Influence of Patient Factors and Ablative Technologies on Outcomes of Radiofrequency Ablation of Intra-Atrial Re-Entrant Tachycardia in Patients With Congenital Heart Disease

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OBJECTIVES
The goal of this study was to identify factors associated with radiofrequency catheter ablation (RFCA) outcomes of intra-atrial re-entrant tachycardia (IART).

BACKGROUND
Radiofrequency catheter ablation of IART is difficult. The influence of patient and procedural factors and novel technologies on outcomes is unknown.

METHODS
Acute and chronic RFCA outcomes were studied in patients with congenital heart disease and IART. Clinical status was measured using a multiaxis severity score. Multivariate analyses identified associations of clinical, procedural and technological factors with outcomes.

RESULTS
A total of 177 procedures were performed in 134 patients; 139 procedures (79%) resulted in RFCA of ≥1 IART circuit and 117 (66%) in RFCA of all targeted circuits. Multivariate analysis associated acute success with irrigated ablation and absence of atrial fibrillation. Twenty-two complications were noted, nine related to vascular access. Electroanatomic mapping failed to decrease procedure or fluoroscopy time. Improvement in clinical status occurred in most patients (severity score preablation: 6.2 ± 1.6, postablation: 3.0 ± 2.3, p < 0.0001). At mean follow-up of 25 ± 11 months, 42% of patients had IART recurrence and 28% required cardioversion. Six deaths occurred (1.8%/patient-year), and two patients underwent transplant. Chronic outcomes were associated with higher right atrial saturations, use of electroanatomic mapping, fewer IART circuits encountered and acute procedural success.

CONCLUSIONS
Improvement of acute RFCA outcomes was contemporaneous with introduction of novel technologies. Intra-atrial re-entrant tachycardia recurrence was common, and no effect on mortality was discerned, but most patients had effective palliation of symptoms. Chronic outcome predictors included the underlying disease severity, application of novel technologies and successful ablation of all targeted arrhythmia circuits. (J Am Coll Cardiol 2002;39:1827–35) © 2002 by the American College of Cardiology Foundation

Radiofrequency ablation procedures for treatment of intra-atrial re-entrant tachycardia (IART) in patients with congenital heart disease (CHD) are technically demanding. The earliest reports of clinical outcomes of IART ablation predated the advent of nonfluoroscopic mapping techniques and irrigated catheters (1–5). Techniques used to map IART for ablative attempts in these series included fluoroscopic visualization of catheter position (5), inference of surgical anatomy (2,4), entrainment pacing (3) and identification of “dead zones” of scarred tissue and split potentials (1). Acute success was typically defined as the termination of a targeted IART circuit by application of radiofrequency energy, with subsequent ascertainment of “noninducibility” by unspecified postablation atrial stimulation. Using this approach, acute success rates were observed in the range of 70% to 100%, with a mean reported value of 78% drawn from 132 patients in the five largest series (1–5). Although some reports indicated spontaneous tachycardia recurrence in only a minority of patients, one carefully documented follow-up study of IART ablations revealed a recurrence rate of 50% at 24-month follow-up of patients treated with these conventional mapping and ablative techniques (6).

Recently, new clinical tools for spatially precise three-dimensional activation mapping of IART have been reported (7–9). These techniques have improved understanding of the clinical mechanisms of IART circuits in patients with CHD and the relations of these circuits to the underlying atrial myocardial substrate. Additionally, novel ablative techniques such as irrigation of the ablation catheter.
tip have been introduced, and their potential efficacy has been demonstrated for the ablation of refractory accessory pathways, common atrial flutter and ventricular tachycardia (10–13). It remains unclear whether these newer mapping and ablative techniques are associated with greater procedural efficacy in IART.

The current study presents acute and intermediate term data for a large, single-center series of patients with CHD undergoing ablation of IART and explores the influence of procedural and clinical variables, including the application of novel mapping and ablative technologies, on clinical outcomes.

METHODS

Retrospective analysis of the acute and intermediate term outcomes of all patients with CHD undergoing attempted ablation of IART at Boston Children’s Hospital between January 1993 and December 2000 was performed. Clinical records were reviewed with approval from the hospital’s institutional review board. For those patients not followed locally, referring cardiologists were contacted to assess interim and current health and arrhythmia status. Outcomes for patients who underwent radiofrequency catheter ablation (RFCA) between January 1993 and December 1998 have been previously reported (5,6) and were updated for this report. Informed consent for clinical procedures was obtained in accordance with hospital policies. All patients had a history of sustained and/or recurrent atrial tachycardia. Patients were studied under general anesthesia after hemodynamic evaluation. Intra-atrial re-entrant tachycardia was defined as a sustained (>60 s) and entrainable atrial rhythm, induced and/or terminated by pacing, independent of atrioventricular conduction, and with sudden onset and constant cycle length (14).

Fluoroscopic mapping. Fluoroscopy was used as the primary guide for catheter placement in all cases performed before January 1, 1999. Atrial angiography and spot fluoroscopy were used at the discretion of the operator to record atrial anatomy and catheter location.

Electroanatomic mapping. Fluoroscopy was supplemented by electroanatomic mapping in all patients catheterized after January 1, 1999, using the CARTO system (Biosense Webster, Inc., Diamond Bar, California). An intercaval location reference sensor was applied and an atrial reference electrode placed to record left atrial activation, either from the coronary sinus or transesophageally. Activation mapping was performed by initial systematic and broad sampling of the atrial endocardial surface, followed by more detailed mapping of areas of interest. In the event that patients arrived in the catheterization laboratory in sustained IART, mapping and ablation of the circuit were undertaken immediately. More commonly, mapping of sinus and/or atrially paced rhythm was undertaken to characterize the atrial substrate, followed by induction of IART by atrial extrastimulation protocol (8), and burst atrial pacing when necessary.

Standard RFCA. Standard ablation was performed using a variety of power- and temperature-controlled catheters (7F, 4-mm electrode). Power was limited to 50 W and, in the case of temperature-controlled catheters, tip temperature was limited to 70°C. Power was delivered for up to 120 s per lesion using either RFG-3C (Radionics, Burlington, Massachusetts) for power-controlled ablation or an Atakr (Medtronic Cardiorhythm, San Jose, California) for temperature-controlled ablation.

Irrigated ablation. Irrigated ablation was used in patients who failed standard radiofrequency ablation and/or in whom evidence of low-power output was observed at ablation set point. Irrigated lesions were delivered by one of two techniques. External sheath irrigation was performed before the availability of internally irrigated catheter designs by guiding 7F standard ablation catheters to the ablation site using an 8F-long sheath advanced to the distal tip electrode. Slow infusion of room temperature saline was then manually delivered during radiofrequency application, permitting higher power outputs without impedance rise. Alternatively, an internally irrigated catheter with a closed coolant system was used (Chilli, Cardiac Pathways, Inc., Sunnyvale, California). With this technique, lesions were power-controlled, with manual titration of power input until either an impedance drop of 10 Ω to 15 Ω or a tip temperature >40°C was observed.

Acute outcome measures. Acute success was defined as termination of an IART circuit during application of radiofrequency energy without occurrence of an atrial extrasystole or asynchronous pacing event, which was subsequently not induced by programmed stimulation. Limited procedural success was defined as a procedure in which one or more targeted IART circuits were acutely terminated according to the definition noted in the previous text. Complete procedural success was defined as a procedure in which all targeted IART circuits were terminated according to the definition noted in the previous text.

Clinical arrhythmia score. A multiscale index of clinically relevant arrhythmia activity was used to compare severity of IART immediately before ablation and at postablation follow-up. Four subscores were summed to yield a clinical arrhythmia score that ranged from 0 (no arrhythmia activity) to 12 points (severe, incessant and life-threatening arrhythmia activity) (Table 1). This score was calculated before ablation and at each subsequent follow-up visit for which sufficient clinical information was available. Long-term clinical outcome was determined from the subgroup of procedures with: 1) preablation clinical arrhythmia score

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**Abbreviations and Acronyms**

CHD = congenital heart disease
IART = intra-atrial re-entrant tachycardia
RFCA = radiofrequency catheter ablation

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Table 1. IART Clinical Severity Score

<table>
<thead>
<tr>
<th>Documented IART</th>
<th>Frequency of Cardioversion (Prior 3 Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Nonsustained IART only</td>
<td>One cardioversion</td>
</tr>
<tr>
<td>History of sustained IART</td>
<td>AART cardioversions</td>
</tr>
<tr>
<td>Incessant IART</td>
<td>Two or more cardioversions</td>
</tr>
</tbody>
</table>

IART Severity Antiarrhythmic Medications

<table>
<thead>
<tr>
<th>Score</th>
<th>IART Severity</th>
<th>Antiarrhythmic Medications</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No symptoms</td>
<td>None or digoxin only</td>
</tr>
<tr>
<td>1</td>
<td>Palpitations only</td>
<td>Class II or class IV</td>
</tr>
<tr>
<td>2</td>
<td>Syncope/CHF/thrombosis</td>
<td>Class I or class III</td>
</tr>
<tr>
<td>3</td>
<td>Cardiac arrest</td>
<td>Amiodarone toxicity</td>
</tr>
</tbody>
</table>

Score of 0 to 12 points is calculated as the sum of the highest score achieved in each of the four categories. Thrombosis determined by either echocardiographic evidence of intracardiac thrombus or clinical evidence of thromboembolic event. AART cardioversions are defined as one or more automatic or manual cardioversions performed using an implanted atrial pacemaker and not requiring any additional intervention. Amiodarone toxicity includes documented abnormalities of thyroid, hepatic or pulmonary function attributed to amiodarone administration, whether or not necessitating discontinuation of medication.

CHF = congestive heart failure, determined by review of clinical records and/or hemodynamic measurement; IART = intra-atrial re-entrant tachycardia.

A total of 177 ablative procedures were performed, including 22 patients who had two procedures and 11 patients who had three procedures. Mean preablation clinical arrhythmia score was 6.2 ± 1.6 (n = 165 procedures).

Irrigated lesions were applied in 39 procedures (first irrigated procedure: #71, June 30, 1997), and electroanatomic mapping was utilized in 69 procedures (first electroanatomic mapping procedure: #107, January 29, 1999). Patient characteristics were compared for patients undergoing procedures with standard versus irrigated ablation and standard versus electroanatomic mapping. These showed that patients undergoing irrigated ablation had hemodynamic signs of increased right atrial pressure (14 mm Hg vs. 11 mm Hg, p = 0.003) and decreased cardiac output (mixed venous saturation 66% vs. 70%, p = 0.007 and atroventricular O2 difference 31% vs. 27%, p = 0.022), consistent with a slight predominance of patients with the Fontan procedure (72% vs. 45%, p = 0.059) in this population. The surgical and hemodynamic status and

\[ \frac{\text{frequency of cardioversion}}{\text{interquartile range}} \]

\[ \text{SD or median (range) as appropriate. Univariate comparisons were made using paired or unpaired } t \text{ tests for continuous data and Fisher exact test or chi-square for categorical data. Multivariate data analysis was performed using logistic regression, with binary end points of complete procedural success and long-term outcome as defined above. For the purposes of multivariate analysis, ambiguous long-term outcomes that did not meet criteria for either outcome group (e.g., insufficient follow-up, preablation arrhythmia score <5) were not analyzed, resulting in a study group smaller than that used for analysis of acute outcomes. For multivariate logistic analyses, } p \text{-enter was chosen to be } 0.08 \text{ and } p \text{-remove } 0.10. \]  

Factor analysis was performed on the same end points using principle component analysis and varimax rotation with Kaiser normalization for definition of factor groupings (SPSS for Windows, Version 10.0.5, Chicago, Illinois).

RESULTS

Patient population. The study group consisted of 134 patients, with a mean age of 25.3 ± 12.2 years (range 1 month to 62 years). The most common underlying anatomical diagnoses were variants of single ventricle, tetralogy of Fallot/ventricular septal defect and transposition of the great vessels. All but two of the patients had prior cardiac surgical intervention, with the Fontan procedure the most common operation (Table 2).
clinical IART severity of patients undergoing electroanatomic mapping were similar to those undergoing standard mapping.

Acute outcomes. A total of 369 distinct IART circuits were encountered (median: 2 IART circuits/procedure, range: 1 to 6), and 268 circuits were mapped (median: 1/procedure, range: 0 to 5). A total of 238 circuits were targeted for ablation (median: 1/procedure, range: 0 to 5), and 185 were terminated (median: 1/procedure, range: 0 to 5). Overall, one or more IART circuits were terminated (limited procedural success) in 139/177 (79%) procedures, and all targeted IART circuits were terminated (complete procedural success) in 117/177 (66%) procedures.

Figure 1 shows acute success rate in sequential epochs of ablation practice, categorized by technology applied (see caption). These data show an increase in limited and complete procedural success rates after the introduction of irrigated ablation and electroanatomic mapping. Univariate correlation of success rates by mapping and ablation technologies (without respect to procedure date) also showed association between procedural success and technology. Limited procedural success was increased in patients undergoing electroanatomic mapping (87% vs. 73%, \( p = 0.029 \)) and irrigated ablation (92% vs. 75%, \( p = 0.018 \)), while complete procedural success was increased in patients undergoing irrigated ablation (85% vs. 61%, \( p = 0.006 \)). Stepwise multivariate logistic regression showed that significant, independent predictors of acute procedural success were the use of irrigated ablation and the preablation observation of atrial fibrillation (negative predictor) (Table 3).

Univariate and multivariate analysis of clinical outcomes. A total of 483 follow-up encounters were available for analysis in 119 patients after 156 ablation procedures for which an encounter was recorded at \( \leq 3 \) months after ablation (mean: 3.1 follow-up encounters/procedure). Total follow-up duration for these procedures was 329 patient-years, a mean of 25 months/procedure.

During the follow-up period, the clinical arrhythmia score in all patients was reduced from a mean preablation value of 6.2 \( \pm 1.6 \) to 3.0 \( \pm 2.3 \) (3.2 points, \( p < 0.0001 \)), a finding that was stable over increasing duration of...
follow-up (Fig. 2A). A total of 43% of patients had an electrocardiographically documented recurrence of IART (sustained IART >60 s duration) after their most recent ablative procedure, at a mean of 25 ± 11 months, and 28% have had a cardioversion, at a mean of 25 ± 13 months. Compared with patients with the Fontan procedure, patients with other anatomy had a somewhat lower overall rate of documented IART recurrence (36% vs. 52%, p = 0.077) but a similar overall rate of cardioversion (25% vs. 32%, p = 0.451).

Of the 156 procedures with sufficient follow-up, 54 were classified as long-term unfavorable outcomes and 52 as long-term favorable outcomes (see definitions in Methods section) for purposes of further analysis. There was no difference in preablation clinical arrhythmia scores for the two groups (favorable: 6.6 ± 1.4 vs. unfavorable: 6.4 ± 1.1, p = 0.432), with significant difference observed in follow-up score, as contrived by the selection process (favorable: 0.9 ± 1.0 vs. unfavorable: 5.2 ± 1.5 at mean 20 months, p < 0.0001). Distribution and follow-up trends in clinical arrhythmia score are presented for these two groups in Figure 2B. Descriptive univariate statistical comparisons are presented for patient factors, procedural technologies and acute procedural findings and outcomes in Table 4, along with the results of stepwise multivariate logistic regression analysis.

Univariate analysis revealed a number of predictors of long-term favorable outcome. At a significance level of p =
0.1, the univariate predictors of favorable outcome were higher right atrial saturation and complete procedural success. Predictors of unfavorable outcome were diagnosis of single ventricle, older variant of the Fontan procedure, a prior history of atrial fibrillation and higher numbers of IART circuits mapped and ablated. Multivariate logistic regression identified higher right atrial saturation, complete procedural success and use of electroanatomic mapping as positive predictors of long-term favorable outcome, while number of IART circuits was a negative predictor.

Factor analysis was performed to determine whether variables could be combined linearly to account for outcome variability. Using this approach, variables were clustered into three groups, which together accounted for 58% of the variability observed in the clinical outcome. The three groupings could be characterized as: “use of new technology” (dominant variables: procedure date, electroanatomic mapping, irrigated ablation), “Fontan physiology” (dominant variables: diagnosis of single ventricle, older variant of Fontan) and “procedural complexity” (dominant variables: number of IARTs encountered and number of IARTs mapped).

**Deaths, transplantation and procedural complications.**

Six patients (4%) of the study group were deceased on follow-up, with a median time of 11.5 months (range: 2 days to 66 months) to death after procedure. Two deaths were sudden, occurring 11 and 12 months after the procedure, both in patients without documented recurrence of IART; in one of these, an atrial thrombus was diagnosed echocardiographically. The single periprocedural death occurred in a 45-year-old patient with palliated tricuspid atresia and severe congestive heart failure in the setting of incessant atrial tachycardias (IART and atrial fibrillation). Death in this patient ensued from progressive, intractable heart failure, ventricular and atrial tachycardias and hypotension two days after apparently successful mapping and ablation of two IART circuits. Two patients underwent transplantation after IART ablation for hemodynamic indications.

Procedural complications were encountered in 22 patients (16%). Nine of these were femoral vascular access complications, which resolved. Injury to pacemaker lead function was observed in three cases, and transient phrenic nerve palsy, transient ischemic events or atrial/superior vena caval thrombi were observed in two cases each. Also noted in single patients were a renal embolic event, pleural effusion, hemoptysis and complete heart block.

Pulsed fluoroscopy time (anteroposterior + lateral time: 65 min fluoroscopy vs. 87 min electroanatomic mapping, \( p = 0.001 \)) and total procedure time (5 h 28 min fluoroscopy vs. 6 h 2 min electroanatomic mapping, \( p = 0.033 \)) were prolonged in all cases but longer in cases employing electroanatomic mapping.

**DISCUSSION**

In this report, novel outcome measures and multivariate statistical techniques were used to analyze a large series of IART ablations in patients with CHD. In contrast to prior smaller series on this topic, it was possible in this study to correlate outcomes to factors specific to the patient and the ablation procedure. While not a curative procedure in many cases, the majority of patients showed substantial clinical improvement in terms of practical end points such as need for repeated cardioversion or use of antiarrhythmic drugs. Multivariate analyses suggest that the utilization of advanced mapping and ablative technologies was, in part, responsible for improved acute and chronic success. Clinical
outcomes also depend on a variety of patient-specific factors, including the presence of univentricular anatomy and prior performance of the Fontan procedure, the complexity of the arrhythmia substrate encountered and mapped during the procedure and achievement of an acutely successful ablation outcome. From our analysis, we conclude that the acute outcomes of catheter ablation of IART are improving and that ablation is a reasonable approach to management of IART in the large group of patients who do not have a specific hemodynamic defect as an indication for cardiac surgery.

**Factors contributing to acute outcome.** A variety of factors were significantly associated with acute success in IART ablation, defined in this series as the ablation of all targeted IART circuits. Multivariate analysis of these factors identified the use of catheter tip irrigation as a positive association and a prior history of atrial fibrillation as a negative association with procedural success.

The favorable effect of catheter irrigation may reflect the difficulties creating transmural ablative lesions in low-flow environments (15,16). An association of irrigation with ablative success has been reported for postinfarction ventricular tachycardia (13) and recurrent atrial flutter (17), arrhythmia substrates that are likely to resemble that encountered in IART. The presence of low convective flow in the atria has been predicted (18) and observed experimentally (19) in certain types of surgical anatomy, particularly older variants of the Fontan procedure. Temperature controlled ablation in these conditions is likely to result in low power applications and smaller ablative lesions. Additionally, extensive lesions may be required to block anatomic pathways of unfavorably large dimension, and atrial tissue may be unusually thick and hypertrophied in postoperative congenital heart patients, a finding that has been observed anecdotally, but is not well documented in the literature.

Atrial fibrillation is likely to represent a marker for a complex arrhythmia substrate and/or more severe hemodynamic derangement. Both of these factors increase the difficulty of the ablation procedure and the probability of terminating the procedure without completing all targeted ablations. This observation is of practical significance, as nearly 15% of procedures in this series were performed on patients with a history of atrial fibrillation. Kirsh et al. (20) recently reported that, although IART is the most common rhythm diagnosis at cardioversion of patients with congenital heart disease, as many as 30% also have a history of atrial fibrillation. Thus, patients with a documented history of atrial fibrillation may comprise a subgroup that may be better served by medical, surgical or device therapies.

**Factors contributing to long-term outcome.** In this report, a long-term favorable outcome was considered to be a significant and sustained reduction of a simple, multidimensional score of arrhythmia symptoms and therapies. Multivariate analysis revealed that positive predictors of chronic success included the successful ablation of all targeted arrhythmias, the use of electroanatomic mapping to guide ablation and higher right atrial saturation; mapping of a larger number of IART circuits during catheterization was a negative predictor of chronic success. Although anatomical diagnosis of single ventricle and surgical anatomy consisting of an older variant of the Fontan procedure showed univariate association with poor chronic outcome, this was not a factor in multivariate models, perhaps because of correlation of this finding with right atrial saturation. These results were echoed by factor analysis, which showed that most of the variation in chronic outcome was accounted for by linear combinations of highly correlated variables that roughly described factors related to: 1) the availability of advanced mapping and ablative technology, 2) the underlying cardiac anatomy and severity of illness, and 3) the complexity of the arrhythmias encountered during the procedure.

First recurrence of tachycardia has traditionally been used as a gold standard for evaluation of efficacy of arrhythmia therapy. Looking solely at first reported recurrence among patients in the current series, patients with the Fontan procedure were somewhat more likely to have documented IART recurrences after attempts at catheter ablation of IART. This stands in contrast with the multivariate analysis of chronic success and reflects the fact that many patients in this series, including those with Fontans, experienced a substantial decrease in the frequency and severity of IART symptoms and/or need for therapy after ablation despite one or more documented IART recurrences.

Patients with biventricular anatomy of all varieties had long-term freedom from recurrence in approximately 65% of cases, a value that still compares unfavorably with freedom from recurrence rates of 80% to 90% over similar time frames in adult studies of atrial flutter ablation outcomes (21,22). However, a more appropriate comparison might be to the less favorable adult experience with atrial flutter before adoption of bidirectional isthmus block as an end point, as this well-validated procedural ablation end point is difficult and often impossible to apply to congenitally abnormal anatomy. The development of versatile, validated techniques for the confirmation of conduction block in diverse anatomical locations remains a challenge to physicians engaged in the development of ablative techniques for complex re-entrant arrhythmias.

**Clinical arrhythmia score.** We observed a discrepancy in clinical outcomes measured by time to IART recurrence in comparison with the overall improvement noted in the clinical arrhythmia score. The following clinical vignette is taken from this series: a patient requiring multiple cardioversions each week while on amiodarone before ablation would be classified a “treatment failure” after ablation due to a single documented episode of tachycardia occurring months after ablation and off antiarrhythmic therapy. Given the intermittence of arrhythmia recurrence, significant practical and theoretical problems exist in the determination and use of time of first recurrence as an arrhythmia outcome measure. This is especially true for patients with atrial arrhythmia, in whom clinically relevant episodes of recur-
rence may sometimes be difficult for the patient to detect, due to variable atrioventricular conduction.

These problems have been recently analyzed by Kaemmerer et al. (23), who demonstrated that atrial arrhythmia recurrence in their study group was a complex stochastic process and that a frequency-based outcome measure for arrhythmia therapies may be markedly superior to time of first recurrence for detection of treatment effect. In prospectively designed studies, measurement of arrhythmia frequency implies the need for dense and regular sampling of cardiac rhythm over an extended time. For the current study, we developed a scale for measurement of arrhythmia activity that incorporated the dimensions of arrhythmia frequency, severity of symptoms and need for medical and interventional therapy. Similar scales have been used in the past to assess quality of life outcomes in arrhythmia ablation (22,24). In this way, we were able to obtain a global sense of the impact of arrhythmia activity on the patient’s life, using data that was easily available on a retrospective basis. Although this scale has not been validated against other measures of arrhythmia activity or quality of life indexes, it provided an objective metric that was useful for defining good and poor outcomes, facilitating analysis of patient and procedural characteristics contributing to these outcomes.

**Morbidity, mortality and procedural complications.**

Overall mortality in our study group was 6 patients in 329 patient-years of follow-up or 1.8%/patient-year. Prior studies of patients with IART occurring after surgical palliation of congenital heart defects suggest that annual mortality in these patients may be similar or slightly higher (25,26). A recent follow-up study of 94 Fontan patients by Ghai et al. (27) indicated a mean survival of approximately 20 years, a value that is consistent with our annualized mortality and that was not strongly influenced by the occurrence of IART. Among our mortalities and transplants, the majority was attributable to hemodynamic deterioration, emphasizing the overall severity of illness in this group. Unfortunately, this observation also indicates that, although successful arrhythmia control may favorably affect quality of life in these patients, it may be difficult to measure an improvement in overall mortality.

Approximately 10% of patients experienced a major complication unrelated to vascular access but attributable to the ablation procedure, including embolic phenomena and systemic venous thrombus. As is the case with mortality, it is unclear as to what extent these complications are a manifestation of an atrial environment, which is now understood to be thrombogenic, even in the absence of intervention (27–30) and what role the creation of radiofrequency ablation lesions in either the systemic or pulmonary venous atrial chamber plays in triggering thrombosis.

Of interest, use of electroanatomic mapping resulted in a paradoxical lengthening of fluoroscopy time in this difficult group of patients. This suggests that, for the operators in this study, electroanatomic mapping was not a sufficient intuitive means of catheter navigation to obviate the need for extensive use of biplane fluoroscopy.

**Study limitations.** Data for this study was acquired retrospectively, and number, interval and documentation of follow-up encounters varied considerably between patients. Although date of procedure was not strongly correlated with acute or chronic outcomes, the fact that all procedures were performed at a single center by a small number of operators may have contributed to a learning curve effect, which has been previously described in pediatric ablation (31). Although this was not isolated in multivariate analysis, such an effect may have contributed to the improvement in outcomes associated with the advent of new mapping and ablative technologies.

**Conclusions.** Acute outcomes of IART ablation in patients with congenital heart disease have improved contemporaneously with the introduction of novel technologies for mapping and ablation of these arrhythmias. Although many patients have had recurrence of IART, significant clinical palliation of clinical symptoms has apparently been achieved in our patient population. Predictors of chronic clinical improvement include the underlying severity of the patient’s heart disease, the application of advanced mapping ablative technologies, the number of tachycardia circuits encountered and the successful acute ablation of all targeted arrhythmia circuits.

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### REFERENCES


