Radiofrequency Catheter Ablation in Infants ≤18 Months Old

When Is It Done and How Do They Fare?

Short-Term Data From the Pediatric Ablation Registry

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Background—The objective of this study was to determine the indications, the safety, and the efficacy of pediatric radiofrequency catheter ablation (RFCA) in infants.

Methods and Results—Data from the pediatric RFCA registry were reviewed. Between August 1989 and January 1999, 137 infants, defined by age 0 to 1.5 years (median 0.7 years; weight 1.9 to 14.8 kg, median 10 kg), underwent 152 procedures in 27 of 49 registry centers (55%), compared with 5960 noninfants undergoing 6610 procedures during a comparable period. Structural heart disease was present in 36% of infants, compared with 11.2% of noninfants ($P<0.0001$). RFCA in infants was performed more commonly for drug resistance or life-threatening arrhythmias than in noninfants. No differences were found between infants and noninfants in success for all tachycardia substrates (87.6% versus 90.6%, $P=0.11$), for single accessory pathways (94.5% versus 91.5%, $P=0.4$), or for total (7.8% versus 7.4%, $P=1$) and major (4.6% versus 2.9%, $P=0.17$) complications. Neither success for infants with a single accessory pathway nor complications for the entire infant group were related to weight, age, center size, or the presence of structural heart disease. Centers that performed infant procedures, however, enrolled more patients overall in the registry than those that did not perform infant procedures, and successful procedures in infants were performed by more experienced physicians than failed procedures.

Conclusions—Compared with noninfants, RFCA in infants is usually performed for drug resistance or life-threatening arrhythmias, often in the presence of structural heart disease. The data support the use of RFCA by experienced physicians in selected infants. (Circulation. 2001;104:2803-2808.)

Key Words: catheter ablation ■ pediatrics ■ arrhythmia

Experience with radiofrequency catheter ablation (RFCA) in pediatric patients has been growing considerably since its first use a decade ago.¹,² Success has been improving steadily and complication rates have been declining with increased user experience.³,⁴ Because medical therapy has a lower success rate⁵ and involves additional morbidity while requiring rigid compliance, RFCA is becoming the first line of therapy for many arrhythmias in most pediatric patients. There has been concern, however, about the use of RFCA for the treatment of infant arrhythmias.

Concerns about RFCA in infants are related to a number of factors, including the natural history of most tachyarrhythmias in infants, technical issues with RFCA in small hearts, and the potential for unknown long-term effects of RF applications on the maturing myocardium.⁶ The most common tachyarrhythmias in infants are those that involve accessory pathways (APs),⁷ in which ≈33% of the substrates spontaneously resolve by the time the child is 1 year of age.⁸,⁹ In addition, previous studies have shown a greater complication rate for RFCA in children weighing <15 kg.⁴,¹⁰ Although limited intermediate-term follow-up studies have revealed no significant increase in ventricular arrhythmias¹¹,¹² and no evidence of coronary abnormalities by traditional angiography at up to 6 months after ablation,¹² a report of late development of asymptomatic coronary artery stenosis after right free wall RFCA in 2 young boys with Ebstein’s malformation¹³ and a report from the Pediatric Ablation Registry of a very small number of procedure-related late deaths after the ablation procedure suggest some caution in the use of RFCA in the younger pediatric population in general.¹⁴ As yet, no data have been published to assess the long-term risks of RF lesions on myocardial function, coro-

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*A list of members of the Pediatric Catheter Ablation Registry that performed infant ablations during the study period is listed in the Appendix.

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nary perfusion, or arrhythmogenicity in a group of developing infants and children. Animal studies, however, suggest that RF lesions in the developing myocardium may have the potential to expand with time and may effect coronary perfusion. Thus, the potential for spontaneous arrhythmia resolution as well as the short- and long-term risks associated with infant RFCA have been arguments against infant RFCA.

There are also several reasons why RFCA may be desirable in infants. Arrhythmias in infants may produce more problems than in older children and are often difficult to manage medically. Infants with congenital heart disease are at particular risk of hemodynamic compromise with arrhythmias before or after surgery. In addition, because infants are unable to communicate, arrhythmia recurrence and drug side effects are more likely to go unrecognized until symptoms have progressed further than in older children. Thus, in the absence of safety issues, a definitive cure with RFCA may be even more appealing in infants than in older children. This investigation was undertaken to determine whether the efficacy and risks of infant RFCA warrant its use in selected infants.

Methods
Data from the pediatric RFCA registry were reviewed to determine the indications, safety, and efficacy of RFCA in infants, defined as age 0 to 1.5 years, who underwent RFCA between August 1989 and January 1999. The infant data were compared with those for noninfants (1.6 to 21 years old) who underwent RFCA during a comparable period (1991 to 1998). Registry data were submitted by any member of the Pediatric Electrophysiology Society performing RFCA in any of the 49 centers participating during the study periods. All RFCA procedures were done in accordance with each center’s respective institutional guidelines. Data were collected on a standardized form. Selection criteria for data parameters were chosen by the center submitting the data and were not validated. Thus, how some of the parameters were chosen, such as indications, may have varied by center.

Statistical Analysis
Indications and complications were determined for each procedure. Success was based on individual substrate elimination rather than all substrates for a given patient. Group comparisons were made by Pearson’s χ² for multiple group comparisons, Yates’ χ² for 2×2 comparisons, or Student’s unpaired t test wherever applicable.

Results
During the study period, 137 infants underwent 152 procedures for 171 substrates. Infants were younger, weighed less, and had a greater presence of structural heart disease than noninfants (Table 1). Forty-nine infants (36.1%) had structural heart disease.

### TABLE 1. Patients

<table>
<thead>
<tr>
<th></th>
<th>Infants</th>
<th>Noninfants</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>137</td>
<td>5960</td>
<td>…</td>
</tr>
<tr>
<td>Procedures, n</td>
<td>152</td>
<td>6610</td>
<td>…</td>
</tr>
<tr>
<td>Substrates, n</td>
<td>171</td>
<td>7160</td>
<td>…</td>
</tr>
<tr>
<td>Age, y</td>
<td>0.7 (0.05–1.5)</td>
<td>13.1 (1.6–20.9)</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>7.4 (1.9–14.8)</td>
<td>50 (8–139)</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Structural HD, %</td>
<td>36%</td>
<td>11.2%</td>
<td>&lt;.00001</td>
</tr>
</tbody>
</table>

Structural HD indicates structural heart disease.

### TABLE 2. Structural Heart Disease

<table>
<thead>
<tr>
<th>Heart Disease</th>
<th>Count, n</th>
<th>% of Infants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ebstein’s malformation of tricuspid valve</td>
<td>11</td>
<td>8.3</td>
</tr>
<tr>
<td>LV dysfunction</td>
<td>9</td>
<td>6.6</td>
</tr>
<tr>
<td>Single-ventricle/L-TGA complex</td>
<td>5</td>
<td>3.6</td>
</tr>
<tr>
<td>TOF</td>
<td>5</td>
<td>3.6</td>
</tr>
<tr>
<td>HCM</td>
<td>3</td>
<td>2.2</td>
</tr>
<tr>
<td>ASD or PAPVR</td>
<td>3</td>
<td>2.2</td>
</tr>
<tr>
<td>VSD</td>
<td>3</td>
<td>2.2</td>
</tr>
<tr>
<td>Aortic stenosis or coarctation of the aorta</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Tricuspid atresia</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Tumors</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>TGA</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>2.2</td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td>36.1</td>
</tr>
</tbody>
</table>

LV indicates left ventricular; L-TGA, physiologically corrected transposition of the great arteries; TOF, tetralogy of Fallot; HCM, hypertrophic cardiomyopathy; ASD, atrial septal defect; PAPVR, partial anomalous pulmonary venous return; VSD, ventricular septal defect; and TGA, transposition of the great arteries.

### Indications
The distribution of indications differed significantly between the infant and noninfant groups (P < 0.001, Figure 2). The presence of a life-threatening rhythm or rhythm refractory to drug therapy was the most frequent indication in the infant group (Figure 2). Whereas just over 50% of the noninfant procedures were done by patient or guardian choice versus 4.2% of infant procedures, a life-threatening rhythm was the indication for 33% of infant procedures versus 7.7% of noninfant procedures. Thus, infant procedures were more likely to be done for rhythms that were perceived to be more dangerous. Infants with structural heart disease were perceived to have a much greater incidence of life-threatening rhythms than either the infants with normal hearts or the noninfants.

### Tachycardia Mechanisms
As with noninfants, most infant RFCA procedures were performed in patients with AP-mediated tachycardias...
Ectopic atrial tachycardia, however, was the second most common infant substrate ablated and was more prevalent in infants \( (P<0.0001) \). Although uncommon in both groups, ventricular tachycardia and junctional ectopic tachycardia were more prevalent in infants \( (P<0.03) \), whereas atrial flutter was equally uncommon in both groups \( (P=NS) \).

### Other Procedure Variables

Procedure times varied widely (25 to 580 minutes, median 210 minutes), as did fluoroscopy times (5 to 194 minutes, median 33 minutes). Although 5F, 6F, and 7F ablation catheters were used, 6F were used most commonly (5F 31%, 6F 38%, 7F 31%). Procedures involved a median of 6 RF applications (1 to 46 applications). Anticoagulation with heparin was used during 79% of the procedures and continued postprocedure with heparin or aspirin in 69% of the procedures.

### Procedure Success

There was no statistical difference in the elimination of individual substrates for infants versus noninfants with regard to all substrates taken together (87.6% versus 90.9%) or for any individual substrate (Table 3). Successful procedures occurred when individual physicians were significantly more experienced \( (171 \pm 155 \text{ previous reported RFCA procedures vs } 81 \pm 55 \text{ previous reported RFCA procedures, } P<0.01) \). Catheter French size did not influence success. To eliminate potential confounding effects due to differences in the distribution of substrates, success for AP-mediated tachycardias, the largest substrate group for infants and noninfants, was analyzed separately. Again, there was no statistical difference in success between infants and noninfants in this subset of patients \( (88\% \text{ versus } 91\%, \ P=NS) \).

Factors associated with successful AP elimination within the infant group were sought. Success was not related to age, weight (Figure 3), the presence of structural heart disease, or physician experience. Although there was a difference in the frequency of APs in different locations \( (\text{left free wall } 51\%, \text{ septal } 34\%, \text{ right free wall } 15\%) \), success was not statistically different between any of these locations. The approach to left-sided APs \( (\text{antegrade across the atrial septum or retrograde from the left ventricle}) \) did not affect elimination of these pathways. Success was significantly reduced for the 9
procedures in the 9 infants (6.6%) who had multiple APs ($P<0.003$). These 9 infants had 21 APs: 6 had 2 APs and 3 had 3 APs. Only 14 of 21 APs (67%) were eliminated, and in only 5 of 9 patients (56%) were all APs eliminated in a single procedure.

Complications

A total of 12 complications occurred in the infant group, and these are divided into major and minor categories (Table 4). Neither the total nor the major complication rates were statistically different in infants versus noninfants (7.8% versus 7.4% and 4.6% versus 2.9%, $P=NS$). One death occurred in an infant with Ebstein’s anomaly undergoing RFCA for ventricular tachycardia. Complications in infants were not related to age, weight (Figure 4), the presence of structural heart disease, individual physician experience, procedure time, fluoroscopy time, catheter French size, number of RF applications, or the approach to left-sided APs, but the low number of complications made correlations difficult to assess. Patients who developed complications had undergone RFCA for elimination of an AP ($n=8$), ectopic atrial tachycardia ($n=3$), or ventricular tachycardia ($n=1$). Within the AP subset, the complication rate was significantly greater for septal APs than for left free wall or right free wall (15.4% versus 3.4% versus 0%, respectively, $P=0.03$).

### Discussion

The most important findings of this study were that (1) RFCA in infants is performed for more serious indications than in noninfants, and only rarely for patient choice; (2) although APs are the most common ablation substrate, the distribution of substrates was significantly different than for noninfants; and (3) despite these differences between infants and noninfants, procedure success and complications were not significantly different from procedures in noninfants. An additional interesting finding was that RFCA for infants is performed in the centers that report the most data to the registry.

### Indications

In agreement with the literature, the differences in indications between infants and older children demonstrate that infants who underwent an ablation procedure were sicker on presentation and were perceived to be at greater risk from their arrhythmia. These perceptions appear to be heightened for infants with structural heart disease, who made up a much larger proportion of the infants than noninfants; the incidence of structural heart disease does not entirely account for these findings, however, because the differences were also present for infants with structurally normal hearts.

### TABLE 3. Substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Infants</th>
<th></th>
<th></th>
<th></th>
<th>Noninfants</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Prevalence, %</td>
<td>Success, %</td>
<td>Prevalence, %</td>
<td>Success, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessory pathway</td>
<td>115</td>
<td>67.3</td>
<td>87.8</td>
<td>4731</td>
<td>66.1</td>
<td>90.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVNRT</td>
<td>7</td>
<td>4.1</td>
<td>100</td>
<td>1576</td>
<td>21.6</td>
<td>97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT</td>
<td>29</td>
<td>17.1</td>
<td>89.7</td>
<td>332</td>
<td>4.9</td>
<td>87.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JET</td>
<td>6</td>
<td>3.5</td>
<td>100</td>
<td>13</td>
<td>0.3</td>
<td>76.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atrial flutter</td>
<td>4</td>
<td>2.4</td>
<td>50</td>
<td>312</td>
<td>4.3</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT</td>
<td>10</td>
<td>5.9</td>
<td>70</td>
<td>196</td>
<td>2.8</td>
<td>65.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AVNRT indicates AV nodal reentrant tachycardia; EAT, ectopic atrial tachycardia; JET, junctional ectopic tachycardia; and VT, ventricular tachycardia.

$P=NS$ for infants vs noninfants for success for all substrates.

### TABLE 4. Complications

<table>
<thead>
<tr>
<th>Complications</th>
<th>n</th>
<th>Substrate</th>
<th>Heart Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pericardial effusion</td>
<td>2</td>
<td>L lateral AP/P septal AP</td>
<td>ASD</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>2</td>
<td>A septal AP/R EAT</td>
<td>VSD</td>
</tr>
<tr>
<td>2° AVB</td>
<td>1</td>
<td>M septal AP</td>
<td></td>
</tr>
<tr>
<td>3° AVB</td>
<td>1</td>
<td>M septal AP</td>
<td></td>
</tr>
<tr>
<td>Horner’s syndrome</td>
<td>1</td>
<td>L lateral AP</td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>1</td>
<td>RV-VT</td>
<td>Ebstein’s</td>
</tr>
<tr>
<td>Minor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transient 3° AVB</td>
<td>2</td>
<td>A septal AP/P septal AP</td>
<td>VSD</td>
</tr>
<tr>
<td>Hematoma</td>
<td>1</td>
<td>R EAT</td>
<td></td>
</tr>
<tr>
<td>Sinus bradycardia</td>
<td>1</td>
<td>R EAT</td>
<td>LV dysfunction</td>
</tr>
</tbody>
</table>

2° AVB indicates 2nd-degree AV block; 3° AVB, 3rd-degree AVB; L lateral, left lateral; P septal, posteroseptal; A septal, anteroseptal; R EAT, right atrial ectopic atrial tachycardia; M septal, midseptal; and RV-VT, right ventricular tachycardia.
This difference, however, may arise because rela-
tion.4,10,21 This difference between infants and older children was that infant
infants who might benefit from RFCA. Another interesting
necessarily correct and should not deter attempts in those
will be less successful for infants with heart disease are not
presence of structural heart disease. Thus, beliefs that RFCA
elimination in infants was not influenced statistically by the

probable accounts for the higher frequency of multiple APs in
lower rate of AP elimination. These infants, however, are

First, it spanned

large overlap of weight, suggesting that, within infant group,
weight did not influence presence of acute complications.

Importantly, success was related to increased individual
physician personal experience. Unlike the former registry
studies involving the entire pediatric age span,10 substrate
elimination in infants was not influenced statistically by the
presence of structural heart disease. Thus, beliefs that RFCA
will be less successful for infants with heart disease are not
necessarily correct and should not deter attempts in those
infants who might benefit from RFCA. Another interesting
difference between infants and older children was that infant
AP elimination was not shown to be related to AP loca-
tion.4,10,21 This difference, however, may arise because relatively
few infants had right free wall APs. As in reports in
adults,21 the presence of multiple APs was associated with a
lower rate of AP elimination. These infants, however, are
often also the most difficult to manage medically, which
probably accounts for the higher frequency of multiple APs in
this small group.

Complications
This study did not confirm previous registry findings dem-
strating a higher complication rate in cases involving
patients weighing <15 kg.10 The data set studied here was
different from the previous ones. First, it spanned >5
additional years, at a time when increasing experience was
clearly affecting outcomes.3 Furthermore, this study confined
the patient base to those <1.5 years old, regardless of weight.
Thus, we did not analyze the data of the 231 patients
weighing <15 kg but >1.5 years old in the pediatric RFCA
registry. This group of patients suffered 17 complications, of
which 12 were major. When these patients are combined with
the “infants” from this study, the major but not the total

Figure 4. Complications and patient weight. Distribution of
infant weights is plotted according to whether or not RFCA was
associated with acute complication. This graph demonstrates a
large overlap of weight, suggesting that, within infant group,
weight did not influence presence of acute complications.

Success
This study demonstrated that successful elimination of each
arrhythmia substrate was not statistically different in infants
and noninfants. This finding is in agreement with other large
pediatric RFCA studies, in which lower weight was not a
factor in predicting the success of substrate elimination.5,10

This study had one death in a patient with structural heart
disease. Although this is one instance and therefore not
significantly different from the noninfant procedures, the
0.74% mortality for infant RFCA is higher than that reported
by Schaffer et al14 for all children in the registry, 0.12%.
Schaffer’s study included data from follow-up forms sent to
the registry and also contained the report of an infant with a
structurally normal heart who died 2 weeks after RF ablation
of an AP-mediated tachycardia. Through the period of
Schaffer’s study, ~111 infant RF procedures were per-
formed, yielding an associated infant mortality of 0.9%.
Although another 18-month-old patient with congenital heart
disease died of fever and hypotension on the day after RF
ablation, no details are given except that no definitive link
between the death and the procedure was established. Our
infant death was not included in the Schaffer report because
of differing study periods and because no subsequent
follow-up data are available. Interestingly, despite the per-
ception that medical management of supraventricular
tachycardia in infants is benign, mortality rates of ~5% have
been reported in infants with Wolff-Parkinson-White syn-
drome and supraventricular tachycardia who were treated
terically.22,23 Furthermore, no comparable mortality data
exist for medical management of only those infants who have
life-threatening arrhythmias or a group with congenital heart
disease.

Infant Procedure Modifications
Several modifications from the standard procedure can be
used when undertaking RFCA in infants. A transesophageal
catheter can replace an intracardiac catheter for atrial pacing.
A single catheter can be used to record the His-bundle
electrogram and to pace the ventricle, and a smaller 5F
catheter can replace an intracardiac catheter for atrial pacing.

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used when undertaking RFCA in infants. A transesophageal
catheter can replace an intracardiac catheter for atrial pacing.
A single catheter can be used to record the His-bundle
electrogram and to pace the ventricle, and a smaller 5F
catheter can replace an intracardiac catheter for atrial pacing.

conservative RF applications with a lower-temperature set
point (50°C) and short duration (5 seconds) can be used to
limit tissue damage to the single location at which success is
achieved.25,26 Application times can then be extended to 15 to
30 seconds only if both AP conduction is lost and AV
conduction is preserved. Despite lack of conclusive proof
regarding these techniques, similar modifications have been
used and reported elsewhere by centers contributing to the
registry.27
Study Limitations

Because this study was a retrospective review of short-term results, certain data were not obtainable. Other procedure-related variables, such as catheter tip length, may have been related to outcome, but because the data had not been recorded in the registry, this could not be analyzed. Clearly, any concerns regarding the long-term effects of RF ablation remain unanswered in this short-term study. Follow-up studies are needed to determine these risks.

Conclusions

Compared with noninfants, RFCA in infants is usually performed for drug resistance or life-threatening arrhythmias, often in the presence of structural heart disease. No significant differences were found for success and complication rates between infants and noninfants. The data support the use of RFCA by experienced physicians for arrhythmia management in selected infants. Finally, this retrospective analysis of the short-term results of infant RFCA procedures may have important implications for the management of arrhythmias in sick infants.

Appendix

Members of the Pediatric Catheter Ablation Registry that performed infant ablations during the study period: Arkansas Children’s Hospital, Little Rock; Arrhythmia Associates, Fairfax, Va; Atlantic Children’s Heart Center, Ga; Boston Children’s Hospital, Mass; Children’s Hospital of Philadelphia, Pa; Children’s Hospital of Pittsburgh, Pa; Children’s Hospital of San Diego, Calif; Children’s Hospital of the King’s Daughters, Norfolk, Va; Children’s Memorial Hospital, Chicago, Ill; Cook Children’s Medical Center, Fort Worth, Tex; Floating Hospital for Children, Boston, Mass; Long Island Jewish Medical Center, New Hyde Park, NY; Miami University School of Medicine, Fla; Michigan University Medical Center (Mott), Ann Arbor; Minneapolis Children’s Heart Clinic, Minn; Mount Sinai Medical Center, New York, NY; Oregon Health Science University, Portland; Rainbow Babies & Children’s Hospital, Cleveland, Ohio; South Carolina Children’s Heart Program, Charleston; St Louis Children’s Hospital, Mo; Stanford University, Stanford, Calif; Tampa General, Fla; Texas Children’s Hospital, Houston; Toronto Hospital for Sick Children, Canada; University of Texas Southwest Medical Center, Dallas; University of Alabama, Birmingham; University of California, San Francisco; and Vanderbilt University, Nashville, Tenn.

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