Use of Radiofrequency Current to Ablate Accessory Connections in Children

Macdonald Dick II, MD; Brian K. O’Connor, MD; Gerald A. Serwer, MD; Sarah LeRoy, RN, MS; and Brian Armstrong

**Background.** Several investigators have recently ablated electrophysiologically mapped accessory connections in the adult human myocardium by using radiofrequency current. To examine the effectiveness and safety of radiofrequency current for ablation of accessory connections in children, 20 consecutive patients (age, 3–18 years) with preexcitation and/or supraventricular tachycardia were evaluated by electrophysiological study.

**Methods and Results.** Nineteen of the 20 patients were completely studied and demonstrated accessory connections. After identification of the earliest retrograde atrial activation site, a steerable 7F catheter (with a 4-mm-long electrode at the distal tip) was placed within the ventricular cavity ipsilateral to the accessory connection and positioned at the atrioventricular valve annulus directly opposite the earliest point of retrograde atrial activation. Radiofrequency current was delivered at 50–65 volts for 10–60 seconds at a frequency of 500 kHz. Radiofrequency pulses were delivered for two to 26 trials. Upon completion of radiofrequency trials, repeat electrophysiological testing was performed. Thirteen of 19 subjects (68%) experienced definite successful ablation of their accessory pathway; an additional patient had probable successful ablation, yielding an overall success rate of 74%. Eighty-seven percent of individuals with a left-sided pathway had permanent ablation and 100% with a manifest left-sided pathway experienced successful ablation. Only 29% of the first seven patients had a successful result; in contrast, 92% of the next 12 patients had successful interruption of their accessory pathways. After ablation, 4-day continuous electrocardiographic telemetry disclosed no significant arrhythmias. CPK enzyme rises peaked at 12–24 hours. The rise was excessive and associated with general anesthesia in five patients. The isoenzyme MB fraction rose mildly in five other patients and returned to normal within 72 hours. No clinical or electrocardiographic evidence of myocardial ischemia was detected. Follow-up for 4–12 months indicates no return of preexcitation or tachycardia in any patient whose accessory connection was successfully ablated.

**Conclusions.** This experience indicates that radiofrequency current is an effective and safe technique for ablation of accessory connections in children. (Circulation 1991;84:2318–2324)

Supraventricular tachycardia (SVT) is the most common sustained cardiac arrhythmia in children; approximately 50–60% of SVT is supported by a reentrant circuit comprising the atria, atroventricular node–His-Purkinje system, ventricular myocardium, and an accessory connection conducting in the retrograde direction.\(^1\) When this tachycardia is frequent, sustained, and associated with significant symptoms (palpitations, faintness, dizziness, presyncope, syncope, and, rarely, cardiac arrest; 3.7% in our population of children with preexcitation, four as the first symptom, one of whom died), medical management is required. Chronic prophylaxis of this arrhythmia can often be achieved by pharmacological agents altering refractoriness and/or conduction within one or more of the limbs of the reentrant circuit. Corrective therapy has, until recently, required surgical division of the accessory connection or direct current energy ablation of the accessory connection.\(^2,3\) Direct current creates a dispersive shock lesion in the targeted area of the myocardium and, in most instances, can be directed only toward right posterior septal pathways. In 1987, Borggrefe and associates\(^4\) reported the use of radiofrequency current to ablate accessory connections in humans. Since then, multiple preliminary reports in older patients\(^5–12\) and one in children\(^13\) have de-
scribed the use of radiofrequency current delivered through the catheter electrode tip juxtaposed to the accessory connection as an alternative mode of ablation. In this report, we outline our experience using radiofrequency energy in 19 children to ablate accessory connections.

Methods

Twenty consecutive children (age, 3–18 years, median age, 12.5 years; 16 boys, four girls) with preexcitation and/or SVT submitted to diagnostic electrophysiological study were shown to have an accessory connection. One of the 20 subjects was excluded from the study because the coronary sinus could not be entered, leading to incomplete mapping of the accessory connection; his very fast conducting left posterior pathway was successfully divided at surgery. Thus, 19 patients compose the study group (Table 1). Eighteen of these 19 patients had documented recurrent symptomatic SVT; 13 were unresponsive to at least one antiarrhythmic medication. Two (No. 14 and No. 19) had experienced documented ventricular fibrillation at initial presentation. Six had not received antiarrhythmic medication because symptoms were either not frequent enough or not sufficiently severe as judged by the parents and patients. One 15-year-old girl (No. 11), initially studied at another institution, had preexcitation with a rapid ventricular response to induced atrial fibrillation (shortest preexcited RR interval during atrial fibrillation was 240 msec, decreasing to 220 msec with isoproterenol infusion) but had no spontaneous or inducible SVT. Informed consent was obtained from the parents and the patient (if age appropriate).

The first seven patients were sedated with intramuscular midazolam (0.1 mg/kg) supplemented by intravenous midazolam (0.1 mg/kg) and morphine sulfate (0.1 mg/kg) as needed during the procedure. Based on the experience of the first seven, the next 13 children were administered general anesthesia because of the anticipated prolonged time of the procedure. Standard programmed (Bloom Associates, Ltd., DTU 110) extrastimulation and electrophysiological recordings (Siemens Mingo 7, paper speed, 100–200 mm/sec) were performed as previously described.3 Precise mapping of retrograde atrial activation during SVT or ventricular pacing was carried out using a 7F orthogonal electrode catheter (Mansfield/ Webster, No. 5211) placed through the left subclavian vein into the coronary sinus in 18 of the 19 patients. The coronary sinus was mapped in patient 13, a 3-year-old boy, using a 5F quadrupolar (inter-electrode distance, 10 mm). A 7F steerable 5-mm-spaced quadrupolar catheter (Mansfield/Webster, No. 5250) was placed through the right femoral vein into the right atrium to map the right atrioventricular groove, if necessary; the catheter positions were finely adjusted to find the earliest site of retrograde atrial activation during SVT or ventricular pacing. The recordings were scrutinized for possible Kent fiber potentials; however, no deliberate attempt was made to record Kent fiber activation and no protocols were performed to verify them if they were thought to be present.

After identification of the earliest activation site, the ventricular aspect of the atrioventricular grooves was mapped by placing the above-noted steerable 7F catheter (with a 4-mm-long electrode at the distal tip) within the ventricular cavity ipsilateral to the accessory connection and positioning it at the atrioventricular valve annulus directly opposite the earliest point of atrial activation (Figure 1) and/or Kent fiber potential (if recorded). The position was confirmed by recording through the ablating electrode catheter atrial (and ventricular) electrograms with the shortest obtainable AV interval antegrade and the shortest obtainable VA interval retrograde equal to or shorter than the shortest interval recorded through the mapping catheter. Because posteroseptal pathways may demonstrate variable antegrade and retrograde activation patterns,14 we mapped the septal region at the coronary sinus os and the tricuspid annulus adjacent to the atrioventricular node. Also, because the anterior septal pathway may lie very adjacent to the His bundle, although separated by the central fibrous body, mapping of suspected pathways in this region were performed with the ablating catheter in a 180-degree curve positioned in the right ventricular cavity under the tricuspid leaflet through both the inferior and superior vena cava approach. One thousand units/kg of heparin was administered intravenously (up to 3,000 units) and repeated every 90–120 minutes.

Radiofrequency current (Radionics, RFG-3C lesion generator system) was delivered at 50–70 volts for 10–60 seconds at a frequency of 500 kHz. Radiofrequency pulses were delivered for two to 28 trials. If an increase in impedance was noted during current delivery, power was immediately discontinued and the ablating electrode catheter was removed and cleaned or replaced. To minimize energy delivered, initial pulses were delivered for 10–15 seconds because, from experience, if the ablating electrode is at the accessory connection, successful ablation occurs promptly upon reaching 50–60 volts (Figure 2). Termination of the trials was indicated by successful ablation (persistent loss of preexcitation or of retrograde conduction through the accessory connection), repeated impedance rises during current delivery (two patients), or a 6-hour time limit on the entire electrophysiological procedure (four patients), whichever came first. Upon completion of radiofrequency trials, repeat atrial and ventricular pacing and extrastimulation were performed to assess both antegrade and retrograde conduction through the accessory connection and normal conduction pathways.

The patient was then returned to a telemetry bed and monitored with continuous electrocardiographic display, a daily 12-lead electrocardiogram, daily serum CPK levels (normal 30–240 IU/ml), and CKMB fractions for 4 days as well as a 24-hour Holter tracing. Follow-up (1–8 months) included clinical
<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Symptoms</th>
<th>Duration (yr)</th>
<th>Treatment</th>
<th>Location AC</th>
<th>Man/Conc</th>
<th>RF Trials*</th>
<th>Volts</th>
<th>Duration (sec)</th>
<th>Result</th>
<th>CPK (IU) MB</th>
<th>Outcome</th>
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<tr>
<td>1</td>
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<td>1</td>
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<td>Posterior</td>
<td>Man</td>
<td>1:2</td>
<td>50-60</td>
<td>20</td>
<td>Ablated</td>
<td>318</td>
<td>2.10%</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>M</td>
<td>PSVT Syncope</td>
<td>3</td>
<td>Quinidine</td>
<td>Ant right septal</td>
<td>Man</td>
<td>13 60</td>
<td>20</td>
<td>Fail</td>
<td>1,071</td>
<td>1.50%</td>
<td>Recurrent arrhythmia</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>F</td>
<td>PSVT</td>
<td>5</td>
<td>Digoxin</td>
<td>Left post septal</td>
<td>Man</td>
<td>23 40-60</td>
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<td>4</td>
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<td>PSVT</td>
<td>2</td>
<td>Propranolol</td>
<td>Ant right septal</td>
<td>Man</td>
<td>3 60 25</td>
<td>30</td>
<td>Fail</td>
<td>30</td>
<td>3.20%</td>
<td>Surgical div successful</td>
</tr>
<tr>
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<td>PSVT</td>
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<td>Digoxin</td>
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<td>Man</td>
<td>7 60 10-20</td>
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<td>Recurrent arrhythmia</td>
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<tr>
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<td>13</td>
<td>M</td>
<td>PSVT Postop</td>
<td>10</td>
<td>Propranolol</td>
<td>Posterior Conc</td>
<td>Conc</td>
<td>17 60 10-20</td>
<td>10-20</td>
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<td>2</td>
<td>None</td>
<td>Post left</td>
<td>Conc</td>
<td>15 65 30-60</td>
<td>Transient ablation</td>
<td>586</td>
<td>2.70%</td>
<td>Recurrent arrhythmia</td>
<td></td>
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<tr>
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<td>9</td>
<td>M</td>
<td>PSVT</td>
<td>9</td>
<td>Digoxin</td>
<td>Post left</td>
<td>Conc</td>
<td>2:3 65 20</td>
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<td>3.40%</td>
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<td>M</td>
<td>PSVT</td>
<td>6</td>
<td>Digoxin</td>
<td>Post left</td>
<td>Man</td>
<td>8:9 60 10-20</td>
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<td>203</td>
<td>6%</td>
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<td></td>
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<tr>
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<td>18</td>
<td>M</td>
<td>PSVT</td>
<td>16</td>
<td>Digoxin</td>
<td>Post left</td>
<td>Man</td>
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<td>2.60%</td>
<td>No arrhythmia</td>
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<td>Fast AC</td>
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<td>None</td>
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<td>Man</td>
<td>17:18 50-65</td>
<td>9-45</td>
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<td>8,858</td>
<td>0.90%</td>
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<td>Man</td>
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<tr>
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<td>PSVT</td>
<td>2:5</td>
<td>Digoxin</td>
<td>Posterior</td>
<td>Conc</td>
<td>28 50-65</td>
<td>8-30</td>
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<td>380</td>
<td>8.70%</td>
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</tr>
<tr>
<td>14</td>
<td>11</td>
<td>M</td>
<td>PSVT Vent fib X4 Postop X4 SSS</td>
<td>11</td>
<td>Digoxin</td>
<td>Digoxin</td>
<td>Ant left</td>
<td>Man</td>
<td>16:22 60</td>
<td>20</td>
<td>3</td>
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</tr>
<tr>
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<td>11</td>
<td>M</td>
<td>PSVT</td>
<td>4</td>
<td>Left lateral</td>
<td>Man</td>
<td>2:3 55 10</td>
<td>Ablated</td>
<td>130</td>
<td>8%</td>
<td>No arrhythmia</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>M</td>
<td>PSVT</td>
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<td>Digoxin</td>
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<td>Conc</td>
<td>6 50-70</td>
<td>15-20</td>
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<td>7%</td>
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<td>M</td>
<td>PSVT</td>
<td>5</td>
<td>Digoxin</td>
<td>Post right</td>
<td>Man</td>
<td>9:10 60 10-30</td>
<td>Ablated</td>
<td>64</td>
<td>1%</td>
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<tr>
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<td>8</td>
<td>M</td>
<td>PSVT</td>
<td>3</td>
<td>None</td>
<td>Left lateral</td>
<td>Conc</td>
<td>2:4 60 10-30</td>
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<td>2,900</td>
<td>1.50%</td>
<td>No preexcitation</td>
<td></td>
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<tr>
<td>19</td>
<td>9</td>
<td>M</td>
<td>Syncope Wide QRS Tach Vent fib</td>
<td>3</td>
<td>None</td>
<td>Left lateral</td>
<td>Man</td>
<td>2:3 60 8-12</td>
<td>Ablated</td>
<td>155</td>
<td>No arrhythmia</td>
<td></td>
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</table>

AC, accessory connection; Man, manifest accessory connection; Conc, concealed accessory connection; RF, radiofrequency; CPK, creatine phosphokinase; IU, International units/ml; MB, MB fraction; PSVT, paroxysmal supraventricular tachycardia; Postop, after operation; Vent, ventricular; Fib, fibrillation; SSS, sick sinus syndrome; Tach, tachycardia; Ant, anterior; Post, posterior.

*First notation indicates trials necessary to achieve transient or permanent ablation; second notation indicates total number of pulses delivered.
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Results

Ablation Outcome

The clinical and electrophysiological data of the 19 patients are summarized in Table 1. Successful ablation (Figure 2) was achieved in 13 (68%) of the subjects, including 11 of the last 12 patients. Two patients (No. 8 and No. 12) required a second session to achieve successful ablation. Two patients (No. 7 and No. 13) had transient interruption of retrograde conduction varying from 7 to 15 minutes. Patient 13, a 3-year-old boy with daily episodes of tachycardia who experienced transient interruption of retrograde conduction, has been arrhythmia-free for 2 months, suggesting that the concealed pathway was interrupted by the evolving ablation lesion at some interval after the transient effect; this interpretation is supported by the observation recorded from continuous electrocardiographic telemetry in patient 12 of transient (approximately 1 hour) return of preexcitation 4 hours after ablation followed again by loss of preexcitation. Twenty-four hours later, repeat electrophysiological study in patient 12 demonstrated no anomalous antegrade conduction and no retrograde conduction. Thus, in summary, the accessory connection in 14 (74% including patient 13) of the 19 patients was successfully ablated. Ablation was successful in 87% of all left-sided pathways and 100% of

Figure 1. Top: Chest radiograph from patient No. 1 in the right anterior oblique (RAO) projection demonstrating the electrode catheter positions. The distal electrode on the ablation (ABL) catheter is placed in juxtaposition to the middle electrodes on the coronary sinus (CS) orthogonal mapping catheter, the site of earliest retrograde atrial activation. The RV catheter was passed through the inferior vena cava, across the tricuspid valve adjacent to the His bundle, and into the right ventricular (RV) apex. The RA catheter is in the right atrial (RA) appendage. Bottom: Chest radiograph from patient No. 1 in the left anterior oblique (LAO) projection. Location of the accessory connection was determined for each patient by electrophysiological mapping (see text).
manifest left-sided pathways. Only one of five right-sided pathways was successfully ablated.

Location of Accessory Pathways

To classify the accessory connection location, we used the schema of Jackman and associates. Fifteen of the patients had left accessory connections: two had a left posterior septal pathway; five, a posterior pathway; four, a left posterior pathway; three, a left lateral pathway; and one, an anterior left pathway (Figure 1). Two of the patients (No. 6 and No. 14) were thought to have multiple pathways; patient 6 had previously undergone surgical division of a left lateral pathway 8 months earlier for preexcitation and SVT; preexcitation, inducible SVT, or retrograde conduction were absent 1 week after surgery. Four months later, recurrent supraventricular tachycardia appeared; electrophysiological study 4 months later demonstrated retrograde conduction through a persistent posterior accessory connection but no preexcitation. Failure of ablation in this patient may be related to the difficulty with mapping; atrial electrograms recorded from both the coronary sinus in the previously operated area through an orthogonal electrode catheter and the mitral annulus through the ventricular ablating catheter were distorted, fragmented, and not well formed, perhaps impairing precise location of the accessory connection. On the other hand, a 10-year-old boy (No. 14) with multiple left lateral accessory connections who had undergone four operations over a 10-year period to interrupt his accessory connections was mapped without difficulty and had successful ablation after one radiofrequency energy application. This patient was the only subject in whom a suspect Kent bundle was observed. Six patients had a concealed posterior pathway; the pathways in three of these patients were successfully ablated. Eleven of the 15 patients with left-sided accessory connections experienced successful interruption of their accessory connection. The left posterior accessory connection in two patients was successfully ablated.

Four patients had right-sided pathways; two, an anterior septal pathway; one, a right posterior pathway; and one, a right posterior septal pathway. In the one patient with a right posterior septal pathway, the shortest atrioventricular and ventricular intervals were noted at the mouth of the coronary sinus. Radiofrequency energy delivered to the os and between the os and the tricuspid annulus was not successful within the preset time limit for the study. The two patients with the right anterior septal pathways were extensively mapped. These patients were early in our experience; because the pathway appeared very close to the His bundle, thus potentially jeopardizing normal atrioventricular conduction, we did not pursue persistent application of radiofrequency energy in that area in these young individuals. A number of investigators have reported successful ablation of accessory connections at this site without injury to atrioventricular conduction. Both patients have had successful surgical division of their pathway.

Potential Complications

No major complications were noted during this study. One 13-year-old girl developed a large hematoma in the right femoral area at the site of catheter insertion; she was treated with rest and iron supplement. Four-day follow-up observation of these patients
with a daily 12-lead electrocardiogram, continuous ECG telemetry, 24-hour Holter examination, echocardiogram, and chest x-ray disclosed no significant abnormalities. One patient had four-beat accelerated idioventricular rhythm before ablation, and another patient had four-beat accelerated ventricular rhythm after ablation at initial but not repeat Holter examination.

Serum CPK enzymes (Table 1) rose in 12 patients, peaking at 12–24 hours at a median of 375 IU/ml (normal, 30–240 IU/ml); five patients had very large increases of 1,071, 1,300, 15,200, 8,858, and 2,900 IU/ml; five different patients had a mild increase in MB fraction (≥3%; 3.4–8.7%); all MB fractions returned to normal within 72 hours except in one patient (No. 2) whose total CPK was normal but whose MB fraction had become slightly elevated at 9%. No patient complained of chest pain in the follow-up period and no ST segment changes suggestive of myocardial ischemia were noted on the daily electrocardiograms. The larger enzyme rise tended to be associated with the use of general anesthesia.

Intermediate Follow-up

In the 4–12-month follow-up period, there was no return of preexcitation or SVT in the 13 patients with an early favorable response. The 3-year-old boy (No. 13) with transient interruption of a concealed pathway had no SVT.

Discussion

During the past 2 years, preliminary reports have appeared in which radiofrequency energy is used to modify the atrioventricular node as well as to ablate accessory connections in older patients. This report confirms the successful application of radiofrequency energy to ablate accessory connections in children and adolescents. Preliminary reports in older individuals indicate a success rate of 90–100%, equal to surgical results. Our experience confirms not only the successful use of this technique in younger individuals but also its safe application. No short-term adverse effects were encountered; the total CPK rise may be related to excessive exercise (patients 2, 8, 10, and 18) before ablation trial and/or the use of the general anesthesia (patients 8, 10, 12, and 18), although most commonly after the administration of halothane and succinylcholine. Importantly, no electrocardiographic evidence of myocardial injury was noted. Direct current ablation as well as cardiac surgery and coronary angioplasty can cause similar MB fraction increases. Although our experience is, at this time, small, and does not yet reach our surgical results, it is probable that the results of radiofrequency ablation in children will continue to improve with increased experience.

Borggreve and associates have recently reviewed the biophysical factors pertinent to the use of radiofrequency energy. Lesions generated depend on a number of factors, including ablating electrode size; in in vitro canine myocardium, an electrode with a length of 4 mm at a current flow up to 500 J or until an impedance rise indicating tissue dessication and coagulation produced lesions in the ventricular myocardium 54 mm² in size. Histology of acute lesions reveals well-demarcated areas of necrosis with a surrounding hemorrhage. Few data are available from humans in which factors such as contact and contact pressure to the target tissue cannot be controlled and in whom tissue is not available. In the one patient who went to surgery 4 weeks after attempted ablation (three pulses) of an anterior septal pathway, no abnormalities were observed on the ventricular epicardium or on the atrial right endocardium. Nonetheless, as indicated by five patients with mild increases in the MB fraction of CPK enzymes, improved monitoring techniques, particularly of the temperature at the catheter tip, would be of value.

The application of this technique for interruption of anomalous atrioventricular conduction and elimination of reentrant tachycardia through accessory connections in children warrants special consideration. Supraventricular tachycardia supported by an accessory connection is a congenital (whether symptomatic or not) disorder of the young; the incidence of a manifest accessory connection (i.e., Wolff-Parkinson-White syndrome) has been estimated at approximately 1.6 of 1,000 in the general population. Children with accessory connections have arrhythmias that appear episodically and abruptly, are potentially albeit infrequently (up to 4% of the patients with manifest Wolff-Parkinson-White syndrome and 3.7% in our experience) life-threatening, and frequently interfere with patient well-being. At least two thirds of patients are symptomatic with palpitations, chest discomfort, and varying degrees of weakness, faintness, and dizziness. Prophylaxis for these tachyarrhythmias requires long-term pharmacological therapy with potentially toxic antiarrhythmic medications. Pharmacological therapy also requires rigorous patient compliance and frequent medical supervision for evaluation of therapeutic and toxic effects. Definitive curative therapy, at this time, requires surgical intervention with its attendant morbidity and mortality and prolonged hospitalization; success rates in eliminating both the tachycardia and its substrate is approximately 90% in children. Non-surgical definitive therapy in the past has been confined to delivery of intracardiac direct current discharge to ablate accessory connections in patients with Wolff-Parkinson-White syndrome and posterior septal pathways and/or to ablate the normal pathway in patients with refractory supraventricular arrhythmias. This technique also requires general anesthesia, delivers a disruptive broad shock wave through the myocardium, uniformly produces CPK isoenzyme elevations, and, by most electrophysiologists, is applicable to accessory pathways located only in the posterior septal region. This technique has a success rate of approximately 75%, depending on the characteristics of the accessory connection. In children, our success has been 33%; individuals not responding to DC ablation went to surgery. Although our success rate of
radiofrequency ablation to date has been only 68%, we have achieved successful ablation of the anomalous pathways in 11 of the last 12 patients. Potential technical problems such as oversized catheters are of minimal concern; large-caliber catheters (7F and larger) have been used extensively in children for balloon intervention procedures with few problems. As with our two patients in whom ablation was unsuccessful at the first session, further trials of ablation in patients in whom successful ablation of the pathway has not been achieved may be warranted.

Conclusions

These data indicate that radiofrequency ablation of accessory connections is a useful and safe procedure for children who have SVT supported by accessory connections. This technique should be included among the therapeutic strategies available for children with accessory connections and SVT, especially those with documented rapid antegrade conduction and those who have frequent tachycardia unresponsive to physiological/pharmacological management. Although the long-term outcome of creating radiofrequency lesions in the young myocardium is unknown, the immediate benefit clearly offsets the very low short-term risk. Furthermore, given the improved patient well-being, the freedom from tachyarrhythmias, the absence of potential rapid conduction across the accessory connection, along with extrapolation from the surgical experience, the long-term clinical course appears to be favorable as well.

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References


KEY WORDS: arrhythmias, supraventricular tachycardia, pediatrics, Wolff-Parkinson-White syndrome.
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