The results of electrophysiological study and radiofrequency catheter ablation in pediatric patients with tachyarrhythmia

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A total of 135 consecutive pediatric patients (pts) with tachyarrhythmia ranging from two to 21 years of age (median age 11 years) underwent electrophysiological study (EPS) between January 1994 and July 2001. Tachycardia could not be induced in 38 of 135 pts (28%) and studies in these patients were accepted as the normal EPS. Supraventricular tachyarrhythmia mechanisms were atrioventricular (AV) accessory pathways in 47 patients (manifest accessory pathways in 23 patients, concealed accessory pathways in 17 patients, permanent junctional reciprocating tachycardia in 7 patients), re-entry without accessory pathway in 26 patients (AV nodal reentry tachycardia in 20 patients, atrial flutter in 5 patients, sinus node re-entry tachycardia in 1 patient) and atrial ectopic tachycardia in eight patients. The diagnosis of ventricular tachycardia (VT) was made in 16 patients. Seventy-three of the 97 patients with the diagnosis of tachyarrhythmia as a result of EPS underwent radiofrequency (RF) catheter ablation. The indications, early results, complications, safety and efficacy of RF catheter ablation were reviewed in these patients. Among the 73 patients who underwent RF ablation (85 procedures), the overall final success rate for all the diagnoses was 82% (60 of 73 patients). The median follow-up period for all patients was 16 months (range 2 to 60 months). Total recurrence rate in 73 patients was 4% (3 patients). Re-ablation was performed in only one of them and was successful. Procedure-related complications occurred in eight patients (11%): transient third-degree AV block in one patient, transient second-degree AV block in one patient, atrial flutter in two patients (1 needed direct current cardioversion), and atrial fibrillation in three patients (2 needed defibrillation and transient pacemaker implantation). In one patient with permanent third-degree AV block a transvenous pacemaker implantation was required. These midterm results suggest that RF catheter ablation has a good success rate and a low complication rate in pediatric patients, especially when it is carried out in experienced pediatric cardiology centers.

Key words: tachyarrhythmia, intracardiac electrophysiological study, radiofrequency catheter ablation, children.

Radiofrequency (RF) catheter ablation was first described in pediatric patients in the early 1990s. Excellent success rates coupled with low complication rates have allowed these procedures to be offered as first-line therapy to many children with cardiac arrhythmia[1-5]. There are several advantages of this therapy when used with correct indications: no exercise restrictions, no need for chronic drug therapy, and avoidance of hospital visits for breakthrough episodes[6]. The initial success rate for RF ablation is 91% for all arrhythmia substrates including virtually every form of supraventricular tachycardia (SVT) and also VT[7,8]. Great success has been achieved with accessory connections, both manifest and concealed[1-6]. Treatment of permanent junctional reciprocating tachycardia (PJRT), which uses a slowly conducting concealed pathway, has been revolutionized with this

therapy[9-11]. Successful modification of the atrioventricular node with ablation of the slow pathway can be safely accomplished with a low incidence of heart block[8,12,13]. Automatic focus tachycardias, such as atrial ectopic tachycardias (AET), have been ablated with good success in children[14,15]. Ablative therapy of postoperative atrial and ventricular tachycardias is being increasingly used today[6,16,18].

Radiofrequency catheter ablation therapy has been performed in our unit since 1994. The purpose of this report is to present the efficiency, safety and midterm follow-up of RF ablation in pediatric patients with a wide range of ages and diagnoses.

Material and Methods

A total of 135 consecutive pediatric patients (51 male and 84 female) ranging from two to 21 years of age (median age 11 years), with symptoms of palpitation, dizziness or syncope and a history of congenital heart disease or surgery were evaluated for cardiac dysrhythmia first by noninvasive diagnostic techniques: resting electrocardiography, Holter monitoring, exercise stress electrocardiography and signal averaged electrocardiography. After the diagnosis of tachyarrhythmia was made based on these data, 135 patients underwent electrophysiological study (EPS) and 85 RF ablation procedures were performed on 73 of them.

Patient Selection for RF Ablation: Patients were referred for one or more of the following indications: 1) life-threatening symptoms: tachyarrhythmia associated with syncope, seizures, or resuscitation from cardiac arrest, 2) medically refractory tachycardia: tachyarrhythmia not effectively controlled by one or more antiarrhythmic medications, 3) withdrawal of medical therapy because of adverse drug effects, 4) ventricular dysfunction associated with incessant tachycardia, 5) impending cardiac surgery: planned cardiac surgery the risks of which could be reduced by RF ablation, and 6) patient preference (only for patients 2 years and older). Specific reasons for the choice were not sought or analyzed.

Radiofrequency Ablation Technique: Procedures were performed after written informed consent was obtained. Premedication was administered using midazolam (0.1 mg/kg, IV). During the procedure, additional intravenous (IV) sedation was performed with ketamine (1 mg/kg, IV). Anticoagulation was achieved using 100 µg/kg of intravenous heparin. After a diagnostic electrophysiologic evaluation, intracardiac mapping catheters sized 5-8 French were used to localize the small area of myocardium responsible for maintaining the arrhythmia before ablation attempts (Fig. 1). When the appropriate site was identified precisely, the mapping catheter was used to deliver low-temperature RF energy (50-65°C) with the applications beyond 10-15 seconds. Thirty minutes after successful ablation, atrial and ventricular restimulation with and without an isoproterenol infusion were performed to determine whether conduction over the tachycardia substrate had recurred. Total fluoroscopic time for both the diagnostic and therapeutic portions of the procedure was recorded. Occurrences of both major and minor early and late complications of the procedure were noted.

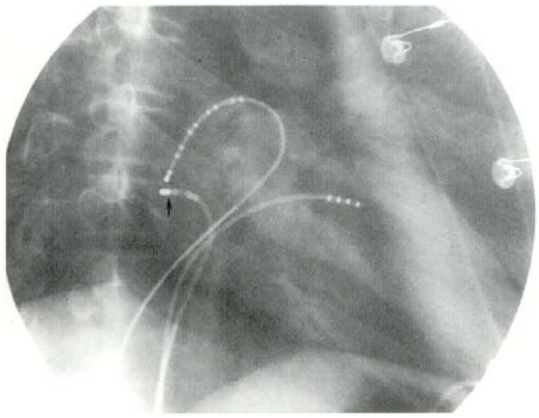

Fig. 1. In the right anterior oblique view of one patient with ectopic atrial tachycardia, maping catheters were placed on crista terminalis of right atrium and His bundle, and radiogrequency ablation catheter was positioned along crista terminalis.

All patients were hospitalized overnight with continuous arrhythmia monitoring and were evaluated by electrocardiogram and echocardiogram before discharge. They received low-dose aspirin therapy for three months and were typically evaluated at 1, 6, and 12 month intervals after the procedure. All patients had an electrocardiogram, echocardiogram and 24-hour ambulatory Holter monitoring performed at each visit during the five-year follow-up.

Statistical Analysis: All data are presented as mean±standard deviation. Kruskal-Wallis analysis was used to compare the mean fluoroscopy times among the manifest and concealed accessory pathways.

Results

One hundred and thirty-five patients underwent EPS between January 1994 and July 2001. Structural heart disease was found in 16 patients (Table I). Clinical tachycardia could not be induced in 38 of the 135 patients (28%) in EPS and their studies were accepted as normal EPS. Three of the 38 patients were treated with sotalol[1] and propranolol[2] because of persisting complaints including palpitation, dizziness and syncope. Mechanisms of tachyarrhythmia diagnoses are illustrated in Table I. Atrioventricular accessory pathways were found to be responsible for supraventricular tachyarrhythmia mechanisms in 47 patients (manifest accessory pathways in 23 patients, concealed accessory pathways in 17 patients, permanent junctional reciprocating tachycardia in 7 patients). Re-entry without accessory pathway was related to atrioventricular (AV) nodal reentry tachycardia in 20 patients, atrial flutter in five patients and sinus node re-entry tachycardia in one patient. Atrial ectopic tachycardia was determined in eight patients. The diagnosis of ventricular tachycardia (VT) was made in 16 patients. VT mechanisms were accelerated idioventricular rhythm (AIVR) in six patients, idiopathic VT in eight patients (right ventricular outflow tract VT in 7 patients, interfascicular reentry tachycardia in 1 patient), catecholamine-related polymorphic VT in one patient and secondary VT to dilated cardiomyopathy in one patient.

Seventy-three patients (median age 11 years, range 2 to 21 years) underwent 85 radiofrequency ablation (RFA) procedures (Table II). Among the 73 patients, the overall final success rate of ablation for all the diagnoses was 84% (61 patients). The median follow-up period of all patients who underwent RFA procedure was 16 months (range 2 to 60 months). Total recurrence rate in 73 patients who underwent RFA procedure was 4% (3 patients). Re-ablation was performed in only one and final success was achieved. Procedure-related complications occurred in eight patients (11%): transient third-degree AV block in one patient, transient second-degree AV block in one patient, atrial flutter in two patients (1 needed direct current cardioversion), and atrial fibrillation in three patients (2 needed defibrillation and transient pacemaker implantation). Permanent transvenous pacemaker implantation was performed in the patient with third-degree

Table I. Results of Electrophysiologic Study in 135 Patients

Tachyarrhythmia	(n)	%	Female (n)	Male (n)	SHD Pts. no.	SHD (n)	Dual AV nodal pathway
Normal EPS	38	28	19	19	5	Operated TOF (4), Operated ASD (1), VSD (1), Right ventricle cardiomyopathy (1)	7
Manifest AP (WPW)	23	17	5	18	2	ASD (2)	2
Concealed AP (AVRT)	17	12	5	12	2	Dilated cardiomyopathy (1), c-TGA (1)	
PJRT	7	5	4	3	–	—	1
AVNRT	20	15	6	14	–	—	20
Atrial flutter	5	4	3	2	1	Operated ASD (1)	–
SNRT	1	1	1	–	–	—	–
EAT	8	6	2	6	1	ASD (1)	–
VT	16	12	6	10	5	Operated TOF (1), Operated ASD (1), Dilated cardiomyopathy (1), Tachycardiomyopathy (1), MVP-MVI (1)	
Total	135	100	51	84	16		

EPS: electrophysiologic study, AP: accessory pathway, WPW: Wolf-Parkinson-White syndrome, AVRT: atrioventricular reentrant tachycardia, PJRT: permanent junctional reciprocating tachycardia, AVNRT: atrioventricularnodal reentrant tachycardia, SNRT: sinus node re-entry tachycardia, EAT: ectopic atrial tachycardia, VT: ventricular tachycardia, SHD: structural heart disease, TOF: tetralogy of Fallot, ASD: atrial septal defect, VSD: ventricular septal defect, c-TGA: congenitally corrected transposition of the great arteries, MVP: mitral valve prolapsus, MVI: mitral valve insufficiency.

Table II. Results of Radiofrequency Catheter Ablation

Tachyarrhythmia	Patient (n)	RFA procedure (n)	Unsuccessful (n)	Recurrence (n)	Success rate n (%)	Fluoroscopy time (mins)	Follow-up (month)	Complications
Manifest AP (WPW)	21	27	2	2*	17/21 (81)	63.6±35.4	23.2±19	Transient 3° AVB (1), Transient 2° AVB (1), A fibrillation (1)
Concealed AP	15	16	1	1	14/15 (93)	32.5±19	22.7±15	–
PJRT	7	7	–	0	7/7 (100)	43±28	22.8±22.5	3° AVB (1)
AVNRT	17	20	1	0	16/17 (94)	39±27	25.7±19.5	A. flutter (2), A. fibrillation (1)
Atrial flutter	3	3	–	0	3/3 (100)	30.6±7.5	12±4.8	–
EAT	6	8	4	0	2/6 (33)	47.6±28.9	11.5±3.5	A. fibrillation (1)
VT	4	4	3	0	1/4 (25)	25.5±19	40±11.3	–
Total	73	85	11	3	60/73 (82)			

AP: accesory pathway, WPW: Wolf-Parkinson-White syndrome, PJRT: permanent junctional reciprocating tachycardia, AVNRT: atrioventricular nodal reentrant tachycardia, EAT: ectopic atrial tachycardia, VT: ventricular tachycardia, RFA: radiofrequency ablation, AVB: atrioventricular block, A: atrial, *recurrences were accepted as unsuccessful and treated medically.

AV block. There was no early or late death after 85 ablation procedures.

Wolff-Parkinson-White Syndrome (WPW (Manifest Accessory Pathway): Two of the 23 patients with WPW syndrome had secundum atrial septal defect. Of 23 patients with WPW, six had left free wall accessory pathway, eight had right free wall accessory pathway, eight had septal accessory pathway and three had parahisian accessory pathway. Two patients had double accessory pathways. RF ablation could not be performed in two patients with parahisian accessory pathway due to risk of complete atrioventricular block. After first ablations (21 procedures), the procedures in five patients were unsuccessful (one left free wall, 2 right free wall and 2 septal accessory pathway). The left patient with free wall accessory pathway underwent a second ablation, but is was again unsuccessful and antiarrhythmic therapy (sotalol) was begun; left atrial ablation via septal puncture was also planned. One of the right free wall accessory pathway patients was treated medically (sotalol). Failure of the procedure in the other patient with right free wall accessory pathway was most probably due to our inability to place coronary sinus catheter. However, delta wave did not disappear on electrocardiogram (ECG) of this patient, and there was no evidence of recurrence of the arrhythmia after the third procedure during follow-up. Ablations of the two septal accessory pathway patients were successful during the second and third procedures, respectively. One month after the first ablation procedures (16 procedures) which were successful, two recurrences were observed associated with the parahisian and septal accessory pathways, and these patints were treated medically (1 with inderal, 1 with amiodarone). The procedure was precisely successful in 17 (81%) of 21 patients with WPW syndrome who underwent ablation therapy. Transient second-degree AV block as a complication was observed in one patient with right free wall accessory pathway during the third ablation procedure and it improved without any treatment. After successful ablation of the one with left free wall accessory pathway, atrial fibrillation appeared via ventriculo-atrial conduction during ventricular stimulation and it was treated by cardioversion. A transient complete AV block in one patient with septal accessory pathway was observed after the

second ablation procedure. After a transient pacemaker implantation, steroid was initiated in this patient. Although complete AV block improved, first-degree AV block persisted during follow-up.

Atrioventricular Re-Entry Tachycardia (AVRT) (Concealed Accessory Pathway): Of 17 patients with AVRT, 15 had left free wall accessory pathway, one had septal accessory pathway and one had parahisian accessory pathway. RFA was not performed in two patients with left accessory pathway. One of these two patients also had dilated cardiomyopathy secondary to thalassemia major and the other had congenitally corrected transposition of the great arteries. These two patients were treated medically (one with sotalol and the other one with amiodarone). Ablation was unsuccessful in the patient with parahisian accessory pathway after first procedures (n=15). He was then followed-up with various antiarrhythmics. Two months after the first ablations (14 procedures) which were successful, a recurrence was observed in a patient with left free wall accessory pathway. Ablation was successfully performed in a second procedure. No major complication was observed during or immediately after the procedures. Overall success rate of the ablation therapy was 93% patients with AVRT.

Permanent Junctional Reciprocating Tachycardia (PJRT): Seven patients with PJRT underwent successful ablation (100%) of posteroseptal accessory pathway. However, ablation procedure resulted in complete AV block in one of these patients and permanent transvenous pacemaker implantation was required.

Atrioventricular Nodal Re-Entry Tachycardia (AVNRT) (Dual AV nodal Pathway): Of 20 patients with AVNRT, 17 had common form with antegrade conduction over the slow pathway and retrograde conduction via the fast AV nodal pathway (slow-fast form). Three patients had uncommon form (fast-slow form). Seventeen of 20 patients underwent ablation of the slow pathway. RFA was not performed in three patients with the common form of AVNRT. In the first patient, a spontaneous Wenckebach AV block was observed during EPS. After stopping the procedure momentarily, second-degree AV block changed to first-degree AV block without any treatment and persisted during follow-up. In the second patient, sick sinus syndrome was detected in addition to AVNRT. The third patient had a very slow tachyarrhythmia rate. Although the first patient was followed without any treatment, the second and third were given sotalol for arrhythmia control during follow-up. After the first procedures (n=17), ablation was unsuccessful in two patients (1 with the common form and the other with the uncommon form). Both underwent a second ablation procedure and it was successful only in the one with the common form. In addition to AVNRT, aberrant ventricular conduction leading to a supraventricular rhythm with right bundle-branch block morphology was determined in the other patient with uncommon form during the procedure. However, the aberrant pathway could not be found and ablated. After the unsuccessful ablation attempts, propafenone was given to this patient for arrhythmia control. As a result, overall success rate of RFA in patients with AVNRT was 94%. After a successful ablation, we observed a transient atrial fibrillation in one patient and atrial flutter in two patients. Although cardioversion was needed to stop one patient's atrial flutter, the other's improved spontaneously. There was no structural cardiac defect in the patients with AVNRT.

Atrial Ectopic Tachycardia (AET): Of eight patients with AET, six had an automatic focus in the right atrium (appendix, high right atrium, coronary sinus, crista terminalis or septum) and two had automatic focus in the left atrium. Ablation could not be performed in two patients due to changing site of automatic focus. Thereafter, although digoxin was given to one of these two patients for arrhythmia management, the other was followed without any treatment. After first ablation procedures in six patients, only one (automatic focus on crista terminalis) was found to be successful. After a second ablation in two of these five patients who underwent an unsuccessful ablation during the first procedure, only one (automatic focus in right atrium) could be ablated successfully. In the second patient with an automatic focus in the left atrium, tachyarrhythmia could not be stimulated, and as a result determination of automatic focus and ablation could not be performed. All the patients (n=4) with unsuccessful ablation attempts were treated with digoxin. Atrial fibrillation as a major

complication was observed in a patient during unsuccessful ablation procedure and transient pacemaker implantation was needed for the treatment. Only one patient with AET had secundum atrial septal defect.

Atrial Flutter (AF): In two of five patients with common type I AF, ablations were not performed. One of two patients with AF had a rapid ventricular response with 2:1 block and she underwent respiratory arrest for a short time during EPS. She was treated with digoxin. The other patient had prior history of cardioversion because of atrial fibro-flutter. But his tachyarrhythmia could not be stimulated during EPS and he was treated with digoxin and quinidine. This patient also had dilated cardiomyopathy secondary to myocarditis. Three of five patients underwent successful RFA of located site between the posterior tricuspid valve and the region of the inferior vena cava. One of them also had WPW syndrome. The other had secundum atrial septal defect (13 mm) and dilated cardiomyopathy. The third patient had a history of repair of atrial septal defect. They were followed-up without any treatment.

Ventricular Tachycardia: The diagnosis of ventricular tachycardia was made in 16 patients. Ventricular tachycardia mechanisms were accelerated idioventricular rhythm (AIVR) in six patients, idiopathic ventricular tachycardia in eight patients (right ventricular fascicular tachycardia VT in 1 patient), catecholamine-related polymorphic VT in one patient and VT in one secondary to dilated cardiomyopathy.

Holter monitoring revealed sustained and nonsustained VT episodes in the patients with AIVR. Three of the six patients with AIVR originating from the right ventricular outflow tract (RVOT) underwent RFA; however all three procedures were unsuccessful. Ablation was not performed in the remainder of the patients. Due to symptomatic (palpitation and chest pain) sustained VT episodes, three of these patients were treated with verapamil.

The patient with left ventricular fascicular tachycardia was ablated successfully. He had also undergone repair of secundum atrial septal defect.

Four of the seven patients with idiopathic VT, found to be resulting from the RVOT, had symptomatic sustained VT episodes including palpitation and chest pain. They were treated medically (propranolol, verapamil). The other three patients were followed without any treatment.

Ventricular tachycardia secondary to dilated cardiomyopathy was successfully suppressed by amiodarone. Digoxin and mexiletine were used together as an initial therapy for catecholamine-related polymorphic VT in one patient. Follow-up controls of this patient showed a newly formed intracardiac thrombus and persistent VT. Amiodarone was started there after since the combined drug treatment failed to suppress the VT, and it was successful in suppressing the VT almost completely.

Fluoroscopy Time: The mean fluoroscopy times in the patients who underwent RFA are shown in Table II. When the fluoroscopy times among the patients with the different accessory pathways were compared, radiation exposure of the patients with right free wall and septal accessory pathways was statistically longer than of the patients with left free wall accessory pathway (Table III) ($p<0.05$).

Discussion

Studies in children with rapidly conducting accessory pathways who present in infancy estimate the chance of resolution to be from

Table III. Results of Fluoroscopy Time and Early Success of Ablation According to Accessory Pathway

Site (%)	Patient (n)	RFA procedure (n)	Recurrence (n)	Fluoroscopy (min)	Success rate n
Left free wall	17	19	1	34±29	16/17 (94)
Right free wall	8	10	–	70±21.8	7/8 (88)
Septal	11	14	2*	69±28.7	8/11 (73)
PJRT	7	7	–	43±28	7/7 (100)
Total	43	50	3		38/43 (88)

Fluoroscopy times were given as mean±SD.
PJRT: permanent junctional reciprocating tachycardia.
RFA : radiofrequency ablation.

60% to 90%. Similary, AET and PJRT patients have a 20% to 50% chance of spontaneous improvement or resolution. However, patients older than the age of five have a very low chance of spontaneous resolution of their SVT. Patients with structural abnormalities and an arrhythmia also have a very low chance of spontaneous resolution. Patients with chronic (incessant) tachyarrhythmias are at risk of developing congestive heart failure and cardiomyopathy. In addition, there is a risk of sudden death as a result of atrial fibrillation with rapid conduction across the accessory pathway leading to ventricular fibrillation in children with manifest WPW. These facts need to be taken into consideration when contemplating RFA as a possible therapy[6,19].

The success rate of this procedure in SVT is quite variable among children and adolescents, ranging from 50 to 96%; highest success rates have been reported among the patients with AVNRT, PRT and left free wall accessory pathway (95-100%)[1,10,12,20,21]. Among the 73 patients, we found that the overall final success rate of ablation for all the diagnoses was 84% (61 patients). The success rates were highest in our patients who underwent ablation of AVNRT and AF (94% and 100%, respectively). Among patients with accessory pathways, success rates were highest during ablation of posteroseptal retrograde decremental accessory pathway (100%) and were lower during ablations of left free wall, right free wall and septal accessory pathways (94%, 88%, 73%, respectively).

Ventricular arrhythmia is seen in only about 2% of the patients in the Pediatric RFA Registry. Although acute success rates have been given as high as 93% (16 patients), longer follow-up is needed to determine the risk of late recurrence[22]. Among four patients with ventricular tachyarrhythmia who underwent ablation, the success rate was 25% in our study.

Although many pediatric centers have advocated a transseptal approach to left-sided ablations, there have been reports of air emboli and perforation[23]. For this reason, we preferred to use the aortic approach in cases with left-sided accessory pathways. We performed septal puncture in only one patient who had automatic focus in left atrium.

Risks such as bleeding, stroke, infection, damage to cardiac valve, cardiac perforation, atrioventricular block and coronary spasm have been reported during RFA in children. The Pediatric Electrophysiologic Society has reported a major complication rate of 2.9% and mortality rate of 0.2%[6,24]. Schaffer et al.[24] published an atrioventricular block rate due to ablation of 1.2%[24]. These complications were 14 complete heart block (3 transient) and nine second-degree block (5 transient). It has been reported that the risk of developing heart block was related to the site of ablation: 2% of anteroseptal connections, 10% of midseptal connections, 1% of right posteroseptal connections, and 1.6% of AVNRT ablations. We observed only atrioventricular block as a complication in three patients (4% during RFA in children. Transvenous permanent pacemaker implantation was required in only one patient with PJRT as a result of complete AV block. In two patients with WPW, although both third- and second-degree AV blocks were transient, complete AV block persisted as first-degree AV block during follow-up. In addition, atrial fibrillation (n=3) and atrial flutter (n=2) were observed during ventricular stimulation after ablation and they improved without any complications. The overall incidence of thromboembolic events has been reported to be between 0.6% and 1.3%[1,6]. The risk is higher in left heart ablations and ventricular tachycardia ablations. We did not observe any thromboembolic complication in our patients.

Rosenthal et al.[25] examined radiation exposure in children and adults in 860 patients. They found radiation exposure to be significantly reduced with younger age. Patients less than 10 years old required a median of 28 minutes fluoroscopy time, those between the ages of 10 and 17 required 35 minutes, and those older than 18 years required 45 minutes. Since our patients were between the ages of 7 and 11, we did not perform statistical analysis among the different ages regarding radiation exposure. On the other hand, we observed that the mean fluoroscopy times of patients with right free wall and septal accessory pathways was statistically longer than of the patients with left free wall accessory pathway ($p<0.05$).

Van Hare et al.[19] found an overall recurrence rate of 15% in 119 patients within six months after ablation. The recurrences were observed mainly in patients with right-sided and septal

connections and AVNRT. We observed an overall recurrence rate of 4% in 73 patients within two months. The recurrences occurred in patients with septal (n=2) and left-sided (n=1) accessory connections.

The use of RFA as a potential cure for multiple arrhythmias in children has increased greatly during the past 11 years. Ablation indications are based on the natural history of various forms of arrhythmias, the risks of the procedure, and the current success rates of the procedures, all of which are dependent upon the age of the patient.

In spite of the high success rates of the ablation procedure, it is important when considering this therapy to also take into account the known risks as well as some of the unknown long-term issues associated with the procedure.

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