Catheter Ablation of Accessory Atrioventricular Pathways in Young Patients: Use of Long Vascular Sheaths, the Transseptal Approach and a Retrograde Left Posterior Parallel Approach

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Objectives. This study retrospectively assesses the technical aspects of the catheter techniques used to ablate 83 accessory atrioventricular (AV) pathways during 88 procedures in 71 pediatric and adult patients (median age 14 years, range 1 month to 55 years). A number of catheter approaches and techniques evolved that may have improved success and shortened procedure times.

Background. Radiofrequency catheter ablation of accessory AV pathways can be highly successful. However, the technical difficulty of many of the procedures is masked by the success rate.

Methods. Left free wall, right free wall and septal accessory pathways were ablated with a variety of approaches.

Results. Left free wall pathways were ablated successfully by using a standard retrograde approach through the aortic valve in only 10 (24%) of 43 cases. The remaining 33 (76%) required an approach that was either retrograde through the mitral valve (2 of 33), transseptal (21 of 33) or retrograde where the catheter was advanced behind the posterior mitral leaflet at the point of mitral-aortic continuity, so that the catheter course was *parallel* rather than *perpendicular* to the mitral anulus (10 of 33). Nineteen of 20 septal pathways were ablated successfully by using either the parallel approach (2 of 29), a transseptal approach (2 of 19), ablation within the coronary sinus or one of its veins (8 of 19) or ablation on the atrial side of the tricuspid valve (7 of 19). Fifteen of 20 right free wall pathways were ablated successfully with a variety of approaches on both the atrial and the ventricular side of the tricuspid valve. Long vascular sheaths were judged to contribute directly to success in 33 (43%) of 77 pathways. The overall success rate has been 93% (77 of 83 pathways), with 100% success for left free wall (43 of 43), 75% for right free wall (15 of 20) and 95% for septal pathways (19 of 20).

Conclusions. Thus, successful ablation of accessory AV pathways in a mixed group of pediatric and adult patients appears to benefit from a wide range of vascular and catheter approaches.

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The use of catheter ablation with radiofrequency energy to eliminate accessory atrioventricular (AV) pathways or produce AV node modification has now been established as highly effective with few immediate side effects (1–3). Although these reported findings are no less than remarkable, the overall success rates fail to portray both the technical difficulty of these procedures and the relative inability to predict that difficulty from pathway location alone. The long period of time often necessary to complete these procedures clearly results in substantial radiation exposure to both patients and physicians (1,4). In addition, for the pediatric age group, alternative techniques must often be employed to assure both accurate and safe catheter delivery because of small patient size.

To address these issues, multiple groups (5–8) have evolved either novel catheters or approaches to decrease procedure time and remove some of the randomness from the catheter positioning technique. This report details the techniques used at Children's Hospital, Boston during catheter ablation procedures for elimination of accessory AV pathways in primarily pediatric patients.

Methods

Patients. The study group consists of 71 patients with 83 accessory pathways who have undergone a total of 88 radiofrequency catheter ablation procedures between March 7, 1990 and March 4, 1992 at Children's Hospital, Boston. Patients were considered eligible for the procedure if they experienced symptomatic tachycardia and had undergone one or more (median two, range one to nine) unsuccessful attempts at pharmacologic control of their arrhythmia. Patients or their parents, or both, were presented the option of additional drug trials, surgical ablation or catheter ablations.

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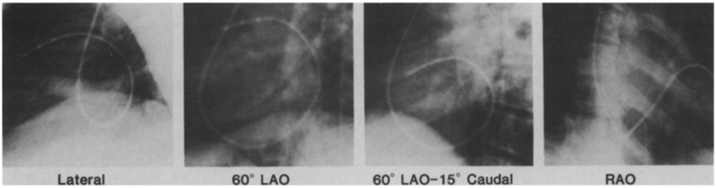


Figure 1. Catheter projections for ablation. Note how left anterior oblique (LAO) plus caudal angulation maximally elongates the mitral anulus. RAO = right anterior oblique.

All procedures were performed under a protocol approved by the Human Investigations Committee at Children's Hospital (January 5, 1990) with informed written consent from the patients or their parents, or both. Patients ranged in age from 1 month to 55 years (median 14 years). The youngest and smallest patient was a 5-week old (previously 34-week premature) baby with the Wolff-Parkinson-White syndrome who weighed 3.2 kg at the time of his procedure. The largest patient weighed 102 kg. The median weight was 54 kg. Six patients had a history of congenital heart disease. Four had Ebstein's disease of the tricuspid valve.

Procedure. Two or more vessels were cannulated percutaneously, including the right femoral vein, left femoral vein, left subclavian vein and right femoral artery. All patients underwent anticoagulation with 100-U/kg body weight (maximum 5,000 U) heparin, with repeat doses based on activated clotting time measurements. Electrode catheters were positioned at two or more sites, including the high right atrium, right atrial appendage, His bundle area, coronary sinus and the right ventricular apex. Electrograms were amplified and filtered between 40 and 400 Hz, and recorded along the four or more surface electrocardiographic (ECG) leads on a 16-channel electrophysiologic recording system (Bloom Associates). Catheter positions were monitored with biplane fluoroscopy. For most accessory AV pathways, ablation cameras were positioned in the 30° right anterior oblique and 60° left anterior oblique projection with 15° caudal projections (Fig. 1). Prior to attempts at mapping and ablation, comprehensive electrophysiologic data were collected according to standard protocols (9).

Mapping. Initial mapping was performed as previously described by Jackman et al. (1). Accessory pathway locations were identified by their characteristic electrograms during either sinus rhythm, orthodromic reciprocating tachycardia or ventricular paced rhythm. Electrograms were examined for the presence of 1) accessory pathway potentials; 2) shortest AV time in pre-excited sinus rhythm or atrial paced rhythm, or both; and 3) shortest ventriculoatrial time during orthodromic reciprocating tachycardia or ventricular paced rhythm (1). Atrial and ventricular stimulation techniques aimed at verification of accessory pathway potentials were not routinely performed (1,2,10). To help localize left free wall and left posteroseptal accessory pathways, either an orthogonal electrode catheter (Mansfield/Webster) or a 2-5-2-mm spaced multielectrode catheter (Bard Inc.) was used in the coronary sinus. To localize right free wall and right posteroseptal accessory pathways, a catheter with a deflectable curve and 2-mm electrode spacing was used to map the tricuspid anulus, either from the right femoral vein or the left subclavian vein. These techniques have previously been well described (1–3).

Ablation catheter manipulation. After initial localization, additional mapping and radiofrequency ablation were performed with introduction of a large-tipped (4 mm) electrode catheter using one or more of the following designs: 6F nonsteerable bipolar electrode (Bard) (2 procedures), 5F, 6F or 7F steerable quadripolar or bipolar catheter (Mansfield/Webster) (82 procedures) or a 6F or 7F steerable quadripolar catheter (EP Technologies) (4 procedures).

For most patients weighing >30 kg, accessory pathways were approached with the "standard" techniques previously described (1). Left free wall accessory pathways were approached by using a deflectable-tip catheter advanced retrograde from the aorta into the left ventricle. An attempt was made to place the catheter tip under and perpendicular to the mitral leaflet (Ao-LV) or through the mitral valve and above the mitral leaflet (LV-LA). Left posteroseptal pathways were approached from the left side by using the retrograde technique with an attempt to deflect the catheter tip under the mitral valve near the aortic anulus, or from the right femoral vein/inferior vena cava or the subclavian vein/superior vena cava into the coronary sinus (IVC-CS and SVC-CS). Right posterior and right posteroseptal pathways were almost always approached from the right femoral vein with a deflectable-tip catheter placed over the tricuspid valve (IVC-RA). Right lateral and right anterior pathways were approached either from the right femoral vein or from the left subclavian vein. For right anterior and right anteroseptal pathways, an attempt was made to approach the pathway from the superior vena cava and place the catheter

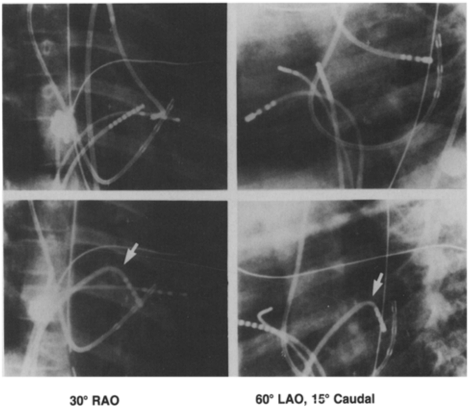


Figure 2. Transseptal approach. Top two cine frames show failed attempt to place the catheter retrograde through the mitral valve on top of the mitral anulus. The transseptal approach (bottom two frames) was successful with the catheter in a position very close to, but slightly different from, the retrograde mitral approach. Note hockey stick appearance of catheter tip (arrow) using the transseptal approach. The 7F Mullins sheath is not visible because of the 7F catheter size. A Jackman orthogonal catheter is in the coronary sinus, an octapolar catheter at the His bundle, a quadripolar catheter at the right ventricular apex. The deflectable ablation catheter has a large tip. Abbreviations as in Figure 1.

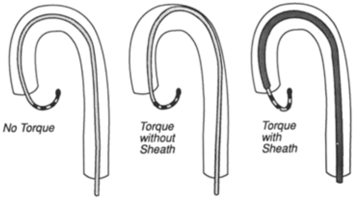
tip through the tricuspid valve orifice on the ventricular side of the tricuspid leaflet (SVC-RV), as previously described (1). These standard techniques were successful in ablating only 30 (36%) of 83 accessory pathways. Consequently, the following techniques were developed during either the same procedure or a second procedure in this patient group.

Transseptal approach. The area of the foramen ovale was first probed with the mapping-ablation catheter for patency. If it was not patent, a standard transseptal puncture was performed (11). The mapping-ablation catheter was then placed through the transseptal sheath into the left atrium. Generally the tip of the ablation catheter was maneuvered into the left ventricle and pulled back until the electrical recording suggested that the catheter was near the AV groove. Then the catheter tip was manipulated through both deflection and clockwise or counterclockwise rotation to map the left AV groove. In many cases, catheter stabilization for mapping and ablation was enhanced by deflecting the catheter and pulling it back in the sheath until only the four electrodes protruded, giving the appearance of a hockey stick (Fig. 2). Then the sheath and catheter could be moved along their long axis as a single unit from the septum to the lateral free wall and the catheter torqued either clockwise (posterior groove) or counterclockwise (anterior groove) within the sheath. Access to left lateral pathways in larger patients sometimes required exchange of the Mullins sheath for a stiffer straight Teflon sheath (Cordis). For septal or posteroseptal pathways, the ablation catheter was occasionally passed all the way through the mitral valve and deflected to try to approach the ventricular side of the AV groove from under the mitral valve.

Long arterial sheath. A 90-cm "Mullins-type" 8F sheath (Cook) was exchanged for the initial sheath and advanced over a wire and dilator to either the ascending aorta or the left ventricle. The dilator and wire were removed, and the 7F deflectable Mansfield catheter was advanced through the sheath into the left ventricle. The presence of the sheath provided both catheter stability and markedly improved torque transmission from the catheter handle to the tip of the catheter in the left ventricle (Fig. 3).

Left posterior parallel approach. For left posteroseptal to posterior lateral pathways that could not be approached with the standard deflection technique in which the tip of the ablation electrode is placed perpendicular to the plane of the mitral groove, a technique evolved to pass the deflectable electrode just under the posterior leaflet of the mitral valve

Figure 3. Diagrams illustrating how the presence of a sheath reduces torque loss in the aorta or other structures and transmits more of the torque to the tip (see text).



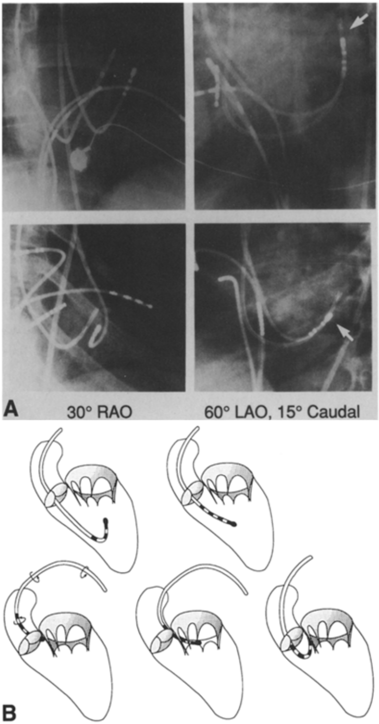


Figure 4. Left posterior parallel approach in two patients. **A,** Top two cine frames show the catheter tip advanced to a left lateral position (arrow); the bottom frames show a left posterolateral tip position. The catheter course near the tip is parallel to the coronary sinus catheter. The tip is at the point of successful ablation in both patients. Drawings (**B**) depict the method for performing the parallel approach (see text for details). Other catheter positions as in Figure 2. Abbreviations as in Figure 1.

and parallel to the mitral ring (Fig. 4). The technique can be performed with or without a long arterial sheath. The technique consists of prolapsing the deflectable-tip catheter through the aortic valve into the left ventricle. The catheter is then straightened and pulled back until the tip lies just under the aortic valve. The catheter tip is then deflected slightly and the handle rotated counterclockwise while observing the catheter tip in the left anterior oblique caudal projection. The tip of the catheter will be seen to rotate toward the posterior septum. When the tip is facing posterior and lateral, the catheter can then be advanced and maneuvered into the narrow space between the posterior mitral leaflet and the posterior wall of the left ventricle parallel to the length of the mitral ring. The tip can then be advanced laterally, in some cases to a far lateral position, but usually stopping posterior laterally. The catheter can be withdrawn slowly with a small amount of deflection to map and ablate the posterior and posterior lateral area. At that point, the tip can be deflected more and the catheter shaft advanced so that the tip lies more perpendicular to the valve, as previously described (1) and shown in Figure 5.

Retrograde transmitral approach. Occasionally, using the retrograde approach, the catheter tip can be manipulated through the mitral valve and made to rest on the mitral anulus on top of the valve. The catheter shaft could then be rotated clockwise or counterclockwise to move the tip along the mitral anulus (Fig. 2) for mapping and ablation. Mitral valve movement is likely to move the tip when it is not resting in one of the commissures.

Use of long sheaths for right free wall pathways. The atrial approach to right free wall pathways can often be improved by use of one of a variety of long sheaths, including 6F or 7F straight and multipurpose sheaths (Cordis) and 7F "Damato" and "right coronary" curved sheaths (Daig). For the ventricular approach to right free wall pathways, a deflectable tipped catheter can be advanced through a long vascular sheath into the right ventricle. The catheter is then deflected and the curve of the catheter advanced against the right ventricular free wall so that the catheter tip is pointed back toward the tricuspid valve. A soft, long sheath (USCI) can then be advanced over the catheter so that the sheath itself is turned and pointed back toward the tricuspid valve. At that point, clockwise and counterclockwise rotation of the catheter with a slight bit of deflection allows it to be directed in a wide range of locations posteriorly and laterally along the tricuspid valve.

It was also possible to use a coronary mapping wire (in 3 patients weighing >50 kg) or an arteriogram of the right coronary artery (n = 6) to help identify the location of the AV groove (12,13), as with the coronary sinus for the left AV groove.

Ablation. Radiofrequency energy at 500 kHz was applied by using a voltage-controlled generator (model RFG-3C, Radionics). It was delivered in a unipolar fashion from the catheter tip to a large skin reference electrode positioned either on the patient's lower back, buttocks or leg. During each radiofrequency application, voltage, power, current and impedance were continuously monitored. The duration of each application was also noted. For earlier procedures, only a filtered surface ECG was monitored during radiofrequency energy delivery. After the 24th procedure, appropriate filters were installed so that intracardiac electrograms could also be monitored during delivery (Fig. 6). Before we were able to monitor intracardiac electrograms, ablation was

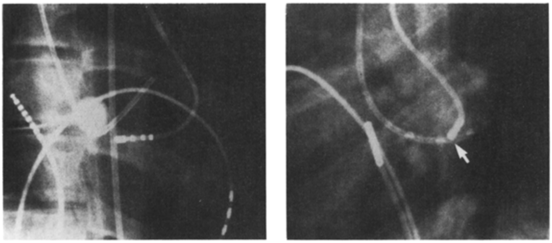


Figure 5. Angiograms in the right anterior oblique (**left panel**) and left anterior oblique (**right panel**) projections. Standard retrograde Ao-LV catheter approach to a posteroseptal pathway. The catheter tip (**arrow**) is perpendicular to the plane of the mitral anulus.

performed during either sinus rhythm or orthodromic reciprocating tachycardia. After intracardiac ECGs could be monitored, ablations were also performed with right ventricular pacing and observation of retrograde VA conduction during the ablation (Fig. 6). Radiofrequency lesion ablation was only attempted when an appropriate electrogram was recorded, and the catheter position was fluoroscopically stable. For most applications, the initial generator output was set at approximately 20 W (about 40 to 50 V, depending on impedance). Applications were made for 10 s unless the delta wave disappeared, tachycardia terminated or there was a noted change in VA conduction. If any of these three conditions was met, the radiofrequency application was continued for 40 to 60 s or until there was an increase in impedance. Often, the power was increased to 25 to 30 W (50 to 70 V) after the initial 20 to 30 s of application.

After a successful ablation, patients were observed in the electrophysiology laboratory for 30 min, when repeat electrophysiologic testing was performed. At the end of 30 min, an isoproterenol infusion was begun at 0.02 to 0.08 μg/kg per min and electrophysiologic testing was again repeated. If no residual accessory pathway function was noted, the catheters were removed.

Postablation evaluation and follow-up. Continuous ECG monitoring and a heparin infusion (15 to 25 U/kg per h) were maintained until the morning after the procedure. A chest X-ray film, ECG and echocardiogram were obtained within 6 h of the procedure in the first 20 subjects. After that, only

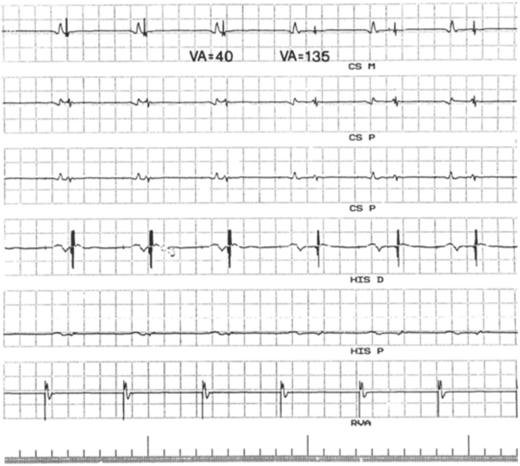


Figure 6. Catheter stability was assisted by performing ablation with right ventricular pacing (note the pacing spikes in the right ventricular apex (RVA) electrogram, **bottom tracing**). Note the abrupt change in the local ventriculoatrial (VA) interval from 40 ms to 135 ms in the coronary sinus and His bundle leads (HIS) as retrograde conduction changes from over the accessory pathway to over the atrioventricular (AV) node at the 6th s of radiofrequency energy application. Atrial activation at the proximal coronary sinus (CS P) preceded that in the distal His catheter even when retrograde conduction was completely through the AV node. Coronary sinus recordings are from an orthogonal catheter. The mid-coronary sinus (CS M) has relatively later timing after accessory pathway ablation. Electrograms are not disturbed by the presence of radiofrequency energy (20 W, not shown). Large timing marker (**bottom**) are 1 s. D = distal; P = proximal.

Table 1. Ablation Results by Pathway Location

	Pathways (% total)	Pathways Successfully Ablated (%)	Patients (%)	Patients With Successful Ablation (%)	Procedures
Left free wall	43 (52)	43 (100)	39	39 (100)	43
Posteroseptal	16 (19)	15 (94)	16	15 (94)	20
Anterior/midseptal	4 (5)	4 (100)	4	4 (100)	6
Right free wall	20 (24)	15 (75)	15	12 (75)	22
Total	83	77 (93)	71*	66 (93)	88

*Patient numbers add to 71 because one patient had left and right free wall pathways, one patient had one right posteroseptal and one right pathway, one patient had one right anterior septal and one left free wall pathway, and one patient had left posteroseptal and one left lateral pathway. Three of the four required multiple procedures.

the chest X-ray film and ECG were obtained. Sixty-five patients were observed for 18 to 24 h in the hospital, but 6 required longer observation periods (up to 7 days) because of treatment for minor vascular complications or other conditions such as structural congenital heart disease. The average stay was 1.2 days. An ECG was obtained in all patients before discharge. Outpatient follow-up visits generally occurred at 1, 6 and 12 months for physical examination, symptom review, ECG in all patients, and Holter monitoring where appropriate. Thirty-four patients also had either an esophageal (n = 19) or an intracardiac (n = 15) electrophysiologic procedure, or both, performed between 2 days and 4 months after the procedure. Esophageal electrophysiologic studies were performed for follow-up only when previous easy arrhythmia inducibility had been demonstrated with esophageal pacing before the ablation and there was a relative contraindication to an intracardiac procedure, such as patient age, size or preference. During intracardiac follow-up studies, coronary artery angiograms were obtained to demonstrate the coronary anatomy near the site of the ablation.

Statistical analysis. For data not normally distributed, values are reported by median and range. For normally distributed data, values are reported as mean value ± SD. Group comparisons are all made using Kruskal-Wallis rank order comparison for multiple groups with correlation for multiple comparisons where appropriate. A p value < 0.05 was considered significant.

Results

Of the 71 patients, 12 were found to have multiple pathways. Eleven of the 12 had two pathways, and one had three, giving a total of 83 pathways. Fifty-one of the 83 pathways (64%) had both anterograde and retrograde conduction, one had only anterograde conduction, 31 had only retrograde conduction (concealed) and 8 had the permanent form of junctional reciprocating tachycardia. Two of the patients with Ebstein's disease had multiple pathways, one with two and one with three pathways.

Of the 83 pathways in 71 patients, 77 (93%) were successfully ablated in a total of 66 patients (Table 1). Thus, 93% of patients were successfully cured of their arrhythmia. Results by pathway location are presented in Table 1. Left free wall was defined as a location >1 cm, or approximately 30° of the mitral valve anulus, into the coronary sinus. The 1-cm definition was used for patients of adult size and the 30°C definition was used for smaller patients. Right free wall was defined as >1 cm, or 30°, to the right of the His catheter location when viewed in the left anterior oblique caudal projection. Posteroseptal pathways were defined as being between the left and right free walls and >1 cm below the His catheter in the right anterior oblique projection. Anteroseptal or midseptal accounted for the remaining pathways.

Four of 43 patients with a left free wall pathway required two procedures (9%), all due to arrhythmia recurrence after the procedure. For right free wall pathways, 8 of 20 pathways and 6 (38%) of 16 patients required multiple procedures. All five of the currently unablated right free wall pathways are in three patients who each underwent two procedures. For posteroseptal pathways, six patients and pathways (38%) required two procedures. For anterior or midseptal pathways two patients and pathways (50%) required two procedures. Thus, in total, 16 (22%) of the 71 patients had two or more procedures, 11 because of arrhythmia recurrence and 5 for initial failure. Five of the 15 patients who had more than one procedure also had multiple pathways. One patient has undergone surgical ablation at the time of repair of tetralogy of Fallot, and four remain without pathway ablation.

Of 52 pathways with anterograde conduction, 45 (87%) were successfully ablated. This translated into successful ablation in 40 (89%) of 45 patients with manifest pathways (Wolff-Parkinson-White syndrome). Thirty of 30 concealed pathways (100%) in 30 (100%) of 30 patients were also successfully ablated.

Procedure characteristics. Total procedure time ranged from 1 to 11 h (median 4 h); total fluoroscopy time ranged from 11.9 to 259 min (median 74.3). Transition points between catheter insertion, diagnostic electrophysiology and mapping and ablation were not recorded consistently. Total procedure time, but not fluoroscopy time, decreased minimally but not significantly with the relative date of the

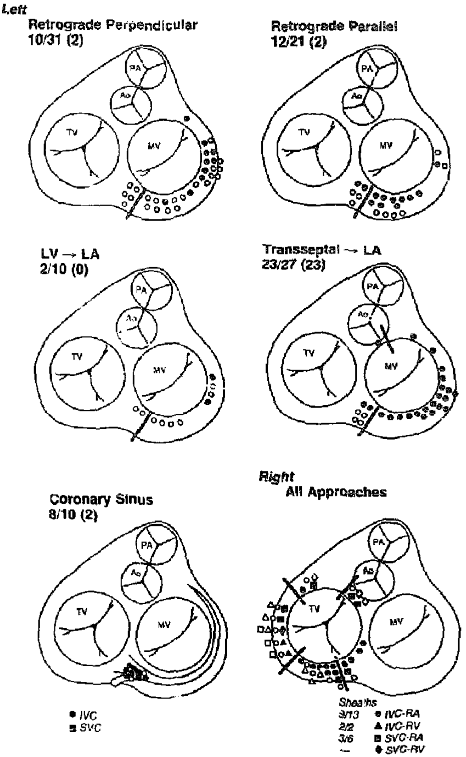


Figure 7. Successful (**closed markers**) and unsuccessful (**open markers**) ablation attempts using various approaches. **Dark lines** separate septal, posterior and anterior pathways from left and right free wall pathways. The **numbers** next to each title indicate *successful attempts* and the *total number* of attempts (see Table 2). The number of times a long vascular sheath was used in a successful attempt is in parentheses. Text and other figures describe various approaches. Ao = aorta. IVC-RA = inferior vena cava to atrial side tricuspid valve; IVC-RV = inferior vena cava to ventricular side tricuspid valve; LV→LA = retrograde from aorta to left ventricle to left atrium; MV = mitral valve; PA = pulmonary artery; SVC-RA = superior vena cava to atrial side tricuspid valve; SVC-RV = superior vena cava to ventricular side tricuspid valve; TV = tricuspid valve.

procedure. The number of radiofrequency applications ranged from 1 to 62 (median 9) with approximately 80% of the applications lasting ≤10 s. For the successful applications, 62 ± 12 (range 38 to 75) V was delivered into an impedance of 153 ± 25 (range 90 to 236) Ω for 43 ± 13 (range 10 to 63) s, yielding a power of 25 ± 6 (range 7.5 to 40) W and a current of 415 ± 120 (range 180 to 660) mA.

Approach by pathway location. Figure 7 details the number of times various approaches were used at each site and their success. The approaches are those detailed under Methods and shown in Figures 2, 4, 5 and 8. Table 2 summarizes the number of times that each approach was used, initially or as a second approach and in total, and the number of successes with that approach.

Left free wall pathways (Table 2A). The standard retrograde approach *perpendicular* to the mitral ring was used initially for 26 of 43 left free wall pathways but was successful in only 10 (39%) of 26 attempts. The technique was successful for only 2 of 10 attempts to ablate posterior pathways and 8 of 16 attempts to ablate left lateral to anterior pathways. The retrograde *parallel* approach to the mitral ring was not intentionally used until the 32nd procedure, but including retrospective analysis was successful in 10 (63%) of 16 attempts to ablate left free wall pathways (Fig. 7). The

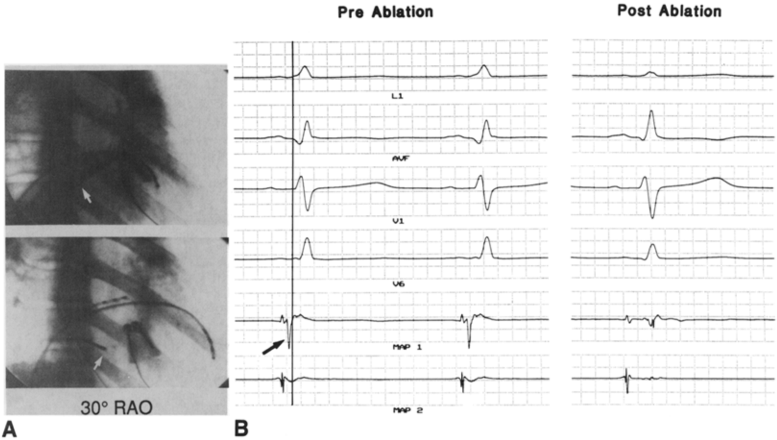


Figure 8. A, Injection of dye shows the coronary sinus and slight filling of a large proximal vein (arrow in A). The ablation catheter had been advanced all the way into the coronary sinus vein and was pulled back to the os of the vein where the accessory pathway potential (arrow in B) was recorded and the ablation was successful. Note that the accessory pathway potential precedes the surface QRS delta wave and is absent after (Post) ablation (B). Power application was begun at 4 W and increased to 10 W without an increase in impedance. L = lead; MAP = map; Pre = before.

parallel approach was frequently successful for left posterior (8 of 12 attempts) and posterolateral (1 of 1 attempts) pathways, but successful for only 1 of 3 attempts to ablate left lateral pathways. A retrograde approach through the aortic valve and then retrograde through the mitral valve was used to successfully ablate only two (25%) left lateral pathways in eight attempts (Fig. 7). Results were not improved

Table 2. Approaches Used and Their Success

A. Left Free Wall Approaches

	Standard Ao-LV	Parallel Ao-LV	LV-LA	Transseptal	MOCS/CS Vein
Approach 1	9/25	3/5	0	13/13	0
Approach 2	1/1	7/11	2/8	8/8	0
Total (%)	10/26 (39)	10/16 (63)	2/8 (25)	21/21 (100)	0

B. Left Posteroseptal Approaches

	Standard Ao-LV	Parallel Ao-LV	LV-LA	Transseptal	MOCS/CS Vein
Approach 1	0/4	0	0	0	5/7
Approach 2	0/1	2/5	0/2	2/6	3/3
Total (%)	0/5 (0)	2/5 (40)	0/2 (0)	2/6 (33)	8/10 (80)

C. Right Septal and Free Wall Approaches

	Posteroseptal and Midseptal (n = 5)	Posterior (n = 10)	Lateral (n = 8)	Anterior and Anteroseptal (n = 4)
IVC-RA	4/5 [1]	7/11 [3]	0/4 [3]	1/3 [1]
IVC-RV	—	0/3 [3]	2/4 [4]	—
SVC-RA	1/1 [0]	1/1 [1]	2/5 [2]	3/3 [1]
SVC-RV	—	—	1/2 [—]	0/3 [1]

Data are expressed as number of successful ablations/number of attempted ablations (% success) [number of sheaths used]. Ao-LV = retrograde from aorta to left ventricle; MOCS/CS = mouth of coronary sinus/coronary sinus vein; other abbreviations as in Figure 7.

Table 3. Procedure Characteristics by Approach

	Ao-LV (n = 20)	Transseptal (n = 13)	Ao-LV/Transseptal (n = 7)
Total procedure time (h)	3.3 (2.0 to 9.5)	4.3 (2.0 to 6.0)*	5.0 (3.0 to 6.5)†
Fluoroscopy time (min)	52 (18 to 259)	58 (14 to 197)	119 (86 to 194)*
Age (yr)	15 (8 to 25)	5 (0.1 to 13)*	16 (8 to 27)*
Weight (kg)	54 (28 to 72)	22.8 (3.2 to 100.3)*	66 (35 to 78)*

*Statistically different from the Ao-LV approach ($p < 0.05$). †Statistically different from transseptal approach ($p < 0.05$). Values are expressed as median value (range). Ao-LV = retrograde from aorta to left ventricle.

with a dumbbell-shaped tip (14). The transseptal approach was tried initially in 13 patients, primarily in those weighing <30 kg, until December 1991. The technique was uniformly successful for left anterior, lateral, posterolateral and posterior pathways (21 of 21 attempts). As an additional method of assessing the relative efficacy of the retrograde approach through the aortic valve to the transseptal approach, the data for 20 left-sided pathways that were approached only with the Ao-LV approach and were successfully ablated can be compared with that for 13 accessory pathways that were approached and successfully ablated transseptally and 7 accessory pathways that were initially approached retrograde through the aortic valve but, because this approach failed, were secondarily approached through the atrial septum. The medians and ranges of the procedure time, fluoroscopy time, weight and age of the patients in these three groups are shown in Table 3. Because of selection bias, the weights and ages of the patients in the transseptal group were significantly less than those in the other two groups ($p < 0.05$). The other two groups were not significantly different in that regard. The retrograde approach yielded significantly shorter total procedure and fluoroscopy times than the procedures in which both approaches were necessary ($p < 0.05$). In addition, the transseptal group had median fluoroscopy and total procedure times that fell between but were not significantly different from those of the other two groups. For all groups, procedure and fluoroscopy times varied widely and were not significantly related to each other. These data were not corrected for the small trend toward lower procedure and fluoroscopy times with date of catheterization. Thus, it seems that in our hands, when the retrograde aortic approach is successful, it yields on the average the shortest procedure times, but a much lower success rate than the transseptal approach.

Left posteroseptal pathways (Table 2B). As a group, the 12 left posteroseptal pathways were the most difficult to ablate. They often required more than one procedure and required the most number of approaches. Figure 7 and Table 2B detail the approaches used and their success for left posteroseptal pathways. The retrograde perpendicular and retrograde transmitral approaches were never successful, whereas the retrograde parallel and transseptal approaches were occasionally successful (Table 2B, Fig. 7). As reported by Jackman et al. (1) and Lesh et al. (15), eight left posteroseptal pathways could be ablated only within the os or a vein of the coronary sinus (Fig. 7). When the catheter was lodged in a vein off the coronary sinus, the impedance was generally higher (up to 236 Ω), and power was set initially at low levels of 3 to 10 W. Large accessory pathway potentials were often found near the os of a coronary sinus vein or within the coronary sinus (Fig. 8). Application of low power radiofrequency energy in these areas never resulted in disruption of the vein wall, a significant increase in impedance or pericardial effusion secondary to an inflammatory reaction.

Right free wall and septal pathways (Table 2C). For right-sided pathways, successful approaches are best evaluated by classifying the right-sided pathways into posteroseptal and midseptal, posterior, lateral and anterior-anteroseptal. Table 2C and Figure 7 detail the relative success of approaches from the inferior or superior vena cava to the right atrial or right ventricular side of the tricuspid valve for each of these areas. Table 2C also includes the number of times that a long vascular sheath was used to facilitate successful ablation. In general, right posteroseptal and midseptal pathways could be ablated without a sheath from the inferior vena cava approach. Right posterior pathways were also ablated most commonly from the inferior vena cava approach, but the use of a long vascular sheath was more frequently required. For both posteroseptal and posterior pathways, an approach from the superior vena cava could be used with success; however, this approach was only rarely attempted. Right lateral pathways were the most difficult to ablate, and three of these pathways remain unablated. For the five with successful ablation, only one was ablated using a standard approach from the inferior or superior vena cava (Table 2C). Right anterior and anteroseptal pathways were generally best ablated from the superior vena cava.

Sheaths. Long vascular sheaths were either helpful or necessary in the procedures for 33 (43%) of the 77 successfully ablated pathways. Although only rarely useful for the retrograde approach to the left ventricle (4 [8%] of 52), a long sheath of either a Mullins variety or a straight, stiff sheath was used in 20 transseptal procedures. On three occasions, a patent foramen ovale was initially used without the presence of a sheath, but inadequate catheter stability required the insertion of a long sheath across the septum. On one of these occasions, a transseptal puncture had to be performed at a position in the septum lower than that of the foramen ovale to achieve an effective entrance angle into the left atrium. By our qualitative estimation, sheaths contributed directly to success in two inferior vena cava approaches to the coronary sinus, five inferior vena cava approaches to the atrial side of the tricuspid valve and three superior vena cava approaches to the atrial side of the tricuspid valve. Sheaths were believed to be critical in all approaches to the ventricular side of the right ventricle from the inferior vena cava and were used in all three successful procedures using that approach (Table 2C).

Complications. Eight patients had complications as a result of their ablation procedure. Two patients had complications that resulted directly from application of radiofrequency energy to the myocardium. One, who was the 13th patients in this series, had complete heart block during successful ablation of a midseptal accessory pathway. The heart block occurred at 4 s into the radiofrequency application. It was preceded by a brief episode of junctional acceleration. It was initially transient, lasting 15 to 30 min, returning to second degree block and eventually to 1:1 sinus rhythm for 4 to 6 h; however, high grade second degree block with only occasional conducted beats returned and was still present 2 weeks after the procedure when a dual-chamber (DDD) transvenous pacemaker was implanted.

One 3.2 kg, 5-week old infant with the Wolff-Parkinson-White syndrome died. The patient was found to have two accessory pathways, one posteroseptal and one left lateral, both of which were successfully ablated. The only immediate complication, transient venous stasis in the right leg, resolved after 72 h of heparin therapy. Because of a history of transient successes during the ablation procedure, the patient was discharged on a regimen of propranolol (1 mg/kg daily) 4 days after the procedure. Two weeks after the procedure, the patient had a cardiorespiratory arrest. Although he was eventually resuscitated and found to have no evidence of pre-excitation, extensive brain ischemia led to death within a few hours of hospital admission. Autopsy revealed a normally patent left circumflex artery, small punctate lesions within the coronary sinus and along the left AV groove where brief radiofrequency applications had been made, and a small tear in the posterior leaflet of the mitral valve, with a 2 × 5-mm ablation lesion in the left ventricular wall just under the mitral valve tear. The left ventricular papillary muscle structure was abnormal, with five papillary muscles. The cause of death is not clear but was probably associated with a ventricular arrhythmia. This patient is described in detail in a report pending publication.

Six patients had complications not directly attributable to application of radiofrequency energy to the myocardium. Two early patients had second-degree skin burns at the reference electrode site. At that time, an R2 pad (R2 Medical Systems) was used as a ground on the lower back. Because inadequate skin contact was believed to be the source of the burns, a standard electrosurgical pad (3M Medical Surgical Division) was used on the buttocks or left leg for all subsequent procedures. No further skin burns have been noted. Two patients had transient right brachial plexus injuries due to hyperextension of the right arm during general anesthesia and a long procedure. These patients were also treated earlier in our experience. Since then, we have kept both the right and the left arm at the patient's side and no further injuries have been noted. One patient had transient foot drop believed to be due to neural injury at the heel. This complication has not been seen with the addition of egg-crate padding to both heels. Finally, one patient with rheumatic aortic valve disease had a transient increase in the degree of aortic regurgitation after a long vascular sheath had been used retrograde for the Ao-LV approach. No other complications were associated with the use of a long vascular sheath. Also, no pericardial effusions were noted by echocardiogram, physical examination or chest X-ray film.

Follow-up. Follow-up has ranged from 1 to 23 months (median 7). Forty-two patients have undergone either esophageal electrophysiologic study (n = 19), intracardiac electrophysiologic study (n = 15), or Holter monitoring (permanent junctional reciprocating tachycardia; n = 8), demonstrating absence of either accessory pathway conduction, arrhythmia inducibility or previous incessant arrhythmia. The remainder have been evaluated by ECG and symptom review. In 14 patients who underwent selective coronary angiograms, findings were normal on all angiograms.

Discussion

The primary result of this study is the observation that with a wide variety of catheter manipulation techniques, successful ablation of accessory AV pathways in young patients can be performed in all areas of the AV groove. While novel catheter delivery methods may be imperative in the pediatric age group because of the limitation of patient size, such techniques also expand the available methods and may increase success rates in adults as well. Despite development of these techniques in our laboratory and elsewhere, total procedure times, fluoroscopy times and subjective difficulty have decreased only slowly and continue to have a relatively wide variance.

Total procedure duration in our hands was comparable to or less than that reported by other investigators (1,2). However, Kuck and Schluter (8) recently reported a series of ablations in a primarily adult study group with left free wall accessory pathways in which the overall procedure duration was decreased to 2 ± 1.1 h and fluoroscopy time to 22.8 ± 20.4 min (median 17.3). Of their 150 patients, 69 (46%) had evidence of a manifest left free wall accessory pathway by surface ECG. Their selection criteria included adequate pre-excitation to accurately diagnose a left free wall position, making 49 (33%) of their original 150 patients eligible for the single-catheter technique. Applying the same criteria to our patient group, 18 (26%) of our 68 patients had a suggestion of a left lateral pathway by surface ECG, but because of minimal pre-excitation (n = 2), small patient size (<10 kg, n = 2), or multiple pathways (n = 3), only 11 (16%) of 68 of our patients would have been good candidates for such a procedure. In fact, when the procedure was attempted, only ≈30% of our left free wall pathways could be ablated with the standard retrograde ventricular approach. Considering the age and size of our patients and the distribution of their accessory pathways, the single-catheter technique in our hands appeared to be inadequate for general use.

Left free wall pathways. For left free wall pathways, the transseptal approach seems to be the most consistently successful. Although on average, the transseptal approach requires more time than a successful retrograde approach, it requires less time than a combined approach procedure. The transseptal approach was not associated with any complications. Specifically, there were no atrial wall punctures, no aortic root punctures and no air embolism through sheaths in the left atrium. In addition, only one recurrence was noted with this approach, and the pathway was reablated successfully using the transseptal approach. In general, the patients who underwent the transseptal approach as the initial procedure were younger and smaller because of an institutional bias that patients <30 kg were at risk for arterial injury by having a 7F sheath reside for long periods in the femoral artery. On the basis of these findings, a case can be made for initially attempting a retrograde ventricular approach using the perpendicular, parallel or transmitral catheter positioning techniques in all larger patients, but perhaps limiting the attempts to an arbitrary fluoroscopy time of ≈15 to 30 min. If the procedure is unsuccessful, or if the patient is smaller, a transseptal approach should be strongly considered for left free wall pathways in all locations.

Left posteroseptal pathways. Performance of ablation of left posteroseptal pathways ranged from very easy, with a procedure time of 1 h (fluoroscopy time 27.6 min) in one patient with permanent junctional reciprocating tachycardia, to a combined time from two procedures of 17 h in one patient with a concealed pathway. Multiple approaches were necessary in 7 of the 14 patients (Fig. 7). The retrograde perpendicular approach was never successful, and the retrograde parallel and transseptal approaches were only occasionally successful. Although new catheter designs might slightly improve the ability to use these approaches, we found that eight left posteroseptal pathways were successfully ablated either within the os of the coronary sinus or within a coronary sinus vein. Of these, six were associated with extremely large accessory pathway potentials (Fig. 8). This phenomenon of successful ablation within a coronary vein has been previously reported but has been associated with the complication of venous wall rupture and acute pericardial effusion (1). To avoid that complication, we noted that the impedance within these veins was quite high, suggesting a large amount of catheter tip–surface area contact (16). Consequently, low power settings were used beginning at between 3 and 10 W and progressing to the very beginning of increase in impedance or until 15 or 20 W was reached. With this technique, no significant increases in impedance causing tissue charring were noted, and there were no pericardial complications. Ablation of pathways in this area accounted for 10% of our total accessory pathways. Entrance into the coronary sinus veins often required an angiogram of the coronary sinus taken through a long vascular sheath. From these findings, one might speculate that epicardial ventricular connections along the coronary veins in this area occur more frequently than previously recognized and may be important in future procedures (15). Thus, it seems prudent to probe the coronary sinus and its proximal veins early in the course of attempted ablation of left posteroseptal pathways, particularly if a retrograde parallel approach has been unsuccessful.

Right posteroseptal and midseptal pathways. Only four accessory pathways were classified as right posteroseptal (posteroseptal and outside the coronary sinus os). Three of these occurred in patients with Ebstein's disease of the tricuspid valve. Although our single case of heart block did occur early in our experience with an inferior vena cava approach to the atrial side of a midseptal pathway, in general the inferior vena cava–right atrial–approach without a sheath appears adequate for these posteroseptal and midseptal pathways.

Right free wall and anteroseptal pathways. Overall, ablation attempts in this group of pathways were the least successful, and required multiple procedures as well as a variety of approaches. Similar findings have been reported for both right-sided and septal pathways (17). Figure 7 and Table 2C summarize the results from various approaches. It seemed that with one rare exception, a standard right atrial approach from the inferior vena cava was successful and adequate only for posterior right free wall pathways. Attempts to manipulate the catheter tip to the ventricular side of the tricuspid valve were successful only for right lateral pathways and required the use of a long, soft vascular sheath. In agreement with one previous report (18), anterolateral, anterior and anteroseptal pathways could be successfully ablated by using a superior vena cava approach with the catheter tip placed on the atrial side of the tricuspid valve. Subjectively, catheter stability was believed to be the major problem with all attempts at ablation of right-sided pathways from the atrial side of the tricuspid valve. Potentially, both accurate electrophysiologic and anatomic identification of the right AV groove may have been facilitated by placement of a recording wire within the right coronary artery (12,13). Our limited experience with this technique in three larger patients has been promising, but prolonged placement of such a wire in smaller coronary arteries is of unknown risk.

Long vascular sheaths. Catheter stability, torque transmission, coaxial steering and catheter repositioning after an increase in impedance may all be significantly enhanced through the use of long vascular sheaths (Fig. 3 and 9). Although their precise value is difficult to quantify, sheaths were found to be either very helpful or necessary in most transseptal procedures, all right ventricular approaches to right lateral pathways and, occasionally for both the retrograde approach to left-sided pathways and the anterograde

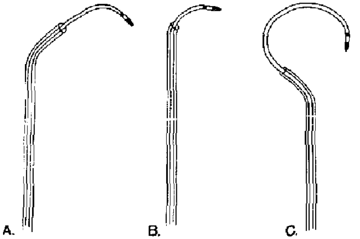


Figure 9. Diagrams showing examples of how long sheaths allow for coaxial steering.

approach to right-sided pathways. The high recurrence rate for right free wall pathways, despite initial success, suggests that enhanced catheter stability and torque transmission provided by appropriately designed long sheaths might improve right-sided results. Use of long vascular sheaths in multiple configurations for enhancement of catheter ablation procedures has not been previously reported.

Radiofrequency ablation in pediatric patients. Of our 71 patients, 56 were <18 years old. The results in these patients were similar to those of the group as a whole and similar to those previously reported (12,19). Although a controlled study was not performed comparing a retrograde left ventricular approach with a transseptal approach for left-sided pathways in small patients, the known complications of an indwelling 7F sheath in a small femoral artery, combined with the increased likelihood of ventricular puncture with a deflectable ablation catheter, led us to electively perform transseptal procedures in small patients (9). These procedures were without complications, resulted in uniform success and added only a small to moderate amount of total procedure and fluoroscopy time. Of note, one severe complication of late probable arrhythmic death was seen in a 5-week old, 3.2-kg former premature baby. This infant had been unsuccessfully treated with trials of six pharmacologic regimens, including amiodarone, and was in nearly incessant supraventricular tachycardia with decreased left ventricular function. Although the autopsy revealed that some damage had been done to both the mitral valve and the left ventricle, death was not obviously related to catheter manipulation. Initial attempts at ablation with a specially constructed 5F catheter with a 2-mm tip (Mansfield Webster) were unsuccessful, and a 6F deflectable-tip catheter with a 4-mm long tip was eventually used. It is our impression that improved catheter design with smaller variably deflecting catheters may provide the option of smaller lesion size in very young patients.

Conclusions. The findings reported here in our mixed group of pediatric and adult patients, combined with those previously reported by others, suggest that 1) left lateral pathways in larger patients may be approached initially by using a catheter directed retrograde through the aortic valve, 2) left posterior pathways can be approached most quickly with the retrograde technique attempting to deflect the catheter tip parallel to the mitral ring, 3) a transseptal approach to the mitral ring is useful for left free wall pathways in all locations and should probably be the initial procedure in smaller patients, 4) ablation of left posteroseptal pathways is facilitated by a coronary sinus angiogram followed by careful probing of the floor of the coronary sinus and any large veins that insert near the os, and 5) lack of predictability of success with any single approach suggests that time spent on each approach should be limited to 30 to 45 min (15- to 30-min fluoroscopy time).

For right-sided pathways, our data suggest that 1) midseptal, posteroseptal and posterior pathways can be approached initially from the inferior vena cava to the atrial side of the tricuspid valve; 2) anterior and anteroseptal pathways can be approached initially from the superior vena cava; and 3) lateral pathways may require an approach from the ventricular side of the tricuspid valve by using a soft long sheath. In addition, our data suggest that long vascular sheaths facilitate successful ablation in all areas but specifically 1) for transseptal approaches where a sheath should be considered even in the presence of a patent foramen ovale, and 2) for right free wall pathways in all locations. Future developments for ablation of right free wall pathways might include stiffer deflectable sheaths to improve catheter steerability and stabilization.

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