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Catheter Ablation for Atrial Tachycardia in Adults With Congenital Heart Disease

Electrophysiological Predictors of Acute Procedural Success and Post-Procedure Atrial Tachycardia Recurrence

Christopher S. Grubb, BS,[a] Matthew Lewis, MD,[b] William Whang, MD, MS,[c] Angelo Biviano, MD, MPH,[a] Kathleen Hickey, EdD, FNP, ANP,[a] Marlon Rosenbaum, MD,[b] Hasan Garan, MD[a]

ABSTRACT

OBJECTIVES This study sought to determine the electrophysiological predictors of acute procedural success and of post-ablation recurrence of atrial tachyarrhythmias (AT) in our adult congenital heart disease (ACHD) population undergoing catheter ablation for treatment of AT.

BACKGROUND Catheter ablation is frequently performed to treat persistent AT in ACHD. The predictors of post-ablation AT recurrence have not been well studied in the ACHD population.

METHODS We performed a retrospective study of all catheter ablations for treatment of AT performed in ACHD patients between December 1, 2005, and July 20, 2017, at Columbia University Medical Center. Pre-specified clinical and procedural data of interest and the time from ablation to recurrence were determined by chart and procedure report review.

RESULTS A total of 140 patients (mean age: 45 years) underwent catheter ablation for 182 AT. Of the AT, 179 (93%) were intra-atrial macro-re-entrant tachycardia, and 12 (7%) had a focal origin. The presence of a single mechanism was a predictor of acute procedural success that could be achieved in 89% of the patients. At a median of 49.9 months, 62 patients (44%) had recurrent AT. Time to recurrence was significantly shorter (12.5 months) for recurrent AT in 13 of the 20 patients with previous Fontan procedure. By multivariable analysis, acute procedural success was a positive predictor and prior surgical maze procedure was a negative predictor of AT-free survival. Of the 62 patients with recurrent AT, 42 (68%) had a second catheter ablation procedure, and in 22 of these, the AT mechanism was different than previously observed.

CONCLUSIONS Catheter ablation for AT in ACHD patients is an effective method of arrhythmia control. More than 1 AT mechanism per patient is common. Acute procedural success is a predictor of freedom from AT recurrence. The majority of patients achieve multiple arrhythmia-free years. (J Am Coll Cardiol EP 2019;■:■–■) © 2019 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

The prognosis of patients with adult congenital heart disease (ACHD) has improved steadily over the years mainly due to early diagnosis and improvements in surgical corrective techniques (1,2). Latent atrial tachyarrhythmias (AT) in older survivors have become a major clinical problem causing morbidity and even affecting mortality in more than one-half of these patients (3). The majority

From the [a]Cardiac Electrophysiology Unit, Division of Cardiology, Department of Medicine, Columbia University Medical Center, New York, New York; [b]Division of Cardiology, Department of Medicine, Schneeweiss Adult Congenital Heart Center, Columbia University Medical Center, New York, New York; and the [c]Helmsley Center for Electrophysiology, Division of Cardiology, Mount Sinai Health System, New York, New York. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Dr. Hickey received funding from the National Institutes of Health. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.
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ABBREVIATIONS AND ACRONYMS

ACHD = adult congenital heart disease

AT = atrial tachyarrhythmia

AV = atrioventricular

CTI = cavotricuspid isthmus

ECG = electrocardiography

IQR = interquartile range

PCS = programmed cardiac stimulation

of these AT are intra-atrial re-entrant tachycardias based on an arrhythmia substrate created by surgical scars, fibrosis, and residual lesions causing atrial chamber enlargement and hypertrophy, but focal AT may also be present (4). Antiarrhythmic drugs are often not effective and the long-term use of these drugs may cause adverse side effects. Consequently, there is increasing reliance on catheter ablation technique to treat persistent AT in ACHD patients (3-6). The arrhythmogenic substrate may continue to evolve and transmute due to progression of the underlying structural disease, and therefore recurrence of post-ablation AT is common and may require further treatment and repeated catheter ablation procedures (5-11). In older individuals with complex congenital disease, effective arrhythmia control may influence critical decision making as their condition progresses to end-stage disease (12,13).

The purpose of this study is to describe the spectrum of AT in ACHD, critically evaluate the efficacy of catheter ablation for AT, and to identify the cardiac electrophysiological predictors of acute procedural success and post-ablation AT recurrence in our ACHD population.

METHODS

STUDY DESIGN. This is a retrospective analysis of catheter ablation outcomes in all patients with ACHD who underwent catheter ablation procedures specifically for AT in the adult electrophysiology laboratory at Columbia University Medical Center between December 1, 2005, and July 20, 2017. The catheter ablation procedures carried out for treatment of supraventricular tachycardias with an underlying mechanism of atrioventricular (AV) nodal re-entry and AV re-entry with an accessory pathway, and ventricular tachycardia, were excluded from this analysis because our specific aim was to study the underlying mechanisms and catheter ablation results for AT. The Columbia University Medical Center institutional review board approved this study prior to the onset of study procedures. During this 12-year period, there was consistent operator experience and uniform cardiac electrophysiological protocols for programmed cardiac stimulation (PCS) and catheter mapping in our laboratory. The clinical background information was acquired through chart review. Cardiac electrophysiological data were acquired from all the procedure reports, recordings, and images and reviewed in detail.

ELECTROPHYSIOLOGY STUDY AND CATHETER MAPPING. Electrophysiology studies were performed with patients under conscious sedation, using standard multielectrode catheters, recording equipment, and electroanatomic mapping (CARTO, Biosense Webster, Diamond Bar, California) system. Following vascular access, multielectrode catheters were positioned in the atria depending on the individual cardiac anatomy and within the coronary sinus and His bundle region whenever feasible. Transseptal puncture for left atrial access or transbaffle puncture for systemic atrial access was performed in 19 patients to perform complete biatrial mapping. Intracardiac echocardiography was used to guide access and catheter placement in these 19 patients, but otherwise intracardiac echocardiography was not employed routinely. Catheter mapping was performed by a quadripolar electrode catheter with an 8-mm nonirrigated tip (Navistar, Biosense Webster), 4-mm closed irrigated tip (CHILLI, Boston Scientific, Natick, Massachusetts), or a 3.5-mm open-irrigated tip electrode (Navistar Thermocool; Biosense Webster). Mean fluoroscopy time was 30.5 ± 1.5 min.

Patients whose baseline cardiac rhythm was the clinically documented AT underwent complete activation sequence and voltage mapping of both atria. Entrainment mapping was performed to define the underlying mechanism before an ablation strategy was formulated. In patients whose baseline rhythm was sinus rhythm or atrial pacing, programmed right and left atrial stimulation and atrial burst pacing were performed to induce AT. The cycle length and surface electrocardiographic (ECG) morphology of the induced arrhythmias were compared with those with documented clinical arrhythmias whenever possible. Isoproterenol infusion (1 to 5 μg/min) was used as needed for AT induction. After catheter mapping and ablation of spontaneous or induced AT, further PCS was performed for AT induction. If the induced tachycardia was the same as the one just mapped and ablated, further mapping and ablation followed. If the post-ablation PCS induced an AT with a different mechanism, whether this new AT mechanism also required catheter mapping and ablation was a clinical decision by the operating cardiac electrophysiologist.

Arrhythmia mechanism and type were determined based on the results of activation sequence mapping by the electroanatomical CARTO system and the results of entrainment mapping from multiple disparate sites during AT. A local electrogram recorded from proximal coronary sinus by a deflectable electrode catheter locked in position was used as reference for activation sequence mapping for the majority of the cases. If coronary sinus was not accessible or catheter position in the coronary sinus was not stable, another stable anatomic site was chosen individualized to each case and catheter stability was confirmed fluoroscopically and by the electroanatomic mapping system during the mapping. The width of the window of interest was the AT cycle length during the initial map, and the onset was chosen to have equal periods before and after the reference electrogram. Repeat maps were common and the onset preceding the reference electrogram during the repeat maps could vary 60 to 120 ms depending on the data from the initial map or on the presence of a clearly delineated P-wave on the surface ECG. Arrhythmias were defined as macro-re-entrant intra-atrial re-entrant tachycardia if the activation sequence mapping identified a circular pathway, the spread of local activation times covered 90% of the AT cycle length, and post-pacing intervals matching the AT cycle length were observed from disparate sites located along the circular pathways. The entrainment site where pacing resulted in local concealed fusion and where the post-pacing interval was <30 ms was considered the "critical isthmus." The mechanism was classified as focal if the activation sequence mapping revealed centrifugal spread from a single source and if the spread of local activation times was <70% of the cycle length of the AT. None of the patients included in this study underwent pulmonary vein isolation for atrial fibrillation, for example, and if sustained, atrial fibrillation was terminated by direct current cardioversion.

Radiofrequency ablation was initiated with 50 W power (temperature-controlled at 65°C) using 8-mm nonirrigated tip catheters, or 25 to 40 W (temperature-controlled at 43°C to 45°C) using irrigated tip catheters. Catheter ablations were performed using the contact force-sensing technology for the most recent 49 procedures (35%). In cases of re-entrant atrial tachycardia/flutter, when radiofrequency energy was delivered across a critical isthmus to create a linear zone of conduction block, differential pacing was used to confirm conduction block across ablation lines. Acute success was defined as termination of all identified AT by RF energy application followed by inability to induce sustained AT by PCS. At the time of repeat ablative procedures for recurrences, arrhythmias were categorized as "new" or "old" based on their underlying mechanism and location of the arrhythmogenic substrate compared with the findings from the initial ablation procedure.

PRIMARY ENDPOINT. The primary endpoint was time from initial catheter ablation to the first recurrence of clinical, documented AT. Patients were followed until a recurrence of AT or a maximal date of follow-up. Patients reaching maximal follow-up time were censored from analysis given their current status. The primary points of interest were the predictors of acute procedural success and the cardiac electrophysiological predictors of post-procedure AT recurrence. We also evaluated the arrhythmia-free survival after repeat catheter ablation procedures in patients who had more than 1 catheter ablation procedure. Post-radiofrequency ablation recurrence was defined as recurrent, symptomatic palpitations with documented AT by ECG, Holter, or other extended cardiac rhythm monitoring devices.

STATISTICS. Data were expressed as frequency (percentage), median (interquartile range [IQR]), or mean ± SEM as appropriate. Univariate testing for prediction of acute procedural success was performed using chi-square tests, Fisher exact tests, or logistic regression as appropriate. Multivariate testing was performed with logistic regression. Univariate and multivariate testing for AT recurrence was performed for the primary endpoint using a Cox proportional hazard model. Variables reaching $p < 0.10$ in the univariate analysis were included in the multivariate analysis. Kaplan-Meier survivor function was performed for the primary endpoint by diagnosis for both initial and follow-up ablative procedures. Statistical analysis was performed using both SPSS statistical software (version 24, IBM Corp., Armonk, New York) and STATA statistical software (version 15.1, StataCorp, College Station, Texas).

RESULTS

Between December 1, 2005, and July 20, 2017, 140 patients with ACHD underwent catheter ablation procedures for treatment of documented AT. Patient characteristics are shown in Table 1. The time from corrective surgery to AT diagnosis was 29 ± 14 years. Of the 20 patients with Fontan status, 13 had undergone atriopulmonary anastomoses, 4 had undergone lateral tunnel procedures, and 3 had extra-atrial conduits.

CARDIAC ELECTROPHYSIOLOGICAL FINDINGS. In the cardiac electrophysiology laboratory, the baseline cardiac rhythm was AT in 93 patients, sinus rhythm in 45 patients, atrial pacing in 1 patient, and junctional rhythm in 1 patient. In all 47 patients whose baseline rhythm was not AT, PCS including burst pacing, with the use of isoproterenol if necessary, induced sustained AT. Access was difficult in 3 patients due to inability to access the left atrium, or major limitations in catheter maneuverability due to distorted

TABLE 1 Patient Characteristics

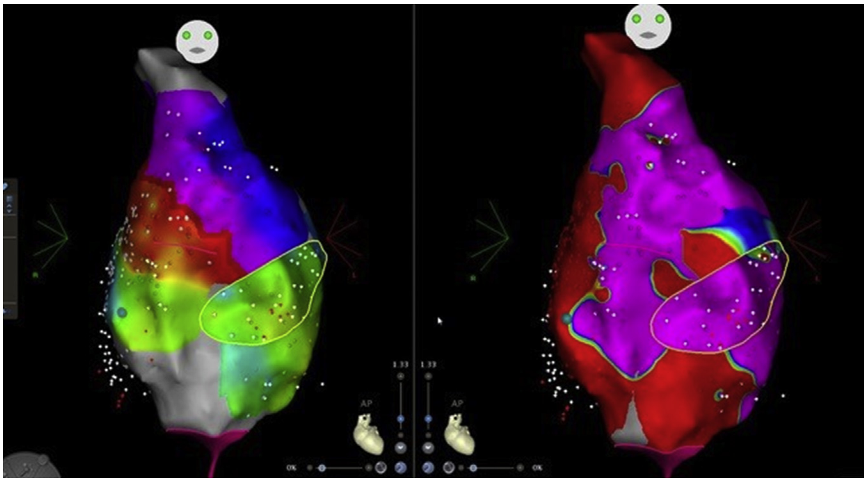
Male	71 (50.7)
Age, yrs	45.0 ± 1.2
Diagnosis	
Atrial septal defect/ventricular septal defect	44 (31.4)
Aortic stenosis/bicuspid aortic valve	7 (5.0)
Tetralogy of Fallot/pulmonic stenosis	38 (27.1)
Atrioventricular canal defect/endocardial cushion defect	7 (5.0)
Ebstein status	4 (2.9)
Fontan status	20 (14.3)
Mustard/Senning status	12 (8.6)
Other (partial anomalous pulmonary venous return/mitral stenosis/absent pericardium/double outlet right ventricle/ Rastelli status/congenitally corrected transposition)	8 (5.7)
Medications	
Amiodarone	22 (15.7)
Sodium channel blockers	1 (0.7)
Beta-blockers	78 (55.7)
Sotalol	14 (10.0)
Calcium-channel blockers	8 (5.7)
Transseptal/transbaffle puncture	19 (13.6)
Prior surgical maze	8 (5.7)
History of requiring cardioversion	55 (39.3)
Body surface area, m^2	1.86 ± 0.4
Cycle length of clinical AT, ms	275 ± 5

Values are n (%) or mean ± SEM.
AT = atrial tachyarrhythmia.

anatomy, and in 2 of these patients, underlying AT could not be ablated because complete bi-atrial mapping could not be performed. We include these patients as acute success failures. After catheter mapping and ablation of the baseline or induced AT, further PCS induced AT with a different mechanism in 36 patients. Thirty-two patients had 2 distinct mechanisms identified, and 4 patients had more than 2. Altogether, 182 distinct spontaneous (baseline) and induced AT mechanisms were mapped and ablated in all 140 patients during the first catheter ablation procedure. Using the criteria described in the methods, 170 of these mechanisms (93%) were macro-re-entry, and 12 (7%) were focal. Of the 170 re-entrant mechanisms, 103 could be classified as perivalvar in the sense that 84 were cavotricuspid isthmus (CTI)-dependent and 19 were mitral isthmus-dependent by activation sequence, entrainment, and termination criteria (Figure 1). Sixty-four patients (45%) had CTI-dependent atrial flutter as the only mechanism. Forty-six mechanisms were directly related to scar tissue at an incision site, using an isthmus between closely spaced scarred regions as substrate (Figure 2). Eight mechanisms could be described as re-entry within the lateral tunnel in Fontan patients, and the remaining ones were complex macro-re-entry mechanisms related to scarring caused by atrial septal and ventricular septal patches and baffle lines of the atrial switch operations.

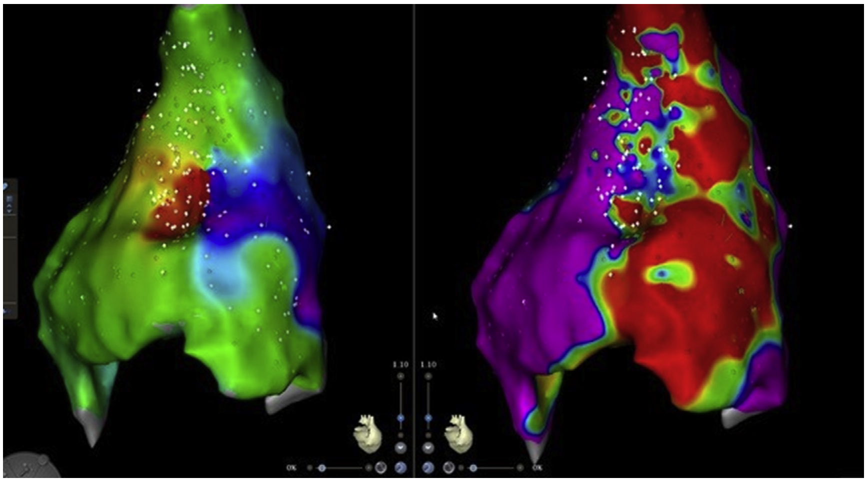
The ablation technique for treatment of macro-re-entrant AT involved creation of linear lesions with details determined by local concealed entrainment and other anatomic and electrophysiological observations such as scar edges, baffle edges, regions of

FIGURE 1 Perivalvar Intra-Atrial Re-Entrant Tachycardia



Perivalvar re-entrant tachycardia in a patient with congenitally corrected transposition of great arteries with ventricular septal defect and pulmonic stenosis, who underwent more than 1 cardiac surgery. The right atrial activation sequence map of the perivalvar tachycardia is shown on the **left panel,** and the voltage map of the right atrium is shown on the **right panel.** The wave front is broad and circulating around the tricuspid valve annulus.

FIGURE 2 **Incisional Intra-Atrial Re-Entrant Tachycardia**



Incisional intra-atrial tachycardia in the same patient as the one in Figure 1. The activation sequence map **(left panel)** and the voltage map **(right panel)** of the posterior right atrium are shown. The mechanism is different from the one described in Figure 1. There is heavy scarring (red zone) from previous surgeries and there is a critical isthmus in the scarred zone.

low voltage, and valve annuli. The ablation technique for focal AT involved delivering energy multiple times to the site of earliest activation during AT until it terminated.

ACUTE PROCEDURAL SUCCESS. Acute procedural success, as defined in the Methods, could be achieved in 124 patients (89%). Univariate and multivariate predictors of acute procedural success are shown in Table 2. In 64 patients with CTI-dependent atrial flutter as the only mechanism, the acute success was 98.4%, whereas in the other 76 patients (55%) with more than 1 mechanism or more complex single mechanisms, the acute success was 80%. The presence of a single mechanism was a multivariate predictor of acute procedural success ($p = 0.03$). However, acute success was also achieved in 26 of the 36 patients (72%) with more than 1 mechanism, whereas in 7 patients with a single mechanism, acute success was not possible. Presence of at least 1 non-CTI-dependent macro-re-entry mechanism and post-Senning/Mustard status were negative predictors of acute success ($p = 0.04$ and $p = 0.05$, respectively). The baseline cardiac rhythm, the cycle length of the underlying or induced AT, and CTI-dependent flutter mechanism were not multivariate predictors of acute procedural success.

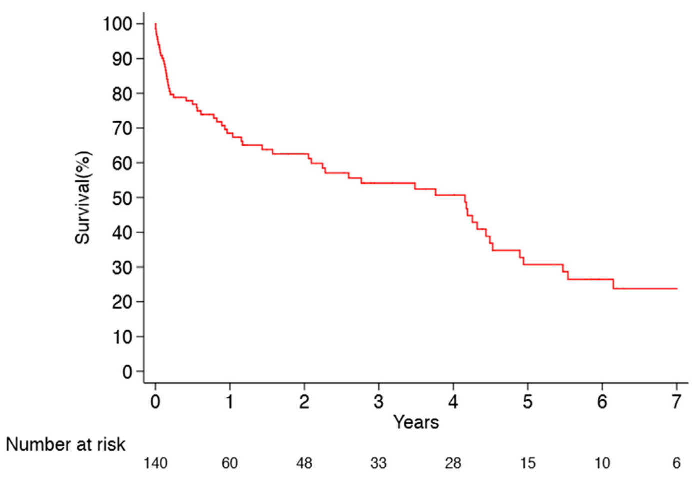
AT RECURRENCE AND PREDICTORS. During the follow-up period, AT recurred in 62 patients (44%) and was documented by 12-lead ECG, Holter monitor, or long-term cardiac rhythm monitoring. Median time to AT recurrence was 49.9 (IQR: 6.7 to 73.7) months and AT-free survival after the first catheter ablation procedure is shown in Figure 3. All 16 patients in whom acute procedural success had not been achieved experienced recurrent AT. Recurrent AT occurred in 49 (40%) biventricular patients and 13 (65%) Fontan patients. Median time to arrhythmia recurrence was significantly shorter for patients with

TABLE 2 **Univariate and Multivariate Predictors of Acute Procedural Success at First Catheter Ablation**

	Univariate		Multivariate	
	HR (95% CI)	p Value	HR (95% CI)	p Value
Sex		0.13		
Age	1.00 (0.96–1.03)	0.99		
ASD/VSD status		0.38		
Fontan status		0.17		
Mustard/Senning status		0.03	4.46 (1.02–19.38)	0.05
Grade of ACHD lesion (ACC/AHA 2008 guidelines [21])		0.52		
Prior surgical maze		0.21		
Failed amiodarone		0.72		
Presented in sinus rhythm		0.49		
Macro-re-entrant AT		0.28		
Single circuit		0.02	0.27 (0.08–0.87)	0.03
Non-CTI-dependent circuit present		0.01	3.74 (1.07–13.04)	0.04
Transseptal/transbaffle puncture required		0.03	2.15 (0.60–7.74)	0.24
Cycle length of clinical tachycardia	0.99 (0.98–1.00)	0.15		

ACC = American College of Cardiology; ACHD = adult congenital heart disease; AHA = American Heart Association; ASD = atrial septal defect; AT = atrial tachyarrhythmia; CI = confidence interval; CTI = cavotricuspid isthmus; HR = hazard ratio; VSD = ventricular septal defect

FIGURE 3 **Arrhythmia Recurrence After First Catheter Ablation**



Kaplan-Meier estimates of arrhythmia recurrence after first catheter ablation for atrial tachyarrhythmia in all adult congenital heart disease patients.

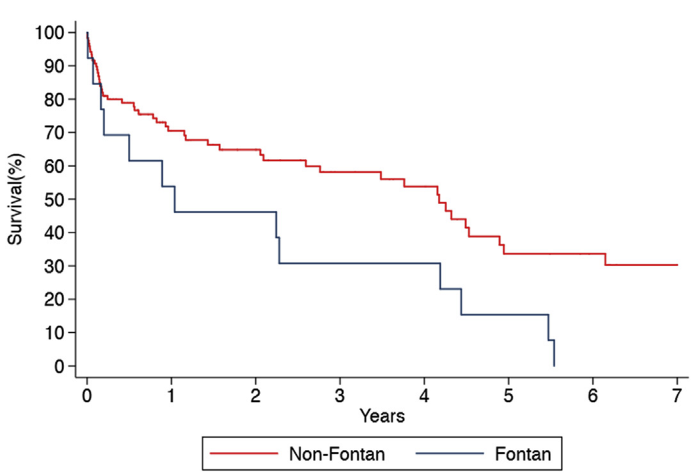
a Fontan procedure (12.5 months for Fontan vs. 50.1 months for all others; $p = 0.01$) (Figure 4). Univariate and multivariate predictors of recurrence after the initial catheter ablation procedure are displayed in Table 3. By univariate analysis, acute procedural success was a positive predictor of AT-free survival. Univariate predictors of AT recurrence included Fontan status, prior surgical maze procedure, and pre-procedural failure of amiodarone therapy. In a multivariable Cox proportional hazards model, acute procedural success was the only positive predictor, and prior maze procedure was a negative predictor of AT-free survival.

Of the 62 patients with recurrent AT, 42 (68%) had a second catheter ablation procedure. The baseline cardiac rhythm at the second catheter ablation procedure was AT in 29 patients and sinus rhythm in 13 patients. In all patients with sinus as the underlying rhythm, AT could be induced with PCS. A total of 57 spontaneous or induced AT mechanisms were studied in detail with activation sequence mapping and entrainment in these 42 patients during their second cardiac catheter ablation procedure. Of these 57, 53 (93%) were macro-re-entry and 4 (7%) were focal AT. In 22 patients (52%) the location of the arrhythmogenic substrate and AT cycle length were new and different from any of the AT mechanisms mapped during the first catheter ablation procedure. In 20 patients (48%) the AT mechanism was, with at most minor differences, among the mechanisms mapped and ablated during the first catheter ablation procedure, indicating that the acute success observed during the previous procedure was not a durable result in these patients. The AT-free survival after the second catheter ablation procedure in this smaller subgroup of patients is shown in Figure 5. An additional 19 of the 42 patients (45%) were able to achieve freedom from arrhythmia recurrence during the follow-up period following repeat ablation. The median time to recurrence after the second ablation was 56.0 (IQR: 22.0 to 90.9) months in this subgroup. Nine patients had 3 and 2 patients had 4 catheter ablation procedures. These numbers were too small for statistical analysis on this small subgroup.

PROCEDURAL COMPLICATIONS. One patient developed immediate post-procedure heart block requiring a pacemaker. One patient died 1 month after procedure due to acute stroke. There were no other major post-procedure complications.

Over the course of the study period, 8 patients died a median 9.2 (IQR: 4.6 to 40.0) months post-ablation and 2 patients underwent heart transplantation a median 23 (IQR: 19.0 to 27.1) months post-ablation.

FIGURE 4 **Arrhythmia Recurrence in Fontan Versus Non-Fontan Patients**



Kaplan-Meier estimates of arrhythmia recurrence after first catheter ablation for atrial tachyarrhythmia in adult congenital heart disease patients stratified by Fontan versus non-Fontan status ($p = 0.01$).

DISCUSSION

Our study attempted to identify specific cardiac electrophysiological factors associated with acute procedural success and with post-procedural AT recurrence in a cohort of 140 ACHD patients. Acute procedural success could be achieved in the large majority (89%) of the patients and was a predictor of AT-free survival. Our findings are similar to the results of previously published studies (11,14) and confirm, in a slightly larger cohort, that multiple AT mechanisms are common in ACHD patients and constitute a major cause of recurrent AT. Also similar to these previous results, our study also shows that AT recurs in a substantial minority (44%) over a median of 50 months, indicating that acute procedural success does not always predict durable outcome, and in patients who have a repeat catheter ablation after AT recurrence, one-half or even the majority may have a new arrhythmogenic substrate site. Nevertheless, overall, the majority of patients appeared to derive significant benefit from 1 or more than 1 catheter ablation procedures to treat their AT.

Findings similar to our study have been reported previously by de Groot et al. (11) in a smaller cohort of ACHD patients. These investigators reported a recurrence rate of 59% within a year of the ablation procedure compared with our rate of 44% during a mean follow-up period of 19 months. Only 1 arrhythmia mechanism was ablated during the first procedure in their study, and in a small subgroup of patients who underwent a second ablation procedure, the investigators observed that the arrhythmogenic substrate location was different from the previously ablated area in all but 1 patient. By contrast, the arrhythmogenic substrate location was different in only one-half of our patients with recurrent AT undergoing a second ablation procedure. These differences may be due to the differences in procedural endpoints used, as well as the differences in the underlying heart disease of the cohorts. In the study by de Groot et al. (11), the patients with prior atrial switch operations constituted 8% of the population, which is similar to our study, but 26% of their patients had Fontan status, compared with our 14%. A recent publication by Ueda et al. (14) conducted in 116 ACHD patients showed that the acute success rates were lower in ACHD patients with single ventricle status and in those with prior atrial switch operations compared with those with less complex anatomy. Had our study population included a more numerous subgroup of such patients, our acute as well as long-term success rates could have been lower.

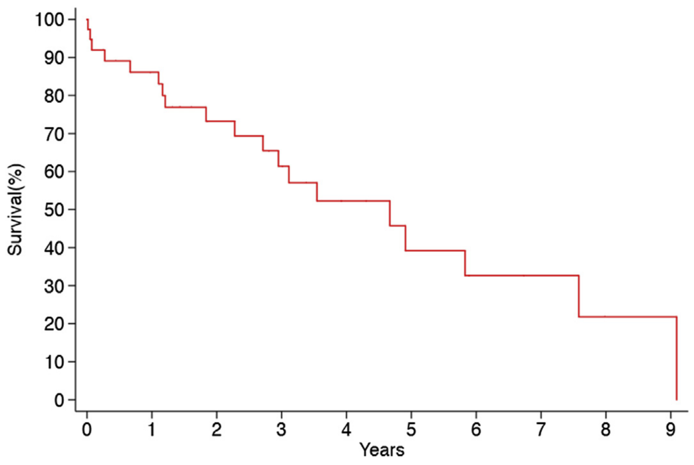
Acute success rates may also be influenced by the complexity of the arrhythmia mechanism as well as by the complexity of the underlying anatomy. Unlike the study by Ueda et al. (14), AV re-entry and AV nodal re-entry mechanisms were excluded in our study because our focus was AT. However, 45% of our patients had CTI-dependent atrial flutter as the only mechanism that is relatively easier to ablate and also less likely to recur compared with other more complex mechanisms. With a greater proportion of complex mechanisms, our overall success rates could have been lower. Other procedural and technical factors that may play a role in acute success include accuracy of mapping, biophysical aspects of

TABLE 3 Univariate and Multivariate Predictors of Recurrence After First Catheter Ablation

	Univariate		Multivariate	
	HR (95% CI)	p Value	HR (95% CI)	p Value
Sex				
Female	1.00	Ref		
Male	1.29 (0.78–2.14)	0.32		
Age	1.00 (0.98–1.02)	0.17		
ASD/VSD status				
Yes	1.00	Ref		
No	0.94 (0.53–1.67)	0.84		
Fontan status				
No	1.00	Ref	1.00	Ref
Yes	2.14 (1.16–3.95)	0.02	1.75 (0.88–3.49)	0.11
Mustard/Senning status				
No	1.00	Ref		
Yes	1.29 (0.58–2.84)	0.54		
Grade of ACHD lesion (ACC/AHA 2008 guidelines [21])				
1	1.00	Ref		
2	1.12 (0.53–2.36)	0.76		
3	1.09 (0.62–1.93)	0.76		
Prior surgical maze				
No	1.00	Ref	1.00	Ref
Yes	4.89 (1.84–12.97)	0.01	3.34 (1.16–9.66)	0.03
Failed amiodarone				
No	1.00	Ref	1.00	Ref
Yes	2.10 (1.15–3.84)	0.02	1.59 (0.79–3.21)	0.19
Presenting cardiac rhythm				
Sinus	1.00	Ref		
AT	0.73 (0.41–1.29)	0.28		
Type of AT				
Macro-re-entrant	1.00	Ref		
Focal	1.29 (0.55–3.02)	0.56		
Multiple circuits				
No	1.00	Ref		
Yes	1.10 (0.61–1.97)	0.75		
Non-CTI-dependent circuit present				
No	1.00	Ref		
Yes	1.27 (0.76–2.11)	0.36		
Transseptal/transbaffle puncture required				
No	1.00	Ref		
Yes	1.16 (0.52–2.56)	0.719		
Cycle length of clinical tachycardia	0.99 (0.97–1.00)	0.172		
Acute procedural success				
Yes	1.00	Ref	1.00	Ref
No	2.35 (1.15–4.80)	0.02	2.16 (1.04–4.49)	0.04

Ref = reference; other abbreviations as in Table 2.

FIGURE 5 Arrhythmia Recurrence After Second Catheter Ablation



Kaplan-Meier estimates for arrhythmia recurrence after second catheter ablation for atrial tachyarrhythmia in all adult congenital heart disease patients.

radiofrequency energy delivery, and possible difficulties in access, although difficult access resulting in acute failure occurred in only 2 patients in our study. Advances in mapping techniques are likely to improve the accuracy of defining the arrhythmogenic substrate and improve acute and long-term success. A recent report by Lactu et al. (15) showed the improved accuracy of defining AT circuits using the automated ultrahigh resolution mapping system.

In the small subgroup of patients with Fontan circulation and recurrent AT, time to recurrence was relatively short, underscoring the importance of close follow-up and frequent monitoring following the ablation procedure. This cohort was still able to derive a median arrhythmia free time of over 12 months post-ablation. Whether and when a patient with a previous "classic" Fontan procedure should undergo Fontan conversion for an arrhythmia-related indication is a critical decision because the perioperative mortality or need for post-operative transplant has been estimated to be between 5% and 15% and the post-conversion arrhythmia recurrence rate has been reported to be nontrivial and between 14% and 23% (16,17). A prolonged period of management strategy involving serial catheter ablations to maintain sinus rhythm as long as possible may be preferred in select patients without hemodynamic indications for Fontan conversion.

Acute procedural success, defined as inability to induce sustained AT after all ablation has been completed, in every patient may be a difficult endpoint to reach, but to the extent that it predicts AT-free survival, it should be targeted as a goal in this cohort. The benefit of achieving this endpoint should be carefully balanced against the concerns with safety and hemodynamic stability of the patient. Nevertheless, AT recurrence occurred in nearly one-half of the patients in whom acute procedural success could be achieved. In one-half of the patients undergoing a second ablation procedure, the recurrent AT was the result of a previously unobserved underlying mechanism. Even rigorous programmed cardiac stimulation at the end of the first ablation attempt will not identify the mechanisms that develop de novo during the progression of the disease. Ablation success rate is also likely to improve with technological advances in energy delivery systems enabling deeper penetration of energy in chambers with fibrosis and thick walls in ACHD patients. Concerted efforts should be made to develop a national registry for catheter ablation procedures, similar to the NCDR (National Cardiovascular Data Registry) IMPACT (Improving Pediatric and Adult Congenital Treatments) for congenital catheterization procedures (18).

The median age in this cohort was 44 years, and it may not be unreasonable to expect our results to differ from those previously reported for AT in ACHD cohorts of pediatric and young adult patients (4-8,19,20). Because long-term exposure to hemodynamic abnormalities may promote fibrosis, dilation, and hypertrophy, catheter ablation may be more challenging in older patients. However, despite a relatively older age in our cohort, our AT recurrence rate was similar to those previously reported in predominantly pediatric or mixed populations (4-6). In addition, although our cohort had a mean age older than those previously described, major adverse events did not appear to be more prevalent. Fibrosis and scar formation may adversely affect the accuracy of catheter mapping and effective delivery of radiofrequency current because the biophysical properties of myocardium and scar are quite different. This is underscored by our observation that prior surgical maze procedure was a multivariate predictor of AT recurrence. Routine use of contact force-sensing technology, used only in one-third of our patients, has the potential to substantially improve the efficacy and the durability of the radiofrequency lesions.

The cumulative exposure to fluoroscopy, especially in patients such as those with ACHD, who are likely to undergo repeated diagnostic procedures as the underlying disease progresses, is a safety concern. Our fluoroscopy time of 30.5 min is a mean value over procedures spreading over 12 years and does not reflect the length of fluoroscopy during our most recent procedures. Recent techniques such as those using magnetic navigation, to the extent that they become widely applicable to ACHD patients, can drastically decrease exposure time to ionizing radiation. In the recent study by Ueda et al. (14), in 1 of the subgroups where remote magnetic navigation was used, the median fluoroscopy time was 4.2 min despite longer total procedure times.

STUDY LIMITATIONS. Our study has the inherent limitations of a retrospective study carried out at a single institution. Despite our efforts to keep our methodology uniform and standard, some degree of interoperator variability is inevitable. For example, the endpoint of each catheter ablation procedure was operator-dependent and was influenced by the clinical characteristics of each individual patient and hemodynamic stability. We also recognize that our sample size is limited to a small cohort of 140 patients and consequently our analysis may be underpowered to detect other significant electrophysiological predictors of catheter ablation outcome. The distribution of the underlying anatomic diagnoses reflects the nature of our referral population. The size of the subgroups of patients with Fontan status and with prior atrial switch operations are likely to influence the overall acute and long-term success rates. Furthermore, the cohort presented in this study is a select group because they were deemed suitable candidates for nonpharmacological catheter ablation method of treatment. Therefore the findings may not be applicable to the population of ACHD patients at large, especially to those with clinical backgrounds different from our cohort.

CONCLUSIONS

Catheter ablation for AT in ACHD patients is a safe and effective method of arrhythmia control. The majority of patients achieve multiple arrhythmia-free years, but multiple arrhythmia mechanisms are common, and so are latent recurrences requiring repeat procedures. Elimination of all spontaneous and electrically induced AT may be challenging, but nevertheless appears necessary for durable AT-free survival.

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ADDRESS FOR CORRESPONDENCE: Dr. Hasan Garan, Cardiac Electrophysiology Unit, Division of Cardiology, Department of Medicine, 161 Fort Washington Avenue, Suite 648, New York, New York 10032. E-mail: Hg2017@cumc.columbia.edu.

PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: This work has implications and applications in the areas of medical knowledge and patient care.

TRANSLATIONAL OUTLOOK: This work contributes to the publications about AT in patients with ACHD. The authors recognize the difficulties of studying a small population and therefore suggest a national registry for catheter ablation procedures, similar to the NCDR IMPACT registry for congenital catheterization procedures.

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