Journal of Interventional Cardiac Electrophysiology 5, 443–453, 2001

Radiofrequency Ablation in Pediatric and Adult Patients: Comparative Results

Antonis S. Manolis[2], Vassilis Vassilikos[1], Themos N. Maounis[1], John Chiladakis[2], and Dennis V. Cokkinos[1]

[1]*Cardiology Department, Onassis Cardiac Surgery Center, Athens*
[2]*Cardiology Division, Patras University, Patras, Greece*

Abstract. Background: **Radiofrequency (RF) catheter ablation has been widely and successfully employed to cure adult and pediatric patients of a variety of arrhythmias. Only limited data exist which compare the results in these two groups. The aim of this study was to compare the efficacy and safety of RF catheter ablation in pediatric versus adult patients performed by an adult electrophysiology (EP) team.**

Methods: **The study group included 327 consecutive pediatric ($n = 47$) and adult ($n = 280$) patients, aged 7–82 years (mean 40 ± 19), with symptomatic tachyarrhythmias, who underwent RF ablation during the last 6 years. All but ten patients underwent a full EP study during the same session. Procedures were performed in all but five patients with use of local anesthesia and deep or light sedation. The left heart was approached with use of transaortic ($n = 36$) or transseptal ($n = 55$) or both ($n = 6$) techniques. RF ablation was performed for manifest or concealed accessory pathways in 132 patients, AV nodal slow pathway in 119, atrial tachycardia in 24, atrial flutter in 15, atrial fibrillation in one, ventricular tachycardia in 29, and AV node/His bundle in 7 patients.**

Results: **RF ablation was successful in 271 (96.8%) patients in the adult group and in all patients (100%) in the pediatric group, with a mean of 15 ± 18 (median: 8) vs 12 ± 10 (median: 8) RF applications respectively ($P = $ NS). Complications occurred in four patients (1.4%) in the adult group and in one patient (2.1%) in the pediatric group ($P = $ NS). Fluoroscopy time averaged 43 ± 40 min vs 39 ± 27 min and procedures lasted for 3.0 ± 1.9 hours vs 2.8 ± 1.4 hours respectively ($P = $ NS). During long-term follow-up of 25 ± 19 months, there were 12 (4.4%) recurrences among the adult patients, and three (6.4%) recurrences in children, with nine of them successfully treated with repeat RF ablation. Procedural variables were dependent on the type of arrhythmia ablated, rather than on patient's age. Patients with multiple accessory pathways or atrial flutter required the greatest number of RF applications and the longest fluoroscopy exposure and duration of the procedure; the lowest values of these variables concerned ablation of the slow AV nodal pathway or the AV node/His bundle.**

Conclusion: **RF ablation in adult and pediatric patients performed by an adult EP team is equally efficacious and safe offering cure of symptomatic cardiac tachyarrhythmias in both patient populations.**

Key Words. **radiofrequency ablation, tachyarrhythmias, pediatric patients, accessory pathways, atrioventricular nodal reentrant tachycardia, atrial tachycardia, ventricular tachycardia**

Introduction

Radiofrequency (RF) catheter ablation has been widely and successfully employed to cure adult and pediatric patients of a variety of cardiac arrhythmias [1–21]. Few data have been available in the literature comparing RF ablation procedures in adult and pediatric patients [22,23]. Thus, the aim of this study was to compare the efficacy and safety of RF ablation in a consecutive series of 327 adult and pediatric patients at our institutions performed by an adult electrophysiology (EP) team.

Patients and Methods

Patients

The study included 327 consecutive adult ($n = 280$) and pediatric ($n = 47$) patients undergoing RF catheter ablation in our institutions over the last 6 years (Table 1). These were 175 male and 152 female patients, aged 7 to 82 years (mean 40 ± 19), who underwent RF ablation for diverse symptomatic supraventricular tachyarrhythmias including atrioventricular (AV) nodal reentrant tachycardias, tachyarrhythmias related to accessory pathways causing manifest or concealed preexcitation, antidromic tachycardia

Address for correspondence: Antonis S. Manolis, MD, Professor & Director of Cardiology, 41 Kourempana Street, Agios Dimitrios, Athens 173 43, Greece.
E-mail: asm@otenet.gr

Received 14 November 2000; accepted 5 June 2001

involving an atriofascicular pathway, atrial tachycardia, atrial flutter, atrial fibrillation, and ventricular tachycardia. Procedures were performed in all but five patients with use of local anesthesia and deep or light sedation. In five pediatric patients general anesthesia was employed. The left heart was accessed with use of transaortic and/or transseptal techniques. Electrophysiologic testing and RF ablation were performed during the same session in all but 10 patients. All procedures, including those in pediatric patients, were performed by electrophysiologists of the adult EP service. All patients or patients' parents gave informed written consent for the procedures. Procedures were performed in two institutions, of which one has both an adult and a pediatric cardiovascular surgery service, as well as a pediatric cardiology service, while the other one (where mostly older children and adolescents were treated) has a thoracic surgery service; both institutions have facilities for pediatric anesthesia.

Table 1. *Clinical and procedural characteristics of 47 pediatric and 280 adult patients undergoing radiofrequency (RF) catheter ablation*

	Children	Adults
Patients	47	280
age (years)	14.5 ± 3.0	45 ± 16
male/female	33/14	142/138
Presenting symptoms		
palpitations	24	173
presyncope	14	77
syncope	5	24
collapse/cardiac arrest	2	6
none	2*	
Presenting arrhythmia		
narrow-QRS tachycardia	31	208
wide-QRS tachycardia	11	49
both	2	7
syncope	2	
none/unknown	1	16
SVT/VT, cycle length (ms)	306 ± 52	342 ± 64
Ablation target		
accessory pathway	26	106
slow pathway	16**	104
atrial focus	2	38
ventricular focus	4	25
AVN/HB		7
Successful ablation	47/47 (100%)	271/280 (96.8%)

AVN/HB = AV node-His bundle; SVT = supraventricular tachycardia; VT = ventricular tachycardia.
* One patient with incessant ventricular tachycardia and tachycardic myopathy and one patient with asymptomatic Wolff–Parkinson–White syndrome.
** One patient had both accessory and slow pathway ablation.

Patients presented with recurrent episodes of palpitations ($n = 194$), palpitations and presyncope ($n = 91$), palpitations and syncope ($n = 29$), hemodynamic collapse ($n = 2$), or cardiac arrest ($n = 6$), while three patients presented with symptoms of heart failure and two patients were asymptomatic. Presenting arrhythmias included narrow-complex tachycardia ($n = 230$), wide-complex tachycardia ($n = 61$), narrow- and wide-complex tachycardia ($n = 9$), chronic ($n = 6$) or paroxysmal ($n = 2$) atrial fibrillation, syncope ($n = 2$) or palpitations ($n = 16$) with no documented arrhythmia (14 had manifest preexcitation), or asymptomatic preexcitation syndrome ($n = 1$). The electrocardiogram had shown a Wolff–Parkinson–White pattern during sinus rhythm in 101 patients. Incessant tachycardia was the presenting arrhythmia in 8 patients, one of whom was asymptomatic.

Patients aged older than 18 years ($n = 280$) constituted the adult group with an age range from 19 to 82 years, and patients aged $\leq$18 years (range, 7–18 years) ($n = 47$) were considered as pediatric patients. Initial results from part of the pediatric group have already been described [17]. The mean age of the adult group was 45 ± 16 years (median: 45) and of the pediatric group 14.5 ± 3.0 years (median: 15); 16 pediatric patients (34%) were aged $\leq$13 years. The pediatric group constitutes 14.4% of all patients undergoing RF ablation in our institutions. This series does not include any pediatric patients having congenital heart disease.

Electrophysiologic Study

The diagnostic electrophysiologic (EP) study was performed in the fasting state after all antiarrhythmic agents had been discontinued for at least five drug elimination half-lives, except for a patient with atrial tachycardia and three patients with ventricular tachycardia, who were kept on antiarrhythmic agents for rate control. Routinely, three 5F or 6F quadripolar electrode catheters were introduced from the left femoral vein and with fluoroscopy guidance were positioned at the high right atrium, across the tricuspid valve for His bundle recording, and at the right ventricular apex. Either a 5F quadripolar or a 6F steerable quadripolar catheter was placed in the coronary sinus from the right femoral vein. Standard recording methods, programmed stimulation techniques, protocols and definitions were employed [1–5,8–17].

Ablation Procedure

After completion of the electrophysiologic study, a 6F or 7F steerable quadripolar deflectable-tip

catheter with a 4-mm distal electrode and 2-5-2-mm interelectrode spacing (Cordis-Webster, Baldwin Park, CA) was employed for precise mapping and subsequent ablation with delivery of radiofrequency current. The transseptal approach for obtaining access to the left heart was used for ablation of left-sided accessory pathways [19] in 48 patients, and of left atrial foci in eight patients. The transaortic technique for ablation of left-sided accessory ($n = 21$) or slow AV nodal ($n = 1$) pathways was employed in 22 patients, and for ablation of ventricular foci in 14 patients. Both techniques were employed in six patients with accessory pathways. Patients undergoing ablation of a left-sided arrhythmia focus received anticoagulation with heparin.

A conventional electrosurgical unit (Osypka 200S or Osypka 300 or Atakr-Medtronic) was used to generate RF current at a frequency of 500 kHz. The RF current was delivered between the distal electrode and a cutaneous indifferent dispersive pad positioned on the posterior thorax or left thigh. Once the target site was identified, 20–50 Watts of RF energy was delivered via the ablation catheter. In 233 patients, RF ablation was guided by monitoring the temperature at the catheter tip, which was limited to maximum 70°C. If loss of preexcitation (in case of manifest accessory pathways) or termination of the tachycardia (in case of concealed accessory pathways or atrial tachycardia) or accelerated junctional rhythm (in case of slow pathway ablation in patients with AV nodal tachycardias) occurred within 5–15 sec, the RF current application was continued for 30 sec, otherwise it was stopped and attempts of mapping and ablation continued. If impedance rose during ablation, RF application was interrupted, the catheter was removed and cleaned prior to reinsertion. Half-an-hour to 1 hour after ablation, programmed stimulation was repeated with and without the infusion of isoproterenol. In patients with an accessory pathway, intravenous adenosine was administered to confirm the absence of accessory pathway conduction. After the procedure, patients were monitored for 24–48 hours prior to discharge. During this period serial electrocardiograms were obtained to evaluate for recurring arrhythmia, and an echocardiogram was performed to evaluate for cardiac complications. Intravenous heparin for those who underwent ablation in the left heart was continued for 12–24 hours after the ablation procedure.

Patient Follow-up

After discharge from the hospital, patients were followed-up at our arrhythmia clinic or by their referring cardiologists every 3–6 months for the first year and annually thereafter. All patients after the RF ablation procedure received one aspirin (100 mg or 325 mg) tablet daily for 1–3 months. A number of patients participated in protocols of periprocedural use of antithrombotic treatment, including use of ticlopidine [24]. All values are expressed as mean ± SD. Comparisons were performed with use of t-test or analysis of variance for quantitative data, or chi-square or z-statistic for qualitative data. Statistical significance was considered at a P value < 0.05.

Results

Ablation Results and Procedure Variables

In the 280 adult patients RF ablation was performed for accessory pathways in 106 patients, for slow AV nodal pathways in 104 patients with AV nodal reentrant tachycardia, for atrial foci in 38 patients with atrial tachycardia ($n = 22$) or atrial flutter ($n = 15$) or atrial fibrillation ($n = 1$), for ventricular foci in 25 patients with ventricular tachycardia, and for AV node/His bundle in seven patients with refractory atrial fibrillation. Ablation was successful initially in 271 (96.8%) patients with a mean of 15 ± 18 RF applications (median: 8). Two sessions were required in three patients with accessory pathways, one patient with atrial flutter and one patient with atrial fibrillation. Ablation failed in five patients with accessory pathways, two patients with atrial tachycardia plus atrial flutter and two patients with atrial flutter. However, a late effect was observed in three patients with accessory pathways, raising procedural success to 97.9%. The left heart was accessed via a transseptal approach in 47 patients, a transaortic technique in 33 patients, a combined transseptal and transaortic approach in four patients, while two patients had a left-sided accessory pathway ablated via the coronary sinus. Exposure to radiation averaged 43 ± 40 min (median: 29), and the procedure duration 3.0 ± 1.9 hours (median: 2.5). Over 25 ± 19 months of follow-up, arrhythmia recurrences were noted in 12 patients (4.4%) (four with an accessory pathway, three with atrial flutter, and five with ventricular tachycardia), of whom six were successfully submitted to repeat RF ablation.

In 47 children RF ablation was performed for symptomatic arrhythmias in all but one asymptomatic athlete with a Wolff–Parkinson–White pattern. Serious or life-threatening symptoms included acute heart failure ($n = 1$), atrial fibrillation with rapid ventricular response in patients with Wolff–Parkinson–White syndrome ($n = 4$), or incessant tachycardia with tachycardic myopathy ($n = 3$), while the remaining 38 patients had failed 1.4 ± 0.7 antiarrhythmic drugs prior to ablation. Ablation was performed for manifest ($n = 17$) or

concealed ($n=8$) or right atriofascicular ($n=1$) accessory pathways in 26 patients, slow AV nodal pathways in 16 patients (one patient had both accessory and slow pathway ablation), atrial tachycardia foci in two patients, and right ($n=1$) or left ($n=3$) idiopathic ventricular tachycardia foci in four patients. The mean cycle length of the supraventricular tachycardia in 36 patients was 306 ± 52 ms (range, 220 to 440 ms). Procedures were performed in 40 pediatric patients with use of local anesthesia combined with deep or light sedation, while in seven patients general anesthesia was used. The left heart was accessed via a transaortic approach in six patients and via a transseptal technique in 11 patients. Radiofrequency ablation was successful in all patients (100%) with 1–42 RF applications (mean: 12 ± 10, median: 8) (Table 1). Fluoroscopy time averaged 39 ± 27 min and total procedure duration was 2.8 ± 1.4 hours. Comparative data between the two groups are presented in Tables 1 and 2.

Accessory Pathway Ablation

Of the 106 adult patients with accessory pathways (84 with manifest preexcitation), a single pathway was ablated in 80 patients and multiple (2 to 3) pathways in 26 patients. Ablation was successful initially in 101 (95.3%) patients; a second session was needed in two patients. However, a late effect was observed in three patients, raising the success of the procedure to 98.1%. A median of 12 RF applications (mean, 19 ± 22) were needed; fluoroscopy time and procedure duration averaged 55 ± 50 min and 3.5 ± 2.2 hours respectively.

In 17 pediatric patients with Wolff–Parkinson–White syndrome, 23 accessory pathways were detected (18 manifest and five concealed), a single pathway in 12 patients, two pathways in each one of four patients, and three pathways in one patient. In another eight patients, nine concealed accessory pathways were detected. Accessory pathways were localized to the anteroseptal ($n=6$), mid-septal ($n=3$), right posteroseptal ($n=4$) or right posterior ($n=1$) areas, middle cardiac vein ($n=1$), left posteroseptal ($n=1$) and in the left free wall ($n=16$). Of the 17 left-sided accessory pathways (seven manifest and 10 concealed), three were approached via a transaortic technique (operator's choice) and 14 transseptally. In a 9-year old boy who presented with wide-complex tachycardia, a decremental right lateral atriofascicular accessory pathway (Mahaim fiber) was detected and successfully ablated. Ablation of this decremental accessory pathway was guided by a Mahaim potential recording at the right lateral aspect of the tricuspid annulus; a long vascular sheath, which stabilized the catheter in that position, facilitated the procedure.

Overall, among the entire cohort of patients, 101 patients had a single pathway ablated and 31 patients had ablation of multiple (≥ 2) accessory pathways. In this latter group, a greater number of RF lesions and a longer fluoroscopy time were required, while the procedure lasted longer, compared with those procedural variables in patients having ablation of a single pathway (Table 4, Fig. 1).

Slow Pathway Ablation for AV Nodal Reentrant Tachycardia

In 104 adult patients with AV nodal reentrant tachycardia, slow pathway ablation was successful in all patients (100%) with a median of five RF lesions (mean 8 ± 7). In all patients but one, ablation of the slow AV nodal pathway was successful on the right side within the triangle of Koch; in one patient a left-sided approach was required. Fluoroscopy time was 23 ± 14 min and the duration of the procedure 2.1 ± 1.0 hours.

During electrophysiologic evaluation of the pediatric group, dual AV nodal pathway physiology was shown in 16 patients and AV nodal reentrant tachycardia was induced in 15 patients (one patient also had ablation for a preexcitation syndrome). Using a combined anatomic and electrophysiologic approach, successful ablation of the slow pathway was effected in all 16 patients (100%). Following slow pathway ablation, a persistent jump in the A–H interval could be detected only in eight of 16 cases, while the tachycardia was no longer inducible in any patient. In two patients, in addition to the typical (slow-fast) AV nodal reentrant tachycardia, a slow-slow type of AV node reentry was induced and successfully ablated with additional RF current applications at the area of the slow pathway.

Ablation of Atrial Tachycardia

In 22 adult patients, an atrial tachycardia was successfully ablated in all but two patients (91%); the focus was in the right atrium in 15 and in the left atrium in seven, the latter accessed via a transseptal approach. A mean of 9 ± 7 RF lesions were required. Fluoroscopy time averaged 46 ± 35 min and the procedure lasted for 3.3 ± 1.8 hours.

In two pediatric patients an ectopic atrial tachycardia was diagnosed. In a 7-year-old boy with incessant wide-complex tachycardia, who presented with acute heart failure and hemodynamic collapse, the focus was localized at the orifice of the left inferior pulmonary vein where

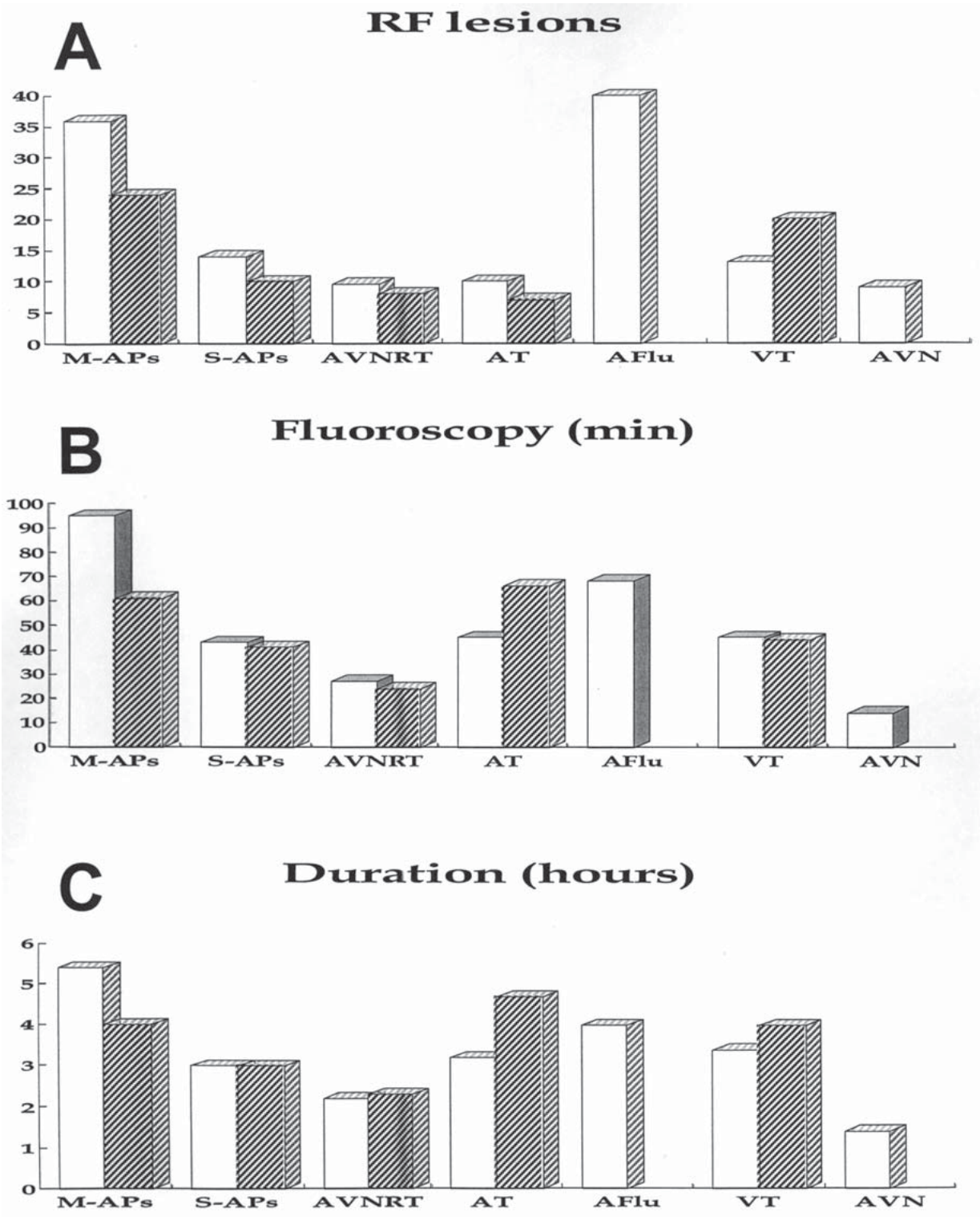

Fig. 1. *Procedural variables according to the ablation target in both age groups (adults: white bars; children: hatched bars).* ***A****, mean number of radiofrequency (RF) lesions applied.* **B***, mean fluoroscopy time (min).* **C***, mean procedure duration (h). All these variables were dependent on the specific target of ablation rather than on patient's age, being greatest during ablation of multiple accessory pathways (M-APs) or ablation of atrial flutter (AFlu), and lowest with ablation of slow atrioventricular (AV) nodal pathway for AV nodal reentrant tachycardia (AVNRT) or ablation of the AV node (AVN)/His bundle. AT = atrial tachycardia; S-APs = single accessory pathways; VT = ventricular tachycardia.*

successful ablation was effected. A 17-year-old male patient had frequent episodes of palpitations due to a narrow-QRS tachycardia and a moderately decreased left ventricular ejection fraction (45%). An automatic right atrial tachycardia was diagnosed and its origin was localized at the base of the right atrial appendage. In this patient initial attempt of ablation was successful, but a second session was needed during hospitalization due to a recurrence at 24 hours. At 12 months later this patient has remained free of arrhythmia recurrence.

Ablation of Atrial Flutter/Atrial Fibrillation

Among 15 adult patients with atrial flutter, RF ablation was successful in severing the isthmus in 13 (87%); two sessions were required in one patient. The mean age was 54 ± 14 years (range, 22–69). A mean of 40 ± 33 RF lesions were applied. Fluoroscopy time averaged 68 ± 37 min, and the procedure lasted for 4.0 ± 1.6 hours. Over 24 ± 14 months of follow-up, arrhythmia recurrences were observed in three patients (23%), of whom two were submitted successfully to repeat RF ablation. In one patient with lone atrial fibrillation, ablation was successful in eliminating one right atrial and two left atrial foci (upper pulmonary veins).

AV Node-His Bundle Ablation

In seven adult patients, aged 72 ± 9 years, with drug-refractory atrial fibrillation, AV node/His bundle ablation was successfully undertaken with a right-sided approach. A mean of 9 ± 6 RF lesions were required; fluoroscopy time averaged 14 ± 8 min and the duration of the procedure lasted for $1.4 \pm .7$ hours. A VVIR ($n = 6$) or a DDDR ($n = 1$) pacemaker was subsequently implanted. Over 9 ± 6 months of follow-up, AV conduction did not recover.

Ablation of Ventricular Tachycardia

In 25 adult patients, aged 49 ± 13 years, a ventricular focus was successfully ablated (100%). These were 14 patients with right ventricular outflow tachycardia, five with left idiopathic ventricular tachycardia, one with right ventricular dysplasia, two with cardiomyopathy and three patients with ischemic ventricular tachycardia. The mean cycle length of the tachycardia was 367 ± 74 ms. A mean of 12 ± 10 RF applications were required. Fluoroscopy time was 45 ± 30 min and the procedure lasted for 3.4 ± 1.4 hours. Over a mean follow-up of 25 ± 18 months, there were arrhythmia recurrences in three patients with left idiopathic VT, two patients with cardiomyopathy and one patient with ischemic VT; repeat RF ablation was successful in three patients.

In four pediatric patients, an idiopathic ventricular tachycardia was diagnosed and successfully ablated. Of these, one had a right ventricular outflow tract tachycardia (incessant repetitive monomorphic tachycardia with no symptoms) and the other three had a symptomatic focal fascicular left ventricular tachycardia. Ablation was guided by earliest activation mapping in the first patient and by Purkinje potential recordings in the other three patients.

Complications

Among all RF ablation procedures, five serious complications were observed, four (1.4%) in the adult group and one (2.1%) in the pediatric group. One adult patient undergoing ablation of a left-sided accessory pathway developed a transient ischemic attack. Among adult patients having slow pathway ablation, there occurred a pneumothorax in one patient and complete heart block in two patients. Other salutory inconsequential events included transient complete heart block lasting only for a few seconds in two patients having slow pathway ablation, while transient PR prolongation was observed in another patient also having slow pathway ablation.

In the pediatric group there was one serious complication in a patient with Wolff–Parkinson–White syndrome and two accessory pathways. After successful ablation of a manifest posteroseptal pathway, complete heart block occurred during successful ablation of a second concealed midseptal accessory pathway. During ablation of a slow pathway in another patient with atrioventricular nodal reentrant tachycardia, transient complete heart block was observed which only lasted for 5 seconds.

Follow-up

During follow-up of 25 ± 19 months, there were arrhythmia recurrences in 12 adult and three pediatric patients. Recurrences were noted in four adult patients with accessory pathways, three patients with atrial flutter, and five patients with ventricular tachycardia. Among the pediatric patients, recurrences were observed in one patient each with slow or accessory pathway ablation and the patient with a Mahaim fiber. Repeat RF ablation was successfully performed in seven adult and two pediatric patients. Transient complete heart block was observed late in one patient, at 48 hours after slow pathway ablation; conduction was restored completely, aided with a short course of steroid therapy.

Discussion

Radiofrequency Ablation in Children

Exclusively pediatric EP centers are generally scarce, which is the reason why in some institutions with an adult EP service, an adult EP team may perform RF ablation in pediatric patients, usually in collaboration with an experienced pediatric interventional cardiology team [10–17]. In a previous study we demonstrated the efficacy and safety of such an approach in the pediatric population [17]. Subsequently, extending our initial results in children, we sought to compare them with those in our larger adult patient population.

In the present study, RF ablation in pediatric patients constituted 14% of our total number of ablation procedures. The success (100%) and complication rate (2.1%) in our pediatric patients were similar to the respective rates (97% and 1.4%) in the adult group, and compare favorably with those rates in pediatric institutions, whereby overall success rates of 75–85% and complication rates of 4.8–10% have been reported [14,20,21]. However, in experienced centers procedural success may not be influenced by patients' age [23,25]; recent data from the pediatric Registry show improved results in pediatric patients without structural heart disease [25]. The present series did not include infants or very young children, whereby higher complication rates might be observed [14], and other controversial issues might be of concern, such as developmental effects due to lesion size increase during child growth [26]; body weight < 15 kg has been reported as an important predictor of procedural complications [25], and thus a decisive determinant of patient selection. In our group only 34% were aged ≤ 13 years; we had no patients with congenital heart disease. Therefore, these results do not apply across the whole range of pediatric ages and groups and should only be interpreted in light of these specific circumstances.

Comparison with the Adult Patient Series

The success of the procedure was equally high for both populations (97% in adults vs 100% in children). Similarly equivalent results in the two groups were obtained in the mean fluoroscopy time, duration of the procedure, number of RF current applications, and procedural complications (Table 2). During long-term follow-up an equal number of recurrences were observed, with most patients undergoing a successful repeat procedure.

To our knowledge, only two previous studies in the literature compare the results of RF ablation between adult and pediatric patients [22,23] (Table 3). An equally high procedural

Table 2. *Procedural variables in adult and pediatric patients*

	Adults	Children	*P* value
Patients	280	47	
Procedure success	96.8%*	100%	NS
Number of RF lesions	15 ± 18	12 ± 10	NS
Fluoroscopy time (min)	43 ± 40	39 ± 27	NS
Procedure duration (h)	3.0 ± 1.9	2.8 ± 1.4	NS
Major complications	4 (1.4%)	1 (2.1%)	NS
Transient ischemic attack	1		
Pneumothorax	1		
Complete heart block	2	1	
Arrhythmia recurrences	12 (4.4%)	3 (6.4%)	NS

* A late effect was observed in 3 patients, raising procedural success to 97.9%. NS = not significant.

Table 3. *Literature reports comparing radiofrequency (RF) catheter ablation results in adult and pediatric patients*

First Author/Year	Park/1994 [22]	Tai/1995 [23]	Manolis/2001
No. of adult patients	278	1008	280
Success (%)	95%	97.5%	97%
Complications (%)	3.6%	1.5%	1.4%
No of pediatric patients	135*	49*	47**
Success (%)	94%	98%	100%
Complications (%)	1.5%	0%	2.1%
Accessory pathways (adults/children)	214/111	565/35	106/26
Slow AV nodal pathways (adults/children)	64/24	443/12	104/16
Atrial foci (adults/children)	–	–	38/2
Ventricular foci (adults/children)	–	–	25/4
AVN/His bundle (adults/children)	–	–	7/0

* aged < 20 years ** ≤ 18 years.

success has been demonstrated in those and the present study for both pediatric and adult age groups (94–100%). These success rates in pediatric patients have been higher than previously reported by dedicated pediatric institutions (75–85%) [14,20,21], which supports the contention that previous large experience in the adult population for the same type of arrhythmias has mainly contributed to a high procedural success in the pediatric group in these three comparative studies (Table 3). Thus, patients' age did not influence the results of RF ablation in any of the three studies. In one study, the critical variable affecting procedural performance was accessory pathway location, with right free wall and septal accessory pathways exhibiting the greatest procedural difficulty [22]. In the present study, analysis of variables affecting outcome demonstrated that it was the specific type of arrhythmia ablated that influenced the results, with multiple accessory pathways and atrial flutter standing out as the most demanding arrhythmia substrates during ablation (Table 4, Fig. 1).

Specific Arrhythmias

The study included all coming patients with a variety of arrhythmias (Table 4). Procedural variables were dependent on the type of specific arrhythmia ablated (Table 4, Fig. 1), rather than on patients' age group (Table 2). Patients with multiple accessory pathways or atrial flutter required the greatest number of RF applications, and the longest fluoroscopy exposure and duration of the procedure. In both patient populations, the two main largest groups were patients with accessory pathways and AV nodal reentrant tachycardia. Probably due to patient reference pattern, arrhythmias related to accesory pathways constituted 38% and AV nodal reentrant tachycardia 37% of all arrhythmias in the adult cohort, while in children accessory pathways were ablated in 55% and the slow pathway in 34%. A lower incidence of AV nodal reentrant tachycardia has been reported in pediatric patients, which increases with age [22]. Indeed, the incidence of this arrhythmia was 25% in our group of ≤ 13 years, with 75% having arrhythmias related to accessory pathways in this age group, while in older (> 13 years) patients AV nodal tachycardia was noted in 39% and accessory pathways in 45%.

Left-sided accessory pathways were approached using a retrograde (in 21 adults and three children) or a transseptal (in 40 adults and 10 children) or both techniques (in four adults), while all left atrial foci (eight in adults and one in children) were accessed transseptally. Although the two techniques may be considered alternative and/ or complementary approaches to the left heart [19], the transseptal method might have some advantages particularly in the pediatric population. Among these, producing atrial rather than ventricular lesions would potentially be less seriously arrhythmogenic, while avoiding catheter insertion through the aorta and the valves would obviate the possibility of incurring trauma to the coronary ostia and the valve apparatus. Furthermore, acccording to one of the authors' (ASM) personal experience, another important reason that the transseptal approach is preferred is because it makes catheter maneuvering easier, electrogram recording better, and the ablation procedure more expeditious. Additionally, recent data from our laboratory indicate that the application of RF current on the atrial side of the mitral annulus via a transseptal technique confers a lower degree of myocardial injury, reflected by lower levels of cardiac troponin I, compared with RF current applications delivered via the transaortic approach [27]. Only left ventricular tachycardia foci were routinely accessed via a transaortic technique in both age groups. With regards to the approach to right free-wall accessory pathways, long vascular sheaths stabilized the catheter at the tricuspid annulus and greatly facilitated the procedure.

In the adult cohort there were also other types of arrhythmias, less frequent in the pediatric group, such as atrial flutter, more cases of atrial and ventricular tachycardia, and patients with refractory atrial fibrillation undergoing ablation of the AV node/His bundle with subsequent implantation of a pacemaker. An interesting subgroup of patients were those with incessant tachycardia, four adults and two children with atrial tachycardia, one adult with AV nodal tachycardia, one adult with right ventricular outflow tract VT, and two adults with permanent junctional reciprocating tachycardia, which in some patients (four adults and two children) led to varying degrees of left ventricular dysfunction. However this "tachycardic cardiomyopathy" was reversible when the tachycardia was ablated [12,28].

Radiation Exposure

A major concern in any age group, but particularly in children and young adults, is the amount of radiation exposure incurred during these relatively lengthy procedures [29,30]. However, with increasing experience with these procedures, in both adult and pediatric populations, the fluoroscopy time has decreased significantly compared with earlier series, and it is now comparable to that of other radiologic procedures known to be associated with low risk for malignancy. Different

Table 4. *Procedural variables according to the type of procedure in both age groups*

	Accessory pathways		Slow AV nodal	Atrial foci			
	Single	Multiple	Pathway	AT	Aflu/AF	Ventricular foci	AVN/His bundle
Patients	101	31	120	24	16	29	7
Adults/Children	80/21	26/5	104/16	22/2	16/0	25/4	7/0
Age (years)	34 ± 17	32 ± 15	43 ± 18	41 ± 19	54 ± 14	45 ± 16	72 ± 9
Adults/Children	38 ± 15/14.7 ± 2.9	35 ± 14/13.8 ± 3.2	48 ± 15/14.5 ± 2.6	43 ± 18/12 ± 7		49 ± 13/16.8 ± 2.0	
Success	96%*	96.8%	100%	92%	87.5%	100%	100%
Adults/Children	95%/100%	96.2%/100%	100%/100%	95%/100%		100%/100%	
RF lesions	13 ± 16**	33 ± 25**	9 ± 11	10 ± 7	40 ± 33	14 ± 10	9 ± 6
Adults/Children	14 ± 17/10 ± 7	36 ± 25/24 ± 20	9 ± 10/8 ± 7	10 ± 7/7 ± 7		13 ± 10/20 ± 13	
Duration(h)	3.0 ± 1.8**	5.2 ± 2.1**	2.3 ± 1.3	3.3 ± 1.8	4.0 ± 1.6	3.4 ± 1.3	1.4 ± 0.7
Adults/Children	3.0 ± 1.9/3.0 ± 1.6	5.4 ± 2.1/4 ± 2	2.2 ± 1.2/2.3 ± 0.8	3.2 ± 1.8/4.7 ± 2.5		3.4 ± 1.3/4.0 ± 1.4	
Fluoroscopy (min)	42 ± 39**	89 ± 54**	27 ± 24	46 ± 35	68 ± 37	45 ± 28	14 ± 8
Adults/Children	43 ± 41/41 ± 25	95 ± 55/61 ± 47	27 ± 22/24 ± 13	45 ± 34/66 ± 51		45 ± 30/44 ± 19	
Recurrence	3%	10%	0.8%	0%	21%	17%	0%
Adults/Children	2.5%/4.8%	7.7%/20%	0%/6.3%	0%		20%/0%	

AFlu = atrial flutter; AT = atrial tachycardia; AV = atrioventricular; AVN = AV node; RF = radiofrequency. * Late effect was observed in 3 patients, raising success to 99%. ** $P < 0.0001$ comparing these variables between patients with single and multiple accessory pathways.

types of procedures, however, are associated with variable radiation exposure. Procedures of longer duration and X-ray exposure were those involving ablation of atrial flutter, multiple accessory pathways and certain cases of atrial and ventricular tachycardia (Table 4, Fig. 1). The least amount of fluoroscopy time concerned ablation of the slow AV nodal pathway and of the AVN/His His bundle.

Study Limitations

This is a consecutive series of RF ablation procedures performed by an adult EP team, and it is thus limited by the relatively small number of pediatric patients studied. Larger series are needed to confirm the efficacy and safety of this approach to pediatric RF ablation. However, adult electrophysiologists have apparently gained a wider experience with RF ablation than their pediatric counterparts due to a larger adult patient population undergoing ablation, and their success rates are not limited any longer by a learning curve, which appears to exert such a great influence on the results of pediatric series, particularly those from dedicated pediatric institutions [20,21]. Finally, the present study is further limited by not including smaller children or those suffering from congenital heart disease.

Clinical Implications

As operator experience with RF ablation of cardiac arrhythmias in adult patients has steadily increased over the years, adult EP teams, as demonstrated in the present study, can perform these procedures successfully and safely in both adult and pediatric patients. However, maintaining a close collaboration with interventional pediatric cardiologists can only enhance patient safety, especially when dealing with smaller children or patients with congenital heart disease. Finally, success of RF ablation has already reached a plateau at very high levels in both adult and pediatric patient populations, and procedural variables are dependent on the specific arrhythmia substrate rather than on patient's age.

Acknowledgement

The authors wish to acknowledge the valuable assistance of the staff of the electrophysiology laboratories at both institutions. Also thanks are due to the staff of the Anesthesiology Department and to *Drs. John Papayiannis and Spiros Rammos,* at the Onassis Cardiac Surgery Center, for their assistance with some of the pediatric procedures.

References

1. Jackman WM, Wang X, Friday KJ, et al. Catheter ablation of accessory atrioventricular pathways (Wolff-Parkinson-White syndrome) by radiofrequency current. *N Engl J Med* 1991;324:1605–1611.
2. Calkins H, Langberg JL, Sousa J, et al. Radiofrequency catheter ablation of accessory atrioventricular connections in 250 patients. *Circulation* 1992; 85:1337–1346.
3. Lesh MD, Van Hare GF, Schamp DJ, et al. Curative percutaneous catheter ablation using radiofrequency energy for accessory pathways in all locations: results in 100 consecutive patients. *J Am Coll Cardiol* 1992;19:1303–1309.
4. Jackman WM, Beckman KJ, McClelland JH, et al. Treatment of supraventricular tachycardia due to atrioventricular nodal reentry by radiofrequency catheter ablation of slow pathway conduction. *N Engl J Med* 1992;327:313–318.
5. Kay GN, Epstein AE, Dailey SM, Plumb VJ. Role of radiofrequency ablation in the management of supraventricular arrhythmias: experience in 760 consecutive patients. *J Cardiovasc Electrophysiol* 1993;4:371–389.
6. Scheinman MM. NASPE survey on catheter ablation. *PACE* 1995;18:1474–1478.
7. Manolis AS, Wang PJ, Estes NAM III. Radiofrequency catheter ablation for cardiac tachyarrhythmias. *Ann Intern Med* 1994;121:452–461.
8. Manolis AS, Wang PJ, Estes NAM III. Radiofrequency ablation of slow pathway in patients with atrioventricular nodal reentrant tachycardia: do arrhythmia recurrences correlate with persistent slow pathway conduction or site of successful ablation? *Circulation* 1994;90:2815–2819.
9. Manolis AS, Wang PJ, Estes NAM III. Radiofrequency ablation of atrial insertion of left-sided accessory pathways guided by the "W sign". *J Cardiovasc Electrophysiol* 1995;6:1068–1076.
10. Van Hare GF, Lesh MD, Scheinman M, Langberg JJ. Percutaneous radiofrequency catheter ablation for supraventricular arrhythmias in children. *J Am Coll Cardiol* 1991;17:1613–1620.
11. Saul JP, Hulse JE, De W, et al. Catheter ablation of accessory atrioventricular pathways in young patients: use of long vascular sheaths, the transseptal approach and a retrograde left posterior parallel approach. *J Am Coll Cardiol* 1993;21:571–583.
12. Walsh EP, Saul JP, Hulse JE, et al. Transcatheter ablation of ectopic atrial tachycardia in young patients using radiofrequency current. *Circulation* 1992; 86:1138–1146.
13. Klitzner TS, Wetzel GT, Saxon LA, Stevenson WG. Radiofrequency ablation: a new era in the treatment of pediatric arrhythmias. *Am J Dis Child* 1993;147: 769–771.
14. Kugler JD, Danford DA, Deal BJ, et al. for the Pediatric Electrophysiology Society. Radiofrequency catheter ablation for tacyarrhythmias in children and adolescents. *N Engl J Med* 1994;330:1481–1487.
15. Dhala A, Bremner S, Deshpande S, et al. Efficacy and safety of atrioventricular nodal modification for atrioventricular nodal reentrant tachycardia in the pediatric population. *Am Heart J* 1994;128:903–907.

16. Van Hare GF, Witherel CL, Lesh MD. Follow-up of radiofrequency catheter ablation in children: results in 100 consecutive patients. *J Am Coll Cardiol* 1994; 23:1651–1659.
17. Manolis AS, Vassilikos V, Maounis T, Chiladakis J, Cokkinos DV. Radiofrequency ablation in older children and adolescents by an adult electrophysiology team. *J Interv Card Electrophysiol* 1999;3:79–86.
18. Hindricks G, on behalf of the Multicenter European Radiofrequency Survey (MERFS) Investigators. Complications of radiofrequency catheter ablation of arrhythmias. *Eur Heart J* 1993;14:1644–1653.
19. Manolis AS, Wang PJ, Estes NAM III. Radiofrequency ablation of left-sided accessory pathways: transaortic versus transseptal approach. *Am Heart J* 1994; 128:896–902.
20. Bubolz B, Case CL, McKay CA, O'Connor BK, Knick BJ, Gillette PG. Learning curve for radiofrequency catheter ablation in pediatrics at a single institution. *Am Heart J* 1996;131:956–960.
21. Danford DA, Kugler JD, Deal B, et al. The learning curve for radiofrequency ablation of tachyarrhythmias in pediatric patients. *Am J Cardiol* 1995;75:587–590.
22. Park JK, Halperin BD, McAnulty JH, Kron J, Silka MJ. Comparison of radio-frequency catheter ablation procedures in children, adolescents, and adults and the impact of accessory pathway location. *Am J Cardiol* 1994;74:786–789.
23. Tai C-T, Chen S-A, Chiang C-E, et al. Accessory atrioventricular pathways and atrioventricular nodal reentrant tachycardia in teenagers. *Jpn Heart J* 1995;36:305–317.
24. Manolis AS, Maounis T, Vassilikos V, et al. Pretreatment with antithrombotic agents during radiofrequency catheter ablation: a randomized comparison of aspirin versus ticlopidine. *J Cardiovasc Electrophysiol* 1998;9:1144–1151.
25. Kugler JD, Danford DA, Houston K, Felix G. Radiofrequency catheter ablation for paroxysmal supraventricular tachycardia in children and adolescents without structural heart disease. *Am J Cardiol* 1997;80:1438–1443.
26. Saul JP, Hulse JE, Papagiannis J, Van Praagh R, Walsh EP. Late enlargement of radiofrequency lesions in infant lambs: implications for ablation procedures in small children. *Circulation* 1994;90:492–499.
27. Manolis AS, Vassilikos V, Maounis T, et al. Detection of myocardial injury during radiofrequency catheter ablation by measuring serum cardiac troponin I levels: procedural correlates. *J Am Coll Cardiol* 1999;34:1099–1105.
28. Chiladakis JA, Vassilikos VP, Maounis TN, Cokkinos DV, Manolis AS. Successful radiofrequency catheter ablation of automatic atrial tachycardia with regression of the cardiomyopathy picture. *PACE* 1997; 20(I):953–959.
29. Lindsay BD, Eichlins JO, Ambos HD, Cain ME. Radiation exposure to patients and medical personnel during radiofrequency catheter ablation for supraventricular tachycardia. *Am J Cardiol* 1992;70:218–223.
30. Geise RA, Peters NE, Dunnigan A, Milstein S. Radiation doses during pediatric radiofrequency catheter ablation procedures. *PACE* 1996;18(Pt. I): 1605–1611.