Experience and Results During Transition from Radiofrequency Ablation to Cryoablation for Treatment of Pediatric Atrioventricular Nodal Reentrant Tachycardia

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Background: *Cryoablation has emerged as a new, theoretically safer, modality for treating atrioventricular nodal reentrant tachycardia (AVNRT). The purpose of this study is to compare procedural aspects and outcomes during the transition from radiofrequency (RF) ablation to cryoablation for pediatric AVNRT.*

Methods: *Data were obtained retrospectively from 80 consecutive pediatric patients who underwent AVNRT ablation from 10/2001– 4/2006 (RF n = 42, Cryo n = 38). Statistical analysis was performed using unpaired t-test, chi-square test, and analysis of variance.*

Results: *RF ablations were performed anatomically in NSR while three different mapping techniques were used during cryoablation: ablation during AVNRT (26%), anatomic in NSR (48%), and anatomic with S_1 S_2 pacing (26%). There was no difference in the number or duration of lesions between the three cryo subgroups. Acute success was obtained in 95% of RF and 97% of cryo cases. There was no difference in the number of total, mapping, or full-duration lesions between the RF and cryogroups. Despite accounting for longer cryolesion time, total ablation time ($P < 0.001$), mapping time ($P = 0.002$), and full duration lesion time ($P < 0.001$) were longer in the cryogroup. There was no significant difference in total procedure time; fluoroscopy time was shorter in the cryoablation group ($P = 0.049$). There was one confirmed recurrence of tachycardia in each group with a 2% recurrence rate.*

Conclusions: *Cryoablation for treatment of pediatric AVNRT is as safe and efficacious as RF ablation. Although cryolesions are intrinsically longer in duration, total procedure times were not increased and fluoroscopy times were decreased compared to RF. (PACE 2008; 31:454–460)*

pediatrics, electrophysiology–clinical, ablation, SVT

Introduction

Atrioventricular nodal reentrant tachycardia (AVNRT), a common form of paroxysmal supraventricular tachycardia (SVT) in pediatrics, accounts for 13% of SVT in children and is more prevalent in adolescence.[1,2] While this type of tachycardia is not life-threatening, it does affect patients' quality of life.[3] Radiofrequency (RF) ablation has been used successfully in the treatment of pediatric supraventricular tachyarrhythmias since the early 1990s and has become the gold standard for ablation[2]; however, it is not free of complications. The prospective assessment after pediatric cardiac ablation (or PAPCA trial)[4] demonstrated excellent success rates of >95% for RF ablation of supraventricular tachycardia, but also showed a 2.1% risk of permanent atrioventricular (AV) block in AVNRT ablations. Comparable adult studies have demonstrated a 1.3–1.9% risk for permanent AV block.[5,6] PAPCA-1,[7] the follow-up study to PAPCA, described a SVT recurrence rate of 4.8% at 12 months. Other known complications of RF ablation include cardiac perforation, coronary artery damage, and thromboembolism.[8–11]

Cryoablation, initially used during surgical ablations in the 1970s, reemerged in the late 1990s as a potentially safer modality for transvenous catheter ablations due to the properties of cryoadherence and reversibility. There have been no reported cases in the literature of permanent AV block occurring with cryoablation. Recent reports have suggested a higher recurrence rate of up to 22% with cryoablation for paroxysmal supraventricular tachycardia.[12–18] The FROSTY trial,[13] which evaluated the safety, efficacy, and mapping utility of the Freezor® Cryocath (CryoCath Technologies Inc., Montreal, Canada), demonstrated excellent acute procedural success for AVNRT (91%) with a 6-month freedom from tachycardia rate of 94%, slightly lower than comparable RF trials.

The authors have no conflicts of interest.

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In 2006, the first study directly comparing RF and cryoablation for the treatment of pediatric AVNRT was published,[12] which demonstrated shorter procedural times in the RF group with comparable fluoroscopy times. Both groups had high acute success rates (100% RF, 95% cryo) with few more recurrences in the cryogroup (8% vs. 2% in RF, $P = 0.19$).

At our institution, we have used cryoablation exclusively for all AVNRT ablations since acquiring our Cryo system in April 2004. In this report, we describe our experience during the transition period from radiofrequency ablation to cryoablation for the treatment of pediatric AVNRT.

Methods

Patient Population

After obtaining approval from the Institutional Review Board at Washington University, a retrospective review was undertaken to identify patients who underwent AVNRT ablation at St. Louis Children's Hospital (SLCH). As April 2004 was the transition point, we collected consecutive patients undergoing typical AVNRT (slow-fast pathway) ablation from November 2001 through April 2006. The time frame for patients, who underwent RF-AVNRT ablation, was November 2001–April 2004, and for cryo-AVNRT from April 2004 to April 2006. All ablations were performed under the direct supervision of a single pediatric electrophysiologist at a teaching institution. Data were then obtained through review of the medical record, procedure log, and electrophysiology (EP) database. Exclusion criteria included: (1) presence of major congenital heart disease (i.e., single ventricle physiology), (2) more than 1 arrhythmia substrate, and (3) age >21 years. The length of procedure was defined from initial 12-lead electrocardiogram (EKG) to removal of sheaths. Observation times were defined as the time from the final lesion to sheath removal.

Radiofrequency Ablation

Patients underwent EP study and ablation in the electrophysiology lab using conventional catheter mapping with CardioLab version 5.2 (Prucka Engineering, GE Medical, 2003, Wauwatosa, WI, USA) for mapping. The type of sedation used for the procedure was left to the discretion of the physician, but did take into account age and cooperativity. Ablations were then performed under fluoroscopic guidance using the RF Marinr® catheter (4-mm tip) (Medtronic, Minneapolis, MN, USA) and the Atakr® II RF ablation system (Medtronic) with maximum power to 60 W and maximum temperature to 70°C. Anatomic ablation of slow pathway was performed while monitoring for the presence of accelerated junctional rhythm. Fast pathway conduction was monitored retrograde during junctional rhythm. RF application was terminated if ventriculoatrial (VA) dissociation was seen or if the junctional rate was >150 beats/min. Lesions were divided into mapping lesions (<10 seconds) or full-duration lesions (≥10 seconds).

Cryoablation

Cryoablations were performed using either the Freezor® (4-mm tip) or the Freezor® Xtra (6-mm tip) catheter with the CryoConsole (CryoCath Technologies Inc.). Ablations were performed using three distinct mapping techniques depending on the reproducibility of AVNRT: (1) during free-running AVNRT, (2) anatomic ablation with S_1 S_2 pacing, and (3) anatomic ablation in normal sinus rhythm.

Mapping Technique 1: During Free-Running AVNRT

This was the preferred technique when the patient had easily inducible and sustained tachycardia. While performing these ablations, cryothermy was initiated in the area of slow pathway, typically found in the mid-to-lower third of the triangle of Koch by the upper lip of the coronary sinus[17] (Fig. 1). Acute success was achieved when tachycardia was terminated. If no effect was seen after 15 seconds at <0°C of cryothermy, the lesion was aborted.

Mapping Technique 2: Anatomic Ablation with S_1 S_2 Pacing

This technique was utilized for those patients who were unable to have sustained tachycardia, but did have either reliably reproducible A_2 H_2 jumps or reproducible nonsustained tachycardia on specific drive trains. These ablations empirically started in the location of slow pathway with the addition of pacing during cryothermy. Once cryoadherence was achieved as seen by an increase in artifact on the ablation catheter (around −25°C), atrial extrastimuli drive trains that previously had produced either tachycardia induction or A_2 H_2 jumps were initiated. If slow pathway conduction persisted after 15 seconds at <0°C of cryothermy, the lesion was terminated and another area was attempted; if slow pathway conduction was absent, the lesion was continued for the full 4 minutes.

Mapping Technique 3: Anatomic Ablation in NSR

These ablations were performed in cases of confirmed AVNRT but with intermittent or difficult to reproduce A_2 H_2 jumps or nonsustained and difficult to induce AVNRT. Once an atrioventricular signal relationship of approximately 1:2 was determined, with or without slow pathway potentials, an ablation line was drawn from the tricuspid valve annulus in the lower portion of the

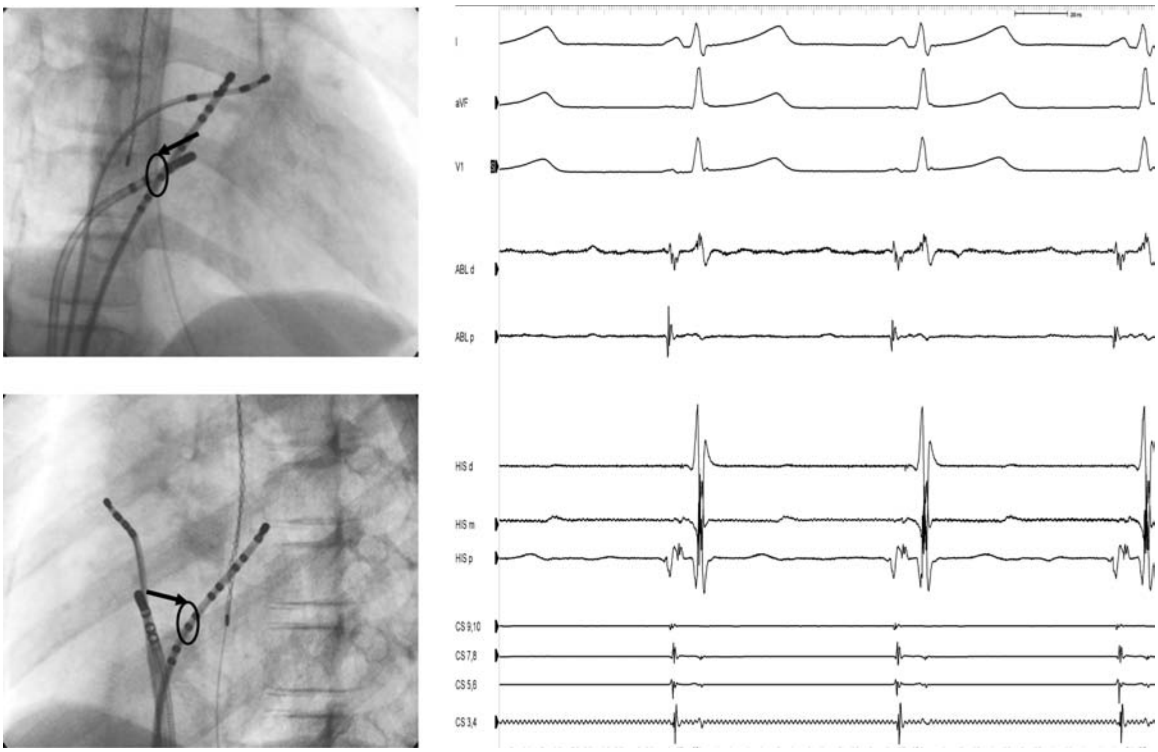

Figure 1. *A RAO (top) and LAO (bottom) projection demonstrating the position of the ablation catheter during anatomic ablation of slow pathway. The intracardiac electrograms demonstrate slow pathway potentials on the distal ablation catheter. The oval represents the coronary sinus ostium and the arrow illustrates the first line created during anatomic slow pathway ablation.*

middle third of the triangle of Koch back toward the mouth of the coronary sinus (Fig. 1). If there was continued evidence of slow pathway, a second line was then drawn from the first line with more caudal progression toward the compact AV node. The anterior extension was continued until PR lengthening or second-degree AV block was seen with cryothermy. When this was seen, the lesion was aborted. During these ablations, all lesions delivered were full-duration lesions.

Cryolesions were divided into three types of lesions: cryomapping lesions (created by a 4-mm CryoCath of any duration where maximal temperature achieved was $\geq -40^{\circ}$C), fast-map lesions (full cryothermal energy with temperature $< -40^{\circ}$C lasting <30 seconds), and full-duration lesions (full cryothermal energy with temperature $< -40^{\circ}$C lasting ≥ 30 seconds). For the purposes of data analysis, mapping lesions were defined as either cryomapping or fast-mapping lesions.

Endpoints

Acute procedural success was defined as absence of repetitive AV node reentry without reinduction of AVNRT despite postablation testing. Presence of a residual A_2 H_2 jump and single echo beat were acceptable endpoints as well.

Follow-Up

Patients were followed up at 1 day, 1 month, and approximately 1 year after successful ablation with history, physical examination, and 12-lead EKG. For those patients followed by outlying cardiologists, the primary cardiologist was contacted for follow-up data. Recurrence was defined as electrocardiographically proven tachycardia. Patients with recurrent symptoms were reevaluated with ambulatory event recorders.

Statistical Analysis

After data collection was completed, data analysis was undertaken using Student's *t*-test, chi-square, Fisher Exact Test, and analysis of variance. Data are described as median ± range. Statistical significance was set for $P \leq 0.05$.

Results

Demographics

A total of 80 patients were identified with 42 patients in the RF group and 38 patients in the cryoablation group. There was no significant difference in demographic data, including gender, age, and body mass index (Table I). Comparison of the past medical history of the two groups revealed

Table I.

Demographic Data

	RF (n = 42)	Cryoablation (n = 38)	P value
Gender	Female 67%	Female 71%	0.81
Age (in years) median (range)	14.2 (0.7-19.7)	14.3 (5.5-19.1)	0.23
Body Mass Index median (range)	19.7 (13.4-31.5)	21.0 (14.6-77.6)	0.18
Presence of Congenital Heart Disease	3 (7.1%)	4 (10.5%)	0.70
Presence of Cardiomyopathy	0	1 (2.6%)	0.48
Prior Ablation Attempts	1 (2.4%)	1 (2.6%)	1
Sedation	General = 76% IV sedation = 24%	General = 66% IV sedation = 34%	0.33

no statistical difference regarding the presence of structural heart disease or cardiomyopathy. In the RF group, there were three patients with structural heart disease, including one patient with moderate aortic insufficiency and mitral regurgitation, another patient with mild mitral valve prolapse with trivial mitral regurgitation, and the last patient with a complete atrioventricular canal and moderate pulmonary stenosis. Within the cryoablation group, there were four patients with congenital heart disease. These included one patient with a patent ductus arteriosus, one patient with moderate pulmonary stenosis, one patient with mild mitral valve prolapse with mild mitral regurgitation, and lastly, a patient with a complete atrioventricular canal and subaortic stenosis. There was one patient with dilated cardiomyopathy who underwent cryoablation. The most common reason for ablation was patient or family choice in both groups. One patient in each group had undergone a previous RF ablation attempt at other centers.

Procedural Data

Sustained AVNRT was inducible in 71% of RF cases and 79% of cryo cases (P = NS). Isoproterenol was used for induction of tachycardia in 67% RF and 79% cryo cases, and in postablation testing in 67% of RF and 58% of cryo cases (P = NS). There was no difference found between procedure times in the two groups. Fluoroscopy times were significantly longer in the RF group with shorter observation times when compared with the cryoablation group (Fig. 3). There was no statistical difference between the use of intravenous sedation or general endotracheal anesthesia (Table I).

All radiofrequency ablation catheters had 4-mm tips. Two different size catheters were used in the cryoablation population; 63% of patients underwent ablation with a 6-mm catheter tip and 37% had a 4-mm catheter tip.

Ablation Data

Comparison of the ablation data revealed no significant difference in the total number of lesions, number of mapping lesions, or number of full-duration lesions (Figs. 4 and 5). Despite accounting for the longer duration of full-duration cryoablation lesions, the mapping and full duration cryolesions were longer (Table II).

Table II.

Procedural Data

	RF	Cryoablation	P value
Procedure Time (min) median (range)	174 (68-443)	176 (97-324)	0.25
Fluoroscopy Time (min) median (range)	21 (4-158)	19 (6-49)	0.49
Observation Time (min) median (range)	34 (17-82)	52 (14-114)	0.001
Median total # lesions	6 (1-44)	11.5 (1-43)	0.203
Total time of lesions (sec) median (range)	207 (51-905)	2015 (360-6143)	< 0.001
Median # mapping lesions	3 (1-15)	4 (1-19)	0.642
Time of mapping lesions (sec) median (range)	17 (4-78)	95 (13-628)	0.002
Median # full-duration lesions	5 (1-30)	9 (3-26)	0.126
Time of full-duration lesions (sec) median (range)	199 (38-861)	1935 (144-5783)	< 0.001

Table III.

Cryoablation Subgroup Lesion Data

	In AVNRT (n = 10)	Anatomic in NSR (n = 18)	Anatomic with S_1 S_2 pacing (n = 10)	P value
Median # total lesions	13 (5-43)	11 (1-30)	16 (8-29)	0.303
Total time of ablation lesions (sec) median (range)	1953 (1200-6143)	2147 (720-5131)	2138 (360-5678)	0.73
Median # mapping lesions	3 (0-19)	1 (0-12)	4 (0-25)	0.519
Time of mapping lesions (sec) median (range)	80 (0-360)	26 (0-618)	103 (0-1371)	0.2
Median # full duration lesions	9 (5-24)	9 (3-19)	8 (4-26)	0.756
Time of full duration lesions (sec) median (range)	1912 (1200-5783)	2124 (720-4513)	1814 (144-5678)	0.9

Mapping Technique

Three different mapping modalities were used in the cryoablation group: (1) during tachycardia (26%), (2) anatomic ablation with S_1 S_2 pacing (26%), and (3) anatomic ablation in normal sinus rhythm (48%). Given three distinct ablation strategies within the cryoablation group, we analyzed data to determine if any one methodology was superior. There was no difference in the total number or duration of ablation lesions, mapping lesions, or full duration ablation lesions (Fig. 6, Table III). For those patients who underwent a strict anatomic ablation, two lines were created in 67% of patients, and a single line in 33% of cases.

Acute Outcomes

Acute success, defined as elimination of repetitive AV node reentry with no reinduction despite pacing with or without isoproterenol, was obtained in 95.4% of RF cases (41/43 patients) and 97.4% of cryoablation cases (36/37 patients). Using an intention-to-treat analysis, there was a failure rate of 4.5%, or two cases in the RF group. One case was failure of RF during postablation testing. This patient was then crossed-over into the cryoablation group and underwent an acutely successful cryoablation. The second patient was a teenage male with dilated cardiomyopathy who was supported with extracorporeal membrane oxygenation and had persistent AVNRT refractory to medical therapy. We were unable to achieve adequate power with the RF generator, presumably due to low-flow and poor convective cooling. This patient crossed-over to the cryoablation group and underwent an acutely successful ablation with termination of tachycardia.

In the cryoablation group, there was a failure rate of 2.5% (one case). This patient was encountered early in our cryoablation experience and was switched to RF due to poor catheter positioning and inability to eliminate slow pathway conduction with repeated cryothermy.

Table IV.

Patient Outcomes

	RF	Cryoablation
Temporary Events		
None	0 (100%)	29 (76%)
Transient AV Block		9 (24%)
Long-Term Complications	1 (2.4%)	1 (2.6%)
Duration of follow-up (yrs) median (range)	3.5 (2.1-4.5)	0.8 (0.1-2.1)
Recurrence	1 (2.4%)	1 (2.6%)

Complications

Temporary side effects were defined as effects seen in the EP lab that resolved before the patient left the lab. Such side effects were noted in the cryoablation group only, with 26% of patients experiencing temporary second-degree (AV) block that resolved with the removal of cryothermal energy. No temporary AV conduction disturbances were noted in the RF group.

Long-term complications were noted in one patient from each group (2.4 and 2.6%, respectively for RF and cryo) (Table IV). In the RF group, a 16-year old female patient (53 kg) with preexisting first-degree (AV) block developed intermittent second-degree AV block with symptomatic bradycardia postablation. She underwent elective pacemaker placement 4 months following her ablation procedure. The complication from the cryoablation group was a 9-year-old male (29 kg) who developed asymptomatic first-degree AV block after his ablation.

Follow-Up and Recurrence

Follow-up data were obtained on patients in both groups excluding five patients who were lost to follow-up: two from the RF group and three from the cryogroup. Due to the retrospective design, patients in the RF group had a longer follow-up time (mean 3.47 years, compared to 0.89 years for the cryogroup).

Assuming no recurrence in the five patients lost to follow-up, one patient in each group (2.4–2.6%) had recurrence of AVNRT (Table IV). The child in the RF group who had recurrence of AVNRT underwent ablation prior to repair of his complete atrioventricular canal. His tachycardia recurred post-ablation; however, he had no further episodes after surgical repair of his congenital heart disease. The patient in the cryoablation group was initially ablated using a 6 mm cryocatheter who later developed recurrence of her tachycardia and underwent a repeat successful cryoablation (also with a 6-mm cryocatheter).

Discussion

Cryoablation can be used successfully for the treatment of pediatric AVNRT, with acceptable results during the transition phase from RF ablation despite the learning curve for a new technology. Unlike previous studies, our data show acute procedural success and median term follow-up success equivalent to RF ablation using cryoablation.

The length of procedure was comparable in both groups,[19] although the postablation observation time was longer in the cryoablation group. This may be due to the fact that the cryoablation patients underwent more vigorous postablation testing since a newer modality was being used. The shorter fluoroscopy time in the cryoablation group may be partially accounted for by cryoadherence; however, we did not routinely monitor application of RF lesions under fluoroscopy. The shorter fluoroscopy time may also be partially due to the reversibility of lesions and enhanced mapping ability. Regardless, cryoablation procedures may be completed in a timely manner comparable to their RF counterparts.

Our data also demonstrated equivalent number of lesions in the cryo and RF groups. Our technique involves the application of "insurance" lesions directly within the vicinity of the "kill" lesion. This may account for our lower recurrence rates than previously reported in the literature. A recent study looking at increased duration of cryoablation lesions and application of additional lesions[10] demonstrated that the group which received 6-minute long cryolesions with repeat lesion after the 30-minute observation period had lower recurrence of tachycardia at follow-up. Also, our increased use of the 6-mm cryocatheter may have contributed to our lower recurrence rate. Although a significant portion of patients undergoing cryoablation have temporary side effects with transient AV block, there were no long-term sequelae resulting from this. Other studies have also demonstrated this phenomenon[1,3,4,11,13] with no reported long-term complications.

Study Limitations

We attempted to correct the retrospective study design by enrolling consecutive patients and minimizing exclusionary criteria. Also, as a referral medical center, several of these patients were not followed up at SLCH. If all patients lost to follow-up were assumed to recur, the overall success rate would be reduced; however, the equivalent success rate of cryoablation to radiofrequency ablation would be maintained. Given the study design, patients who had cryoablation had shorter follow-up periods than the RF patients.

Conclusion

The use of cryoablation during the transition period from RF for treating pediatric AVNRT appears to be as safe and efficacious as RF ablation. Although cryolesions are intrinsically longer in duration, total procedure times were not increased and fluoroscopy times were decreased when compared to RF. Due to its improved safety profile,[20] cryoablation can be used safely and effectively for the treatment of pediatric AVNRT.

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