Supraventricular tachycardia is a relatively common disorder in children and adolescents, frequently necessitating therapy. Radiofrequency catheter ablation of the arrhythmic focus is a standard therapy in adult patients, and it has gained a growing acceptance in the treatment of the pediatric population. Our results and issues surrounding radiofrequency ablation in pediatrics are discussed. Sixty-four radiofrequency ablation procedures were done in 57 patients with ectopic atrial tachycardia (5 patients), atrioventricular node reentry tachycardia (20 patients), and atrioventricular reciprocating tachycardia due to the presence of a bypass tract (32 patients). The age ranged from 2 mo to 18 y (mean, 14.3 y). There were 27 males. General anesthesia was used in 60% procedures. The combined, early success rate for all types of tachycardia was 88%. The procedure was most successful in young patients with atrioventricular node reentry tachycardia (96%). The success rate in interruption of the left-sided bypass tracts was 90% and 75% for the right-sided bypass tracts. Automatic atrial focus was eliminated or attenuated in 4 of 5 patients. The overall recurrence rate was 14%. Only minor and transient complications were observed. Our results match those reported by the North American Pediatric Radiofrequency Registry. In conclusion, catheter treatment of supraventricular tachycardia in children and adolescents is safe and efficacious. It may be offered as a therapy-of-choice in older children. Several factors including failure of antiarrhythmic medications may prompt radiofrequency ablation in a younger child. Proper organization of the electrophysiology laboratory is emphasized.

SUPRAVENTRICULAR tachyarrhythmia affects more than 1% of the adult population. Almost 40% of patients with paroxysmal supraventricular tachycardia (PSVT) present before the age of 20 y.2 Although usually well tolerated, PSVT may become a debilitating disorder for a significant number of children and adolescents. In the absence of a structural heart defect, PSVT may become a life-threatening condition in few patients only.

Incessant and rapid tachycardia may lead to progressive biventricular dilatation and loss of contractility, producing a clinical picture of dilated cardiomyopathy.3,4 Patients with Wolff-Parkinson-White (WPW) syndrome face a risk of sudden death.5,6 Predisposition to atrial fibrillation in patients with ventricular pre-excitation combined with short atrioventricular (A-V) bypass tract recovery times 7,8 may allow for "transmission" of fibrillation onto the ventricles. Lastly, syncope which is known to complicate PSVT may result in injuries but demise is unlikely.

Management of heart-rhythm disturbances in children and adolescents poses unique therapeutic problems. In general, pharmacologic and invasive therapies used in very young patients have evolved from...
Experience in the adult population. Radiofrequency (RF) ablation, first applied in adults, quickly made its way into the pediatric population. Still, because of unknown long-term side effects in infants and children, only frequent, disabling and drug-resistant PSVT constitutes a clear indication for RF therapy in the very young. We present our experience with RF ablation in patients younger than 18 years of age.

Patients and Methods

From 1994 till 1996, RF ablation procedures for PSVT were done in 57 infants, children, and adolescents with a normal cardiovascular system. The age ranged from 2 mo to 18 y, with a mean of 14.3 y. Six children were less than 10 years old. There were 27 males. Indications for catheter ablation varied, depending on the age. In teenage patients, catheter ablation was done as the procedure-of-choice for frequent and symptomatic PSVT or for tachycardia producing syncpe. The majority of adolescents were treated with antiarrhythmic medications prior to the procedure. In younger children, RF ablation was performed when there was failure to control the arrhythmia after using at least 3 drugs. A 1-month-old child presented with severe dilated cardiomyopathy and cardiac arrest secondary to incessant orthodromic reciprocating AV tachycardia, at a rate of more than 230/min. The child failed digitalis and beta-blockers. Although she responded to amiodarone, subclinical hypothyroidism was detected after one month of therapy. RF ablation of a concealed bypass tract was done at 2 months of age.

Electrophysiology studies and catheter ablation were performed under general anesthesia with intravenous propofol, inhaled nitric oxide, or halothane in 60% of the procedures. The catheter ablation was done following standard guidelines. Briefly, in all patients with AV bypass tracts, RF ablation was done from the atrial approach. Left-sided pathways were accessed via a foramen ovale or through a transseptal puncture under fluoroscopic guidance, with or without the assistance of transesophageal echocardiography (TEE). In patients with ventricular pre-excitation in sinus rhythm, RF applications were targeted at sites showing the earliest ventricular activation on the AV valve ring preceding the delta wave. Confluent atrial and ventricular electrograms and the presence of the Kent potential were also ascertained. During ventricular pacing or during orthodromic AV reciprocating tachycardia in patients with ventricular pre-excitation or with concealed AV bypass tracts, RF energy was targeted at the AV valve ring sites showing the earliest atrial activation and short intervals between the atrial and the ventricular electrograms. In patients with AV nodal reentry tachycardia, the slow pathway modification was done on the atrial side of the tricuspid valve below and above the coronary sinus ostium. Reinduction of the tachycardia was attempted after RF pulses, producing premature junctional beats or an accelerated junctional rhythm. RF application was interrupted immediately if very rapid junctional rhythm was induced or AV dissociation occurred. In patients with ectopic atrial tachycardia, RF was aimed at sites with atrial electrograms preceding the surface P wave. Presence of fractionated electrograms was of lesser importance. Heparinization was instituted in all left-sided procedures. With the exception of the oldest patients, children were hospitalized overnight. Oral aspirin at 80 mg/d for 3 months was started in all patients who underwent left-sided procedures.

Results

Sixty-four RF catheter ablation procedures were done in 57 patients. In all but 4 patients, the procedure was attempted immediately following the diagnostic electrophysiology study. Twenty-one patients had WPW syndrome, 11 had a concealed atrioventricular (AV) bypass tract, 20 had AV node reentrant tachycardia, and 5 had ectopic atrial tachycardia. The combined early success rate for all types of PSVT was 88%. Within 3 to 40 mo follow-up, there were 8 recurrences (14%) of the initially successful procedures. A repeat RF session was attempted in 7 patients; in three the ablation failed initially and PSVT recurred in 4 patients. The fluoroscopy time ranged from 16 to 129 min, with a mean of 47 min. From 1 to 25, RF pulses had to be delivered to prevent pace induction of the tachycardia after successful procedures (mean, 8.5).

AV Reentrant Tachycardia

Thirty-five catheter ablation procedures were done in 32 patients with an accessory bypass tract. A left-sided pathway was much more frequent (78%) than the right-sided bypass tract (22%). Two AV bypass tracts were found in 2 patients (6%). The early success rate was 86% of all mapped bypass tracts. Almost 90% of left-sided bypass tracts were interrupted compared
to 75% of the right-sided pathways. RF ablation failed in 2 patients with left paraseptal pathways, in a patient with a left posterior pathway, and in 2 children with pathways located in the right anterior paraseptal area, close to the bundle of His. There were four late recurrences, which constitute 13% of the initially successful ablations. The fluoroscopy time ranged from 20 to 129 min, with a mean of 57 min. Successful catheter ablations ranged from 1 to 25 RF pulses. The mean number of RF applications was 8.7 for left-sided pathways and 8 for pathways on the right side. There were no complications related to transseptal punctures. Transient electrocardiographic ST-segment abnormalities, suggestive of acute ischemia over the inferior wall during RF energy application, were observed in 2 patients; one when RF pulse was delivered on the lateral aspect of the tricuspid annulus and one during left posterior pathway ablation. TEE revealed clot formation on the electrode catheters prior to heparinization in three of ten investigated patients. Following the procedure, no patient presented with any clinical signs of embolism.

AV Node Reentrant Tachycardia
AV node reentrant tachycardia of the common type with a short RP interval was induced in all 23 patients. In two, the atypical, long RP interval AV node reentry tachycardia could be initiated in the electrophysiology laboratory as well. In 3 patients, a transient 2:1 A-V block during tachycardia was observed. RF catheter modification of the slow conducting A-V node pathway was successful in 96% of the procedures. In one patient in whom the procedure failed, the parents did not consent to target sites high on the tricuspid valve ring and close to the conduction axis. In three other patients (14%), tachycardia recurred later. RF modification of the slow A-V node input was associated with the shortest fluoroscopy times, from 16 to 65 min, with a mean of 28 min. Also the smallest number of RF pulses had to be delivered to assure ablation of the arrhythmic substrate, from 1 to 13, with a mean of 6.8. There were no permanent complications. One patient presented with a 10-s transient complete heart block during RF application which resolved completely. In three children, it was a right bundle-branch block which was most likely produced by catheter trauma. The block resolved by the time the patients went home. The use of general anesthesia rendered A-V node reentry tachycardia noninducible in 3 patients, two of whom are not included in this report. An attempt to lift anesthesia and continue the procedure succeeded in 1 patient only. However, two other patients became combative and the procedure had to be abandoned.

Ectopic Atrial Tachycardia
All studied patients with atrial tachycardia presented with the more common automatic type. In none of the 5 patients atrial reentry could be documented. Catheter ablation eliminated tachycardia in 2 patients with an arrhythmia focus at the base of the left atrial appendage and in a patient with the ectopic focus between the inferior vena cava and the coronary sinus. One patient with a left-sided tachycardia required two procedures. Another child with an ectopic focus in the proximity to the sinus node presented with much less frequent tachycardia after the procedure. RF ablation failed in a child with an arrhythmia focus located in the posterior interatrial septum. Successful catheter ablation required from 6 to 22 RF applications and from 32 to 77 min of fluoroscopy. There were no complications.

Discussion
Recently documented improvement in the quality of life following successful catheter treatment of PSVT6 attests to favorable clinical experience. The procedure is safe and costs less than other treatments in the United States.17 Our results match those of the North American Pediatric Radiofrequency Registry, reporting a permanent cure from the tachycardia in more than 85% of young patients with accessory AV bypass tracts, AV node reentrant tachycardia, and automatic or reentrant atrial tachycardia.11 The highest success rate of more than 90% has been recently achieved in children with AV node reentry.14,18 the second most common form of PSVT in children with normal cardiovascular system.19 Modification of the slow pathway (slow conducting approach to the AV node) is preferable and associated with fewer complications than targeting the fast pathway. Catheter treatment of left-sided bypass tracts is efficacious in a similar percentage of cases.13,14 A success rate of more than 80% is achieved in patients with paraseptal bypass tracts, different types of right-sided bypass tracts, and in patients with ectopic or reentrant atrial tachycardia.13,14,20,24 RF ablation may eliminate an automatic focus in junctional tachycardia.25 RF destruction of the AV conduction axis with concomitant implantation of a pacemaker should be avoided in children unless other measures fail to control rapid heart
rate and life-threatening heart failure. Growing experience should permit successful catheter ablation of type I atrial flutter in the pediatric population. II.14.27 A somewhat lower, than in the adult population, success rate may result from smaller experience in this age group and a more careful approach to RF therapies in children.

Adult patients and adolescents should be offered an option of RF treatment for their recurrent PSVT as a therapy-of-choice. A debate still continues if patients with asymptomatic WPW syndrome should undergo such invasive procedure despite a documented, although low, risk of cardiac arrest. 28 The risk of catheter ablation complications might set off an estimated 0.1% risk of sudden death per year. Catheter ablation may have a role, however, in patients with asymptomatic ventricular pre-excitation who participate in competitive sports, in those with family history of WPW syndrome, and in those older adolescents who plan further career in high-risk professions. Another controversy centers around the dilemma at what age catheter ablation should be offered as a preferred treatment in children. Some centers with large experience offer catheter ablation to all schoolage and symptomatic children, especially if they failed medical treatment. In our more conservative approach, catheter ablation will be offered after the age of 10 to 12 y except for patients who continue to have significant symptoms despite treatment with several medications. Although, in general, PSVT is not a malignant condition, the child's perception of symptoms has to be examined, independent of the parents' complaints. A symptomatic child could be the one with very few but prolonged episodes of PSVT associated with significant malaise, chest pains, dyspnea, or lightheadedness. Fear of recurrent tachycardia ought to be viewed as an important symptom. Frequent but short bursts of tachycardia might not be perceived by a patient or may produce an annoying sensation of palpitations. Although uncommon, syncope indicates serious hypotension, and in patients with WPW syndrome, it might indicate a life-threatening atrial fibrillation. The decision to proceed with catheter ablation should depend on the operator's experience, knowledge of the risks of such treatment at different ages, and availability of an electrophysiology laboratory experienced in the care of children. There are several other factors which might also influence the decision to perform RF ablation in a small, symptomatic child. Aside from the effectiveness of medical therapy, the physician ought to be aware of the custodian's ability to get and pay for the antiarrhythmic medications and the availability of medical follow-up and emergency services which sometimes depend on the patient's geographic location.

In 1994, the Pediatric Electrophysiology Society reported complication rates of 3.7% in all patients and 10% in small children who weigh less than 15 kg. II Recently, the complication rate has dropped to 1%. The most common complications related to RF energy application reported in children and adolescents were bundle-branch or transient AV block, pericardial effusion, valve injury, microemboli, and inappropriate sinus tachycardia following the treatment. 11.14.29 We also observed transient ischemic changes on the electrogram, most likely due to irritation and spasm of a coronary artery. The RF lesions may be at times quite deep 30 and both coronary arteries lie in the AV grooves close to the ablation sites for accessory AV tracts. Late side effects relating to the presence of a thermal scar and possible coronary artery injury are unknown. In small children, the ablation scar may enlarge with time. Y Although uncommon, serious complications of RF ablation might be devastating. Complete AV block, cardiac perforation with tamponade, myocardial infarction, macroembolism producing cerebrovascular, pulmonary or peripheral arterial occlusion, and death have been reported. 11.31 A less than 5% risk of a complete AV block is associated with RF treatment for A V node reentry tachycardia and ablation of right-sided pathways located in the immediate proximity to the conduction axis. It must be stressed that children leaving the hospital with such complications will require several electrode and pulse generator replacements in the future, which are costly and pose additional risks. Other reported procedure-related complications were hematoma, arteriovenous fistula, hemothorax, pneumothorax, and complications of sedation or general anesthesia. When deciding to proceed with RF ablation, a clinician must balance the risks of invasive therapy with the degree of expected clinical improvement.

The RF treatment success rate is enhanced and the complication rate is minimized by proper organization of the pediatric electrophysiology laboratory and conduct of procedures. Personnel experienced in electrophysiology studies and pediatric cardiac catheterization will be of tremendous help to the operator. Two cardiologists with experience in RF ablation techniques should be present for flawless interpretation of electrograms and fluoroscopic images.

A pulse, biplane fluoroscopy unit is advisable to limit the radiation exposure and verify precise catheter position expeditiously. We do not premedicate children before electrophysiology studies although premedication has been recommended by some centers. General anesthesia is extremely helpful, especially in children and younger adolescents, as it alleviates patient anxiety and the discomfort of the procedure, including a long stay in one position on the operating table. General anesthesia may render PSVT noninducible, especially with the use of propofol.32 Inhalation anesthesia, especially with halothane, may have a proarrhythmic effect.33 In our experience, it may still blunt inducibility of a clinical tachycardia. An attempt to lift anesthesia, in the middle of the study, rendered the AV node tachycardia inducible in one of our patients. Two other patients became confused and combative, and the study could not be continued.

Systemic heparinization should be used in all cases of left-sided ablation and in patients with shunts. It is recommended that the activated clotting time is maintained above 300 s during the procedure. Small multipolar electrodes are now available and allow for multiple electrogram recordings in young children. Three 2-French multipolar electrode catheters can be accommodated into a 7-French sheath. Additional left atrial recordings may be obtained through an esophageal lead. Transesophageal echocardiography will allow for safe transseptal puncture and precise application of RF pulses in left-sided accessory AV tracts. It is possible that the use of TEE will reduce fluoroscopy time and the number of RF applications.34 In patients in whom TEE was performed, we documented presence of clots on the electrode catheters which formed within minutes after catheter introduction into the atrium. Since electrode catheters are relatively stiff, gentle manipulation in a small child is essential. Left-sided AV bypass tracts may be approached retrograde across the aortic valve with an only minimal risk of valve damage. Because of easier catheter manipulation, we favor the transseptal approach despite a small risk of embolism and cardiac perforation associated with the transseptal puncture. Overnight hospitalization following RF ablation allows children to recover ITom the procedure and general anesthesia and to return to regular diet.

A routine electrocardiogram and an echo cardiogram in cases where valve injury is suspected may be done on the following day.

Conclusions

In conclusion, catheter treatment of supraventricular tachycardia in children and adolescents is safe and efficacious. It may be offered as a therapy-of-choice in older children. Several factors including failure of antiarrhythmic medications may prompt RF ablation in a younger child. Proper organization of the electrophysiology laboratory is emphasized.

References

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