These results are confirmed by data obtained after antiarrhythmic-procedures documenting SR rates of 80% in patients after CABG and/or aortic valve surgery.

Patients not converting to SR during the study period had larger left atrial dimensions but duration of AF did not have influence on rhythm success. If patients had left atrial dimensions above 50 mm, the cumulative SR-percentage was significantly lower compared to patients with smaller left atria (67% vs. 83%; \( P = 0.02 \)). In general with increments of left atrial dimensions relative rhythm success becomes increasingly lower (3% relative lower efficacy per 1 mm larger left atrium) but no cut-off value for left atrial dimension predicting high rates of not successful antiarrhythmic procedures can be determined.

### Histological evaluation of ablation lesions

In patients who died during the initial hospital stay (\( n = 9 \)), autopsy and histological evaluation of the lesion morphology was obtained. Seventy-seven percent of all studied lesions were transmural but lesions within the thick myocardial layer of the left atrial isthmus were transmural in only one case (11%). Even though non-transmural lesions appear to occur often, left atrial secondary incisonal tachycardia occurs rarely (1.3%). The subjective criterion used in our experience (whitish superficial discolouring) to determine completeness of lesion formation during ablation only predicts complete transmurality in 77% of the lesions. Adapting energy output to the thickness of the underlying myocardial layer may help create more complete lesions even though the effect on long-term rhythm success is unclear.

In contrast to unipolar ablation, bipolar RF ablation techniques provide consistent transmurality of ablation lesions. Due to handling of the bipolar ablation probes (forceps), electrical exclusion of the pulmonary veins may be achieved during epicardial ablation without accessing the left atrium but establishing consistent intra-atrial linear lesions may be difficult. In our experience, treatment of permanent forms of AF implies complex intra-atrial linear ablation patterns that are easier to perform using endocardial unipolar ablation pens. So far no studies indicating differences in efficacy or safety of the two-ablation techniques exist. Epicardial ablation may be favoured in patients with paroxysms of AF—mostly due to focal ectopic firing—impeding the need for intra-atrial ablation.

### Adverse events/mortality

The early mortality (4.1%) in a patient collective with a EuroSCORE of 6.4 is below the expected mortality rate. There seems to be no added risk when performing a concomitant SICTRA procedure even though a mean of 17 min is added to the aortic clamp time. Restriction towards a limited left atrial approach can be favourable in patients with longer surgical procedures. Some studies have shown a favourable effect of re-established SR on postoperative survival compared to patients who remained in AF. Recovered SR implements a lower risk for stroke and cardiac events. Larger trials need to analyse the prognostic value of anti-AF surgery.

No SICTRA-related complications such as esophageal or circumflex artery damage—as documented with other forms of intra-operative radiofrequency ablation—were encountered. In autopsy, no damage to mediastinal organs was documented. A possible explanation for this discrepancy to other reports may be the specific technique lifting up the atrial tissue from the underlying mediastinum during ablation preventing ‘collateral’ damage.

The rate of implanted pacemakers in our patient cohort (4.5%) is comparable to published data on different types of antiarrhythmic procedures (3.5–15%; 5, 6, 9). There is no difference in regard to pacemaker-dependent bradycardia in patients undergoing ablation-modified anti-AF surgery or classical cut-and-sew technique surgery (4.9 vs. 5.8%).

### Limitations

In our patient collective rhythm success was documented based on serial ECG recordings and one-time holter-ECG during follow-up. This procedure may underestimate the occurrence of transient, asymptomatic episodes of AF. Documentation of atrial contraction though indicates stabilized atrial mechanical function implementing stable electrophysiology. Long-term follow-up studies need to evaluate possible late reoccurrence of AF and determine stability of SR using long-term holter-ECG recordings.

In conclusion, SICTRA as a concomitant procedure to treat permanent AF in patients undergoing different open-heart surgical procedures is safe and effective in restoring SR and atrial contraction. The efficacy of the SICTRA procedure is not influenced by the performed cardio-surgical procedure. A left atrial alone approach appears sufficient to establish SR in most of the patients. A postoperative therapeutic regimen including regular ß-blocking agents without
specific antiarrhythmic treatment (no antiarrhythmic drugs, no DC-shock cardioversion) is sufficient and leads to spontaneous conversion to stable SR in 76% of patients. By implementing intra-operative visual estimate of ablation lesion completeness (superficial whitening of endocardium), histologically transmural lesions are achieved in 77%. Difficulties inducing transmural thermal damage can be observed in areas with thick atrial muscular tissue (left atrial isthmus) but incisional sustained regular atrial tachyarrhythmia rarely occur.

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References