Radiofrequency Endocardial Catheter Ablation of Accessory Atrioventricular Pathway Atrial Insertion Sites

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Background. High rates of success using radiofrequency ablation energy have rapidly transformed catheter ablation from an investigational procedure to the nonpharmacological therapy of choice for symptomatic Wolff-Parkinson-White syndrome. Prior studies of radiofrequency accessory pathway ablation were based on a ventricular approach. Risks associated with prolonged arterial catheter manipulation, retrograde left ventricular catheterization, and production of ventricular lesions required for successful ventricular insertion ablation can be avoided using atrial insertion ablation procedures. The purpose of the present study was to define the safety and efficacy of accessory pathway ablation using radiofrequency energy delivered solely to accessory atrioventricular pathway atrial insertion sites.

Methods and Results. One hundred fourteen patients with accessory pathway-mediated tachycardia underwent attempted radiofrequency current ablation at the accessory pathway atrial insertion site. All catheters were introduced transvenously. Left-sided accessory pathways were approached using transseptal left atrial catheterization techniques. Retrograde localization of the atrial insertion site during reentrant tachycardia was characterized by 40±15-msec local ventriculoatrial and 79±17-msec surface QRS to local atrial electrogram intervals. Presumed accessory pathway potentials were present in only 30% of ablation site electrograms. Successful ablation required 6.2±5.3 radiofrequency energy applications. Cumulative energy dose required for success was 2,341±2,233 J. There were no complications associated with transseptal catheterization. Energy delivery to accessory pathway atrial insertion sites was associated with non-life-threatening complications in two patients. Recurrent conduction requiring repeat ablation occurred in 10 of 115 (9%) successfully ablated accessory pathways, all within 1 month of the ablation procedure. After 21.2±4.6 months of follow-up, 108 of 114 (95%) patients are asymptomatic and without evidence of accessory pathway conduction.

Conclusions. The atrial insertion approach to accessory pathway ablation is safe and highly effective. This approach compares favorably with the retrograde ventricular insertion ablation technique. Atrial insertion ablation eliminates the need to produce ventricular lesions and avoids the risks of prolonged arterial catheter manipulation and retrograde left ventricular catheterization. (Circulation 1993;87:487-499)

KEY WORDS • Wolff-Parkinson-White syndrome • catheters • accessory pathways

Closed-chest catheter ablation of anomalous atrioventricular connections has been attempted using a variety of methods since initially reported in 1983.1 Initial use of direct current ablative energy resulted in variable success rates and high rates of procedural complications, particularly when used within the coronary sinus.2-6 The advent of steerable large surface area electrode catheters, allowing accurate and effective myocardial delivery of radiofrequency energy, has markedly enhanced the safety of closed-chest catheter ablation techniques. Several investigators have recently reported large clinical series of accessory atrioventricular pathway ventricular insertion radiofrequency ablation.7-10 High rates of success using ventricular insertion ablation have rapidly transformed catheter ablation from an investigational procedure to the nonpharmacological therapy of choice for symptomatic Wolff-Parkinson-White syndrome.

Although short-term success is very well documented, long-term arrhythmogenic effect of the often multiple radiofrequency ventricular lesions created during accessory pathway ablation remains undefined. The potential of arrhythmogenesis led us to consider accessory atrioventricular pathway ablation from an atrial approach. Atrial insertion ablation procedures also avoid the inherent risks of prolonged arterial catheter manipulation and retrograde left ventricular catheterization required for ventricular insertion ablation procedures directed at left-sided accessory pathways. Finally, the atrial aspect of both tricuspid and mitral annuli is a relatively smooth, nonobstructed surface that simplifies catheter movement, thereby permitting rapid and accu-
rate accessory pathway localization. The purpose of this study, therefore, was to evaluate the efficacy and safety of radiofrequency catheter ablation techniques developed to eliminate accessory atrioventricular pathway conduction by direction of ablative energy solely to endocardial atrial insertion sites.

Methods

Patient Population

The study population comprised 114 patients (31 female and 83 male; mean age, 31.0±12.9 years), which represents the initial 1-year experience at each of the supporting hospitals. One hundred eleven patients experienced symptomatic orthodromic atrioventricular tachycardia, and 23 had spontaneous atrial fibrillation (21 of the 23 also experienced recurrent atrioventricular tachycardia). Thirty-three patients experienced one or more syncopal episodes, and four survived aborted sudden cardiac death due to rapidly conducting atrial fibrillation–induced ventricular fibrillation. Subjects had undergone 2.5±1.5 (range, zero to seven) unsuccessful medical therapy regimens before referral for ablation. Two patients in this series were asymptomatic at the time of presentation. They were referred for electrophysiological evaluation of Wolff-Parkinson-White syndrome due to their potentially hazardous active duty military career fields. They underwent ablation after documentation of sustained orthodromic atrioventricular reentrant tachycardia and theoretically lethal accessory pathway physiology at baseline electrophysiology study. Twelve of the 114 patients had undergone unsuccessful accessory pathway ablation attempts at other institutions (four surgical, seven radiofrequency catheter ventricular insertion, and two direct current catheter). Two of the patients previously underwent two unsuccessful surgical ablation attempts. One patient underwent four unsuccessful ventricular insertion catheter ablation attempts (two direct current and two radiofrequency), the last of which was complicated by pericardial tamponade.

Preablation Evaluation

Patients referred for accessory pathway ablation underwent preprocedure evaluation including routine physical examination, 12-lead ECG, echocardiographic examination with Doppler assessment for mitral or tricuspid insufficiency, signal-averaged ECG, and maximal Bruce protocol exercise stress testing. After providing written informed consent, patients were brought to the cardiac catheterization laboratory in a postabsorptive, mildly sedated state. Percutaneous venous access was established via right and left femoral and left subclavian veins. A modified Seldinger technique was also used for right femoral arterial access for the purpose of continuous blood pressure monitoring. Standard 6F quadrupolar catheters were advanced to high right atrial, His bundle, and right ventricular apex positions. A 7F 5-mm spaced decapolar catheter with lumen (Mansfield-Webster, Boston Scientific Corporation, Watertown, Mass.) was placed in the coronary sinus. Electrophysiological testing was performed to characterize functional properties of the accessory pathways. This included standard atrial and ventricular single extrastimulus techniques, atrial and ventricular ramp pacing, coupled atrial extrastimulus, and induction of atrial fibrillation, when possible. Electrophysiological evaluation was followed by angiographic assessment of coronary artery anatomy in the first 70 patients using small amounts of hand-injected contrast in a variety of standard and hemiaxial views. Accessory pathway ablation protocol utilized in this series of patients was independently approved by the institutional review boards at the Veterans Administration Medical Center and Georgetown University Hospital.

Accessory Pathway Localization

Initial regional localization of accessory pathways was achieved by analysis of delta wave vector on surface 12-lead ECG and area of earliest retrograde atrial activation with ventricular pacing or orthodromic atrioventricular reentrant tachycardia induced during electrophysiological evaluation. More accurate epicardial identification of the atrial insertion site was done with either coronary sinus mapping for left-sided tracts or with right coronary artery mapping in selected right-sided accessory pathways. Coronary artery mapping was reserved for only right free wall accessory pathways, which could not be adequately mapped from the endocardial aspect of the tricuspid annulus. Septal accessory pathway localization was accomplished using endocardial mapping alone.

Endocardial localization of accessory pathway atrial insertion was accomplished using a transseptal approach for all left-sided tracts, as illustrated in Figure 1. A modified Brockenbrough method was used for transseptal catheterization in patients without a patent foramen ovale. Briefly, anteroposterior positioning of the transseptal catheter on the right atrial aspect of the interatrial septum was established fluoroscopically in a 30° right anterior oblique projection and guided by use of the coronary sinus catheter as a posterior puncture limit and a 6F straight pigtail catheter introduced to the aortic valve as the anterior puncture limit. Septal puncture was accomplished under continuous fluoroscopic observation using a 10–30° left anterior oblique view. In this view, the pigtail catheter advanced to the aortic valve noncoronary cusp level defined the most superior point of safe transseptal puncture. The adult, 59-cm, 8F transseptal sheath system (USCI Angiographic Systems Division, C.R. Bard Inc., Billerica, Mass.) was modified before transseptal catheterization. Extent of sheath modification required for each case was deduced from the relative anteroposterior position of the targeted accessory pathway as determined during the epicardial localization. The transseptal sheath curve was almost entirely removed for anterior or left fibrous trigone accessory pathway positions. Less of the curve was removed as accessory pathway position progressed posteriorly from left anterior to left free wall, left posterior, and left posterior paraseptal locations. After transseptal puncture, the pigtail catheter was removed, and patients were anticoagulated using a 5,000-unit bolus of heparin followed by additional 2,000-unit doses every hour, if necessary, for the duration of the procedure. Use of a modified 59-cm sheath for stabilization and catheter backing often aided mapping and ablation of right-sided accessory pathways as well.

Endocardial mapping was accomplished using a steerable 7F 3–4-mm tip electrode catheter with 2-mm
Fluoroscopic localization/ablation of the mitral annulus from anterior to posterior. HBE, His bundle; HRA, high right atrium; RVA, right ventricular apex.

Electrode spacing (Mansfield-Webster, Boston Scientific Corporation). Bipolar (30–500-Hz bandpass filter) and distal electrode unipolar (0.01–500-Hz bandpass filter) electrograms were continuously recorded from the localization/ablation catheter. A sinus rhythm bipolar atrioventricular electrogram amplitude ratio ≥1 and unipolar PR segment displacement without ST segment displacement were used to identify the atrial aspect of the atrioventricular groove. Accessory pathway atrial insertion localization involved both anterograde and retrograde local conduction interval evaluation. Shortest surface QRS onset to local atrial activation time and local ventriculoatrial time during orthodromic atrioventricular reentrant tachycardia or right ventricular pacing were used as the primary method of retrograde atrial insertion identification. Anterograde conduction evaluation, including local atrioventricular conduction time and local ventricular electrogram to delta wave onset interval, was performed when possible.

After atrial insertion localization and characterization, endocardial ablation catheter contact and stability were assessed. Demonstration of PR segment displacement from baseline as recorded on the distal unipolar electrogram confirmed atrial tissue contact. Catheter stability was inferred from consistent atrial and ventricular bipolar electrogram amplitudes and ratios. Fluoroscopic demonstration of concordant coronary sinus catheter (left sided) or coronary artery (right sided) motion with the endocardial ablating catheter tip was also used to gauge stability.

Ablation Procedure

Radiofrequency ablating energy used in this patient series was unmodulated 500-KHz alternating current derived from a standard electro surgical unit (System 5000, C.R. Bard Inc.). Energy was delivered in a monopolar fashion between the ablation catheter tip electrode and a large surface area (114 cm²) skin electrode (R2 Cath-Pads, Darox Corp., Niles, Ill.). Energy delivery protocol used during this study varied as experience developed. For the initial 30 cases, all radiofrequency applications were 25 W delivered for 30 seconds, regardless of effect. Energy delivery was interrupted before 30 seconds only if stable catheter position was lost or if impedance rise occurred. This protocol was modified to permit cessation of energy delivery after 10 seconds if no accessory pathway effect was observed or after 20 seconds if accessory pathway block was noted within 5 seconds of energy application. Ablation catheter position was fluoroscopically monitored throughout each energy application to ensure stable catheter position and appropriate delivery of energy to the targeted tissue. When necessary, repeat mapping and ablation attempts were pursued until accessory pathway block was achieved. Patients were observed for recurrent accessory pathway function in
the catheterization laboratory for 1 hour after successful ablation. During this period, repeat selective coronary angiography and electrophysiological evaluation were performed. Immediate postablation electrophysiological evaluation included a full anterograde and retrograde study at baseline and during an isoproterenol infusion sufficient to increase resting heart rate at least 20%.

Definitions

Ablation procedure duration was recorded from the start of local anesthetic injection for vascular access sheath placement to the removal of all sheaths. Procedure duration includes time required for vascular access, catheter placement, diagnostic electrophysiological evaluation, selective coronary angiography, atrial insertion mapping, ablation, and a 1-hour period of observation for accessory pathway recovery after successful ablation. Fluoroscopy time is reported for the total procedure, including diagnostic catheter positioning, selective coronary angiography, transseptal catheterization, accessory pathway localization, and ablation. All radiofrequency energy applications are counted and reported for each case regardless of power or duration. Total ablation energy refers to only the energy applied at the site of successful accessory pathway ablation. Cumulative radiofrequency energy values include the total energy application to all ablation sites for the procedure.

Follow-up Evaluation

All patients were continuously monitored on a telemetry ward for 2 days after the ablation procedure. Patients were not anticoagulated after the accessory pathway ablation procedure. Serial 12-lead ECG and creatine phosphokinase-MB fraction evaluation was performed every 6 hours for the initial 24 hours after ablation. Repeat echocardiographic, signal-averaged ECG, and maximal exercise stress evaluation was performed before discharge on the second postablation hospital day.

Routine outpatient follow-up using serial 12-lead ECGs was supplemented with repeated formal electrophysiological and angiographic evaluation 4–6 weeks after ablation when possible. Patients were then seen as outpatients every 3 months for the first year after ablation and yearly thereafter.

Statistical Analysis

Data are reported as mean±1 SD. The median value for number of radiofrequency applications per case is also reported due to an extremely asymmetric distribution of the data. Comparisons were analyzed for statistically significant differences using a two-tailed Student’s t test for nonpaired data. χ² Analysis was used for analysis of proportional data. Differences in data populations were considered statistically significant at a value of p<0.05.

Results

Accessory Pathway Physiology

One hundred twenty-two accessory pathways were identified in the 114 patients. Pathways were left free wall in 76, posteroseptal in 13, right free wall in 12, midseptal in 11, and anteroseptal in 10. Seven patients had two accessory pathways, and one patient had three accessory atrioventricular connections. Twenty-four accessory pathways were concealed (22 left free wall, one midseptal, and one right free wall), and one left free wall tract conducted anterograde only. Anterograde accessory pathway refractory period was 289±46 msec and maximal 1:1 atrioventricular conduction occurred at 311±66 msec. Sustained atrial fibrillation was inducible in 51 patients and resulted in a mean shortest preexcited RR of 204±39 msec. Ventricular fibrillation occurred in two patients during episodes of induced atrial fibrillation; one of these patients was a prior sudden death survivor. Retrograde conduction characteristics of accessory pathways included an effective refractory period of 289±41 msec and maximal 1:1 conduction at 292±51 msec. Orthodromic atrioventricular reentrant tachycardia was inducible in 112 patients and had a mean cycle length of 324±39 msec.

Accessory Pathway Localization

Accessory pathway atrial insertion was characterized by a local ventriculointerstitial interval of 40±15 msec during orthodromic atrioventricular reentrant tachycardia and 38±16 msec during ventricular pacing. Retrograde accessory pathway atrial insertion mapping was performed during orthodromic atrioventricular tachycardia in 55 patients and during right ventricular pacing in 68 patients. Surface QRS onset to local atrial electrogram interval during orthodromic atrioventricular reentrant tachycardia was 79±17 msec, and right ventricular pacing stimulus to local atrial electrogram interval was 141±27 msec at the atrial insertion site. Anterograde mapping at the accessory pathway atrial insertion site in 39 patients revealed a local ventricular electrogram to delta wave onset interval of 18±13 msec and a local atrioventricular interval of 38±10 msec (p=NS compared with local ventriculointerstitial interval). Although not specifically sought, atrial insertion electrograms containing possible accessory pathway potentials were noted in only 30% of cases. However, pacing protocols were not performed to validate the origin of presumed accessory pathway recordings. Accessory pathway atrial insertion sites had an atrial electrogram–to–ventricular electrogram amplitude ratio of 1.1±0.8 during orthodromic atrioventricular reentrant tachycardia and 2.3±2.2 in sinus rhythm. Atrial electrogram stability, defined by the ratio of lowest amplitude to largest amplitude electrogram through a full respiratory cycle, was 0.8±0.2. PR segment deviation of 0.45±0.29 mV was recorded at the ablative atrial insertion sites. No ST segment deviation was present at these sites.

A characteristic orthodromic atrioventricular reentrant tachycardia electrogram sequence obtained from a left free wall accessory pathway atrial insertion site is shown in Figure 2. Forty-five-degree left anterior oblique (Figure 3A) and 30° right anterior oblique (Figure 3B) views of the catheter positions used to record the Figure 2 electrograms are shown in Figure 3. Endocardial retrograde atrial activation preceded epicardial (coronary sinus) atrial activation in all except one left free wall accessory pathway patient. Endocardial activation occurred 9.8±1.4 msec before earliest epicardial activation.

Typical features of a retrograde right free wall accessory pathway electrogram sequence obtained during
orthodromic atrioventricular reentrant tachycardia are shown in Figure 4. Figures 5A and 5B demonstrate the catheter positions associated with the electrogram sequence in Figure 4. A 30° right anterior oblique projection is shown in Figure 5A, and a 45° left anterior oblique view is shown in Figure 5B. Four of the 12 right free wall accessory pathways could not be adequately localized using a standard endocardial tricuspid ring map alone. Right coronary artery mapping successfully localized accessory pathway insertion site in three of the four patients, permitting successful ablation. In the fourth patient, a ventriculoatrial conduction time of 20 msec was recorded across a large extent of the tricuspid annulus without a discrete atrial insertion site location. Ablation in this patient was not successful.

Figure 6 illustrates the sinus rhythm electrogram characteristics of a midseptal accessory pathway. Septal accessory pathways were localized and ablated using a femoral venous approach as demonstrated in the 30° right anterior oblique (Figure 7A) and 45° left anterior oblique views (Figure 7B). The atrial insertion site of posteroseptal accessory pathways was localized within the right atrial portion of the coronary sinus os. Midseptal accessory atrioventricular connections were defined by an insertion site between the coronary sinus os and compact atrioventricular node, usually within 5 mm of the proximal His bundle recording site. Anteroseptal accessory pathways were characterized by an atrial insertion site anterior to the atrioventricular node but inferior to the right coronary artery os. A femoral venous approach, aided by the use of a modified 59-cm sheath (USCI Angiographic Systems Division, C.R. Bard Inc.), provided the most stable catheter placement along the interatrial septal aspect of the tricuspid annulus. Mapping and ablation of all septal accessory pathways were performed on the atrial aspect of the tricuspid annulus.

**Ablation Procedure**

Monopolar delivery of radiofrequency alternating current between the endocardial ablation catheter tip electrode and large surface area skin electrode eliminated accessory pathway conduction in 116 of 122 accessory pathways (95%). Patients required 6.2±5.3
FIGURE 3. Catheter positioning for left free wall accessory pathway ablation. Panel A: In a 45° left anterior oblique view, a decapolar catheter descends from the superior vena cava into the coronary sinus (CS). The large-tip bipolar ablation catheter (ABL) ascends from the inferior vena cava and is positioned in close proximity to the fifth coronary sinus catheter electrode at the site of successful ablation. The ablation catheter crosses the interatrial septum at a level just above the His bundle catheter (HBE) (arrow). Panel B: A shallow right anterior oblique view of the same catheter positions demonstrated in panel A reveals superimposition of the ablation catheter distal electrode on the fifth coronary sinus catheter electrode. HRA, high right atrium; RVA, right ventricular apex.
(range, 1–24; median, 4) radiofrequency energy applications to eliminate accessory pathway conduction. As with other measures of ablation procedure efficiency, the number of radiofrequency applications required for successful ablation declined as knowledge and experience accumulated. The final 30 procedures in this series required only 3.3±3.0 energy applications for success (range, 1–12; median, 2). A “learning curve” phenomenon was also noted in total procedure and fluoroscopy times required for successful ablation. Overall time of ablation procedures for this patient series was 4.9±2.2 hours, and fluoroscopy time was 62.6±47.1 minutes. However, these times gradually declined to 3.4±0.9 hours and 30.9±12.6 minutes, respectively, for the final 30 procedures.

Cumulative energy delivery per patient in this series was 2,341±2,233 J. At the site of successful ablation, a radiofrequency power of 25.7±2.6 W was delivered for 21.0±8.9 seconds yielding a total successful ablation site energy application of 546±252 J. The applied radiofrequency power required 126.4±20.9 V (peak-to-peak) to deliver 1.29±0.19 amp (peak-to-peak) through a resistance of 99.8±18.9 Ω. Accessory pathway block was noted after only 2.4±2.2 seconds of energy delivery. At the site of successful ablation, radiofrequency energy application produced permanent accessory pathway block within 10 seconds of energy application in all except one patient.

**Follow-up**

One hundred fifteen of 122 accessory pathways were successfully ablated during an initial procedure as shown in Figure 7. Follow-up electrophysiological study was obtained in 95 of 114 (83%) patients. None of the patients lacking follow-up electrophysiological study have recurrent symptoms of accessory pathway mediated tachycardia or ECG evidence of ventricular preexcitation. Conduction recurred in ten accessory pathways before the 1-month follow-up visit. All of the recurrences were evident on a routine 12-lead ECG demonstrating ventricular preexcitation (eight patients) or were associated with symptoms of recurrent palpitations (two patients). Location of accessory pathways that recurred after initial ablation success was left free wall in five patients (6.6% recurrence rate), septal in three patients (8.8% recurrence rate), and right free wall in two patients (16.7% recurrence rate). Regional recurrence rate differences were not significantly different by $\chi^2$ analysis. A second ablation procedure was performed on 16 accessory pathways (10 recurrent and six
FIGURE 5. Catheter positioning for ablation of a right free wall accessory pathway. Panel A: In a 30° right anterior oblique view, the large-tip ablation catheter (ABL) ascends from the inferior vena cava and prolapses in the high right atrium (HRA) to a position along the atrial aspect of the tricuspid annulus. Panel B: In a 45° left anterior oblique view, the large-tip hexapolar ablation catheter is positioned on the anterolateral aspect of the tricuspid annulus where successful accessory pathway atrial insertion ablation occurred. HBE, His bundle; RVA, right ventricular apex.
primary failures). The second ablation procedure was successful on 14 of 16 accessory pathways, but three recurred. These three patients elected to undergo a third ablation attempt, which again was only temporarily successful in all three.

Overall, six of 114 patients were not successfully treated with the atrial insertion ablation technique. Four of the six patient failures were among the first 30 cases attempted. Location of these accessory pathways was right free wall in four patients, left anterior in one patient, and left free wall in one patient. Three patients opted for surgical ablation (one after primary failure and two after third recurrence), and three patients remain on medical therapy (two after second failure and one after third recurrence). Two of the unsuccessful ablation patients had two accessory pathways at baseline. One of the two accessory pathways was successfully ablated in each of these patients. Atrial insertion ablation was successful in 11 of the 12 patients who had previously unsuccessful surgical or ventricular insertion ablation attempts at outside institutions. After two ablation attempts, conduction through a left fibrous trigone accessory pathway that was previously unsuccessfully addressed using an epicardial dissection technique could not be interrupted.

After atrial insertion ablation, no detectable myocardial enzyme release occurred in 99 patients. There were no detectable adverse hemodynamic or anatomic consequences of energy delivery in this patient series. No serial changes were found in preablation and postablation echocardiographic evaluation that included color flow Doppler assessment of valvular function. In addition to echocardiographic evaluation, 70 patients underwent preablation and postablation coronary angiography. No vessel lesions or permanent alteration of coronary anatomy occurred in this patient population. At 21.2±4.6 months of follow-up (range, 13.3–29.7 months), 108 of 114 patients (95%) remain asymptomatic off all antiarrhythmic medications without evidence of accessory pathway conduction.

Complications

No life-threatening complications occurred in this series of accessory pathway atrial insertion ablation procedures. Two patients experienced a complication directly attributable to manipulation of the mapping/ablation catheter or delivery of radiofrequency ablation energy. One patient, in whom ablation of a left posterior paraseptal accessory pathway was accomplished from within the coronary sinus via a small posterior vein, was found to have occlusion of a posterolateral segmental branch of a left dominant circumflex coronary artery immediately after delivery of radiofrequency energy. She did not experience any discomfort associated with vessel closure, and serial creatine phosphokinase measurements remained normal. Echocar-

**Figure 6.** Tracings of sinus rhythm electrograms at the site of successful midseptal accessory pathway ablation. The local atrioventricular conduction time obtained at the site of ablation (BIPOLAR ABL) is 25 msec, although nearly continuous activity is present between the atrial and ventricular electrograms. The local ventricular electrogram onset precedes surface delta wave onset by 15 msec (Delta-V). PR segment displacement is present on the unipolar recording obtained from the ablation electrode (UNI DISTAL). The bipolar atrioventricular electrogram ratio is 1:2. HRA, high right atrium; HBE, His bundle.
FIGURE 7. Catheter position during midseptal accessory pathway ablation. Panel A: Close proximity of a successful midseptal ablation site to the His bundle (HBE) region is demonstrated in this 30° right anterior oblique radiograph. His bundle recording was obtained from the most distal electrode pair of the low septal atrial catheter (HBE) in this patient. Accessory pathway ablation was achieved using a 10-second 15-W radiofrequency energy application. Panel B: In a 45° left anterior oblique view, the ablation catheter (ABL) rests medial and inferior to the His bundle recording site (HBE). RVA, right ventricular apex; HRA, high right atrium; CS, coronary sinus.
diographic examination revealed no wall motion abnormalities. At the time of her postablation evaluation, coronary anatomy was completely normal, suggesting spasm as the initial cause of coronary closure. A second patient developed complete heart block during a midseptal accessory pathway ablation. Radiofrequency energy application at the site of earliest retrograde atrial activation was 2–3 mm posterior to the bipolar His bundle recording electrodes. Simultaneous disappearance of accessory pathway and atrioventricular dissociation occurred after 6 seconds of radiofrequency energy application. A permanent pacemaker was implanted 2 days after the ablation procedure due to persistent type I second-degree atrioventricular block.

Two patients experienced procedural complications that were not directly attributable to ablation catheter manipulation or energy delivery. One patient developed septic thrombophlebitis associated with a peripheral intravenous access, requiring a prolonged course of parenteral antibiotic therapy for resolution. One patient was found to have an asymptomatic left pneumothorax on routine postprocedure chest radiograph after an ablation procedure that included left subclavian vein access. The pneumothorax was not present on an immediate postprocedure radiograph but was readily diagnosed on a repeat evaluation 4 days later. The pneumothorax resolved with conservative medical management.

Discussion

In this study, we evaluated a transvenous approach to accessory pathway localization and ablation that limits ablative energy delivery to atrial tissue. Overall efficacy of atrial insertion accessory pathway ablation was 95%. This compares favorably with the results of ventricular insertion ablation. In the reports of Jackman et al and Schluter et al, several patients with left-sided accessory pathways were not successfully ablated from the ventricular insertion, but success was achieved using a modified atrial approach in which the ablation catheter was positioned retrogradely through the mitral valve. In contrast, atrial insertion site ablation was a dependable technique for successful outcome in this study. Direction of ablation energy solely to the atrial insertion...
of accessory pathways is as effective as a primary ventricular insertion approach.

Multiple investigators have independently reported the importance of direct accessory pathway recordings as a predictor of successful ventricular insertion ablation.\textsuperscript{5,13,14} However, the utility of using direct accessory pathway recordings as an ablation target is negated during retrograde mapping techniques that identify the accessory pathway atrial insertion site. This is due, at least in part, to the relatively large amplitude and long duration of local ventricular electrograms that overlap and obscure low-amplitude accessory pathway activity during retrograde atrial insertion mapping. During atrial insertion mapping, orientation of the recording bipolar nearly perpendicular to the expected accessory pathway activation vector also minimizes the likelihood of direct accessory pathway potential detection. Atrial and ventricular insertion ablation site recordings also differ with respect to the atrioventricular electrogram amplitude ratio. Atrioventricular electrogram ratio was 0.25 in the study of Kuck and Schulte.\textsuperscript{12} In contrast, the atrial insertion atrioventricular electrogram ratio was 1.1±0.8 during atrioventricular tachycardia and 2.3±2.2 during sinus rhythm in the present study. The atrioventricular electrogram ratio difference between atrial and ventricular insertion sites is expected and most readily explained by the difference in catheter positioning. Primary use of earliest endocardial retrograde atrial activation as the sole marker of accessory pathway atrial insertion in this study was sufficiently accurate to permit successful ablation in a very high percentage of patients.

Based on the number of radiofrequency applications required for success, accuracy of retrograde mapping techniques used in this study compares favorably with the anterograde mapping techniques used for identification and ablation of accessory pathway ventricular insertion sites.\textsuperscript{8–10} Atrial insertion ablation required a mean of 6.2±5.3 and a median of four radiofrequency applications. As noted previously, however, increasing levels of experience and knowledge led to a progressive decline in the number of radiofrequency applications required for success. The final 30 ablation procedures in this series required a mean of 3.3±3.0 and a median of two radiofrequency applications for such cases.

The 8.7% incidence of recurrent accessory pathway conduction after initially successful atrial insertion ablation is comparable to the 8–12% incidence reported after ventricular insertion ablation.\textsuperscript{8,10,13} After ventricular insertion ablation, right-sided and concealed left-sided accessory pathways are the most likely to recur after initial success.\textsuperscript{15} Although not statistically different, the 16.7% recurrence rate of right free wall accessory pathway conduction was somewhat greater than that of septal (8.8%) or left free wall (6.6%) locations following atrial insertion ablation. However, concealed left free wall accessory pathway recurrence rate was indistinguishable from the recurrence rate for bidirectional left-sided accessory pathways in this study. Twidale et al\textsuperscript{16} reported that absence of accessory pathway potentials before initial ventricular insertion ablation also heralded conduction recurrences. No preablation electrogram characteristics predicted recurrent accessory pathway conduction after atrial insertion ablation. All accessory pathway recurrences in this study occurred before the initial 1-month follow-up visit and electrophysiology test. Studies of ventricular insertion ablation suggest recurrent accessory pathway conduction is also evident in most patients within 2 months of the original procedure.\textsuperscript{15,16} After more than 1 year of follow-up, our patient series has not provided any suggestion of atrial arrhythmogenesis following radiofrequency atrial insertion ablation. Atrial fibrillation induction during standard electrophysiological evaluation was markedly reduced from 51 of 114 patients before ablation to only 7 of 106 patients at the time of follow-up electrophysiological study. There have been no instances of new-onset atrial or ventricular tachycardia after accessory pathway ablation in this patient series.

Any consideration of catheter ablation procedures must include not only the short-term clinical outcome but also the long-term effects of ionizing radiation exposure. The fluoroscopy time of 62.6±47.1 minutes reported in this study reflects a combination of early learning experience and current skill level. Nevertheless, mean patient radiation exposure in this study produces an added lifetime risk of approximately one fatal neoplastic disorder per 1,000 patients, which is <1% of the spontaneous risk.\textsuperscript{17,18} Fluoroscopy time required for atrial insertion ablation in this patient series compares favorably with that reported by investigators using ventricular insertion ablation techniques.\textsuperscript{8,10} A consistent decline in total fluoroscopy times accompanied accumulation of case experience and catheter skills. By the final 30 ablation procedures, average fluoroscopy time was reduced to 30.9±12.6 minutes per case. This degree of fluoroscopic support is indistinguishable from that reported for routine percutaneous transluminal coronary angioplasty procedures.\textsuperscript{19,20} Development of more efficient and accurate accessory pathway localization techniques and the future use of pulsed fluoroscopy technology will result in even further reduction of an already acceptable level of ionizing radiation exposure.

Safety of a transseptal approach to left-sided accessory pathways was documented in this study. There were no complications associated with transeptal catheterization or ablation. A transeptal approach to left-sided accessory pathway ablation avoids the inherent risks of prolonged arterial catheter manipulation and retrograde left ventricular catheterization required for ventricular insertion ablation procedures. Reported complications associated with arterial cannulation during ventricular insertion ablation procedures include femoral artery pseudoaneurysms, femoral arteriovenous fistula, femoral hematomas, thrombotic iliac artery occlusion, retroperitoneal hemorrhage, and transient neurological deficits.\textsuperscript{7,10,21} Although steerable catheter technology has reduced the risk of aortic valve damage and inadvertent coronary artery cannulation during retrograde catheterization, these complications have also been reported during ventricular insertion ablation procedures.\textsuperscript{9,21} The potential of cardiac perforation during transseptal catheterization did not occur in this study. Use of anatomic markers in the form of the coronary sinus catheter posteriorly and an aortic root pigtail catheter anteriorly has minimized the potential of inappropriate puncture site selection. Furthermore, the limbus of the fossa ovalis is well defined in the relatively young population undergoing accessory path-
way ablation so proper transseptal catheter placement is routinely ensured. Presence of a probe patent foramen ovale is a common finding in this age group, occurring in ≤30% of patients, and lowers risk even further since needle puncture is not necessary for successful interatrial septal crossing. The long-term effects of transseptal catheterization have been well defined with essentially no adverse consequences even after balloon mitral valvuloplasty procedures using a much larger diameter transseptal sheath than that used for accessory atrioventricular pathway ablation.22,23

In conclusion, the transvenous atrial insertion approach to accessory atrioventricular connection ablation is very safe and highly effective. Overall, atrial insertion ablation efficacy is equivalent to previously reported ventricular insertion ablation technique results. The transvenous atrial insertion ablation technique may have safety advantages when used for left-sided accessory atrioventricular connections since prolonged arterial cannulation, retrograde left ventricular catheterization, and catheter manipulation in the ascending aorta are not necessary. Prospective direct comparative studies of atrial and ventricular insertion ablation techniques will be required to establish firm guidelines for optimal accessory pathway ablation method.

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