Radiofrequency Catheter Ablation of Atrial Tachycardias in Congenital Heart Disease

Results With Special Reference to Complexity of Underlying Anatomy

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BACKGROUND: Radiofrequency catheter ablation has become the treatment strategy of choice for atrial tachyarrhythmias in patients with congenital heart disease (CHD). We analyzed results of radiofrequency catheter ablation in a large cohort of patients with CHD with special reference to complexity of underlying anatomy.

METHODS AND RESULTS: One hundred and forty-four patients with CHD and atrial tachyarrhythmias undergoing radiofrequency catheter ablation were classified according to complexity of underlying CHD: simple CHD, n=18 (12%); moderate CHD, n=53 (37%); and complex CHD, n=73 (51%). Overall acute success was achieved in 81% of the patients. Acute success was lower for tachycardias involving the left atrium compared with right atrial tachycardias. Complexity of CHD was associated with longer procedure duration. Tachycardia recurrence was observed in 54% of the patients after a total follow-up of 7.4 years. 75% of all recurrences occurred within the first year. Recurrence of tachycardia was more likely in patients with complex surgical atrial anatomy (ie, Fontan palliation or atrial switch procedure). Major complications occurred in 4 patients and were related to vascular access.

CONCLUSIONS: Acute procedural success of atrial tachycardia ablation in congenital heart patients was not influenced by complexity of CHD. Long-term outcome with regard to tachycardia recurrence was worse in patients with complex surgical atrial anatomy.

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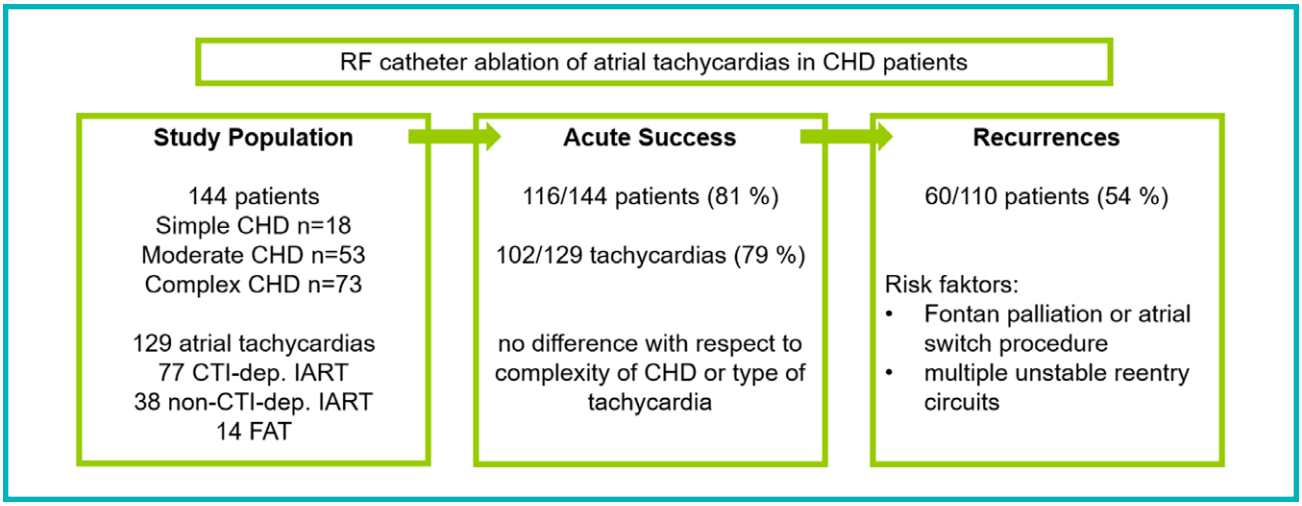

WHAT IS KNOWN?

- Atrial tachyarrhythmias have a major impact on mortality and morbidity in patients with congenital heart disease.
- Radiofrequency catheter ablation is a cornerstone treatment strategy of atrial tachyarrhythmias in those patients.

WHAT THE STUDY ADDS?

- Complexity of congenital heart disease was not associated with acute procedural success in a large group of patients with congenital heart disease.
- Tachycardia recurrence was more likely in patients with complex surgical anatomy (ie, Fontan palliation or atrial switch procedure) and in presence of multiple unstable atrial reentry circuits.

A continuous increase in atrial tachyarrhythmias has been reported during long-term course in patients with congenital heart disease (CHD).[1,2] These tachycardias, particularly intraatrial reentrant tachycardia (IART) and focal atrial tachycardia (FAT), have been shown to be a significant risk factor for morbidity and mortality in this population and, therefore, require rigorous treatment.[1,3] Antiarrhythmic medication alone is often unsatisfactory and associated with side effects in a significant number of patients. Radiofrequency ablation of the tachycardia substrate, therefore, has emerged as treatment of choice for patients with symptomatic atrial tachycardias (ATs) as recommended in a recent consensus statement.[4]

Electroanatomic mapping systems (EAMs) have improved our understanding of the different mechanisms of ATs in this population and results of catheter ablation. Depending on tachycardia substrate and type of CHD, acute success of catheter ablation was reported in 65% to 96% of the patients studied.[5–13] Several factors, namely difficult access to the targeted cardiac chambers, thickened atrial myocardium, and presence of >1 tachycardia mechanism was identified having a negative impact on success. Up to now, the majority of studies on AT ablation in patients with congenital heart defects were limited by small number of patients. Data on larger patient cohorts is limited.[5–13]

For the purpose of the present study, we hypothesized that complexity of the underlying cardiac defect had a negative impact on outcome of catheter ablation of ATs in patients with CHD.

PATIENTS AND METHODS

The authors declare that all data and supporting materials are available within the article.

Patients

All 144 patients with CHD who had undergone electrophysiological study (EPS) and radiofrequency catheter ablation of ATs at our institution between January 2003 and February 2016 were enrolled into the study. Redo procedures for tachycardia recurrence were not analyzed. Hospital charts were reviewed with respect to demographic and procedural data. For data analysis, patients were categorized into 3 groups with respect to severity of their individual CHD: simple CHD, moderate CHD, and complex CHD according to the American College of Cardiology/American Heart Association 2008 guidelines for the management of adults with CHD.[14] Table 1 provides detailed information on patients and underlying types of CHD, as well as assignment to severity categories. To investigate the impact of our institutional experience on outcome, early (2003–2010) and late (2011–2016) data were analyzed separately. The study was approved by the hospital's institutional review board and fully complies with the Declaration of Helsinki.

Table 1. Patients' Diagnosis Related to Severity of Congenital Heart Disease According to Warnes et al[14]

Complexity of CHD	All Patients (N=144)
sCHD	n=18 (12%)
Atrial septal defect	12 (8%)
Ventricular septal defect	3 (2%)
Aortic/mitral valve disease	3 (2%)
mCHD	n=53 (37%)
Tetralogy of Fallot	22 (15%)
Atrioventricular septal defects, partial or complete	10 (7%)
Pulmonic valve stenosis	6 (4%)
Ebstein anomaly	6 (4%)
Coarctation of the aorta	3 (2%)
Subvalvular or supravalvular aortic stenosis/Shone complex	3 (2%)
Anomalous pulmonary venous drainage, partial or total	3 (2%)
cCHD	n=73 (51%)
Single ventricle/Fontan procedure	30 (21%)
d-Transposition of the great arteries	28 (20%)
Pulmonary atresia	8 (5%)
cc-Transposition of the great arteries	6 (4%)
Truncus arteriosus communis	1 (1%)

cc indicates congenitally corrected; cCHD, complex congenital heart disease; CHD, congenital heart disease; mCHD, moderate congenital heart disease; and sCHD, simple congenital heart disease.

EPS and Catheter Ablation

Indications for EPS and catheter ablation included documentation of sustained (>30 seconds) AT regardless of symptoms or nonsustained symptomatic AT on either 24-hour Holter monitor or on pacemaker or implantable cardioverter-defibrillator (ICD) event storage. Antiarrhythmic medication had been discontinued for at least 5 half-lives before the procedure. Preablation evaluation included patient's history, physical examination, 12-lead ECG, 24-hour Holter monitor, and 2-dimensional echocardiography. Pacemaker or ICD interrogation was performed prior and post-ablation when applicable. Oral anticoagulation with either vitamin K antagonists or novel oral anticoagulants or anticoagulation with subcutaneous low molecular weight heparin was initiated in all patients with AT on diagnosis.

EPS and catheter ablation were performed under conscious sedation with propofol or under general anesthesia where appropriate. Before EPS, complete cardiac catheterization and angiography, including coronary angiography, were performed to assess hemodynamics and visualize individual patient's anatomy if necessary.

Electrophysiological Study

For programmed atrial stimulation and as a stable reference for activation mapping, a steerable decapolar 5F electrode catheter (Livewire; St. Jude Medical, St. Paul, MN) was placed into the coronary sinus or within the left atrial (LA) appendage in patients after atrial switch procedure for d-transposition of the great arteries. If a stable endocardial position of the reference catheter could not be achieved, a transesophageal electrode catheter (Esoflex S; FIAB SpA, Firenze, Italy) was used. In patients after lateral tunnel Fontan procedure, a 6F quadripolar electrode catheter (Supreme; St. Jude Medical) within the systemic venous atrium (SVA) was used for pacing, and a transesophageal probe served as reference. AT was induced either by programmed atrial stimulation or atrial burst pacing. Isoproterenol was applied at a dosage of 0.01 $\mu g \cdot kg^{-1} \cdot min^{-1}$ as continuous infusion if necessary. For substrate and activation mapping of the tachycardias, different 3-dimensional mapping systems were used depending on era and availability: Ensite NavX System (n=77), EnSite 3000 Multielectrode Array (n=45; both from St. Jude Medical), and CARTO (Biosense Webster, Diamond Bar, CA; n=7). Fifteen patients with typical atrial flutter had mapping and ablation performed without the use of an electroanatomical mapping system.

Voltage mapping was performed during sinus rhythm or atrial pacing if appropriate to identify endocardial scars or fibrosis, which was defined as areas with endocardial signals <0.1 mV. IART was diagnosed as an intraatrial circus movement tachycardia with a constant cycle length inducible by programmed atrial stimulation or burst atrial stimulation. The critical isthmus of the reentry circuit was verified by entrainment pacing as described before.[15] IART was categorized into reentry circuits dependent on the cavotricuspid isthmus (CTI) or cavomitral isthmus (in patients after atrial switch procedure; CTI dependent) and into reentry circuits involving other parts of one or both atria (non-CTI dependent). FAT was defined as tachycardia with centrifugal spread of atrial activation from a focus other than the sinoatrial node.

Radiofrequency Application

For radiofrequency ablation, 7F and 8F open-irrigated radiofrequency catheters were used (Sprinkler XL [Medtronic, Minneapolis, MN]; CoolPathDuo and TactiCath Quartz [St. Jude Medical]). Radiofrequency current was delivered in a temperature-controlled mode (45°C, 30–50 W) for a maximum of 45 seconds as point-by-point applications. If a contact force sensing catheter (TactiCath Quartz) was used, target catheter contact force of 10 to 40 g was sought.

In 9 of 144 patients (6%), radiofrequency ablation was performed within the LA/pulmonary venous atrium (PVA) either using a retrograde transaortic access (n=5) or via a transseptal/transbaffle access (n=4).

Procedural Success

Acute procedural success was defined as termination of tachycardia during ablation with subsequent verification of bidirectional conduction block across the critical isthmus/radiofrequency lesion line. After ablation of the primary tachycardia, programmed atrial stimulation was routinely performed to test for reinducibility of the primary tachycardia or for inducibility of other tachycardias.

Complications

Major complications related to the procedure were defined as situations requiring any additional diagnostic or

therapeutic procedures beyond standard institutional procedural care.

Follow-Up

After the procedure, patients were monitored for another 48 hours in the hospital. 12-lead ECG, a 24-hour Holter monitor, and 2-dimensional echocardiography were obtained. Oral anticoagulation, if started preablation, was continued for at least 3 months after ablation. If patients were free from recurrence and if there was no other indication, anticoagulation was withdrawn 3 months after ablation. In patients lacking indication for oral anticoagulation, low-dose aspirin (2–3 $mg \cdot kg^{-1} \cdot d^{-1}$ in children and 100 mg/d in adolescents and adults) was recommended for 3 months after ablation. All patients were seen regularly 4 weeks after the ablation and then at a minimum interval of 6 months at our outpatient clinic or by their referring cardiologists. Follow-up included a 24-hour Holter monitor or pacemaker or ICD interrogation when appropriate.

Statistical Analysis

Statistical analysis was performed using SPSS, version 24.0 (IBM Somers, NY). Data are presented as mean±SD if not otherwise indicated. Univariable comparisons between the 3 groups were performed using 1-way ANOVA with multiple *t* test with Bonferroni correction or Mann–Whitney *U* test with Bonferroni correction after Kruskal–Wallis test depending on variable distribution. For categorical data, χ^2 test was used with pairwise comparison if overall result indicated statistical significance. Multivariable analysis for acute success and AT recurrence were performed using binary logistic regression analysis and Cox regression analysis, respectively. The log-rank test was used for analysis of tachycardia recurrences. Statistical difference was considered significant at a level of $P<0.05$.

RESULTS

Patient Population

During the study period, a total of 144 CHD patients underwent catheter ablation of AT. Of the 144 patients, 58 were women, and 27 were <18 years of age. According to their individual type of CHD, 18 patients were categorized having simple CHD (12%), 53 patients were categorized having moderate CHD (37%), and 73 patients were categorized having complex CHD (51%; Table 1).

Mean age of the 144 patients at the time of EPS and radiofrequency ablation was 32±15 years (range, 1.3–70 years; Table 2). Patients with complex CHD underwent catheter ablation at a younger age than patients with moderate CHD (27±13 versus 38±15 years; $P<0.001$; Table 2). Mean body weight was 68±23 kg (range, 11–130 kg) for all patients and was not different between the 3 groups. Eighty patients (56%) had been on antiarrhythmic treatment with at least 1 drug, including β-blockers, before ablation. There was no difference in the use of antiarrhythmic medication between the 3 groups of patients.

Regarding the whole cohort, 34 patients (24%) needed a pacemaker, and 25 patients (17%) needed an ICD. No patient in the sCHD group needed a pacemaker or ICD. Prevalence of pacemaker was higher in the cCHD and mCHD groups versus sCHD group ($P=0.047$; Table 2). Mean interval between cardiac surgery and catheter ablation was 22±12 years (range, 3 months to 48 years; n=132) and was not different between the 3 groups. Number of prior cardiac surgical procedures per patient ranged from 0 to 5. Patients with moderate CHD

Table 2. Patients' Characteristics With Reference to Severity of CHD

Patient Characteristics	All Patients (N=144)	sCHD (n=18)	mCHD (n=53)	cCHD (n=73)	*P* for Overall Comparison	*P* for Pairwise Comparison
Age, y	32±15	35±18	38±15	27±13	<0.001	<0.001*
Body weight, kg	68±23	63±18	72±22	66±25	0.21	
AA	80 (56%)	9 (50%)	27 (51%)	44 (60%)	0.51	
PM	34 (24%)	0	10 (19%)	24 (33%)	0.008	0.047†
						0.005‡
ICD	25 (17%)	0	12 (23%)	13 (18%)	0.09	
Atrial thrombosis	4 (3%)	0	0	4 (5%)	§	
Hemodynamic compromise	18 (13%)	2 (1%)	6 (11%)	10 (14%)	0.91	
Time after surgery, y	22±12	21±14	24±13	20±10	0.16	
No. of cardiac surgeries, n	2.1±1.3	1.0±1.0	2.0±1.2	2.4±1.2	<0.001	0.006†
						0.003‡

AA indicates antiarrhythmic medication before ablation; cCHD, complex congenital heart disease; ICD, implantable cardioverter-defibrillator; mCHD, moderate congenital heart disease; PM, pacemaker; and sCHD, simple congenital heart disease.

*Indicates a significant difference between cCHD and mCHD.

†Indicates a significant difference between mCHD and sCHD.

‡Indicates a significant difference between cCHD and sCHD.

§Assumption for χ^2 test not satisfied.

and complex CHD had undergone more surgical procedures before radiofrequency ablation than patients with simple CHD (2.0 and 2.4 versus 1.0 procedures; *P*=0.006 and *P*=0.003; Table 2). Eleven patients did not have any cardiac surgery before catheter ablation (atrial septal defect of secundum type, n=5; congenitally corrected transposition of the great arteries, n=2; Ebstein anomaly of the tricuspid valve, n=2; coarctation of the aorta, n=1; and double chambered right ventricle, n=1).

Symptoms attributable to presence of AT were experienced by 117 of 144 patients (81%; Table 3). Most common symptoms included palpitations (n=88) and dyspnea (n=48). Inappropriate ICD discharges because of rapidly conducted AT were documented in 8 of 25 patients having an ICD (32%). In 27 of 144 patients (19%), AT was diagnosed on 24-hour Holter monitor or during interrogation of pacemaker or ICD event storage during a routine follow-up visit without any symptoms.

Atrial thrombosis had been detected in 4 of 144 patients (3%): after Fontan procedure (n=2) and after atrial switch procedure (n=2). Impaired ventricular function on 2-dimensional echocardiography was evident in 18 of 144 patients (13%). Prevalence of impaired ventricular function was not increased in patients with cCHD when compared with other patients (Table 2).

AT Mechanisms and Substrates

A total of 129 ATs were induced and targeted in 117 of 144 patients. In the remaining 27 patients, no AT could be induced (below).

A single IART with a well-defined reentry circuit could be mapped in 96 of 117 patients, whereas >1 reentry circuit was present in 7 of 117 patients. In 9 of 117 patients, FAT with a single atrial focus was targeted. IART and FAT were present coincidentally in 5 of 117 patients.

A total of 115 IARTs (89% of all ATs; Figure 1) were identified. For the whole group, the reentry circuit was more often located solely within the right atrium (RA)/SVA (83%) and only occasionally involved also the LA/PVA (17%). It is of note that in patients after atrial switch procedure for d-transposition of the great arteries number of tachycardias involving also the PVA was significantly higher (59%; *P*<0.001). In 10 patients with IART involving also the LA/PVA radiofrequency ablation could be accomplished within the RA/SVA (RA) because the critical part of the reentry circuit was located within the RA/SVA.

The CTI was critical part of the reentry circuit in 77 IART (67% of all IART and 60% of all ATs; Figure 1). Prevalence of CTI-dependent IART was not different between the 3 groups (simple CHD, 69%; moderate CHD, 72%; and complex CHD, 50%; *P*=0.06). Patients after a Fontan procedure had significantly less CTI-dependent IART compared with all other patients (19% in Fontan patients and 60% in all patients; *P*<0.001).

A total of 14 FATs (11% of all ATs) were identified. In 2 individuals with FAT, the origin of atrial activation was located within the LA/PVA. Prevalence of FAT was not different among the 3 subgroups (Figure 1). In patients after a Fontan procedure, prevalence of FAT was higher compared with the remaining patients (27% versus 11%; *P*=0.03).

A total of 27 patients had no AT during EPS: in 23 of these patients, empirical conduction block within the CTI was accomplished. In 3 of 27 patients without inducible AT, an isthmus between an atrial scar and the inferior caval vein within an intraatrial Fontan tunnel was targeted. In the remaining patient, a conduction gap within the crista terminalis was identified and ablated during sinus rhythm.

In addition to the aforementioned stable ATs, multiple unstable IARTs were induced in 9 of 144 patients. Because of rapidly changing tachycardia cycle lengths, those IARTs could not be assessed and targeted. In 5 of 9 patients, ablation was performed for a stable IART or FAT, which had been identified before induction of unstable IART (RA/SVA in 2 patients, CTI and RA/SVA in 3 patients). In 4 of 9 patients, a conduction block within the CTI was empirically performed.

Table 3. Symptoms of Patients

	All Patients (N=144)
No symptoms	27 (19%)
Symptoms	117 (81%)
Palpitations	88 (61%)
Dyspnea	48 (33%)
Angina pectoris	10 (7%)
ICD discharge because of rapidly conducted AT	8 (6%)
Syncope	5 (3%)

AT indicates atrial tachycardia; and ICD, implantable cardioverter-defibrillator.

Acute Success

Acute procedural success could be achieved in 116 of 144 patients (81%; Figure 2). There was no significant difference in acute success between the 3 groups (simple CHD, 83%; moderate CHD, 87%; and complex CHD, 75%; *P*=0.26). Acute success in patients after atrial switch procedure or Fontan operation was lower compared with all other patients, but the difference did not reach statistical significance (71% versus 85%; *P*=0.054 in univariable analysis and *P*=0.06 in multivariable analysis). Mean number of radiofrequency lesions was significantly lower in successful procedures (n=116) versus unsuccessful ablations (n=28; 25±15 versus 41±21; *P*=0.001). Success was not dependent on era because results of early (n=72) versus late procedures (n=72) were not statistically different (75% versus 86%; *P*=0.09). Body weight, age, and number

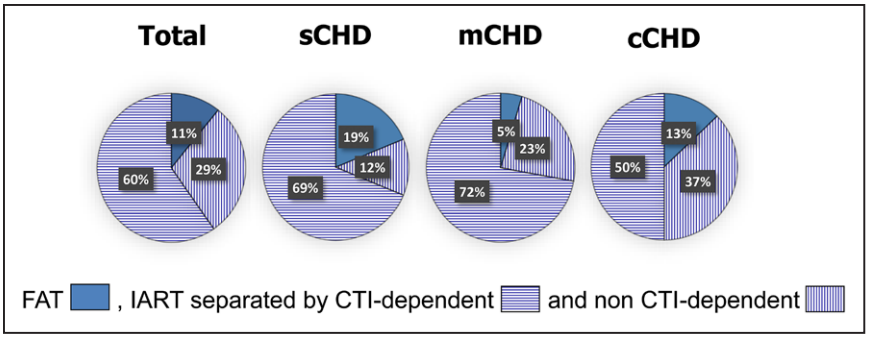

Figure 1. Prevalence of different atrial tachycardia mechanisms with respect to complexity of congenital heart disease (CHD). cCHD indicates complex CHD; CTI, cavotricuspid isthmus; FAT, focal atrial tachycardia; IART, intraatrial reentrant tachycardia; mCHD, moderate CHD; and sCHD, simple CHD.

of previous cardiac surgical procedures did not impact acute procedural success. Acute success was higher in patients in whom a contact mapping system (NavX, CARTO) was used compared with noncontact mapping system (EnSite 3000; 87% versus 73%; *P*=0.046).

For the whole group, AT mechanism had no influence on success (IART 78% versus FAT 86%; *P*=0.52). There was no difference of acute success when comparing CTI-dependent reentry circuits and non–CTI-dependent reentry circuits (79% versus 76%; *P*=0.72). Acute success was lower for ATs involving the LA/PVA (57%) than for ATs within the RA/SVA (83%; *P*=0.007; Figure 2). In 32 of 144 patients (22%), initially stable IART degenerated into atrial fibrillation (AF) either before/during EPS. None of the patients reported in this study had primarily presented with AF. Multivariable analysis revealed no association between acute success and complexity of CHD, Fontan palliation/atrial switch procedure, AF before/during EPS, or multiple unstable ATs (Table 4).

Procedural Characteristics

For the whole group of 144 patients, mean procedure duration was 274.0±101.1 minutes, and mean fluoroscopy time was 24.4±13.5 minutes. Procedure duration was significantly longer in patients with complex CHD than compared with patients with simple or moderate CHD (Table 5). Procedure duration and fluoroscopy time in 9 of 144 ablation procedures within the LA/PVA were not different from those within the RA/SVA. Procedure duration was significantly longer using the noncontact EnSite System (n=47) compared with other EAM systems (n=82; 342.8±101.4 versus 236.6±85.6 min-

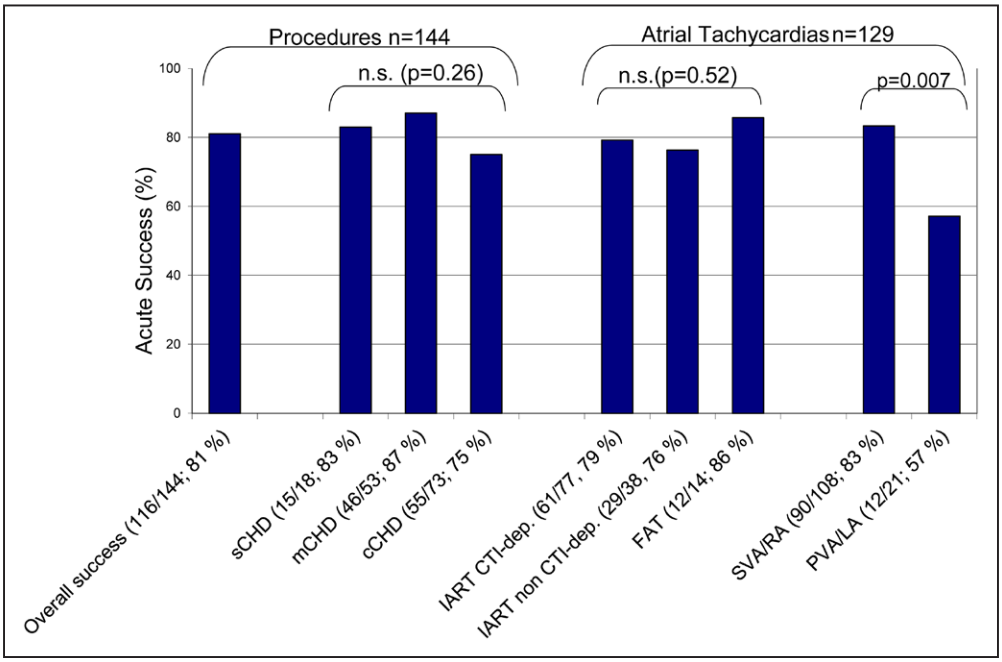

Figure 2. Procedural success of radiofrequency (RF) ablation of atrial tachycardia for patients with simple congenital heart disease (sCHD), moderate CHD (mCHD), and complex CHD (cCHD).
No difference of acute success between the 3 subgroups was found. Likewise, there was no difference of acute success of cavotricuspid isthmus (CTI)-dependent vs non CTI-dependent intraatrial reentrant tachycardia (IART) and focal atrial tachycardia (FAT). Acute success of RF ablation of atrial tachycardias involving also the left atrium (LA)/pulmonary venous atrium (PVA), however, was significantly lower compared with catheter ablation of atrial tachycardias involving only the right atrium (RA)/systemic venous atrium (SVA).

Table 4. Multivariable Analysis of Acute Success

Procedures (N=144)	Multivariable Analysis	
	Odds Ratio (95% CI)	*P* Value
Complexity of CHD	0.99 (0.20–4.86)	0.99
Fontan/atrial switch	0.44 (0.19–1.03)	0.06
AF before/during EPS	1.86 (0.55–6.32)	0.32
Multiple unstable AT	0.85 (0.16–4.42)	0.84

AF indicates atrial fibrillation; AT, atrial tachycardia; CHD, congenital heart disease; CI, confidence interval; and EPS, electrophysiological study.

utes; *P*<0.001). Fluoroscopy time and procedure duration were significantly longer in procedures performed before January 2011 (n=72) compared with procedures performed thereafter (n=72; 28.6±12.5 versus 20.5±13.2 minutes; *P*<0.001 and 332.0±98.9 versus 216.0±63.0 minutes; *P*<0.001, respectively).

Mean number of radiofrequency lesions was 29±17 with a mean cumulative energy of 1070±867 W (37 W per lesion) for the whole group. There was no difference of radiofrequency lesion number between the 3 groups. Significantly fewer radiofrequency lesions with less cumulative power were needed in children and adolescents compared with adult patients (21±13 versus 31±18 radiofrequency lesions, *P*=0.002; 653.1±459.7 versus 1171.3±912.7 W, *P*=0.005).

Follow-Up

Median follow-up was 3.5 years (interquartile range, 4.9 years). After successful ablation, AT recurrence was observed in 60 of 110 patients (54%) after 7.4 years within a median interval of 4.5 months (interquartile range, 13 months) from ablation to recurrence. In the majority of patients, AT recurred within the first year after the initial ablation procedure (41%; n=45/110; 75% of all recurrences). Within 2 years, AT recurred in 52 of 110 patients (47%). Kaplan–Meier analysis of freedom from AT recurrence did not show any difference between the 3 groups (simple CHD, moderate CHD, complex CHD; log-rank nonsignificant; Figure 3). Fontan palliation or atrial switch procedure and induction of multiple unstable IARTs during EPS were independent factors for recurrence of tachycardia on multivariable regression analysis (hazard ratios, 2.34 and 3.35, respectively; Table 6). Recurrence was more likely to occur in patients in whom the noncontact mapping system (EnSite 3000) was used compared with contact mapping systems (NavX, CARTO; 71% versus 48%; *P*=0.03).

Complications

Major complications occurred in 4 of 144 patients (2.8%). All 4 patients needed surgical repair of groin vessel aneurysms. There was no statistical difference concerning complications and severity of CHD.

DISCUSSION

Atrial tachyarrhythmias have a major impact on morbidity and mortality in patients with CHD. In adult patients with CHD, tachyarrhythmias are the most frequent cause for hospital admissions.[3] Catheter-based ablation has become the recommended treatment of choice.[4] The present study was conducted to assess the influence of complexity of CHD on results of catheter ablation of ATs in patients with CHD.

Our main findings are (1) only a minority of patients scheduled for catheter ablation of AT had simple CHD according to the American College of Cardiology/American Heart Association 2008 guidelines classification,[14] whereas 88% of the patients had moderate or complex CHD; (2) IART involving the CTI was by far more common than any other tachycardia mechanism except for patients after a Fontan-type procedure. In these patients, the CTI was less likely a critical part of the reentry circuit; (3) acute success of radiofrequency ablation was not influenced by complexity of CHD or by the tachycardia mechanism (reentrant versus focal, CTI dependent versus non-CTI dependent). Acute procedural success of ablation of ATs within the LA/PVA, however, was lower compared with substrates within the RA/SVA; (4) complexity of CHD was associated with longer procedure duration. Growing institutional experience resulted in shorter procedure duration and

Table 5. Procedural Characteristics With Reference to Severity of CHD

Procedure Characteristics	All Patients (N=144)	sCHD (n=18)	mCHD (n=53)	cCHD (n=73)	*P* for Overall Comparison	*P* for Pairwise Comparison
Fluoroscopy time, min	24.4±13.5	18.5±10.0	25.0±14.8	25.6±12.9	0.13	
Procedure duration, min	274.0±101.1	229.9±73.4	245.6±88.5	305.6±106.2	<0.001	0.002*
						0.01†
RF lesion number	29±17	27±14	28±17	29±18	0.90	

cCHD indicates complex congenital heart disease; mCHD, moderate congenital heart disease; RF, radiofrequency; and sCHD, simple congenital heart disease.

*Indicates a significant difference between cCHD and mCHD.

†Indicates a significant difference between cCHD and sCHD.

Table 6. Multivariable Analysis of Atrial Tachycardia Recurrence After Successful Procedure (n=110)

Procedures	Multivariable Analysis	
	Hazard Ratio (95% CI)	*P* Value
Complexitiy of CHD	1.05 (0.37–2.97)	0.93
Fontan/atrial switch	2.34 (1.02–5.35)	0.04
AF before/during EPS	1.70 (0.94–3.07)	0.08
Multiple unstable AT	3.35 (1.44–7.80)	0.005

AF indicates atrial fibrillation; AT, atrial tachycardia; CHD, congenital heart disease; CI, confidence interval; and EPS, electrophysiological study.

less use of fluoroscopy, whereas success rate remained unchanged; (5) tachycardia recurrence occurred in a substantial number of patients mainly within the first year after ablation; (6) AT recurrence was associated with complex surgical anatomy, that is, after Fontan palliation or atrial switch procedures. Additionally, multiple unstable IARTs during EPS were associated with tachycardia recurrence; (7) usage of a contact EAM (NavX, CARTO) resulted in better acute and long-term outcome than noncontact EAM (Ensite 3000); and (8) major complications were limited to groin vessel aneurysms and were not related to complexity of CHD.

Radiofrequency ablation therapy for AT was more frequently used in patients experiencing moderate and complex CHDs compared with patients with simple CHD. Higher incidence of atrial tachyarrhythmias in those patients probably reflects higher amount of fibrosis and scarring of atrial myocardium because of volume or pressure overload and of surgical scars and patch material.[16–20]

In previous studies, the CTI or the cavomitral isthmus in patients after atrial switch procedures was identified as critical part of the reentry circuit in 46% to 55% of IARTs.[11,21] In the present study, prevalence of CTI-dependent IART was found in a comparable range irrespective from the complexity of the underlying CHD except for patients after Fontan-type procedures (19% CTI dependent). A previous study on catheter ablation of supraventricular tachycardias in patients after extracardiac conduit-type Fontan surgery identified 90% of IART CTI dependent.[22] In the present study, however, the majority of Fontan patients had more old-fashioned types of atriopulmonary or cavopulmonary connections and were, therefore, presumably prone to develop scar-related IART not restricted to the CTI (cavoannular isthmus). These results match with data from 2 recent studies with 21% and 56% of CTI-dependent IARTs in a Fontan population with no or few extracardiac conduits, respectively.[10,23]

Overall success of ablation in our series was well within the range as published in previous studies.[4] In another single-center study covering 130 patients with CHD and AT ablation, history of Fontan palliation and atrial switch procedure for d-transposition of the great arteries were associated with lower success compared with all other patients.[10] In the present study, this difference did not reach statistical significance as far as acute procedural success was concerned. Given the lim-

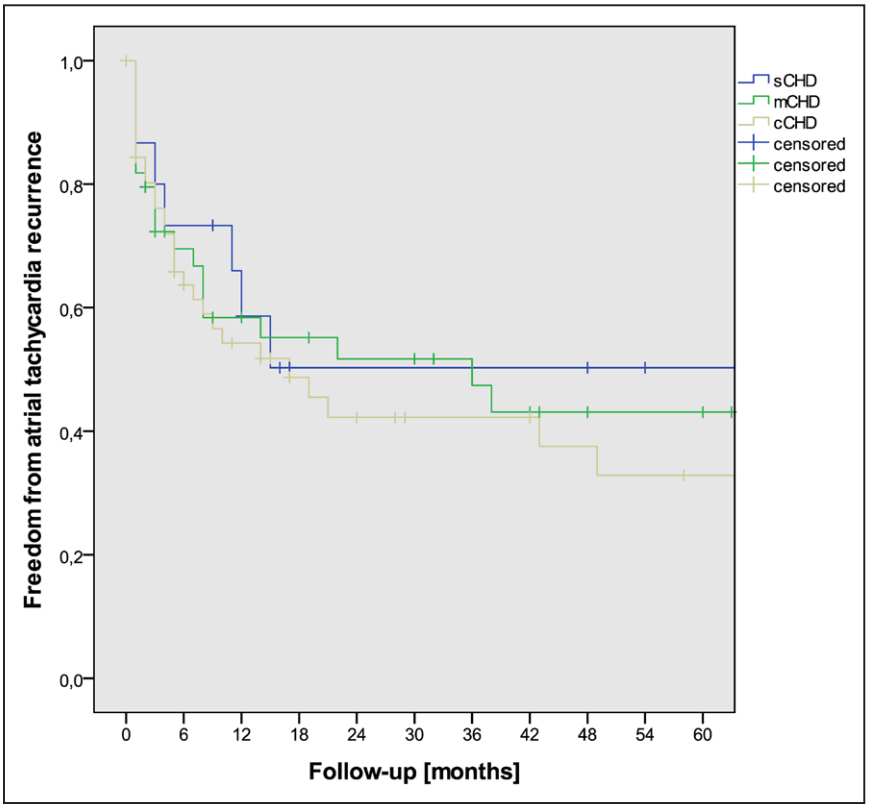

Figure 3. Kaplan–Meier analysis of freedom from atrial tachycardia recurrence within 4 y after catheter ablation (mean follow-up, 50±42 mo) for patients with simple congenital heart disease (sCHD), moderate CHD (mCHD), and complex CHD (cCHD; log-rank P=0.72; nonsignificant [NS]).

ited power of the present study, our results may, therefore, confirm the results of the aforementioned study. Acute procedural success of catheter ablation on ATs in patients with CHD, however, is probably not a good measure for long-term success. Ablation end points like termination of tachycardia during ablation or noninducibility of AT may at least partly be determined by factors like tissue swelling or anesthesia and not solely be because of the destructive effects of radiofrequency energy. Therefore, it would be desirable to visualize tissue destruction in a real-time fashion during ablation. However, to date, it is virtually impossible to routinely measure size and extent of radiofrequency lesions during ablation procedures. In the future, monitoring of lesion size and extension by real-time magnetic resonance imaging might be a measure to close this gap.

Taking the results of previous studies into consideration,[8,11,24] a higher recurrence rate of AT in patients with complex atrial anatomy on long-term course highlights the importance to define alternative procedural end points truly reflecting tissue destruction by radiofrequency energy.

Interestingly, CTI-dependent IART had no better outcome than non–CTI-dependent IART, which is in line with another previous report.[11] Ablation of ATs involving the LA/PVA was associated with a lower procedural success rate. This is in contrast to previously published data from Moore et al[25] and from our institution on catheter ablation within the PVA using a transbaffle approach.[26] In our previous study, a primary success rate of 100% could be achieved by covering redo procedures with the focus on transbaffle approach to the LA/PVA. The higher success rate and lower recurrence rate using contact 3-dimensional EAM versus a noncontact mapping system underlines the significance of contact 3-dimensional EAM for mapping and ablation of AT in CHD.

Interestingly, institutional gain of experience did not result in an improved procedural success rate. This could be because of the circumstance that there is a subset of patients with CHD with AT substrates not amenable for catheter ablation at all either because of multiple substrates that cannot be mapped exactly or because of thickened atrial myocardium precluding the induction of transmural ablation lesions. This assumption is supported by the fact that for more than one and a half decade, no substantial progress toward significant improvement of success could be achieved, despite enormous advances in catheter ablation technology.

AT recurrence was observed in almost half of the patients mainly within the first year after ablation. These findings are in accordance with previous reports and include a long median follow-up period.[8,10,11,24] Although recurrence rates were equally distributed among the 3 subgroups of patients, recurrence rate in patients after atrial switch repair or Fontan palliation were significantly higher, which is in line with a previous study.[10] Recurrence rates after catheter ablation of AT in patients with CHD are still unsatisfactorily high. However, the long-term use of antiarrhythmic medications may be associated with serious side effects. In addition to life-threatening ventricular arrhythmias, antiarrhythmic medication may result in severe bradyarrhythmias. This especially applies for patients with sinoatrial node dysfunction after atrial switch procedures, certain types of Fontan procedures but also occasionally after surgery for tetralogy of Fallot.

To analyze the impact of complexity of the underlying anatomy, categorization of the 2008 American Heart Association/American College of Cardiology guideline was adopted. Our results demonstrate that this scoring system was not useful for prediction of acute and long-term success. This finding, however, has been influenced by the fact that simple CHD was scarce in our group of patients. Our data identified patients with complex surgical atrial anatomy, that is, after Fontan palliation and after atrial switch procedures, having an inferior long-term outcome. It may, therefore, be assumed that for estimating ablation success of AT in patients with CHD, complexity of atrial anatomy is the decisive parameter.

A significant part of the patients have been shown to benefit from AT ablation because they experience less tachycardia recurrences and tolerate AT better than before ablation.[23] Some patients, however, stay free from recurrence only with the cumulative effect of catheter ablation and antiarrhythmic medication. In contrast to a previous study, older age had no impact on AT recurrence in our study.[10] History of AF has been shown to predict a negative outcome of AT ablation in patients with CHD.[7] In our study and another report, outcome was not influenced by history of AF in multivariable analysis.[10] This might at least, in part, be explained by different study populations with a higher number of Fontan patients included.[7] Those patients in our study, however, who had multiple unstable reentry circuits during EPS had a higher risk for tachycardia recurrence compared with the rest of the patients. Therefore, it might be proposed that multiple IARTs occasionally degenerating into AF may be the true predictor of negative ablation outcome. Recently introduced high-density electroanatomical mapping systems may offer additional value for assessment and ablation of multiple, rapidly changing IARTs.

The ablation procedure itself was safe in all our patients. No complications directly related to EPS or radiofrequency ablation were observed.

CONCLUSIONS

Main findings of the present study include that complexity of CHD according to the Warnes classification

correlated with incidence of atrial tachyarrhythmias over time as patients with more complex cardiac lesions being in favor of developing atrial tachyarrhythmias at a younger age, but severity of CHD was not equally distributed within our patient population. Acute outcome of catheter ablation of ATs was not influenced by complexity of CHD according to the Warnes classification. Complexity of surgical atrial anatomy, however, had a significant impact on long-term outcome of AT ablation. AT recurrence was associated with presence of multiple, unstable atrial reentry circuits.

Recurrences after catheter ablation of ATs in patients with CHD were significant. New mapping strategies as the use of multielectrode catheters and high-density mapping systems may hopefully help at least, in part, to contribute to a better outcome.

In accordance with the current Pediatric and Congenital Electrophysiology Society/Heart Rhythm Society consensus statement, catheter ablation of AT should be offered to all patients with CHD and sustained/symptomatic AT, despite a significant recurrence rate.[4] In patients presenting with multiple unstable ATs, catheter ablation therapy seems to be less beneficial using conventional mapping modalities, including conventional 3-dimensional activation mapping. In those patients, high-density mapping might be helpful.

Limitations

This present study is limited by its retrospective and single-center character. An influence of operator skills and technical equipment on the results cannot be entirely ruled out. All operators, however, had the same high level of clinical experience in catheter ablation of ATs in patients with CHD, and all procedures were supervised by a single senior operator (T.P.). To strengthen the power of data, a prospective multicenter study should be performed.

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DISCLOSURES

None.

FOOTNOTES

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Radiofrequency Catheter Ablation of Atrial Tachycardias in Congenital Heart Disease: Results With Special Reference to Complexity of Underlying Anatomy

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