Long-Term Outcome After Ablative Therapy of Postoperative Atrial Tachyarrhythmia in Patients With Congenital Heart Disease and Characteristics of Atrial Tachyarrhythmia Recurrences

Natasja M.S. de Groot, MD, PhD; Jael Z. Atary, MD; Nico A. Blom, MD, PhD; Martin J. Schalij, MD, PhD

Background—Catheter ablation has evolved as a possible curative treatment modality for atrial tachyarrhythmia (AT) in patients with congenital heart defects (CHD). However, data on long-term outcome are scarce. We examined characteristics of recurrent AT after ablation of postoperative AT during long-term follow-up in CHD patients.

Methods and Results—CHD patients (n = 53; 27 men; age, 38 ± 15 years) referred for catheter ablation of AT were studied during a follow-up period of 5 ± 3 years. After ablative therapy of the first AT (n = 53, 27 atrial flutter, cycle length = 288 ± 81 ms; 22 intra-atrial reentrant tachycardia, cycle length = 309 ± 81 ms; 5 focal atrial tachycardia, cycle length = 380 ± 147 ms; success rate, 65%), AT recurred (59% within the first year) in 29 patients; 15 underwent repetitive ablative therapy. Mechanisms underlying recurrent AT were similar in 7 patients (intra-atrial reentrant tachycardia, 2; atrial flutter, 5). The location of arrhythmogenic substrates of recurrent AT (intra-atrial reentrant tachycardia, focal atrial tachycardia) was different for all but 1 patient. After 5 ± 3 years, 5 patients died of heart failure, 3 were lost to follow-up, and the remaining patients had sinus rhythm (n = 31), AT (n = 5), or atrial flutter (n = 14). Antiarrhythmic drugs were used by 18 (57%) sinus rhythm patients.

Conclusions—Successive postoperative AT in CHD patients developing over time may be caused by different mechanisms, including focal and reentrant mechanisms. Recurrent AT originated from different locations, suggesting that these new AT were not caused by arrhythmogenicity of previous ablative lesions. Long-term outcome is often complicated by development of atrial fibrillation. Despite frequent need for repeat ablative therapy, most patients are in sinus rhythm. (Circ Arrhythm Electrophysiol. 2010;3:148-154.)

Key Words: atrial tachyarrhythmias • congenital heart disease • catheter ablation

Atrial tachyarrhythmia (AT) occurring late after cardiac surgery for congenital heart disease (CHD) or acquired heart disease is associated with hemodynamic deterioration, increased risk of thromboembolism, and cardiac death.1-5 Management of postoperative AT with antiarrhythmic drugs is often not successful and accompanied by side effects.1,5-8 In recent years, catheter ablation has evolved as a feasible curative treatment modality for these AT.9-16 Because the arrhythmogenic substrate in patients with prior cardiac surgery is often complex detailed mapping before ablation is essential for successful ablative therapy.17,18

Clinical Perspective on p 154

The first studies of ablative therapy of postoperative AT described ablation procedures using only fluoroscopy. During these procedures, multiple catheters were often required to comprehend the mechanism of the AT. Technological advancement over the years resulted in introduction of 3D electroanatomic mapping techniques such as the CARTO system.19,20 By visualizing the electric activation of the heart chamber mapped in a 3D reconstruction, these systems are able to facilitate ablative therapy. Since their implementation, numerous articles reported on the outcome of ablative therapy of postoperative AT.10,12,21-26 However, data of long-term outcome are scarce,25,26 and there is a lack of information about characteristics of successive postoperative AT for individual patients.

The aim of this study was to evaluate long-term outcome after ablation of late postoperative AT and to examine characteristics of recurrent AT in a large cohort of patients with predominantly complex congenital heart defects.

Methods

Study Population

The study population consisted of 53 consecutive patients with congenital heart disease and postoperative, drug refractory AT referred for ablation to our center between 2000 and 2004. Data

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regarding congenital defects and surgical history were obtained from hospital records. The first visit to the outpatient clinic was 4 weeks after ablation. After this visit, patients were seen every 6 months. Evaluation before ablation and during the follow-up period included history, physical examination, ECG, Holter monitoring, and echocardiographic examination.

**Mapping Procedure**

Mapping was performed using a 3D electroanatomic mapping system (CARTO Biosense-Webster, Diamond Bar, Calif). A detailed description of the underlying technology of electroanatomic mapping has been given previously,19,20 A 7F Navistar (4-mm tip, 2 bipolar electrode pairs, interelectrode distance 2 mm, Biosense-Webster) was used for mapping and ablation. Bipolar electrograms were filtered at 10 to 400 Hz. A bipolar atrial electrogram recorded by a 6F diagnostic catheter (Biosense-Webster) positioned in the right atrium served as a temporal reference. A sensor taped on the back served as a location reference.

If AT was not present at the onset of the procedure, it was induced using programmed electric stimulation. Three-dimensional bipolar activation and voltage maps were constructed during AT to (1) identify the underlying mechanism and (2) select target sites for ablation. Stability parameters (variability in cycle length [CL], local activation time, and beat-to-beat difference of the catheter location) were used to exclude signals with low amplitudes caused by poor contact of the catheter tip with the endocardial wall. The local activation time was determined by automatically marking the maximum amplitude of each bipolar potential.

If necessary, markings were adjusted manually. The peak-to-peak amplitude of bipolar electrograms was used to construct color-coded voltage maps. In the case of fractionated potentials, the peak-to-peak amplitude of the largest deflection was measured. Areas of scar were delineated using a cutoff value of 0.1 mV.18

**Classification of AT**

Based on activation maps, 3 different types of AT were distinguished: (1) typical atrial flutter (AFL): a single (counter)-clockwise, cavotricuspid isthmus–dependent macroreentrant circuit, (2) intraatrial reentrant atrial tachycardia (IART): a macroreentrant tachycardia involving scar tissue, suture lines, or prosthetic materials, (3) local AT (FAT): electric activation originating from a small, circumscribed region from where it expands to the remainder of the atria.

**Ablation Procedure**

After mapping, a radiofrequency catheter ablation procedure was performed. At each site, radiofrequency current was applied for 60 seconds. In the case of noncooled ablation, tip temperature was set at 70°C and the maximum output at 50 W. During ablation, using an irrigated-tip catheter (19% of the procedures), temperature was limited to 45° to 50°C and power to 40 to 45 W, with saline flow of 20 mL/min. Each lesion was tagged on the electroanatomic map. Success was defined as (1) in AFL patients, establishment of a line of conduction block over the cavotricuspid isthmus and (2) in IART/FAT patients, termination during ablation.

**Statistical Analysis**

Data were expressed as mean value±SD or median (range). Statistical significance was defined as P<0.05. A 1-way ANOVA test was used to compare fluoroscopy time and procedure time required for ablation of different types of tachycardia. Survival free from arrhythmia recurrence was analyzed by method of Kaplan-Meier with corresponding log-rank test for differences in distribution between the curves. The 2 groups were defined as patients who underwent a successful ablation procedure and patients in whom ablation was not successful.

**Results**

**Characteristics of the Study Population**

The study population consisted of 53 patients (27 men; median age, 35 [6 to 80] years). Major common congenital heart defects included transposition of the great arteries (n=4), univentricular heart (n=15), ventricular septal defect (n=2), coarctation of the aorta (n=2), atrial septal defect (n=11), tetralogy of Fallot (n=10), or valvular heart disease (n=9). Characteristics of the study population are given in the Table.

**Time to Postoperative AT and First Intervention**

Figure 1 shows age at (1) the time of the first surgical procedure, (2) the onset of the AT, and (3) the first ablation procedure. Patients are grouped according to major common congenital defect; the groups are ranked according to the earliest averaged age at time of cardiac surgery. Age at time of the first surgical procedure ranged from 0 to 55 (median, 7) years. Median age at onset of AT was 31 (4 to 73) years; AT developed 18 (6 months to 44) years after the first surgical intervention. The first ablation procedure was performed at the median age of 38 (6 to 80) years. On average, median time between the onset of AT and the first ablation procedure was 4 years.

**Outcome of First Ablation Procedure**

In the entire study population, mapping revealed 27 AFL (CL=288±81 ms), 22 IART (CL=309±81 ms), and 5 FAT (CL=380±147 ms) at the first ablation procedure.

In 1 patient, 2 AT were eliminated during the same procedure. Successful ablation therapy was achieved in 65% (n=35) of all AT; 20% (n=11) of AT did not terminate, and the other AT converted to either another AT (n=4, 7%) or atrial fibrillation (AF) (n=4, 7%) during ablation.

In the case of AFL, termination during ablation and assessment of a bidirectional conduction block over the cavotricuspid isthmus was achieved in 67% (n=18). Despite

### Table. Characteristics of the Study Population

<table>
<thead>
<tr>
<th>CHD (n, Sex)</th>
<th>Surgical Procedures</th>
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<tbody>
<tr>
<td>TGA (n=4, 3 male)</td>
<td>Mustard procedure</td>
</tr>
<tr>
<td>UVH (n=14, 7 male)</td>
<td>Fontan procedure (atriopulmonary conduit, n=11)</td>
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<tr>
<td>Video (n=2, 1 male)</td>
<td>Mustard operation followed by Jatene procedure (n=1)</td>
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<tr>
<td>Ebstein anomaly (n=1, 1 male)</td>
<td>Conduit left ventricle to pulmonary artery (n=1)</td>
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<td>ASD (n=11, 5 male)</td>
<td>Blalock shunt (n=1)</td>
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<tr>
<td>ToF (n=10, 5 male)</td>
<td>Glenn shunt and ASD closure (n=1)</td>
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<tr>
<td>VHD (n=9, 5 male)</td>
<td>Surgical closure defect</td>
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<tr>
<td>CoA (n=2, 2 female)</td>
<td>Resection stenotic part and interposition of a graft</td>
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<td>CVA (n=9, 5 male)</td>
<td>Total correction (n=9)</td>
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<tr>
<td>VSD (n=8, 4 male)</td>
<td>Closure VSD and creation Blalock-Taussig shunt (n=1)</td>
</tr>
<tr>
<td>ASD (n=11, 5 male)</td>
<td>Valve replacement (n=8)</td>
</tr>
<tr>
<td>CoA (n=2, 2 female)</td>
<td>Surgical valvotomy (n=1)</td>
</tr>
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</table>

TGA indicates transposition of the great arteries; UVH, univentricular heart; VSD, ventricular septal defect; CoA, coarctation of the aorta; ASD, atrial septal defect; ToF, tetralogy of Fallot; and VHD, valvular heart disease.
Entrainment demonstrating cavotricuspid isthmus–dependent conduction, 18% (n=5) of the AFL did not terminate during ablation. Conversion from AFL to AF during ablation occurred in the other 15% (n=4). In those patients, a bidirectional conduction block was assessed after electric cardioversion to sinus rhythm.

Fifty-five percent of the IART terminated during ablation; conversion from IART to another regular AT or AF occurred in, respectively, 14% (n=3) and 5% (n=1). Target areas for ablation of IART were located between (1) areas of scar tissue (n=20) and (2) scar tissue areas and the inferior caval vein (n=2). The critical path of the reentrant circuit was located in the left atrium in only 3 patients. In 27% (n=6), AT did not terminate during ablation despite extensive mapping.

All FAT (n=5) were successfully eliminated by ablation at the site of earliest activation. The majority of the FAT also originated from the right atrium; 1 FAT emerged from the left side of the interatrial septum.

Recurrent AT
Mean follow-up after the first ablation procedure was 5±3 (2.5 to 9) years. AT recurred in 29 patients, and 15 of them underwent therefore more than 1 ablation procedure. Time between ablative therapy and recurrences of AT are shown in Figure 2. Recurrences after the second ablation procedure occurred in 7 patients. In 1 patient, 9 different AT were ablated during a follow-up period of 6 years (not shown). As

Figure 1. Age at the time of the first surgical procedure, onset of the AT, and first ablation procedure for each patient separately. Patients are grouped according to major congenital/acquired heart disease and groups are ranked according to the earliest averaged age at time of cardiac surgery. TGA indicates transposition great arteries; UVH, univentricular hearts; VSD, ventricular septal defects; CoA, coarctation of the aorta; ASD, atrial septal defect; ToF, tetralogy of Fallot; VHD, valvular heart disease.

Figure 2. Long-term time interval between ablative therapy and recurrences of AT. Twenty-nine patients had 1 or more recurrences.
demonstrated in Figure 2, most AT often reappeared within the first year after ablative therapy.

Mechanism and Location of the Arrhythmogenic Substrate of Recurrent AT
Figure 3 shows schematic representations of the atria demonstrating the location of the arrhythmogenic substrate of recurrent IART and/or FAT for patients undergoing repetitive ablative therapy (n=15); patients with recurrent AFL (n=5) are not shown. The mechanism underlying the AT is represented by a symbol and the number indicates the order of recurrences. The outcome of the ablation procedure is represented by the color of the symbol (green: elimination of the AT; red: unsuccessful ablation procedure). In 7 patients with recurrent AT, the underlying mechanism of successive AT was similar—either IART (n=2) or AFL (n=5). Eight patients presented with successive AT caused by different mechanisms, including IART+FAT (n=3), AFL+FAT (n=1), IART+AFL (n=2), AFL+FAT+AF (n=1), or IART+FAT+AF (n=1). Interestingly, the reentrant circuit of IART or the origin of an FAT of consecutive AT was different for the majority of the patients. In 1 patient, the crucial pathway of the reentrant circuit of 2 successive IART was located between the inferior caval vein and the atriotomy scar (first patient in the upper panel).

Long-Term Outcome
During the follow-up period, a total of 77 catheter ablation procedures were performed. In 4 patients, 2 AT were eliminated during the same procedure. Eighty-one distinct AT (29 incessant) were mapped and treated with ablative therapy. In the entire study population, mapping revealed 34 AFL (CL=372±99 ms), 32 IART (CL=275±75 ms), 13 FAT (CL=307±76 ms), and 2 “focal” AF. Ablative therapy was successful in 69% of all AT; 19% of AT did not terminate and the other AT converted to either another AT (5%) or AF (7%) during ablation. Fluoroscopy time during mapping and ablation of IART (55±26 minutes) was significantly longer than during AFL (42±27 minutes) or FAT (40±25 minutes) procedures, P=0.03. The procedure time required for ablative therapy of IART was also longer (300±100 minutes, compared with AFL: 229±76 minutes, FAT: 211±66 minutes, P=0.001).

The relation between the results of the ablation procedure and long-term outcome is demonstrated in Figure 4. During last follow-up visit of the 50 patients excluding 3 subjects lost for follow-up, they had either sinus rhythm (n=31, 59%), a regular AT (n=5, 9%), or AF (n=14, 26%). Five patients died of progressive heart failure 34±28 months after the ablation procedure; rhythm before death was sinus rhythm (n=2) and AF (n=3).

Paroxysms of AT were recorded in 12 sinus rhythm patients who underwent a successful ablation procedure. Antiarrhythmic drugs were used by 18 patients with sinus rhythm. Persistent AF developed during the follow-up period in 14 patients. Seven patients had AF despite a successful ablation; in the other 7 patients, AF resulted from progression of AT to AF. Eleven of the 19 patients with an unsuccessful ablative therapy had persistent AT at the onset of the ablation procedure. Surprisingly, 7 patients who had 1 or more unsuccessful ablation procedures (no termination during ablation, conversion to AF or another AT) remained in sinus rhythm during the follow-up period.

Discussion
This study reports on characteristics of recurrent AT after ablative of late postoperative AT during long-term follow-up in a large cohort of patients with predominantly complex congenital heart defects.

The majority of the ablation procedures were guided by 3D electroanatomic mapping techniques enabling accurate localization of the arrhythmogenic substrate. The key findings of our study are that though ablative therapy of postoperative AT is most often successful, a large number of patients
presented with recurrent AT. However, repeated ablative therapy of recurrent AT was effective in maintaining sinus rhythm in most of the patients. Because the arrhythmogenic substrate of patients who had multiple ablation procedures was located at different atrial sites, it is most likely that recurrent AT are the result of diffuse electropathological alterations of atrial tissue and/or progressive atrial myopathy instead of arrhythmogenicity of prior ablative lesions. Despite recurrent AT in many patients, the majority of the study population was in sinus rhythm at the end of the follow-up period.

AT Mechanism

The mechanism underlying late postoperative AT in our study population was variable; often AFL and IART, less frequently FAT, and rarely focal AF. In a large number of patients, different mechanisms gave rise to successive AT.

Consistent with other reports on the mechanism underlying postoperative AT in patients with CHD, IART and AFL were most often observed.8,27

FAT were less frequently observed. We previously demonstrated that FAT arise mainly from areas where conduction is abnormal.28,29 The atria of patients with CHD contain areas of fibrotic tissue, giving rise to local dissociation in conduction and hence favor development of focal activity.30,31 Reports on focal AF in CHD patients are rare, and the mechanism underlying this AT in our patient population has recently been described in detail.28,29

Ablative Therapy

Most ablation procedures performed in this study population were guided by a 3D electroanatomic mapping system. Triedman et al32 demonstrated the beneficial effect of an electroanatomic mapping system over a conventional, fluoroscopy-based mapping technique on the outcome of ablative therapy of postoperative AT. However, compared with their ablation results, in our study 28% of the IART did not terminate during ablation despite the use of a 3D electroanatomic mapping technique. This outcome emphasizes that ablation of IART remains very difficult despite facilitating mapping techniques.

Crucial pathways of the reentry circuit of most IART were located between areas of scar tissue, indicating necessity of accurate delineation of low-voltage areas.18 In patients who had multiple ablation procedures, target sites for ablation of successive AT were located at different atrial sites, suggesting that new AT were not caused by arrhythmogenicity of previous ablative lesions. Most recurrences occurred in the first year after ablative therapy.

As the reentry circuit of postoperative AT in patients with CHD often consist of multiple reentrant pathways, a new reentry circuit may develop after ablation giving rise to early recurrences. Also, these new AT may simply be the result of diffuse electropathological alterations of the atrial tissue. Late recurrences also indicate progression of atrial myopathy.

After successful elimination of the AT, we did not induce other AT. It can be hypothesized that the incidence of redo procedures can be reduced by additionally ablating other inducible AT. However, low-voltage areas and prosthetic materials are present throughout the atria, and multiple reentry circuits may therefore be possible. Extensive ablation at different sites in the atria would be required to eliminate additional IART (with unknown clinical relevance). This might increase the chance of constructing incomplete lesions, which may in turn be proarrhythmic.

Another interesting finding is that in some patients who had several ablation procedures, mapping revealed different mechanism underlying the AT, for example, an IART during the first ablation procedure and a FAT in the next procedure. To our knowledge, the presence of different mechanisms underlying consecutive AT in patients with CHD has so far not been reported.

Surprisingly, despite some unsuccessful ablation procedures (no termination or conversion to another AT or AF), patients converted to sinus rhythm after the ablation procedure and remained in sinus rhythm during the follow-up period.

Atrial Fibrillation

At the end of the follow-up period, 26% of the patients had AF. Kirsh et al33 demonstrated that AF is not an uncommon AT in CHD patients. In some of our patients, AF resulted from progression of recurrent AT. Experimental mapping studies have demonstrated that a single macroreentrant circuit may degenerate to AF if atrial tissue cannot be activated at a high activation rate and fibrillatory conduction occurs consequently.34 In line with these experiments, we have previously reported on focal activity giving rise to fibrillatory conduc-
tion in 2 patients with CHD. However, AF developed in 7 patients despite successful elimination of the AT by ablative therapy, suggesting that different mechanisms causing AF in this patient group may be involved. Further studies in larger populations are required to gain insight into the mechanism of AF in this patient group.

**Conclusion**

**Focal and Reentrant Mechanisms Underlie Late Postoperative AT in Patients With CHD**

Successive AT developing over time may be caused by different mechanisms. The complexity of the reentrant circuit is associated with the complexity of the CHD and corresponding extensiveness of surgical procedures. In patients who had multiple ablation procedures, the AT originated from different atrial sites, suggesting that these new AT were not caused by arrhythmogenicity of previous ablative lesions. Recurrent AT occurred frequently after successful ablation and occurred mainly in the first year after treatment. The long-term outcome is often complicated by development of AF. However, the majority of the patients were in sinus rhythm.

**Study Limitations**

Holter monitoring was not consistently performed in every patient to determine the incidence of AT after ablative therapy. However, the majority of the CHD patients with an AT recurrence immediately visited the hospital because of symptoms. Data in this study are based on only 15 of 29 patients with recurrent AT who underwent more than 1 ablation procedure.

During the mapping procedure, crucial pathways of reentrant circuits were mainly selected by analyzing electroanatomic activation maps. Entrainment techniques could not always be used as pacing in low-voltage areas was often difficult and frequently resulted in conversion to another AT. When 1 AT was successfully ablated, we did not try to induce other AT. When 1 AT converted to another AT, we did not target this AT as well. Consequently, we do not know whether ablation of multiple AT during 1 ablation procedure could have prevented future recurrences. In addition, irrigated tip ablation was performed in only a minority of the patients, and 8-mm-tip catheters were not used. Hence, the applied mapping and ablation techniques may account for a number of recurrences observed in this study.

**Disclosures**

None.

**References**


**CLINICAL PERSPECTIVE**

Catheter ablation of atrial tachyarrhythmias in patients with congenital heart disease can be challenging, and long-term outcome data are limited. We examined atrial tachyarrhythmias in 53 patients (median age, 35 years) who underwent catheter ablation for atrial arrhythmias after surgery for congenital heart disease. Macreorentrant arrhythmias were most common, but focal tachycardias also occurred. During a follow-up period of 5±3 years, tachyarrhythmias recurred in 29 patients but were often different from the previously ablated tachycardias. Persistent atrial fibrillation developed in 14 patients. Despite the frequent need for repeat ablation, most patients are in sinus rhythm.
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